Journal of Zoology

Journal of Zoology. Print ISSN 0952-8369

Urban badger setts: characteristics, patterns of use and management implications

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Keywords
burrow; den; *Meles meles*; radio tracking; resting site; sett survey; wildlife damage.

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Editor: Nigel Bennett

Received 20 September 2007; revised 16 January 2008; accepted 29 January 2008

doi:10.1111/j.1469-7998.2008.00424.x

Abstract

Damage caused by badger setts is an important source of human–carnivore conflict in urban areas of the UK, yet little is known about the spatial distribution of urban badger setts or their pattern of occupation. We compared the density, spatial distribution and size of setts in four urban and two rural study areas in the UK and assessed the applicability to urban systems of distinguishing between ‘main’ and ‘outlier’ setts. In addition, we used radio-telemetry to investigate diurnal patterns of sett use in one urban area (Brighton). It was possible to distinguish between main and outlier setts in urban environments, and local sett densities were comparable in urban and rural areas. However, urban badgers used substantially fewer setts than did a nearby rural population, and they spent a smaller proportion of days in outlier setts. Social groups with larger ranges had more setts available to them and, within groups, individuals with larger ranges used more setts. Outliers appeared to serve multiple functions, including allowing efficient and safe travel to important parts of the home range. We conclude that sett densities can be high in urban habitats, suggesting significant potential for sett-related problems to arise. The fact that urban main setts can be distinguished from outliers enables management actions to be tailored accordingly. In particular, because main setts seem to represent a particularly valuable resource to urban badgers, alternatives to the closure of problem main setts need to be considered.

Introduction

The presence of carnivores in urban areas can result in conflict with humans in a number of ways, including direct attacks (Gomper, 2002), disease transmission (Jenkins & Craig, 1992) and damage to property (Harris, 1984). In the case of badgers *Meles meles*, Natural England currently receives *c*. 200 applications per year from householders or other urban landowners for licences to interfere with badgers or their setts for purposes of damage prevention (Ward, 2007). Most of these applications relate to setts being excavated in gardens or in proximity to buildings or other structures such as roads or waterways. Management of such problems usually involves destroying all or part of a problem sett if it is considered that other setts are available to the resident badgers.

Typically, a group of badgers has multiple setts within its territory (Kruuk, 1978; Roper, 1992) but makes greatest use of a single large ‘main’ sett. Smaller setts, used occasionally, are termed ‘outlier’ setts (Kruuk, 1978). While the benefits to badgers of using a main sett are believed to include thermoregulatory advantage and predator avoidance (Neal & Roper, 1991), it is less clear why they use outlier setts. Existing evidence suggests that outlier use has multiple functions including enabling animals to reduce their ecto-parasite load (Roper *et al*., 2001), avoid harassment or breeding suppression (Neal, 1977), minimize the costs of travelling between resting and foraging areas (Kruuk, 1978) or take emergency refuge (Butler & Roper, 1995; see summary of hypotheses in Table 1).

The distinction between main setts and outliers is crucial in the application of damage mitigation procedures because destruction of a main sett is likely to have more serious consequences for the resident badgers than destruction of an outlier. Yet, main setts are more likely to cause problems because of their larger size and because they are permanently occupied by an entire social group of badgers. While the characteristics of setts and their use have been relatively well studied in rural environments, no detailed information is available from urban areas. It cannot be assumed that sett use is similar for both urban and rural badgers, because there is evidence that ranging, territorial and social behaviour differ between the two environments (Harris, 1984; Cresswell & Harris, 1988; Davison, 2007).

We aimed to collect data on the characteristics and use of urban badger setts in order to aid the development of a management strategy for dealing with urban badger problems. We analysed sett data from four urban and two rural study areas in order to compare the density, spatial distribution and external characteristics of setts. In addition, we

Table 1 Hypotheses to explain the use of outliers by badgers and predictions resulting from each hypothesis

Hypothesis	Description	Predictions	Rationale
Ectoparasite avoidance	Frequent moving between setts allows animals to reduce their ectoparasite load (Roper *et al*., 2001)	Ectoparasite load of animals will be positively related to the number of different setts they use or the proportion of days spent at outliers	Highly infected animals should make a greater effort to reduce their ectoparasite load. Such a relationship was found by Roper *et al.* (2001)
Territory marking	Animals use setts as territory markers (Kowalczyk, Zalewski & Jedrzejewska, 2004)	Adult males will use more setts or spend a greater proportion of days at outliers than other age and sex classes	Patterns of bite wounding (Delahay *et al*., 2006) and frequency of visits to boundary latrines (Brown, Cheeseman & Harris, 1992) suggest that adult males are most active in territory defence
		The number of used setts or proportion of days spent at outliers will be greater in spring than during other seasons	There is a peak in territorial behaviour in spring (Neal & Cheeseman, 1996)
Avoidance of harassment	Animals avoid harassment from other group members by using outliers (Neal, 1977)	Young animals will spend a greater proportion of days at outliers than other age and sex classes	Young animals are likely to suffer most harassment from dominant animals in the group (Neal, 1977)
Efficient travel	Outliers allow efficient access to important areas within badgers' ranges (Kruuk, 1978)	Animals with larger ranges will use more setts or spend a greater proportion of days at outliers	Wide-ranging animals will gain the greatest benefit from minimising travel between setts and areas used in the course of night-time movements
		Used outliers will be particularly associated with core foraging areas	The most efficient placement of outlier setts will be in the areas of greatest night-time use
Emergency shelter	Animals use outliers for refuge from predators or disturbance if they are unable to return to the main sett for this purpose (Butler & Roper, 1995)	Animals with larger ranges will use more setts or spend a greater proportion of days at outliers	Wide-ranging animals will require emergency refuge in areas distant from the main sett
		Used outliers will be particularly associated with core foraging areas	Emergency refuge will be most frequently required in areas that are most heavily used at night

