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Predicting European badger *Meles meles* sett distribution in urban environments

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Natural England receives an increasing number of complaints about problems caused by badgers *Meles meles* in urban and suburban environments, most of which concern problems caused by the digging of burrows (setts). The aim of our study was to identify factors related to the presence of badger setts in urban and suburban areas, in order to provide information relevant to the development of an urban badger management strategy. We identified habitat factors (including human population density) associated with the presence of badger setts in four extensively surveyed towns or cities in England, in a GIS-based approach using binary logistic regression analysis. Badger sett densities in urban areas were comparable to sett densities in most rural parts of the UK. Thus, badgers can achieve relatively high population densities in urban environments, despite the potential for human-badger conflict. The single most important factor predicting sett location was the type of habitat in which the sett in question was located, followed by the slope of the ground at that location. Sett presence was also predicted by the proximity of other setts, and badgers preferred areas with intermediate human population densities. The population density of badgers in urban and suburban environments appears to be mainly related to the availability of suitable places for locating setts, rather than to factors that would be expected to reflect food availability. This information will help to predict potential sites of badger-related problems and may be relevant to understanding the ecological requirements of other carnivore species that inhabit urban environments, such as red fox *Vulpes vulpes*, stone marten *Martes foina* and racoon *Procyon lotor*.

Key words: England, European badger, GIS, logistic regression, Meles meles, sett distribution, urban ecology

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Owing to a continuing process of urbanisation of the human population (United Nations 2003), urban habitats are of increasing global and regional significance from an ecological and conservation point of view (McIntyre et al. 2000). Although urbanisation is frequently detrimental to biodiversity (Pickett et al. 2001), some species such as fox *Vulpes vulpes*, stone marten *Martes foina*, kestrel *Falco tinnunculus*, European badger *Meles meles* and racoon *Procyon lotor*, which hitherto have not been commonly associated with human settlements, are seen increasingly often in towns and cities (Harris 1984, Rosatte et al. 1991, Broekhuizen & Mueskens 2000, Gloor et al. 2001, Kübler et al. 2005). While human residents generally view the presence of wildlife positively (DeStefano & DeGraaf 2003, Bjerke & Østdahl 2004), some species, in particular carnivores, may cause problems such as damage to property or risk to health (Harris 1984, Conover et al. 1995, DeStefano & DeGraaf 2003, Matthews & Wilson 2005).

Natural England (formerly the Rural Development Service), a UK government body with responsibility for conserving, enhancing and managing the natural environment, receives about 700 complaints per year about problems caused by badgers. The proportion of these complaints deriving from urban areas has risen during the last few years and is now about 20% (Matthews & Wilson 2005). Although badgers can damage property as a result of their foraging activities (Neal & Cheeseman 1996, Moore et al. 1999), a large majority of the complaints received by Natural England relates to the digging of setts, which can damage gardens, impede access and undermine buildings (Conover et al. 1995, Matthews & Wilson 2005).

Although the existence of urban badger populations in the UK has been known for at least several decades (e.g. Harris 1984, Tavecchia 1995), there has been no systematic analysis of their abundance, size or geographical distribution. Nor is it clear why some towns or cities apparently have large populations of badgers, whereas others have smaller populations or none at all. In the case of rural badgers, logistic regression has been used to identify habitat factors associated with the presence of badger setts and, thus, to predict the occurrence of badgers (Thornton 1988, Virgos 2002, Jepsen et al. 2005). In this paper, we apply the same approach to data on urban badgers. Our main aim was to provide information relevant to the future development of an urban badger management strategy based on accepting badgers as a permanent feature of at least some urban environments. In addition, we aimed to identify environmental factors that, because they favour badgers, may help to identify locations where badger management problems are likely to recur.

Methods

Data

We collected data on the locations of setts in the four towns or cities Hastings, Swindon, Yeovil and Brighton. In the case of Hastings, Swindon and Yeovil, local badger groups had established the locations of badger setts through extensive surveys including the whole of the respective urban/suburban area. In the case of Brighton, we collected the data ourselves related to an area of about 537 ha in the Kemptown/Whitehawk district, where we are also conducting an intensive radio-tracking study of urban badgers (Table 1).

