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ORIGINAL ARTICLE

Spatial organisation of European badger (*Meles meles*) in northern Italy as assessed by camera-trapping

Alessandro Balestrieri[1] · Elisa Cardarelli[2] · Michela Pandini[2] ·
Luigi Remonti[2] · Nicola Saino[1] · Claudio Prigioni[2]

Abstract Italy is amongst the European countries for which data on badger *Meles meles* numbers and variation in population size are still too few to assess its conservation status. With the aim of estimating badger density in northern Italy, between February 2013 and March 2014, we extensively surveyed an isolated hilly area for badger setts and assessed group size by monitoring a sample of setts by two sessions of camera-trapping. The size and shape of each home range were assessed from main sett coordinates using the Dirichlet tessellation method. Then, assuming that badger home ranges tend to be delimited by hard boundaries or geographical features, the polygon shapes were successively modified by hand to draw more realistic home ranges. The overall trapping effort was 754 camera trap-days. The number of badger individuals sharing the same sett/entrances was recorded, distinguishing individuals based on the time and hole of emergence and, possibly, tail patterns. Groups consisted of two to four adult individuals, averaging 2.75 badgers/group. Camera-trapping proved to be a cost-effective and time-saving method. Depending on the method used to draw home ranges, in the study area, sett density was 0.34–0.51 sett/km^2, whilst badger density was 0.93–1.4 adult individuals/km^2. Both sett and badger densities were rather high with respect to most available data for continental Europe. As badger mean group size seems to be rather constant throughout both hilly and plain areas of the River Po basin, sett density may be used as an accurate estimator of badger density throughout this wide area.

Keywords Territoriality · Social behaviour · Dirichlet tessellations · Home range · Sett density · Badger

Introduction

The assessment of population density is crucial for planning conservation measures, evaluating the effectiveness of management strategies and assessing the impact of hunting and economic activities on species demography (Nichols and Williams 2006; Caro et al. 2009; Campbell et al. 2011).

In the case of the European badger (*Meles meles*), a widely distributed (Marmi et al. 2006) and relatively common species throughout Europe (Kranz et al. 2008), the estimation of density has both a management interest, due to its role in the transmission of bovine tuberculosis in the UK and Ireland (Garnett et al. 2005), and a theoretical interest, due to the relation between population density and social organisation.

Early research on badger social and territorial behaviour led to apparently opposite results, with badgers living in large social groups in England (Kruuk 1978) and almost solitarily in central Italy (Pigozzi 1987). Although the evidence supporting solitary territoriality has been heavily criticised (Revilla and Palomares 2002; Roper 2010), these findings, together with growing evidence that badgers do not cooperate for either hunting or breeding (Kruuk 1978; Woodroffe and Macdonald 1999), stimulated several attempts to explain its social organisation and yielded some general hypotheses about group formation and the origin of territoriality (Woodroffe and Macdonald 1993).

✉ Alessandro Balestrieri
alebls@libero.it

[1] Department of Biosciences, University of Milan, via Celoria 26, 20133 Milan, Italy

[2] Department of Earth and Environmental Sciences, University of Pavia, via Ferrata 5, 27100 Pavia, Italy

Available information on badger density throughout Europe has been revised by Kowalczyk et al. (2000), Johnson et al. (2002) and Roper (2010). All studies agreed that badger numbers were significantly larger in north-western Europe (up to 25 adults/km^2 in the British Isles; Cheeseman et al. 1987; Rogers et al. 1997) than in the rest of the wide badger range (on average, 1.24 badgers/km^2; Table 1).

The accuracy of density estimates depends on several factors, including the method used for number assessment. Moreover, for social species, to obtain an estimate of population density, the assessment of territory size must be coupled with that of social group size.

