Factors determining badger *Meles meles* sett location in agricultural ecosystems of NW Italy

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Received 24 June 2005; Accepted 28 February 2006

Abstract. The characteristics and density of Eurasian badger *Meles meles* setts and the factors affecting sett-site choice were studied from February 1999 to January 2000 in the River Po Park (Piedmont region, NW Italy). Badger setts were a complex of underground tunnels with, on average, 6.4 entrances. In hilly habitat badger sett density was higher than in lowlands (1.32 *vs*. 0.21 setts/km^2) as well as the mean number of entrances per sett (11.5 *vs*. 3.5). These data were similar to those recorded in many other European areas with low badger population density. In our study area, badgers clearly selected tree-cover (woods and shrubs), also tolerating human disturbance. In a widespread plain area, where the original forest vegetation has been dramatically reduced, sett sites were concentrated in residual wood belts along the slopes of alluvial terraces or in scrubs growing on artificial embankments. This study confirms the badger as a highly adaptable species that can exploit different habitats. Nevertheless badger populations living in predominantly agricultural lands depend on habitats offering sufficient cover for their breeding sett location. The improvement of natural vegetation cover is essential for the future conservation of badger populations in Po plain landscapes.

Key words: Eurasian badger, *Meles meles*, sett characteristics, sett density, sett site selection, agricultural habitat

Introduction

The habit of digging underground setts is one of the most striking characteristics of the Eurasian badger (*Meles meles*), which shows various physiological and anatomical adaptations to a semi-fossorial existence (Neal & Cheeseman 1996).

Main setts are complex systems, which can reach remarkable sizes, with a great number of underground tunnels and entrances (Kruuk 1978, Neal 1986, Woodroffe & Macdonald 1993, Roper et al. 1991) and can be inhabited for decades (Neal & Cheeseman 1996). Time and energetic costs related to their digging suggest that setts play an important role in badgers survival and many hypothesis have been proposed to explain why setts are such precious resources (reviewed by Roper 1993). Moreover, some authors (Neal & Roper 1991, Roper 1992, 1993) have regarded setts as a possible factor promoting sociality in badgers, in disagreement with those who consider food supply as the main factor shaping the social ecology of badgers (e.g. Macdonald 1983, Kruuk & Macdonald 1985, Carr & Macdonald 1986, Woodroffe & Macdonald 1993).

Badgers inhabit a wide variety of habitats and sett density and distribution varies to a great extent both at the local (Dunwell & Killingley 1969, Feore & Montgomery 1999) and wider scale (Thornton 1988). Cover and soil "diggability" (Thornton 1988) are reported as the main habitat requirements which drive badgers choice of sett locations, both in high-density (Dunwell & Killingley 1969,

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Clements 1974, Thornton 1988, Skinner et al. 1991, O'Corry-Crowe et al. 1993, Neal & Cheeseman 1996, Feore & Montgomery 1999) and in low-density badger populations (Virgos & Casanovas 1999, Balestrieri & Remonti 2000, Revilla et al. 2001).

In Italy, the distribution of badger setts has been studied in alpine (Prigioni & Deflorian 2005) and pre-alpine habitats (Biancardi & Rinetti 1998, Marassi & Biancardi 2002) and along the mid course of the River Po (Quadrelli 1993). The wide, west-east oriented plain crossed by the River Po (NW Italy) is a prevailing cultivated area characterized by discontinuous badger distribution and mean recorded density of 0.18 setts/km^2 and 0.9 animals/km^2 (Prigioni 2001). The ecological adaptations of the species to this heavily altered environment are poorly known and yet are of prime interest in defining the extent of badger intraspecific variation (Rosalino et al. 2004).

In this paper we seek to investigate distribution, external characteristics, size and habitat requirements of badger setts in the western part of the River Po plain. We compare results from two different riverine habitats: the hilly right bank and the plain left one of the river. We try to highlight the influence of environmental factors on sett density and architecture.

Material and Methods

Study area

The study was carried out in a 136 km^2 wide area of the River Po Park (south-eastern Piedmont region, NW Italy). The area runs along 83 km of the River Po and includes a system of six natural reserves (in all 35 km^2), interspersed in the remaining territory, classified as safeguard zone. The climate is sub-continental temperate, with an average yearly temperature of 12.4 °C and an average yearly precipitation of about 1000 mm.