It was not possible to develop different predictions with which to distinguish the 'efficient travel' and 'emergency shelter' hypotheses.

described patterns of sett use in a single intensively studied urban badger population. Our main aims were to determine (1) whether main setts can be meaningfully distinguished from outlier setts in urban environments; (2) whether these two types of sett are spatially distributed in the same manner in urban and rural environments; and (3) whether urban badgers use these two types of sett in the same way as rural badgers. In addition, we discuss the results in relation to various hypotheses concerning the function of outlier setts (Table 1).

Methods

Urban badger sett characteristics

Badger sett data

Records of badger sett presence were available from four urban (Brighton, Hastings, Yeovil and Swindon) and two rural (Woodchester Park and South Downs) study areas in southern England (Table 2; Fig. 1). The rural areas were included for comparative purposes and were felt to be relevant for several reasons. First, previous work in these areas has shown that badgers display the characteristic rural pattern of organization into stable social groups, with each group typically defending an exclusive territory and using a single main sett and a number of outliers. Second, the South Downs area was geographically close to the urban study areas of Brighton and Hastings, and so observed differences in sett characteristics are likely to reflect urbanization *per se* rather than other larger scale ecological or historical conditions.

Data were collected by the authors in the case of Brighton; by local badger groups or other interested parties in the case of Hastings, Yeovil and Swindon; and during the course of long-term scientific field studies in the cases of Woodchester Park and the South Downs. Data from Brighton related to a restricted study area in the east of the city, while data from Hastings, Yeovil and Swindon related to the whole of the relevant urban areas as defined by 2001 National Census urban area boundaries (National Statistics website: www.statistics.gov.uk). Rural study area boundaries were as described in previous studies (South Downs: Ostler & Roper, 1998; Woodchester Park: Rogers *et al*., 1997). Sett locations were recorded using eight-figure grid references or on field maps and were digitized using Arcview GIS 3.3 (ESRI, California, USA).

During surveys, setts were categorized as ‘main’ or ‘outlier’ setts following established criteria, in all study areas except Swindon (Table 2). Briefly, main setts usually have more than five entrance holes, large spoil heaps and obvious paths away from and between entrances, and show signs of occupation throughout the year, while outlier setts are smaller and are only intermittently occupied (Kruuk, 1978; Harris, Cresswell & Jefferies, 1989). In parts of the Brighton, Woodchester Park and South Downs study areas, behavioural observations and radio tracking data were also taken into account when classifying setts. Entrance hole counts were carried out at all setts in the Brighton, Hastings and South Downs study areas, and were used as a proxy measure for sett size because setts with more entrance holes are larger (in terms of underground volume) and contain more sleeping chambers (Roper, 1992).

Sett size

Generalized linear models (GLMs) were used to compare entrance hole counts in urban (Brighton and Hastings) and nearby rural (South Downs) study areas. Separate analyses were carried out for main and outlier setts, with land use (urban or rural) entered as a fixed effect and quasi-Poisson error terms used to account for over-dispersion.

Sett distribution

We analysed the spatial dispersion of setts by calculating Ripley’s K-function (Ripley, 1976), using the SPLANCS package for R (Rowlinson & Diggle, 1992). Ripley’s K-function calculates the proportion of all points in a defined study area that fall within a given distance (t) of individual points. $K(t)$ was calculated for values of t between 0 and 1000 in 50-m steps, using Diggle’s (1983) weighted edge correction. If events follow complete spatial randomness (CSR), the expected number of points in a circle of radius t is $n\pi t^2$, where n is the density of points within the whole study area. Commonly, a standardized version of the K-function is calculated, namely the L-function, derived by subtracting the observed from the expected (i.e. assuming CSR)

Table 2 Datasets used in comparisons of urban and rural sett characteristics

Dataset	Land use	Area (km^2)	Sett categories	Size	Data collection	Years	Source
Brighton	Urban	1.86	Y	Y	Radio tracking and field survey	2004–2007	This study
Hastings	Urban	19.50	Y	Y	Field survey	1996	HBPG
Yeovil	Urban	12.47	Y	N	Field survey	1995–2005	J. Brown
Swindon	Urban	40.51	N	N	Field survey	1993–2002	SBG
Woodchester Park	Rural	6.42	Y	N	Radio tracking and long-term field study	2007	CSL
South Downs	Rural	28.33	Y	Y	Radio tracking and long-term field study	1992–1993	J. Ostler

‘Sett categories’ and ‘Size’ denote whether assessments of sett category (into ‘main’ or ‘outlier’ sett) or entrance hole counts were made. ‘Years’ shows the period during which sett records were collected. Key to organizations responsible for the collection of sett data: CSL, Central Science Laboratory; HBPG, Hastings Badger Protection Group; SBG, Swindon Badger Group.