Whilst in the UK, badger populations have been the object of several long-term capture-mark-recapture studies, in continental Europe, group size has been mostly determined by sett-watching at dusk and/or live trapping (e.g. Goszczynski 1999; Rosalino et al. 2004; Acevedo et al. 2014), whilst radio telemetry (e.g. Rodríguez et al. 1996; Do Linh San et al. 2007a) and bait-marking (Delahay et al. 2000) have been the methods of choice to assess home range size. These approaches have some limitations; direct observation tends to underestimate the number of animals per group (Tuyttens et al. 2001; Scheppers et al. 2007),

whilst home range size depends on both the estimator used (White and Garrott 1990) and time interval between successive fixes (De Solla et al. 1999), making it difficult to compare the results from different studies. Sample size is a further problem, as most available studies were based on a few individuals and groups due to the labour intensiveness of trapping and fix recording.

To our knowledge, published badger density data were not available for Italy. Some information is available for sett density, which has been reported to be ca. 0.2 setts/km^2 for plain areas of northern Italy (Quadrelli 1993; Remonti et al. 2006a), whilst higher values have been reported for central Italy (0.7 setts/km^2; Tinelli and Tinelli 1980) and both hilly (1.32 setts/km^2; Remonti et al. 2006a) and Alpine (7.1 setts/km^2; Prigioni and Deflorian 2005) areas. Group size is poorly known, although hair-trapping (Balestrieri et al. 2010), sett clearing (Balestrieri et al. 2006), radio-tracking (Remonti et al. 2006b) and camera-trapping (Mori et al. 2014) suggested the occurrence of small groups including one adult male and from one to three adult females.

With the aim of estimating badger population density, we extensively surveyed an isolated hilly area of northern Italy for badger setts and assessed group size by monitoring a sample of setts by camera-trapping. The size and shape of home

Table 1 Badger density in continental Europe

Country	Density ind/km^2	References
Russia	0.46	(Ivanter 1973)
Kazakhstan	1.52	(Lobachev 1976)
Latvia	0.30	(Zoss 1992)
Finland	0.24	(Kauhala et al. 2006)
Norway	0.50	(Broseth et al. 1997)
Poland	0.31	(Goszczyñski and Skoczyñska 1996)
	0.59	(Goszczynski 1999)
	0.16	(Kowalczyk et al., 2000)
Czech Republic	0.98	(Pelikan and Vackar 1978)
	0.12	(Matyástík and Bicík 1999)
The Netherlands	0.19	(Van Apeldoorn et al. 2006)
Luxembourg	4.7	(Scheppers et al. 2007)
Germany	6.5	(Hofmann et al. 2000)
Switzerland	0.5	(Graf et al. 1996)
	1.0	(Do Linh San et al. 2007a)
	1.8	(Do Linh San et al. 2007b)
Portugal	0.45	(Rosalino et al. 2004)
Spain	0.5	(Martin-Franquelo and Delibes 1985)
	0.36	(Rodríguez et al. 1996)
	1.98	(Lara-Romero et al. 2012)
	0.28	(Revilla et al. 1999)
	3.81	(Acevedo et al. 2014)
Mean ± SE	1.24 ± 0.36	

ranges were estimated by the Dirichlet tessellation method (Doncaster and Woodroffe 1993), which is based on the assumption that setts are a substantial and limiting resource that rules badger spatial organisation. Although the suitability of the method has been criticised (Blackwell and Macdonald 2000; Doncaster 2001), it can be used to estimate territory size and shape from the location of main setts quite accurately (e.g. Macdonald et al. 2004).

Study area

The study area consisted of an isolated, 14.5-km^2 wide, hill (up to 147 m above sea level (asl)) in the middle River Po plain (Lombardy region, ca. 45° 11′ N, 9° 29′ E). It consisted of summital Miocene marls, covered by clays and limestones from the Pliocene and Quaternary alluvial sediments, and was bordered to the north-east by the River Lambro and to the south by the River Po. Woodland (ca. 24 %) consisted of oaks (*Quercus robur* and *Q. petraea*), alder (*Alnus glutinosa*), chestnut (*Castanea sativa*) and black locust (*Robinia pesudoacacia*), with shrubs of *Cornus sanguinea*, *Corylus avellana* and *Crateaegus monogyna*. Permanent cover also included grasslands, fallow fields and shrublands (14 %). Cropland (55 %), mostly vineyards (39 %), was mainly located in the south-eastern part of the hill. The surrounding matrix consisted of an intensively cultivated agricultural area, being mostly maize and rice fields and small urban areas. The climate was subcontinental temperate, with an average yearly temperature of 11.4 °C and an average yearly precipitation of 712 mm.