We only considered setts within town or city boundaries for analysis. For most purposes we did not distinguish between main setts and outliers, annexe setts or subsidiary setts (Kruuk 1978, Thornton 1988), because these distinctions rely on subjective criteria, or the relevant information was not available for all cities or setts. The status of setts may change over time (Ostler & Roper 1998).

Sett locations were transferred to OS 1:10,000 scale raster maps of the four towns or cities (Digimap®, ©Crown Copyright 2006). We then converted these maps to a vector shape file, in order to specify different habitat types. The maps were composed of adjacent polygons and we assigned a habitat category to each polygon with the help of aerial photographs. However, if the pre-defined polygons did not represent habitat patches correctly, we divided them into appropriate shapes

Table 1. Size of areas, number of badger setts and random points, sett density and main sett density.

		Number of			
City	Area (ha)	Setts	Random points	Sett density (setts/ha)	Main sett density[1]
Hastings	2972.5	160	442	0.053	0.024
Brighton	536.7	39	100	0.073	0.020
Swindon	12829.3	57	297	0.006	0.003
Yeovil	1535.2	58	280	0.038	0.021

[1] Note that not all setts had been classified as either main setts or other setts. Unclassified setts were assumed to represent both categories (i.e. 'main sett' or 'other sett') in the same proportion as for setts where the relevant information was available.

using the split polygon option in ArcView 3.3. In the case of Brighton and Hastings, photographs were taken in 1999 and supplied by the Department of Geography, University of Sussex. For Swindon and Yeovil, photographs were accessed through Google Earth 4.0 in 2006. The following habitat categories were used (variable names are written in SMALL-CAPS):

0. Streets and other hard-surfaced areas;
1. Private gardens (GARDENS);
2. Scrubs, bracken, brambles and other types of wasteland; i.e. areas that were not subject to regular (at least monthly) maintenance (SCRUB);
3. Farmland, including arable land and pasture (FARMLAND);
4. Buildings;
5. Coniferous, deciduous or mixed woodlands (WOOD);
6. Coastline and beaches from which vegetation was absent;
7. Playing fields and parks; areas of regularly mown grass, either accessible to the public or belonging to schools (PLAYFIELD);
8. Fresh water; brooks, streams, drainage channels, ponds and lakes (WATER);
9. Sea;
10. Allotment gardens (ALLOTMENT);
11. Bare ground (e.g. building sites).

For some purposes we combined categories 0, 4, 6, 8, 9 and 11 to a new category UNSUITABLE. To compare sites at which a sett was present with sites without setts, we generated approximately 2.5 - 5 times more random points than the number of actual setts present in the area in question (see Table 1). Random points were generated (using Animal Movement program 2.0 Beta 12/9/98; Hooge et al. 1999) within the city borders of Hastings, Swindon and Yeovil. In the case of the Kemptown/Whitehawk district of Brighton, the relevant area consisted of the minimum convex polygon that included all known setts, plus a surrounding 500-m wide buffer zone. The minimum distance between random points was set at 100 m as this was about the nearest distance between two main setts in Brighton.

The factors that were available for each sett or random point are listed in Table 2. In binary logistic regression both categories of the dependent variable (in this case, 'sett' or 'no sett') have to be represented at least once for computational reasons, and it is recommended that each response category has at least 10 cases (Peduzzi et al. 1996). Consequently, it was not possible to use the original habitat categories for random points that were located in a habitat that was *a priori* not suitable for setts (i.e. streets, buildings, coast line, fresh water, sea and bare ground). If we had simply ignored these random points, we would have underrepresented highly built-up areas of cities. Therefore, we substituted the habitat data for these random points by the habitat of the nearest polygon of a suitable category. This approach reduces the likelihood of finding differences in the variable HABITAT between setts and random points (i.e. it is conservative), but it does not affect any of the other variables. Similarly, some of the original habitat categories had to be grouped together because they were found to contain few or no setts, either because the specific habitat covered only a small area (ALLOTMENT and WOOD), or because it was avoided by badgers (PLAYFIELD). PLAYFIELD was grouped with FARMLAND because of similar flatness, lack of cover and homogenous habitat; while ALLOTMENT and WOOD were grouped with SCRUB because, like scrub, they represented relatively low-maintenance types of habitat with heterogeneous structure and at least some cover. As a result, the variable HABITAT was reduced to three categories (see Table 2).