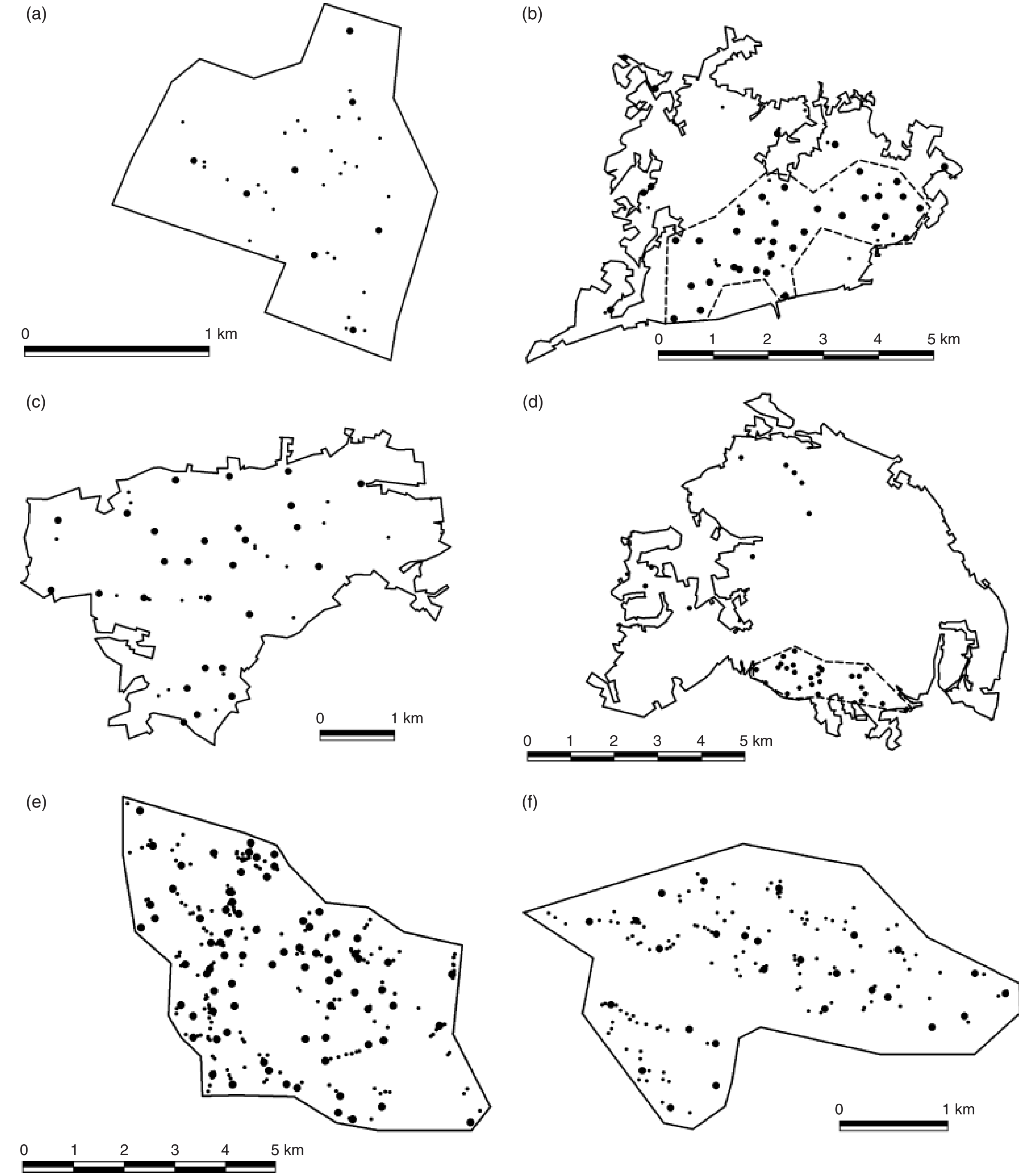

Figure 1 Study areas: (a) Brighton, (b) Hastings, (c) Yeovil, (d) Swindon, (e) South Downs, and (f) Woodchester Park. Solid lines indicate study area boundaries, large points indicate main setts and small points indicate outliers. In Swindon, all setts are represented by medium points, as no assessment of sett type was performed. Dotted lines indicate subset areas of Hastings and Swindon used in *K*-function analyses. Study areas are not to scale with one another. Crown copyright material is reproduced with the permission of the controller of HMSO.

K-function. $L(t)$ was plotted as a function of distance (t) for main and all setts in each study area (or, in the case of Swindon, only all setts). In Swindon and Hastings, subsets of study areas were used so as to exclude large areas in which no, or very few, setts were found (dotted lines in Fig. 1b and d), in order to prevent large-scale patterns of presence and absence from obscuring fine-scale patterns related to territoriality or sett function (Gerber *et al.*, 2003). Monte Carlo simulations were used to construct 95% confidence envelopes around $L = 0$, based on 1000 simulations of random distributions. An observed L-function below the confidence envelope at a given distance indicated over-dispersion at that scale (spatial lag), while a value above it indicated under-dispersion.