Methods

Badger setts were detected by extensive surveys carried out between February 2013 and March 2014, both on the hill and surrounding plain areas. As burrows are preferentially located in areas offering dense vegetation cover (Remonti et al. 2006a; Reid et al. 2012) and slope (Balestrieri and Remonti 2000; Revilla et al. 2001; Reid et al. 2012), potentially suitable sites were first located by land-cover digitalised maps (1:10,000) produced by a Geographic Information System (ArcView®) based on Coordination of Information on the Environment (CORINE) Land-Cover maps and satellite images. For each survey, an ca. 1-km^2-large area was searched on foot for badger setts and signs by four trained surveyors. Badger footprints, paths and latrines were georeferenced and used to infer the location of setts. Setts were defined as 'main setts', multi-entrance (4–15) burrows showing signs of permanent occupation (footprints, bedding material and 'fresh' excavated soil), and 'secondary setts', which were close to a main sett, had a few entrances (1–4) and,

generally, no or scarce signs of use. The latter category included annexes, outliers and subsidiary setts, as defined by Kruuk (1978) and Thornton (1988).

To analyse badger preference towards sett location, we recorded the habitat type where each main sett had been dug. The following four habitat types were considered: woods, vineyards, meadows and urban areas. Expected frequencies were calculated according to habitat availability, assessed from 100 random points created in ArcView by the tool 'random point theme' of the extension Animal Movement (with distance from boundary = 10 m and distance from other points = 50 m). Observed and expected frequencies were then compared by the chi-squared test, with Yates' correction for small samples. Bonferroni's confidence intervals for the proportion of use were then checked for each habitat type (Neu et al. 1974; Byers et al. 1984).

The size and shape of each home range were assessed from main sett coordinates using the Dirichlet tessellation method (DT; Doncaster and Woodroffe 1993), which provides convex, tessellated polygons having the property that every point within a polygon is nearer to the included sett than to any other neighbouring sett. Polygons were drawn using the extension 'Animal Movement' of ArcView 9.2 (Hooge and Eichenlaub 1997).

Assuming that badger home ranges tend to be delimited by hard boundaries (Powell and Mitchell 1998), and these are often left out by most methods for constructing home ranges (Getz et al. 2007), whenever the sides of a tessellation felt next to a clear barrier (e.g. major roads, rivers and canals) or geographical feature (e.g. hill ridges and urbanised areas or other inhospitable terrain), they were successively modified by hand as to draw more realistic home ranges (HRs; Getz et al. 2007; Frantz et al. 2010).

We then calculated the areas of both closed DTs ($N = 9$) and HRs ($N = 12$). For each HR, the percent cover of woods was assessed by ArcView based on CORINE Land-Cover maps and ground surveys, and the relationship between home range size and wood cover was tested by Spearman's correlation coefficient.

To estimate group size, a sample of six setts located in the hilly area was monitored by digital scouting pocket cameras (Multipir 12 and SG550 with Passive Infrared motion sensor), recording 30-s-long videoclips (with a 60-s interval between two successive recordings) throughout the 24-h period. Camera traps were tied to trees about 5 m from each active entrance of each surveyed sett, monitoring both main setts and secondary setts with signs of badger presence simultaneously. Apparently, unused holes were gently closed with branches as to either prevent or detect their use during the trapping session.

Setts were surveyed twice, in March–April 2013 and February–March 2014, respectively, for 7–10 consecutive

days each, using from 9 to 19 cameras. Trapping effort was expressed as the number of camera-days (= number of camera traps × number of working days).