We obtained SLOPE data from OS Landform Profile 1:10,000 (© Crown Copyright 2006) converted to a raster grid, using the ArcView extension Spatial Analyst v 2.0. Information about DRAINAGE was provided by the National Soil Research Institute in the form of The National Soilmap (NATMAP) vectors with a resolution of 1:250,000, compiled in 1999 (NSRI, Cranfield University, UK; available at http://www.silsoe.cranfield.ac.uk/nsri/services/). Information about POPDENSITY, CARDENSITY and FREESTAND (see Table 2 for definitions) were obtained from 2001 Census Area Statistics (ESRC/JISC Census Programme, Census Dissemination Unit, MIMAS, University of Leeds). The data relate to the smallest (coa_code) census district. Values for habitat, slope, drainage and census data were obtained for the exact location of each sett or random point using the Point Analyst 1.0 (Rempel 2003) extension of ArcView 3.3.

We calculated the distance to the nearest sett and to the different habitat categories listed above using the Nearest Features v. 3.8a (Jenness Enterprises) extension to ArcView 3.3. We calculated the percentage coverage of specific habitat types in an area of 125 m radius around each sett or random point by creating a buffer and intersecting this buffer with the

Table 2. Variables entered into the preliminary analyses of badger sett presence or absence. The abbreviations used throughout the article are given in SMALL CAPS.

Variable	Categories
HABITAT	1. farmland & playfield 2. private garden 3. scrub, wasteland, allotment or woodland
SLOPE (in °)	Continuous
DRAINAGE	1. naturally wet 2. impaired drainage 3. slightly impaired drainage 4. good
Human population density (POPDENSITY; humans/ha)	Originally continuous; final model: 1. 0-25 humans/ha 2. 26-79 humans/ha 3. 80 or more humans/ha
Percentage of freestanding buildings (FREESTAND)	Originally continuous; three equal size categories tried
CARDENSITY (cars/ha)	Originally continuous; three equal size categories tried
distance to nearest sett (DISTSETT; in m)	Continuous
distance (in m) to nearest patch of	
- private garden (DISTGARDEN)	Continuous
- scrub or wasteland (DISTSCRUB)	Continuous
- farmland (DISTFARMLAND)	Continuous
- woodland (DISTWOOD)	Continuous
- playfield (DISTPLAYFIELD)	Continuous
- freshwater (DISTWATER)	Continuous
- allotment (DISTALLOTMENT)	Continuous
percent coverage in radius = 125 m buffer zone	
- unsuitable land (streets, buildings, freshwater, sea, coast, bare ground) (%UNSUITABLE)	Continuous
- private garden (%GARDEN)	Continuous
- scrub, wasteland or wood (%SCRUB)	Continuous
- farmland (%FARMLAND)	Continuous
- playfield (%PLAYFIELD)	Continuous
- allotment (%ALLOTMENT)	Continuous

habitat shape file of that town or city in ArcView 3.3. We chose this distance because the buffer area then represents 4.9 ha, which corresponds approximately to the average home-range size of badgers studied in Brighton (J. Davison & M. Huck, unpubl. data).

Binary logistic regression

We used binary logistic regression to find suitable predictors for badger sett presence or absence. All preliminary analyses and model selection procedures were done using data for the city of Hastings because this was the largest of the four data sets in terms of number of setts (see Table 1). In order to compare different models and select the one with best predictive power, we calculated the percentage of correct predictions, r_L^2 (tentatively recommended by Menard 2000), the Nagelkerke R^2 (Nagelkerke 1991), the Akaike Information Criterion (AIC; Canavez et al. 1999), the Kappa value, and the Area Under the Receiver Operating Characteristics curve (AUROC; Hanley & McNeil 1982, Fielding & Bell 1997). It has been suggested that AUROC values between 0.7 and 0.8 represent 'acceptable' discrimination power while higher values indicate 'excellent' discrimination power (Hosmer & Lemeshow 1989, Jepsen et al. 2005). The Kappa statistic measures the proportion of 'specific agreement', taking into account not only correct predictions but also false positives and false negatives. An agreement is considered 'poor' if Kappa is <0.4, 'good' between 0.4 and 0.75, and 'excellent' >0.75