Most of the study area is a cultivated plain, almost equally divided between poplar plantations and maize/rice fields. Riparian woodlands (6.6 %) and scrublands (1 %) are dominated by willows (*Salix cinerea, S. alba*), poplars (*Populus alba* and several hybrids) and alders (*Alnus glutinosa*), with some rare oak (*Quercus robur*). Black locusts (*Robinia pseudoacacia*) and elders (*Sambucus nigra*) are common along embankments, slopes and alluvial terraces. Gravelly and dry soils are colonized by herbaceous associations with a preponderance of *Euphorbia cyparissias*, *Carex liparocarpos*, *Muscari botryoides*, *M. comosum* and *Poa bulbosa*. The River Po has a scarcely meandering course, covering about the 6 % of the study area, with some oxbow lakes resulting from gravel extraction. About 5 % of the study area is wooded hills rising from the right bank of the river to about 350 m a.s.l. Oaks (*Quercus pubescens*), wild cherries (*Prunus* sp.), smooth-leaved elms (*Ulmus minor*), black locusts and elders are the main tree species; the shrub layer is dominated by black locusts, elders and dogwoods (*Cornus sanguinea*). Small villages and rural farms (0.2 %) are scattered throughout the study area.

Field samplings

From February 1999 to January 2000 a sett survey was carried out throughout the study area to outline badger distribution. In order to evaluate sett density, an exhaustive census was made in eight randomly selected sample areas (total surface of 33.8 km^2), representative of the park habitats. Four occurred in the hilly area (5.3 km^2; min-max: 0.32–1.84 km^2) and four in the river plain (28.5 km^2; min-max: 3.89–11.51 km^2).

A sett was defined as a complex of used (fresh signs of digging or bedding and footprints) or abandoned entrances, inter-connected by external paths or, presumably, by underground tunnels; collapsed setts were not considered.

Each sett was geo-referenced and plotted (to a scale of 1:500). The distances between neighbouring entrances, the maximum difference in height between the highest and the lowest entrances and the total area (traced out as the polygon connecting outer entrances) covered by the sett, was measured.

According to Marcum & Loftsgaarden (1980) and Virgos & Casanovas (1999), to analyse badger preference towards sett location, the habitat characteristics of circular plots of 100 m radius centred on badger setts were compared with those of 50 random circular plots of the same radius. Random plots, extracted by dividing the study area into a 2.5x2.5 km grid and randomly drawing by hand 2–3 circular plots for each square, were considered to be in suitable number to estimate habitat availability. Six variables were measured for each plot:

- Po: Poplar plantations (%)
- Wo: Woods (%)
- He: Herbaceous associations (%)
- Sh: Shrubs (%)
- Cu: Cereal crops (%)
- Ri: River (%)

Moreover, in order to assess the level of human disturbance and the risk of floods, the following distances were measured:

- DA: Distance (m) between the centre of the plot and the closest urban settlements (villages, farms, houses or roads)
- DR: Distance (m) between the centre of the plot and the closest river bank.

Data analyses

Sett characteristics and sett density in the river plain and in the hilly area, as well as the environmental variables measured for circular plots with and without setts, were compared by Mann-Whitney U test (two tailed). Because of the great number of repeated tests on related data, the significance level was calculated as the ratio between α=0.05 and the number of tests run (Rice 1989); the resulting threshold value was 0.006.

Principal Components Analysis (PCA) was performed on the data set as an exploratory method, in order to highlight association patterns among the employed variables. On the other hand, discriminating analysis was applied for segregating the two groups of samples. The function was estimated by a StepWise, Forward Selection procedure; the value of Fisher's F statistic corresponding to a probability of 0.05 was used as a threshold value to break off the model procedure. Problems due to violation of parametric statistics assumptions were avoided by logarithmic transformation of DA and DR variables, and by arcsin transformation of the other ones. Data were standardised by an autoscaling procedure in order to avoid problems due to the comparison of variables representing different quantities:

$$z_i = (x_i - \overline{x}) / s$$

where z_i is the i-esime autoscaled variable, x_i is the original value of the i-esime variable, $\bar{x}$ is the mean of the original distribution and s its standard deviation.

Results

Characteristics and densities of badger setts

Twenty five badger setts were found, of which 13 were inside the sample areas, corresponding to a mean density of 0.38 setts/km^2. Sett density in the hilly area (mean: 1.32 setts/km^2, min-max: 0.54–3.14) was higher than in the river plain (mean 0.21 setts/km^2; min-max: 0.17–0.26; Z=0, P=0.02), as well as the mean number of entrances per sett (Z=20.5, P=0.003, Table 1). About the 72 % of overall setts had 1–8 entrances (Fig. 1). Hilly setts covered larger areas (Z=8.5, df=6, P=0.04) than those of the river plain. There was no difference in the distance among neighbouring entrances (Table 1).