Sett use

Radio tracking study area

The radio tracking study area in Brighton contained six main setts and 18 outliers. Between 2005 and 2007, 18 badgers were trapped at the main setts and were fitted with radio collars (TW-3; Biotrack, Wareham, UK; Table 3). Assuming a February birth (Neal & Cheeseman, 1996), study animals were aged as yearling (12–24 months) or adult (>24 months), based on body size, reproductive condition and tooth wear. In addition, the number of fleas (Siphonaptera, particularly *Paraceras melis*) was counted by systematic examination of the skin and hair of immobilized animals on the dorsal and ventral surfaces for 1 min.

Radio tracking data collection

Animals were located at their setts using an LA12-Q receiver (AVM instruments, California, USA) and a Yagi antenna (Biotrack). Locations were recorded once every day, between 08:00 and 17:00 GMT, on at least 15 consecutive days in each calendar month (range = 15–29 days; mean = 18.2 days). Data were collected from individual animals for between 1 and 24 months (mean = 8 months; Table 3).

Seventeen of the study animals were radio tracked at night during the same period. Between 25 and 226 fixes on active animals were used to estimate group and individual ranges using 95% fixed kernels and 100% minimum convex polygons (MCPs). After examining utilization plots for each animal, a representative estimate of the core area was taken as the 70% kernel isopleth, and this was calculated for each animal. Where sufficient fixes were collected (>25 per season), seasonal estimates of individual home and core ranges were produced, using the same estimators.

Analysis of sett use

The number of setts used, proportion of days spent at different setts and duration of stays at different setts (number of consecutive days) were calculated for each animal overall, and on a monthly and seasonal basis (spring = February–April; summer = May–July; autumn = August–October; winter = November–January). The relationships between overall and seasonal measures of sett use and relevant independent variables (range size, ectoparasite load, sex, season and age) were investigated using generalized linear mixed models (GLMMs), with social group or badger nested within social group included as random error terms. GLMs were used to model the effects of main sett size (number of entrance holes) and group range size (95% kernel, ha) on the number of outliers available within group ranges and the number that were used by study animals. Where dependent variables were proportions or counts,

Table 3 Characteristics of radio-collared badgers including 95% kernel range size and measures of sett use

Group	Badger	Duration of data collection (mm/yy)	Sex	Weight at capture (kg)	Flea load	Age class	Range size (ha)	Number of setts used	Percentage time at main sett
MC	206	02/05–03/06	F	10.0	0	Yearling/adult	1.07	1	100
MC	245	02/05–08/06	F	9.9	1	Yearling	1.85	1	100
MC	226	05/05–04/06	M	6.7	1	Yearling/adult	1.47	1	100
MC	234	05/05–08/05	M	7.7	2	Adult	0.78	1	100
MC	286	06/06–07/06	M	14.9	3	Adult	2.67	1	100
FR	296	05/05–06/06	M	8.0	1	Yearling	–	2	65
FR	322	05/05–01/06	F	9.7	1	Adult	2.49	2	98.5
FR	304	07/05–02/06	M	10.7	1	Adult	4.56	5	57.9
FR	246	06/06–08/06	F	10.0	2	Yearling	2.37	1	100
FR	226	05/07–07/07	F	8.9	2	Adult	4.94	1	100
WH	264	05/05–04/07	M	9.1	0	Yearling/adult	6.25	3	87.1
WH	275	05/05–06/07	F	8.3	1	Adult	4.23	3	85.0
SM	347	11/05–01/07	M	11.0	1	Yearling/adult	3.80	1	100
SM	325	10/06–04/07	M	8.8	1	Yearling/adult	2.93	1	100
KT	207	05/06–04/07	F	8.4	1	Yearling/adult	3.53	3	90.6
WT	334	08/06–04/07	M	12.0	0	Yearling/adult	7.75	2	78.9
WT	217	05/07–07/07	F	7.6	1	Yearling	3.87	1	100
WT	317	05/07–07/07	F	7.3	0	Yearling	3.00	1	100

Age class was estimated from toothwear and a February birth assumed for all animals. Some animals progressed from yearling to adult status during the study period. 'Flea load' is a measure of the number of fleas counted during a brief examination at the time of capture on an interval scale of 0 (none)–4 (very high). Key to groups: MC, Manor Close; FR, Freshfield Road; WH, Whitehawk Hill; SM, Saint Mary's; KT, Kemptown; WT, Walpole Terrace.

binomial or Poisson error distributions were used, respectively, and models were checked for over-dispersion (Crawley, 2002). In each case, a minimum adequate model was constructed by retaining or deleting the least significant terms from a maximal model on the basis of likelihood ratio tests (LRTs; Crawley, 2002).

The location of outliers with respect to individual core ranges was also assessed by comparing the proportion of setts falling within animals' core ranges with the proportion expected, assuming that sett location was random within 95% kernel ranges. A χ^2-test for given proportions was carried out using data from six animals where outlier sett use and ranging data were available.