The number of adult badger individuals sharing the same sett/entrances was recorded. Although badgers may emerge from one entrance and re-enter the sett through a different hole several times before going off to forage (Roper 2010), the synchronisation of the date and time of all cameras, together with the exam of tail pattern (Dixon 2003), helped to prevent double counts. All entrances having been monitored; each badger leaving the sett at dusk was considered as a group member until no badger re-entered the sett. Successively, whenever possible, to distinguish individual badgers, the tail pattern of any badger leaving the sett was compared to that of badgers known to have re-entered the sett. In case of ambiguity, leaving badgers were not considered as additional group members. We are confident that the survey period was sufficient to assess group size effectively.

Badger density in the study area was then assessed based on the resulting mean number of badgers per sett and the overall area of both DTs and HRs.

Results

Nineteen main setts were found, of which 10 were in the hilly area and 9 in the surrounding lowland (Fig. 1). In the hilly area, setts were not randomly distributed in the available habitats ($\chi^2 = 11.7$, $P = 0.011$), with woods being used as sett sites more than expected according to their relative availability (Bonferroni's confidence intervals, $P < 0.001$).

The mean area ($\pm$SE) of closed Dirichlet polygons ($N = 9$) was 2.96 ± 0.47 km^2. Correcting polygons' borders by hand, home range size could be assessed for the 10 badger groups with setts on the hill and also for two groups in the plain, whose ranges were clearly delimited by the course of the River Lambro (Table 2 and Fig. 1). Home range size was,
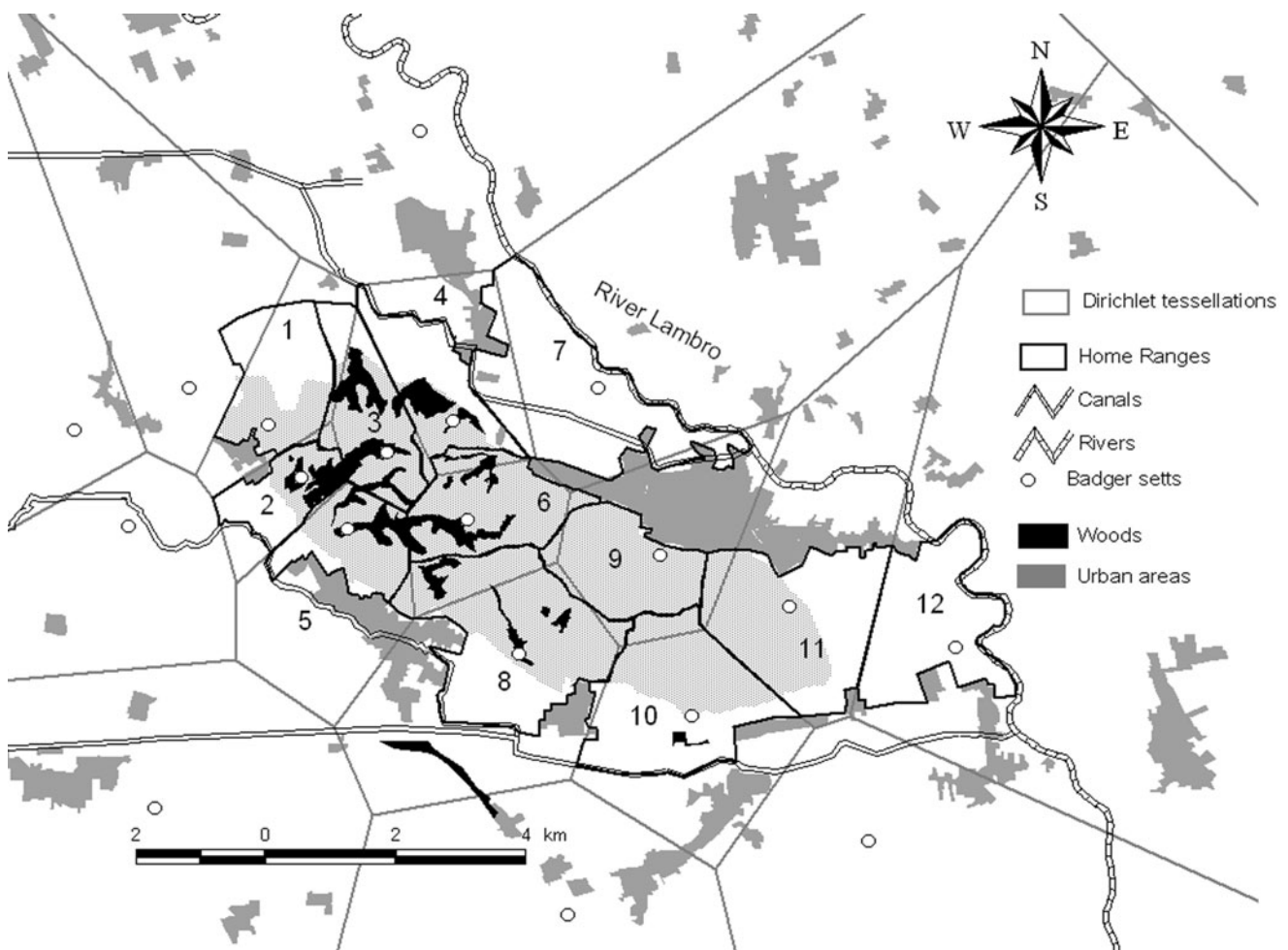