Table 1. Comparison of badger sett characteristics (n = 25) between the two habitats.

		No. of entrances		Distance among entrances (m)		Sett area (m^2)		Sett difference in height (m)	
	No. of setts	Mean (SD)	Min–max	Mean (SD)	Min–max	Mean (SD)	Min–max	Mean (SD)	Min–max
River plain	16	3.56 (3.0)	1–10	5.9 (3.8)	1–20	232.4 (267.6)	24–617	1.4 (2.7)	0–9.5
Hilly area	9	11.55 (8.7)	2–29	7.8 (5.9)	0.5–35	1346.8 (1203.1)	30–3756.4	20.8 (26.1)	0.5–73.5
Total	25	6.44 (6.8)	1–29	7.2 (5.5)	0.5–35	789.6 (1070.9)	24–3756.4	9.2 (18.7)	0–73.5

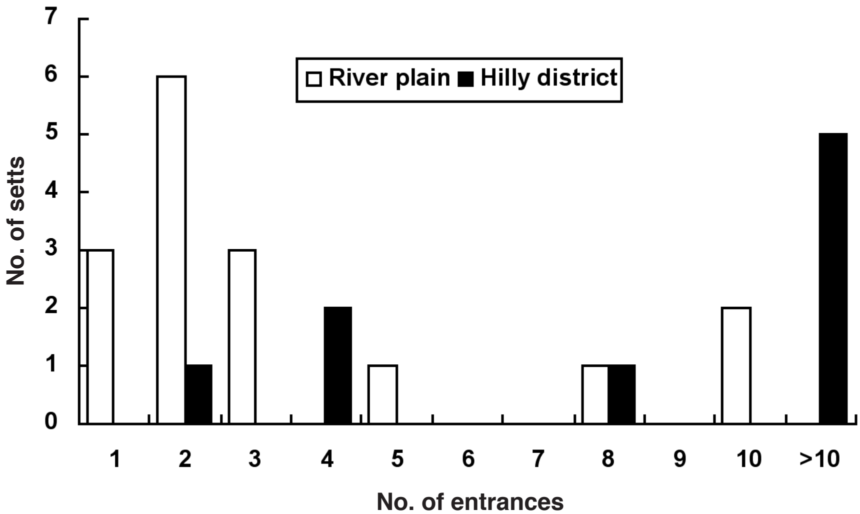

Fig. 1. Number of setts *vs* number of entrances.

Sett site selection

Badger sett sites were nearer to human settlements than random sites. Their surrounding areas showed a higher proportion of woods and a lower proportion of cereal crops with respect to random plots (Table 2). Multivariate analysis by PCA showed that the variables characterizing the total sample were the distance from the river and the proportion of river, woods, poplar plantations and cereal crops. They obtained the highest values of eigenvectors in the first three principal components, which explained 63.5 % of the overall variance (Table 3).

PCA biplot of first and second components showed 80 % of badger sett sites grouped around woods, the most important variable, whilst random sites were characterized by a higher proportion of poplar plantations and cereal crops and by a longer distance from human settlements. The biplot of third and fourth principal components confirmed cereal crops and poplar plantations to be the main factors affecting random sites. The proportion of shrubs was an important variable, but could segregate only some badger setts from random sites (Fig. 2).

Table 2. Comparison between 25 samples with setts and 50 samples without setts (see Methods for variables abbreviations; SD=standard deviation, NS = not significant).

Variables	With sett			Without sett			Z	P
	Mean	Median	SD	Mean	Median	SD		
DA (m)	331.0	319	158.93	759.2	591.5	639.71	242	<0.0001
DR (m)	437.5	300	390.40	310.4	299	245.39	554.5	NS
Po (%)	15.0	0	28.28	35.6	17.5	40.07	435	NS
Wo (%)	51.0	70	41.33	5.7	0	21.24	625	0.0001
He (%)	2.8	0	9.80	12.7	0	29.85	534.5	NS
Sh (%)	10.8	0	23.12	1.2	0	6.15	492	NS
Cu (%)	12.6	0	17.86	38.6	3.5	43.32	459.5	0.0024
Ri (%)	3.4	0	9.87	6.2	0	14.94	583.5	NS