(Landis & Koch 1977 as cited in Fielding & Bell 1997). After eliminating in a backward stepwise procedure the variables with the least explanatory power ($P > 0.3$), we calculated the AIC for all possible combination of the remaining variables. The lowest AIC was used to select the 'best model' for each city, while the other model characteristics were used to evaluate the predictive power of the models. Some of these predictors (e.g. % correct predicted) can have misleadingly high values even if no explanatory variable is included. Therefore we calculated a null model, including only DistWater as a factor since this proved to have no explanatory power ($P > 0.9$ for all towns/cities). We included DistWater as a factor rather than using only the intercept because this was necessary in order to obtain values for the r_L^2, the Nagelkerke R^2 and the AUROC. Since the values for the percentage of correct predictions and the Kappa proved to be exactly the same whether including DistWater or using the intercept only, we are confident that the values given for the other parameters also represent the real null model. Variables in models selected by the AIC that were not significant at $P < 0.05$ were not included in the final best model for that data set. We determined the best model (lowest AIC) for each town/city and the complete data set separately. Additionally, the best model selected for Hastings (the largest data set) was then applied to the other three areas and to the complete data set in order to check the generality of the model.

Although binary logistic regression does not assume a linear relationship between predictor variable(s) and dependent variable(s), it assumes a linear relationship between the logits of the dependent and the predictor. As suggested by Garson (2006), we performed a Box-Tidwell Transformation test (Box & Tidwell 1962) to check for non-linearity in the logits of the variables used. Such non-linear relationships were found for PopDensity, FreeStand and CarDensity. We therefore transformed these originally continuous variables into categorical ones. Initially, we divided the data into three categories with the same number of cases in each category, based on the random point subset in Hastings. The categories of PopDensity were later regrouped to allow comparison between different data sets and to reflect the emerging pattern better (see Table 2).

To avoid using highly correlated variables, we calculated the Variance Inflation Factor (VIF) for all variables in a linear regression. Only the percent coverage predictors, and PopDensity and CarDensity, were highly correlated (VIF >10, see recommendation by Quinn & Keough 2002:128). Thus, for further analyses, we used only one variable in each case. Preliminary analyses suggested that PopDensity was the better predictor, so CarDensity was dropped from further analyses. Percentage coverage predictors added up to 100% and were thus all highly correlated, so that only one of these predictors should be used at the same time. Therefore, we tried each predictor separately with the combination of predictors that had the lowest AIC when not including any percentage coverage predictor. %Unsuitable gave the lowest AIC and P-values and was therefore used solely in further binary logistic regression analyses. After removing these correlated variables, none of the VIF values for the remaining variables exceeded 2.2, suggesting acceptable levels of co-linearity.

Influential outliers can potentially change the outcomes of models. We therefore calculated Cook's distance to indicate the influence that each observation had on the overall result. Values that exceeded 50% of the F-distribution at $df = p$, $n-p$ (where p was the number of variables or categories, and n the sample size) were considered too influential (Cook & Weisberg 1982). None of the data exceeded this threshold.

Additionally, we calculated the medians of sett and random point locations for all continuous variables, separately for each city and for the entire data set. These were compared using Mann-Whitney U-tests, with p-values corrected using the Hochberg-Bonferroni method (Quinn & Keough 2002). P-values <0.0005 were considered significant.

Results

For each town or city, the 'best model' and the characteristics of that model are listed in Table 3. The table also provides, for purposes of comparison, the characteristics of the Hastings model for the other three towns or cities and for the entire database, and the characteristics of the null model. Though the correlation coefficients (r_L^2 and Nagelkerke R^2) given in Table 3 do not correspond directly to Pearson's correlation coefficient, they point to 'weak' to 'modest' overall correlations following the classification for Pearson's correlation coefficients by Fowler & Cohen (1990). The Kappa statistics point to 'good' agreement, whereas all AUROC

Table 3. Model characteristics for the 'best' model on badger sett distribution for the respective town or city (i.e. the model with the lowest AIC), the model including the factors selected by the best model of Hastings (Hastings' model) for the different towns or cities and for the whole data set, and the null model.