Fig. 1 Badger territorial organisation in the study area (a 14.5-km^2 wide hill—marked in *light grey*—and surrounding lowlands in Lombardy region, north Italy), as assessed by Dirichlet tessellations and, successively, modifying polygons' borders by hand, based on the presence of geographical features (home ranges; numbers correspond to those in Table 2)

Table 2 Badger home range size as assessed by Dirichlet tessellations (DTs) and successive modification by hand of polygons' borders according to natural barriers (HRs)

Sett	DT area (km^2)	HR area (km^2)	Woods (km^2)	HR (%)
1	2.21	1.61	0.025	1.5
2	1.21	0.88	0.179	20.2
3	1.31	1.54	0.338	22.0
4	2.90	1.45	0.175	12.0
5	3.45	1.18	0.171	14.5
6	2.17	1.67	0.178	10.6
7	–	3.06	0.000	0.0
8	5.59	3.18	0.069	2.2
9	3.59	1.54	0.064	4.2
10	4.16	2.64	0.020	0.7
11	–	2.70	0.025	0.9
12	-	2.07	0.000	0.0

Wood cover inside each HR is expressed both in km^2 and as percentage of HR overall size

on average, 1.95 ± 0.23 km^2 and was inversely correlated to wood percent cover ($r = -0.75$, $P = 0.005$, $N = 12$).

Nineteen latrines were found, of which 15 were dug next to the main sett and the 4 latrines far from setts were successively found out to be next to Dirichlet sides.

The overall trapping effort was 311 camera trap-days for the first session and 443 for the second one (Table 3). Badgers were recorded a total of 643 times; although they were more active during the second trapping session (one videoclip per 2.9 vs. 0.8 camera-days), the minimum total number of individuals recorded scarcely differed (16 vs. 17 badgers, respectively). Groups consisted of two to four adult individuals (Table 3), averaging 2.75 badgers/group. No young of the year was observed.

Based on the overall area of either DTs (26.6 km^2) or HRs (23.5 km^2) and mean group size, in the hilly area, sett density

was 0.34–0.51 sett/km^2, whilst badger density was 0.93–1.4 adult individuals/km^2, respectively.

Discussion

Whilst at continental scale, badger density may vary according to variation in climate and habitat availability (Kowalczyk et al. 2000), at local scale, density depends on the type of habitat surveyed amongst those available (Johnson et al. 2002) and can vary over time at the same study area (Cheeseman et al. 1987; Macdonald and Newman 2001). As a consequence, every density estimate is likely to be representative of a specific area and time and should not been extrapolated to a wide portion of a species' range. On the other hand, whilst the factors associated with sett location are well known (e.g. Reid et al. 2012; Acevedo et al. 2014), those underlying variations in badger density throughout its wide distribution range are still poorly known, as a consequence of the low number of available estimates, and data on badger numbers and variation in population size are still needed to assess its conservation status in many European countries, including Italy (Roper 2010).