Table 3. Principal Components Analysis (PCA) on 25 environmental samples with setts and 50 samples without setts (see Methods for abbreviations)

Eigenvalues	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Value	2.251	1.474	1.353	1.102	1.003	0.532	0.252	0.033
% of variability	0.281	0.184	0.169	0.138	0.125	0.067	0.031	0.004
Cumulative %	0.281	0.466	0.635	0.773	0.898	0.964	0.996	1.000
Eigenvectors:	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
DA	–0.350	–0.412	–0.147	–0.307	–0.234	0.733	–0.002	0.001
DR	0.566	–0.149	0.070	0.033	0.257	0.299	0.704	0.008
Po	–0.051	–0.396	0.739	0.029	–0.083	–0.113	–0.045	0.521
Wo	0.237	0.668	0.037	–0.253	–0.296	0.295	–0.064	0.504
He	–0.283	0.056	–0.147	–0.390	0.782	–0.047	0.002	0.360
Sh	–0.193	0.154	–0.012	0.808	0.258	0.412	–0.120	0.189
Cu	0.259	–0.389	–0.628	0.155	–0.175	–0.213	–0.087	0.529
Ri	–0.561	0.164	–0.101	0.105	–0.276	–0.238	0.690	0.171

Sett sites were discriminated from random sites by the proportion of woodland and shrubs, with a positive coefficient in the discriminating function, and by the distance from urban settlements with a negative coefficient (Table 4). The equation of the predictive discriminating model correctly classified 92 % of the sites with badger setts and 88 % of the sites without setts.

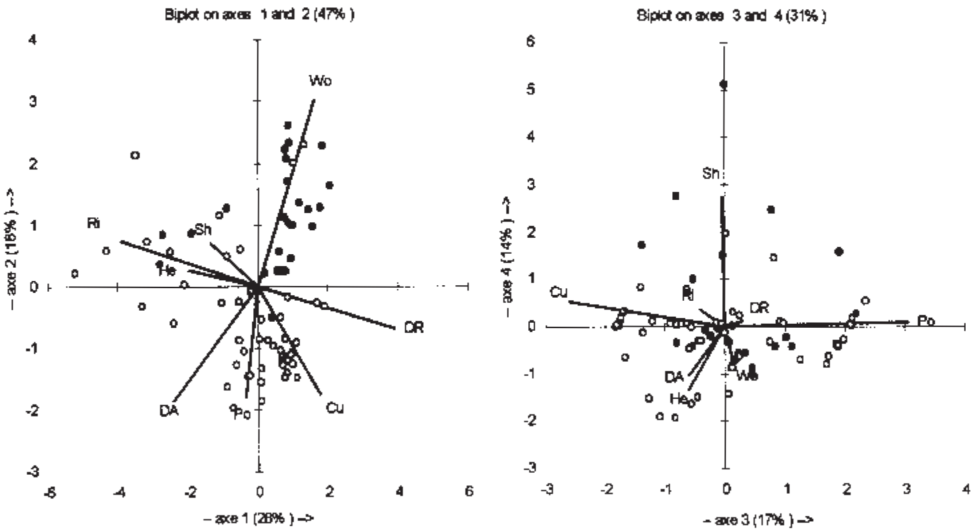

Fig. 2. PCA biplot of PC1 *vs*. PC2 and PC3 *vs*. PC4, for the environmental variables assessed in 25 samples with setts (full circle) and 50 samples without setts (empty circle). Variables (see Methods for abbreviations) are represented by arrows that approximately point towards the direction of maximum variation of each factor. The length of an arrow is relative to the importance of each variable in the assemblage arrangement.

Table 4. Discriminating analysis of 75 environmental samples, 25 with setts (group 2) and 50 without setts (group 1).

Eigenvalue = 1.270	% of variability=100	Cumulative %=100	Correlation=0.748
Wilks‘ Λ=0.44	χ^2=58.6	df=3	P<0.001
Standardized discriminating function coefficients:			
Woods: 0.95	Shrubs: 0.77	Distance from urban settlements: –0.38	
Observations correctly classified: 89.3 %			
	Expected groups		
Groups	1	2	Sum
1	44	6	50
2	2	23	25
1	88%	12%	100%
2	8%	92%	100%

Discussion

In our study area, mean badger sett density fell in the range of 0.04–0.65 setts/km^2, recorded in several European countries (Quadrelli 1993, Rodriguez et al. 1996, Biancardi & Rinetti 1998, Goszczynski 1999, Virgos & Casanovas 1999, Kowalczyk et al. 2000, Prigioni 2001, Revilla et al. 2001), except for England where it ranges from 0.53 to 4.55 setts/km^2 (Cheeseman et al. 1981, Johnson et al. 2002).