Results

Badger sett data

Urban main setts had significantly fewer entrance holes than rural main setts (mean urban = 12.8, rural = 19.8; GLM: parameter estimate area (urban) = −0.44, SE = 0.13, $t = -3.49$, $P < 0.001$) whereas urban and rural outliers were not significantly different in size (mean urban = 3.0, rural = 3.8; GLM: parameter estimate area (urban) = −0.24, SE = 0.16, $t = -1.53$, $P = 0.13$).

The ratio of main setts to outliers was significantly different between study areas (main:outlier ratio: Brighton = 3.5, Hastings = 0.8, Yeovil = 0.8, Woodchester Park = 4.6, South Downs = 2.5; test for equality of proportions: $\chi^2 = 47.74$, d.f. = 4, $P < 0.001$). However, there was no significant difference in sett size distributions between Brighton, Hastings and South Downs (pairwise G-tests, $P = 0.52$–0.75) or between the pooled urban distribution and the rural distribution from the South Downs area ($G = 27.24$, d.f. = 36, $P = 0.85$; Fig. 2).

Point pattern analysis revealed significant over-dispersion of main setts at scales < 570 m in both urban and rural areas (Table 4; Fig. 3). However, there was significant under-dispersion of all setts at the scale of < 150 m in urban areas other than Swindon, and at the scale of < 1000 m in rural areas (Table 4).

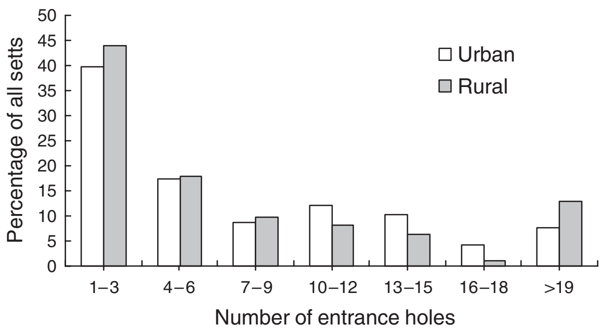

Figure 2 Size distribution of setts, as measured by the number of entrance holes, from urban (Hastings and Brighton; $n = 116$) and rural (South Downs; $n = 280$) study areas.

Table 4 Dispersion of badger setts in urban and rural study areas

		Main setts		All setts	
Habitat	Study area	Point pattern	Lag (m)	Point pattern	Lag (m)
Urban	Brighton	O	200–370	U	100–140
	Hastings	O	50–570	U	0–150
	Yeovil	O	90–450	U	0–150
	Swindon	–	–	NS	–
Rural	Woodchester Park	O	60–420	U	0–1000
	South Downs	O	50–370	U	0–1000

'Point pattern' indicates whether setts were significantly over-dispersed (O), significantly under-dispersed (U), or not significantly different from complete spatial randomness (NS). Lag indicates the spatial scale (m) at which the observed pattern occurred.

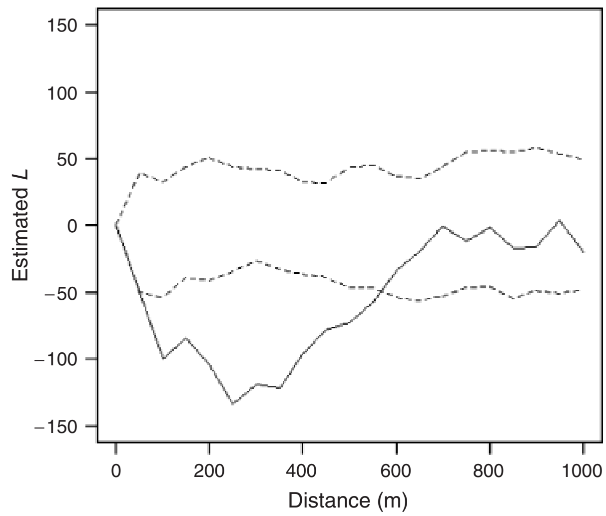

Figure 3 Ripley's L-function for Hastings main setts. The y-axis represents the L-function, where $L > 0$ indicates under-dispersion, $L = 0$ indicates randomness and $L < 0$ indicates over-dispersion. The solid line represents the L function resulting from the real data, and the dotted lines represent the 95% confidence envelope around $L = 0$, constructed using Monte Carlo simulations.

Sett use

Group ranges (100% MCP) in the Brighton urban badger population contained between 1 and 8 setts (mean = 4.7 setts), with four setts falling within two overlapping group ranges. Each group had access to a single large main sett (3–20 entrance holes) and a number of outliers, which were always smaller than the corresponding main sett (1–3 entrance holes). Animals from two groups used only their main sett for diurnal resting, while the remaining groups made use of between 1 and 5 outliers (overall mean = 1.8 outliers used per group). There was a significant positive relationship between the number of setts within a group range and the size of the range (GLM: parameter estimate = 0.26, SE = 0.10, $z = 2.53$, $P < 0.05$; Fig. 4a) and a significant negative relationship between the size of the main sett and the number of outliers used (GLM: parameter estimate =−0.16, SE = 0.07, z =−2.17, P<0.05; Fig. 4b).