Town/city	% correct predicted	Kappa	r^2	Nagelkerke r^2	AIC	AUROC
Hastings	best model: Habitat, Slope, PopDensity, DistGarden, DistSett, %Unsuitable					
> best model	79.7	0.433	0.248	0.364	-55.6	0.828
> (Null model)	(73.4)	(0.0)	(0.067)	(0.011)	(94.4)	(0.559)
Brighton	best model: Habitat, PopDensity, DistScrub					
> best model	84.8	0.549	0.339	0.475	-14.62	0.849
> Hastings' model	84.8	0.588	0.363	0.503	-12.61	0.870
> (Null model)	(72.5)	(0.0)	(0.014)	(0.023)	(26.23)	(0.589)
Swindon	best model: Habitat, Slope, DistGarden, DistSett					
> best model	91.2	0.643	0.461	0.570	-171.43	0.917
> Hastings' model	91.2	0.637	0.466	0.576	-165.3	0.920
> (Null model)	(83.9)	(0.0)	(0.021)	(0.031)	(-43.98)	(0.612)
Yeovil	best model: Habitat, DistArable, DistAllotment, DistSett, %Unsuitable					
> best model	88.2	0.566	0.387	0.498	-134.1	0.902
> Hastings' model	85.2	0.450	0.376	0.487	-122.9	0.892
> (Null model)	(82.8)	(0.0)	(0.0)	(0.0)	(-24.12)	(0.504)
All cities	best model: Habitat, Slope, PopDensity, DistGarden, DistSett, %Unsuitable					
> best model	82.7	0.440	0.270	0.381	-313.294	0.847
= Hastings' model						
> (Null model)	(78.1)	(0.0)	(0.001)	(0.002)	(74.277)	(0.550)

values indicate 'excellent' discrimination capacity in every model except the null models. Thus, for each individual town or city and for the entire data set, it was possible to derive a model that predicted sett locations satisfactorily in terms of a relatively small number of variables.

The odds-ratios for the variables that were selected for 'best models' and their respective significance levels are shown in Table 4. The odds-ratio is the predicted change in the odds (i.e. the probability that a sett is present over the probability that no sett is present) when the independent parameter changes by one unit (Quinn & Keough 2002). For the interpretation of the values of the specific odds in this case it should be kept in mind that the unit is 1 m for the 'Distance' variables, 1% for the 'Percentage Coverage' variables, and 1° for Slope. The best predictor (and the only one that was chosen for all four towns or cities in the model selection procedures) was the habitat where the sett was actually located, namely, Habitat category 3. This habitat, which included scrub, wasteland, woodland and allotments, was always most preferred, followed by private gardens for all cities except Swindon. A second predictor showing a consistent relationship across all towns or cities, though not chosen in the best model in all cases, was Slope (i.e. the steeper the slope the more likely a sett was to be present). To summarise, locations with

Table 4. Odds-ratios of explanatory factors for badger sett presence or absence in four towns or cities and for the complete data set (All cities). Only factors that appear in the 'best model' for a given city and are significant at $P \leq 0.05$ are listed. Odds-ratios >1 correspond to positive correlations, ratios <1 correspond to negative correlations. *** = $P \leq 0.001$. ** = $P \leq 0.01$. * = $P \leq 0.05$. A positive correlation for slopes signifies that the steeper the terrain the more likely sett presence is. A negative correlation between distance to nearest habitat patch or sett means that closer distances correspond to a higher likelihood of sett presence. For %habitat coverage, it signifies that setts are more likely to be found where this habitat type covers less area.

Predicting	Town/City				
factor	Hastings	Brighton	Swindon	Yeovil	All cities
Habitat	***	***	***	***	***
2	5.357	3.006	0.216	4.1	1.345
3	22.4	31.095	4.795	98.254	11.653
Slope	1.043 **		1.454 ***		1.039 **
PopDensity	**	**			*
1	0.454	0.162			0.447
2	1.058	1.338			0.919
DistGarden	0.990 *		0.967 *		0.987 ***
DistScrub		0.990 *			
DistFarmland				1.002 **	
DistWood					
DistPlayfield					
DistWater					
DistAllotment				1.001 *	
DistSett	0.996 ***		0.997 ***	1.003 **	0.998 ***
%Unsuitable	0.975 ***				0.989 ***

For Habitat, 2 indicates gardens and 3 scrub, wasteland, woodland and allotments compared to arable land & playfields.

For PopDensity, 1 indicates 0-25 humans/ha and 2: 26-74 humans/ha compared to ≥75 humans/ha setts were significantly different from locations without sett with regard to several factors, but the importance and identity of these factors varied to some extent between towns or cities.