Some studies suggested that badger density can be inferred from sett surveys, which are more easily performed than direct censuses such as visual count or capture-mark-recapture methods (e.g. Cresswell et al. 1989, Roper 1993). For this purpose, the number of main setts is converted into number of animals using the average group size as a multiplicative constant (e.g. Cresswell et al. 1989). Main setts are generally large breeding sites (five or more entrances; Neal & Cheeseman 1996) used by individuals of the same group throughout the year (Kruuk 1989, Woodroffe & Macdonald 1993). Generally, in each territory a single main sett is found, to which other burrows – named subsidiaries, annexes or outliers, according to different authors (Neal 1977, Kruuk 1978, Thornton 1988, Roper & Christian 1992), may be joined. Nevertheless, as found by Virgós & Casanovas (1999) and Revilla et al. (2001) in Mediterranean habitats, in our study area it was not possible to visually identify main setts without available data about the ranging behaviour of the inhabiting badgers. In a plain area of the park, a radio-tracked (8–12 months) social group (one male and two females) used 5 setts with 1 to 3 entrances, no unequivocal external difference allowing for the distinguishing of the main sett (defined as the sett occupied by at least one individual for the longest period) from the other ones (unpublished data). As a consequence, we could not infer a reliable estimate of badger numbers from sett density, although differences emerged about sett density in plain and hilly areas that could reflect an effective higher badger density along hill sides. Sett size differences between the two habitats could be related to this difference in badger density, although the sett size could also be influenced by sett age (Neal & Cheeseman 1996).

The selection for sites far from the river bed could reflect both the choice of sufficiently cohesive and plastic soils for digging and the need for preserving setts from floods. During the study period, the flood of March 1999 swamped almost all the monitored lowland setts. Even if badgers dug them all again in a few months, recurrent river floods are likely to make setts dug in the plain area scarcely stable.

As expected, badgers clearly selected tree-cover and avoided cultivated lands. In the widespread plain area, where the original forest vegetation has been dramatically reduced, this selection induced the choice of residual wood belts along the slopes of alluvial terraces or that of black locust scrubs growing on artificial embankments. Besides seclusion, these sites offer some slope, which facilitates the removal of excavated soils and assures well drained setts in an area where the water table is near to ground surface (O'Corry-Crowe et al. 1993, Neal & Cheeseman 1996).

Badger setts occurred closer to urban settlements than expected, yet it is unlikely that badgers could take advantage by the closeness of human sources of disturbance. Embankments have been erected to protect riverine villages and setts closeest to them could simply reflect badgers' selection for sites offering cover and slope, although exposed to human disturbance. However there are several examples of badgers living in urban and suburban areas (Gillam 1967, Harris & Cresswell 1987, Tavecchia 1995), and, in the western River Po valley, setts are relatively often dug into railway embankments (Balestrieri & Remonti 2000), supporting the hypothesis that public access does not unavoidably imply sett disturbance (Jenkinson & Wheater 1998).

This study confirms the badger as a highly adaptable species that can exploit different habitats. In Italy, this mustelid is widely distributed and is not considered to need any conservation effort to enhance the long-term survival of the species (Spagnesi & De Marinis 2002). However, in highly altered landscapes, such as our study area (<10% of wooded habitat), badgers are likely to be markedly philopatric and to show low dispersal rates (e.g. Woodroffe et al. 1995), the species being particularly vulnerable to natural habitat loss and isolation (Lankester et al. 1991).

Our results suggest that badger populations living in predominantly agricultural lands tightly depend on habitats offering sufficient cover for their breeding sett location. More research is needed to define to what extent this dependence dictates overall badger density. Diet data suggest that food availability could also play a role in shaping the distribution of badgers (Balestrieri et al. 2004). The plain area supports a lower abundance of earthworms, nearly absent in cultivated fields (Paoletti & Amodeo 1981), and badgers could be forced to enlarge their territories to include suitable habitats for this key resource.

Acknowledgments

We are grateful to the "Parco Fluviale del Po e dell'Orba tratto vercellese-alessandrino" for financial support. Particularly, we wish to thank Laura Gola and Giampaolo Boffito for their fundamental cooperation and Chris Mason for the English revision of the manuscript.

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