All 18 study animals regularly used a main sett, whereas 11 (i.e. 61% of study animals) never used outliers (Table 3). The remaining seven badgers spent between 2 and 42% of days (mean for all badgers = 8% of days) at between 1 and 4 outliers (mean for all badgers = 0.9 outliers; Table 3). One animal (236 from WT group) spent *c.* 21% of days at the main sett of another group (WH). The mean duration of outlier stays per animal varied from 1.4 to 8.0 days (mean = 2.9 days). Up to four animals were recorded using the same main sett on the same day, while there was never more than one animal recorded at an outlier on the same day. There was a significant positive relationship between individual range size and the number of setts used overall (GLMM: parameter estimate = 0.40, SE = 0.20, z = 1.99, P<0.05; Fig. 5) and on a seasonal basis (GLMM: parameter estimate = 0.72, SE = 0.31, z = 2.36, P<0.05). However, neither sex, age, ectoparasite load nor season was significantly related to any measure of outlier use (LRTs: P>0.13), although there was some suggestion of an increase in outlier use in autumn (Fig. 6).

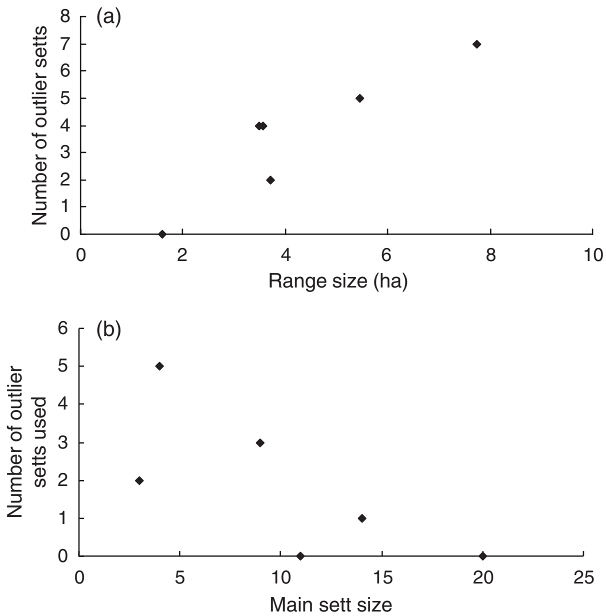

Figure 4 Availability and use of outliers within six urban badger group ranges: (a) number of available setts in relation to group range size (95% kernel; ha); and (b) number of used setts in relation to main sett size (number of entrance holes).

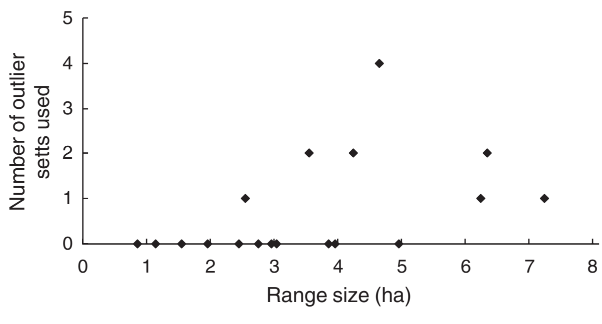

Figure 5 Relationship between range size and the number of outlier setts used by 17 urban badgers.

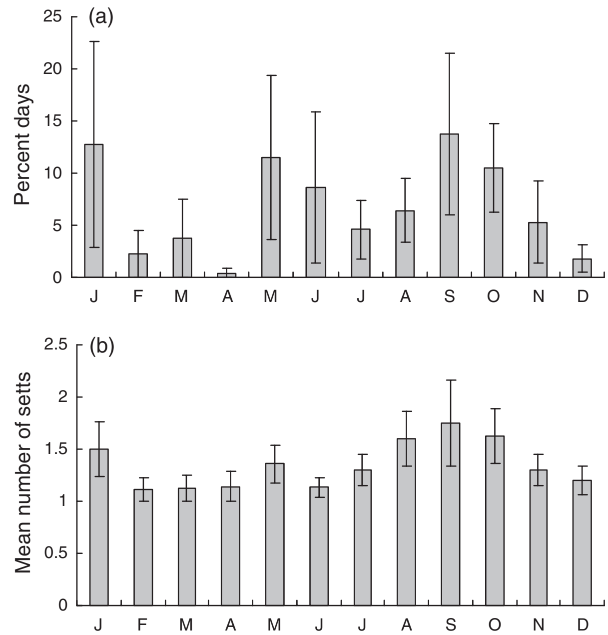

Figure 6 Sett use by 18 urban badgers throughout the year: (a) mean proportion of days (±SE) spent at outliers per month; (b) mean number of setts (±SE) used per month.

Used outliers were found in individual animals' core areas more often than would be expected if setts were located randomly within 95% kernel ranges (total proportion of used setts in core areas = 0.77, total proportion of 95% kernel ranges within core areas = 0.33; test for given proportions: χ^2 = 17.40, d.f. = 6, P<0.01).