Other predictors were less consistent between cities considering only the binary logistic regression models. However, some patterns emerge regarding the median values for all continuous variables at sett sites and random locations (Table 5). Firstly, the median distance to the nearest private garden was lower (though not significantly so) for setts than for non-sett locations in three towns or cities, whereas in Brighton it was (not significantly) higher. This corresponds to significant odds-ratios of < 1.0 for Hastings, Swindon and the complete data set. Secondly, the median percentage of unsuitable land was lower for areas centred on setts than for areas centred on random points. On average, this corresponds to a higher percent coverage with scrub, wasteland, woodland and allotment gardens in areas with setts. Thirdly, the median distance to the nearest scrub, wasteland, woodland, allotment gardens and neighbouring sett was consistently shorter for sett locations than for random points, though only in Brighton did this result in an inclusion of the parameter DistScrub in the best model. Nearest distance to farmland, playing fields and water, and the percentage covered by private gardens, playing fields and farmland, were neither consistent in their direction of correlation between cities, nor were they consistently chosen for the best models.

Finally, there was evidence of a non-linear relationship between setts and PopDensity, with intermediate human densities favouring the presence of setts in all four towns or cities (Fig. 1). In Swindon, however, sett density peaked at a lower absolute human population density than in the other three cases.

Discussion

Three of the four towns or cities that we investigated (Brighton, Yeovil and Hastings) had main sett densities of 0.020, 0.021 and 0.024 main setts.ha^{-1}, respectively. This is somewhat less than has been reported for high-density rural badger populations in the UK, for example in Gloucestershire (Cheeseman et al. 1981: 0.043 main setts.ha^{-1}; Rogers et al. 1997: 0.029 main setts.ha^{-1}) and Oxfordshire (Macdonald et al. 2004: 0.714 main setts.ha^{-1}), but is comparable to results for the suburban Bristol

Table 5. Median values and minimal and maximal values (Slope in degrees, DistHabitat, %Habitat) for independent variables for locations with sett presence and random points without setts in different cities and/or complete data set. Values in bold italics are significant after Hochberg-Bonferroni correction (values of P < 0.0005 were accepted as significant) and values in simple italics are significant at P < 0.05 (Mann-Whitney U-tests). For %Farmland and %Allotment, where medians are often zero, the means are given in parentheses.

	Median values										Min-max values over all town/cities		
	Hastings		Brighton		Swindon		Yeovil		All town/cities				
Variable	No Sett	Sett	No Sett	Sett	No Sett	Sett	No Sett	Sett	No Sett	Sett	No Sett	Sett	Relationship
Slope (in °)	***5.7***	***8.1***	*6.1*	*9.5*	***1.0***	***5.1***	2.9	4	***3.2***	***6.8***	0-69.6	0-48.9	+
DistGarden (in m)	11.7	11.3	16.9	29.9	6.9	6.4	8.3	13.3	10.1	11.3	0-364.6	0-186.2	Inconsistent
DistScrub (in m)	*56.3*	*31.0*	***112.4***	***0.0***	***91.9***	***22.3***	***82.2***	***0***	***76.7***	***13.9***	0-533.8	0-388.8	-
DistFarmland	377.1	423.2	*1025.1*	*1374.8*	*684.3*	*488.0*	*277.8*	*390.25*	461.9	534.5	0-2325.3	0-1946.3	Inconsistent
DistWood	***81.1***	***6.7***	231.6	215.5	**151.1**	***29.3***	*198.6*	*150.5*	***134.5***	***51.2***	0-667.3	0-575.7	-
DistPlayfield	123.9	113.1	80.0	83.1	93.5	114.8	*156.0*	*81.45*	113.2	105.0	0-1208.1	0-1003.3	Inconsistent
DistWater	*142.6*	*140.0*	499.4	609.2	*222.8*	*149.6*	260.9	317.6	*214.9*	*173.2*	0-1336.2	0.1-1149.2	Inconsistent
DistAllotment	692.9	547.3	***310.6***	***118.2***	600.4	445.6	613.0	601.7	*602.2*	*507.2*	0-3546.6	0-3727.4	-
DistSett	***244.0***	***113.0***	***248.9***	***120.4***	***646.3***	***173.9***	251.3	253.9	***304.8***	***148.9***	10.8-2121.1	13.5-1133.5	- (Except Yeovil)
%Unsuitable (in %)	*30.9*	*21.2*	*55.1*	*30.0*	***45.5***	***24.6***	42.7	34.4	***39.1***	***26.3***	0-99.3	0-90.7	-
%Garden	18.8	24.6	15.9	11.0	25.7	21.6	29.7	28.75	23.1	21.4	0-89.6	0-91.3	Inconsistent
%Scrub	***22.1***	***30.8***	***13.3***	***27.6***	***11.0***	***24.6***	***7.3***	***17.9***	5.6	19.9	0-99.5	0-92.2	+
%Farmland	0 (12.5)	0 (11.2)	0 (3.1)	0 (1.4)	*0 (2.5)*	*0 (7.6)*	0 (16.7)	0 (6.3)	0 (10.1)	0 (8.5)	0-99.9	0-95.8	Inconsistent
%Playfield	0.1	0.4	4.1	4.0	2.6	0.6	*0.0*	*4.65*	0.3	0.8	0-100	0-65.7	Inconsistent
%Allotment	0 (0.9)	0 (1.2)	***0 (4.2)***	***0.4 (11.7)***	0 (0.7)	0 (1.0)	0 (0.6)	0 (1.6)	0 (1.1)	0 (2.5)	0-74.1	0-90.1	+