Keeping in mind the difficulty of comparing density estimates from different studies, in our study area, both badger (see Table 1) and sett densities (mean for continental Europe = 0.16 ± 0.03 setts/km^2, calculated from data in Johnson et al. 2002) were rather high with respect to most available data for continental Europe. With respect to neighbouring Switzerland, badger density in our low-altitude area was similar to those recorded, in the pre-reproductive period, in rural areas at 430–630 m asl (1.04 ± 0.71 adults and/or subadults/km^2; Do Linh San et al. 2007b) and 995–1288 m asl (1 ind/km^2; Do Linh San et al. 2007a).

As recorded for other rural areas (Revilla et al. 2001; Remonti et al. 2006a; Do Linh San et al. 2011), woods were preferred as sett sites. In agricultural areas, wood patches offer

Table 3 Results of the two sessions (1: March–April 2013 and 2: February–March 2014) of camera-trapping at six badger setts (numbers correspond to those in Table 2): number of videoclips showing badgers, trapping effort (expressed as camera-days) and minimum total number of adult individuals recorded

Sett	Session 1			Session 2		
	No. of videoclips	Camera-days	No. of badgers	No. of videoclips	Camera-days	No. of badgers
1	14	49	2	95	100	2
2	10	48	2	23	72	2
3	27	42	3	60	90	4
4	16	81	2	60	81	2
5	20	42	3	59	50	3
6	19	49	4	240	50	4
Total	106	311	16	537	443	17

cover seclusion and are often associated with unfit-for-cultivation, sloping soils, which offer suitable conditions for burrowing. In the intensively cultivated landscape of northern Italy, wood patches have been reported to be strongly selected by radiotracked badgers (Balestrieri et al. 2009). The negative correlation between home range size and percent wood cover supports the hypothesis that woods also offer profitable food resources (see Kowalczyk et al. 2003) with respect to crops and vineyards. Accordingly, in intensively cultivated areas, badgers have been reported to have unbalanced diets, disproportionately rich in carbohydrates, probably as a consequence of the scarcity of animal food (Remonti et al. 2011).

The accurate estimation of badger density ensues from precise as possible assessment of both group size and study area (i.e. the territory effectively used by monitored individual badgers).

Home range borders as assessed by Dirichlet tessellations matched well with both geographical barriers/features and the location of four latrines in the north-western half of the hill, where home ranges were small. The match was less precise at the foot of the hill, where the presence of urban areas, roads and wide canals suggested reduction by hand of some polygons areas, but, on the whole, the assumption that range borders lie at the halfway point between adjacent main setts was adequate and allowed almost unbiased estimates of range size.

To date, video cameras have been used to study the behaviour of Japanese badger *Meles anakuma* (Tanaka et al. 2002) and assess the role played by the European badger as a reservoir species of bovine tuberculosis (Tolhurst et al. 2009). Remote-controlled, infrared video surveillance equipment has been also used for continuous nocturnal observation of setts to investigate allo-marking of conspecifics with subcaudal gland secretions by *M. meles* (Buesching et al. 2003). In our study area, camera traps increased the efficacy of group size assessment with respect to direct observation by enabling the continuous monitoring of badger setts over several nights and, frequently, the observation and comparison of tail appearance.

The consistency of badger numbers per sett over the two sampling periods, notwithstanding wide variation in badger activity, indicates that the estimate of group size was accurate. Results were consistent with those obtained in plain areas of northern Italy by the clearing of four main setts (mean group size = 3 adult individuals; Balestrieri et al. 2006).

As available data indicate that badger group size ranges between two and four adult individuals throughout both hilly and plain areas of the River Po basin (Balestrieri et al. 2006; Remonti et al. 2006b; Balestrieri et al. 2010; this study), sett density may be used as an estimator of badger density throughout this wide area (see also Lara-Romero et al. 2012; Judge et al. 2014). The twofold higher sett density on hills with respect to plain cultivated areas (Quadrelli 1993; Remonti et al. 2006a) suggests that residual woods and/or

sloping soils largely influence badger abundance. Further studies are needed to understand which factor—slope, cover and food, i.e. sett site or food availability—plays the main role in shaping badger density.

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