Discussion

Urban sett characteristics

On the basis of size and level of use, Kruuk (1978) distinguished two types of sett, namely main setts and outliers. Other authors have confirmed the validity of this classification, which has also been used in local and national sett surveys in rural areas of the UK and elsewhere (e.g. Wilson, Harris & McLaren, 1997; Schley, Schaul & Roper, 2004). In the urban areas studied here, surveyors were also able to distinguish main setts from outliers on the basis of external criteria such as the number of entrances, signs of use and size of spoil heaps. Although it is impossible to validate this system of classification independently, similarities among rural and urban areas in terms of relative sett sizes and sett dispersion suggest that different surveyors classified setts in a consistent manner. Additionally, the patterns of sett use

Table 5 Main sett densities and total sett densities from urban and rural areas in the present study and other study areas

Habitat	Study area	Number of study areas	Main sett density (km^{-2})	Sett density (km^{-2})
Urban	Brighton[a]	1	4.30	19.40
	Yeovil[a]	1	2.17	3.93
	Hastings[a]	1	2.05	3.69
	Swindon[a]	1	–	0.89
	Bristol[c*]	1	1.88	16.6
	Bristol[b]	1	0.29	2.67
	Bradford[d]	1	0.11	0.16
	Tokyo (Japan)[f]	1	–	>2.53
	Copenhagen (Denmark)[e]	1	–	0.06–0.09
Rural	Woodchester Park[a]	1	4.21	23.40
	South Downs[a]	1	2.79	9.60
	England[ghijk]	7	0.48–8.75	0.98–69.8
	Eire[lm]	4	0.34–2.27	–
	Denmark[n]	3	0.88–2.0	4.80–5.40
	Kazakhstan[o]	1	0.65	–
	Scotland[p]	3	0.58–0.63	–
	Great Britain[q+]	–	0.25	0.71
	Germany[rs]	2	0.22–0.24	–
	Russia[tuv]	3	0.12–0.23	–
	Italy[wx]	1	0.11–0.20	–
	Czech Republic[y]	1	0.18	–
	Luxembourg[z+]	–	0.17	0.29
	Spain[01]	2	0.04–0.16	–
	Netherlands[2]	1	0.01–0.13	0.05–0.87
	Latvia[3]	1	0.11	–
	Poland[456]	3	0.03–0.11	0.07
	Norway[7]	1	0.07	–
	Lithuania[8]	1	0.02–0.05	–

All urban sett densities and rural sett densities from the present study are presented individually, while other rural sett densities are grouped by country. Where data from more than one area per country were available, or repeat surveys of the same area gave different estimates, a range of values is presented.

Sources of sett densities: a, this study; b, Harris (1984); c, Cresswell & Harris (1988); d, Jenkinson & Wheater (1998); e, Aaris-Sørensen (1987)[‡]; f, Kaneko, Maruyama & Macdonald (2006); g, Cheeseman *et al.* (1981)[‡]; h, Macdonald *et al.* (1996)[‡]; i, Ostler & Roper (1998); j, Cheeseman *et al.* (1985)[‡]; k, Macdonald & Newman (2002); l, Feore & Montgomery (1999)[‡]; m, O'Corry-Crowe *et al.* (1993)[‡]; n, Jepsen *et al.* (2005); o, Lobachev (1976)[‡]; p, Kruuk & Parish (1982)[‡]; q, Wilson *et al.* (1997); r, Stiebling & Schneider (1999)[‡]; s, Preimer (1999)[‡]; t, Ivanter (1973)[‡]; u, Shaparev (1977)[‡]; v, Likhachev (1956)[‡]; w, Biancardi & Rinetti (1988)[‡]; x, Quadrelli (1993)[‡]; y, Pelikan & Vackar (1978)[‡]; z, Schley *et al.* (2004); 0, Rodriguez *et al.* (1996)[‡]; 1, Virgos & Casanovas (1999)[‡]; 2, van Apeldoorn, Vink & Matyastik (2006); 3, Zoss (1992)[‡]; 4, Kowalczyk, Bunevich & Jedrzejewska (2000); 5, Gosczynski & Skoczynska (1996)[‡]; 6, Gosczynski (1999)[‡]; 7, Brøseth, Bevanger & Knutsen (1997); 8, Ulevicius (1997)[‡].

[‡]Consulted in Kowalczyk *et al.* (2000).

[‡]Study area within Bristol used by authors for radio tracking study.

[*,+]Results of nationwide survey.

revealed by radio tracking in the Brighton study area support a functional distinction between main and outlier setts: that is, setts that were classified as main setts on the basis of their external appearance were found to be continuously occupied by entire social groups, whereas setts classified as outliers were only intermittently occupied by single animals . We conclude, therefore, that the classification of setts based on survey data is as valid in urban environments as it is in rural ones.

However, urban main setts were significantly smaller than rural main setts, perhaps reflecting a limit on space for sett construction in urban areas. Alternatively, because setts tend to increase in size through time as a result of digging by successive generations of animals (Roper, 1992; Ostler & Roper, 1998), the smaller size of urban main setts may reflect their more recent origin or a lower average social group size in urban badgers.

Taken as a whole, estimates of urban sett density from this study and others are higher than those relating to rural habitats in many countries across the badger's range (Table 5). They are matched only by rural sett densities in England, Eire and Denmark and exceeded only by some rural sett densities in England. Thus, urban setts attain densities that are high in the context of the badger's entire range and similar to those of geographically close rural areas. Nonetheless, it is clear that not all urban habitat is suitable for badgers, because setts were absent from large parts of Swindon and Hastings (Fig. 1b and d).