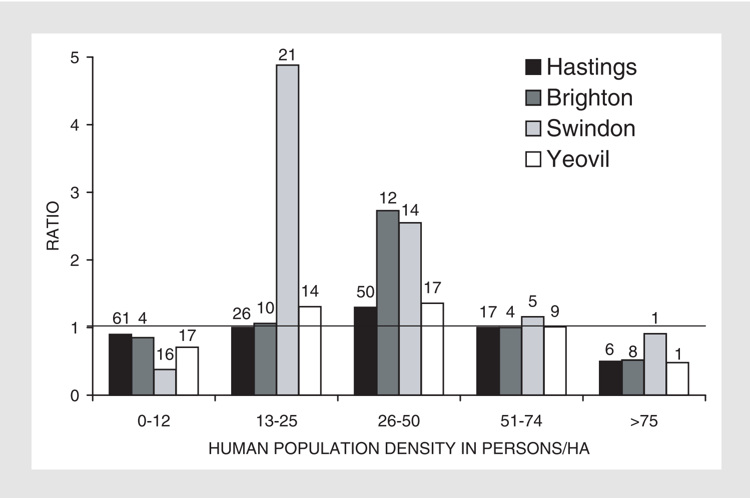

Figure 1. Ratio of observed to expected number of badger setts in the English cities of Hastings, Brighton, Swindon and Yeovil (relative to available area). The expected number of badger setts was calculated by dividing the total number of setts in the respective town or city by the total urban area (in ha) and multiplying by the area covered by census districts with the relevant human density. Values >1 indicate a higher proportion of badger setts than expected, while values <1 indicate a lower than expected proportion of setts. Figures over the bars give the actual number of setts for that category.

(Harris 1984, Harris & Cresswell 1987: 0.027 main setts.ha^{-1}). In the fourth of our towns, Swindon, there were only 0.003 main setts.ha^{-1}, which is comparable to survey results from various rural regions of the UK (0.002-0.018 setts/ha, recalculated from Cresswell et al. 1989) and considerably higher than in many parts of continental Europe (Johnson et al. 2002). For example, in eastern Poland, main sett density can be as low as 0.0003 main setts.ha^{-1} (Kowalczyk et al. 2000). Thus, our results confirm that badgers can achieve relatively high population densities in urban environments in the UK, despite the potential for human-badger conflicts.

An important question arises as to the generality of these results. The towns and cities that we investigated were chosen because they had been well surveyed for badger setts, not explicitly because they were known to harbour unusually large badger populations. Nevertheless, the presence of local badger groups and other individuals interested in recording the presence of badger setts is likely to correlate with high badger population densities. On the other hand, it is clear that problems involving urban setts are widespread in the UK, and especially in the southeast and southwest of England (Matthews & Wilson 2005; J. Davison, unpubl. data). Therefore, it is unlikely that the urban sett densities that we report here are uniquely high, though it remains to be determined how representative they are of the country as a whole.