Patterns of main sett dispersion were very similar for urban and rural areas, with over-dispersion at a spatial lag of <570 m in all areas. In rural areas, over-dispersion of main setts has been attributed to territoriality, because there is typically only one main sett per territory (Kruuk, 1978; Neal & Cheeseman, 1996). However, previous research in urban Bristol and ongoing research in our own Brighton study area suggest that urban badgers lack clear territorial behaviour (Harris, 1984; Cresswell & Harris, 1988; Davison, 2007). The distribution of main setts in urban areas may therefore represent a more subtle system of exclusivity, resulting from less obvious defensive behaviour or competitive exclusion. Alternatively, current urban main sett distribution may be a relic from a time when the areas in question were effectively rural and the badger population was territorial (Harris, 1982, 1984).

Sett use

Less than half of the badgers in our study used outlier setts for diurnal resting, which is lower than the proportion reported for rural populations in the UK or elsewhere (Table 6). Similarly, animals in our study spent a greater proportion of days at the main sett and used fewer setts overall than has been reported in any other population (Table 6). Taken together, these results imply that main setts constitute a more important resource for urban than for rural badgers.

Contrary to what has been reported for a nearby rural population (Roper *et al.*, 2001), we found no seasonal variation in outlier use and no effect of ectoparasite load on outlier use. Nor was outlier use significantly related to the sex or the age class of individual badgers. These results are contrary to the ectoparasite avoidance, territory marking and avoidance of harassment hypotheses (Table 1). On the other hand, groups with small main setts used more outliers, implying that outliers may represent additional resting space to groups of badgers. Having sufficient space could be important in terms of ectoparasite or harassment avoidance.

Animals with larger ranges used a significantly greater number of setts, and larger group ranges contained significantly more outliers. In addition, outliers were more likely to be situated in core areas (i.e. areas of intensive nocturnal activity) than would be expected by chance. These results are consistent with the 'efficient travel' and 'emergency shelter' hypotheses (Table 1). It is not easy to distinguish between these two hypotheses empirically because both explain the value of outliers in terms of use of space away from the main sett. However, the fact that range sizes in our study area were extremely small (range 0.78–7.75 ha; Table 3) means that the amount of energy saved by using an outlier after a period of foraging, as opposed to returning to the main sett, would be minimal. On the other hand, emergency refuges or minimizing travel through dangerous areas may be especially important in urban habitats, where humans, traffic and dogs are commonly encountered.

Management implications

Our results are relevant in various respects to the development of management approaches to deal with badger-related problems. Firstly, it is clear that badgers can thrive in urban areas, attaining sett densities that are at least as high as those of most rural areas. During the last decade, the number of reports of urban badger-related problems has increased (Ward, 2007). The ability of badgers to maintain high densities in urban areas, together with the continuing increase in urbanization of the human population, suggests that this trend is likely to continue.

Secondly, the fact that it is possible to distinguish main setts from outlier setts in urban areas, using the same criteria as have been used successfully in rural areas, is important because it means that management approaches to dealing with problem setts can take account of the type of sett. In addition, it may be possible to use the density of main setts to estimate badger population density in urban environments in the same way as has been done in rural environments (e.g. Wilson *et al.*, 1997).

Table 6 Measures of sett use from this study and other populations

Study area	Country	Mean number of setts used by groups	Proportion of animals using outliers	Mean number of setts used by individuals	Mean proportion of days spent at main sett
Brighton[a]	England	2.8	0.39	1.7	0.92
Wytham[b]	England	5.0	0.57	–	0.65
South Downs[c]	England	5.3	0.58	–	0.76
Białowieża[d]	Poland	9.0	1.00	7.1	0.73
Malvik[e]	Norway	12.0	1.00	9.0	0.32

Sources of sett use data
[a]this study.
[b]Kruuk (1978).
[c]Roper *et al.* (2001).
[d]Kowalczyk *et al.* (2004).
[e]Brøseth *et al.* (1997).

Thirdly, our results show that urban badgers have fewer outliers available and spend less time at them, which suggests that main setts represent a particularly important resource. Consequently, in cases where a main sett is causing a problem, its closure may not be a realistic option because resident badgers may not have adequate alternative setts within their existing home range. This is consistent with evidence that badgers sometimes make vigorous attempts to regain access to a closed sett, and that closure of main setts has a poorer record of success in urban than in rural areas (Ward, 2007). Alternatives to main sett closure therefore need to be considered.

In a wider context, our results demonstrate the importance of ecological and behavioural data in explaining patterns of urban wildlife damage and in informing management policies. On the one hand, the basic aspects of the behaviour and ecology of urban populations may resemble those of rural populations, as is the case with the common use of main and outlier setts by badgers in both types of environment. On the other hand, adaptation to urban habitat may involve detailed changes in behaviour, as is exemplified by the less frequent use of outliers in urban badgers. Management of urban wildlife problems can be improved by taking account of such differences.

Acknowledgements

We thank Julian Brown, Swindon Badger Group and Hastings Badger Protection Society for supplying badger sett data, and the CSL Woodchester Park field team for assistance with badger trapping. This project was funded by Defra WSC under contract WM0304. M.H. was supported by a Marie Curie Intra-European Postdoctoral Fellowship. We also thank Alastair Ward, Richard Brand-Hardy and two anonymous referees, whose comments greatly improved the paper.

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