Our results also identify specific features associated with a higher likelihood of sett presence in urban landscapes. The single most important factor predicting sett location (i.e. highest odds-ratios and lowest P-values; see Table 4) proved to be the type of habitat in which the sett in question was located, followed by the slope of the ground at that location. In rural areas of Denmark, Italy and England, setts have likewise been associated with sloping ground and with cover in the form of scrub or trees (Thornton 1988, Smal 1995, Wright et al. 2000, Jepsen et al. 2005, Remonti et al. 2006). Factors that would be expected to relate to foraging activities, such as the percentage coverage provided by habitats such as scrub/wasteland or allotments, were of less importance, though they did explain some of the variation. Similarly, Thornton (1988) found that factors thought to reflect sett site availability were more important indicators of badger density than factors thought to reflect food availability, in rural badger populations (see also Neal & Roper 1991). Nevertheless, habitats such as scrub, wasteland, woodland and allotments (and gardens, see below) are certainly related to foraging activities of urban badgers, probably because they offer protection against human interference as well as providing food.

Badgers are potentially adaptable and opportunistic foragers, though particular populations often concentrate on one or a few easily available foods (Roper 1994, Rosalino et al. 2005). In the very heterogeneous environment of a city, therefore, they may switch between relatively 'natural' foraging habitats where there is little human interference, and scavenging of anthropogenic food resources (Harris 1984). The latter are likely to be energy rich and locally abundant, especially if provided deliberately by humans, so that a few such sources (e.g. a few gardens) might be sufficient for a social group. In this case, the percentage coverage of gardens might not reflect the true importance of gardens as a source of food.

Anthropogenic food sources may also explain the finding that badgers prefer areas with intermediate human population densities. Though the parameter of human population density was only included in two of the models (for Hastings and Brighton), a similar tendency was apparent in the other two cities (Yeovil and Swindon; see Fig. 1). This may be because in the modelling procedure, we had to use the same population density categories for all cities, whereas, in reality, Swindon and Yeovil had only a few areas that were highly populated, while Brighton had only a few with a low human population density. Other studies modelling badger sett presence over larger scales have found a negative correlation between human population density and sett density (Schley et al. 2004) or a negative relationship between sett density and the extent of urbanised areas (Wright et al. 2000). For urban badgers, however, the probability of having one or more food-providing humans in the vicinity of the sett will rise with increasing human population density, until the latter becomes so high that the associated reduction in foraging grounds or suitable sites for setts, and increasing amounts of traffic or other forms of anthropogenic disturbance, will offset these benefits.

Insights into badger ecology can be gained not only from parameters that contribute significantly to predicting sett presence but also from parameters that do not do so, or do so only inconsistently. For example, playing fields and other areas of mown grass might have been expected to constitute a major foraging resource for badgers in search of earthworms (e.g. Kruuk 1978, 1989). However, neither distance to, nor percentage coverage of, such habitat was a consistent predictor of sett presence; and a radio-tracking study in the Brighton study area confirms that urban badgers make little use of mown grassland for foraging purposes (J. Davison & M. Huck, unpubl. data). This may indicate that badgers are less willing to venture onto open grassland in urban than in rural habitats, owing to the greater threat of disturbance in urban environments.

Management implications

Our results point to surprisingly high-density, and apparently well-established, populations of badgers in at least some English towns and cities, despite the potential that this causes for human-badger conflicts. In the past, urban badger-related problems have been dealt with on a case-by-case basis, usually by excluding badgers from a problem sett and destroying the sett in question (Matthews & Wilson 2005). Our results suggest the need for a more strategic approach to the management of such problems, based on acceptance that badgers are likely to remain a permanent feature of the UK urban landscape. In addition, our analysis points to factors that are relevant to the selection of sett sites by urban badgers and to the ecology of the animals themselves. Ability to predict badger presence by features of the physical habitat, by the proximity of other setts and by moderate human population density may help councils and householders to identify potential sites of badger-related problems before these problems become acute. Differences in the influence of certain parameters, such as human population density, between rural and urban populations show that badgers adapt to the specific conditions offered by urban environments. This may also be relevant for the understanding of other species that inhabit cities and that may come into conflict with humans, such as foxes, stone martens and racoons.

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