Use of farm buildings by wild badgers: implications for the transmission of bovine tuberculosis

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Abstract

Diseases transmitted from wildlife to livestock or people may be managed more effectively if it is known where transmission occurs. In Britain, farm buildings have been proposed as important sites of *Mycobacterium bovis* transmission between wild badgers (*Meles meles*) and cattle, contributing to the maintenance of bovine tuberculosis (TB). Farmers are therefore advised to exclude badgers from buildings.

We used GPS-collars and remote cameras to characterise badgers' use of farm buildings at four TB-affected sites in southwestern Britain. Across 54 GPS-collared badgers, 99.8% of locations fell ≥3m from farm buildings. Remote cameras deployed in feed stores recorded just 12 nights with badger visits among 3,134 store-nights of monitoring. GPS-collared badgers used space near farm buildings less than expected based on availability, significantly preferring land ≥100m from buildings.

There was no positive association between badgers' use of farm buildings and the infection status of either badgers or cattle. Six GPS-collared badgers which regularly visited farm buildings all tested negative for *M. bovis*. Overall, test-positive badgers spent less time close to farm buildings than did test-negative animals. Badger visits to farm buildings were more frequent where badger population densities were high.

Our findings suggest that, while buildings may offer important opportunities for *M. bovis* transmission between badgers and cattle, building use by badgers is not a prerequisite for such transmission. Identifying ways to minimise infectious contact between badgers and cattle away from buildings is therefore a management priority.

Introduction

Diseases transmitted from wildlife to livestock or people can be managed more effectively if it is known where transmission occurs. For example, in Africa people can minimise their own risk of contracting schistosomiasis by not entering stagnant water where the pathogen's intermediate host occurs (Grimes et al. 2014), and may avoid exposing their cattle to the Malignant Catarrhal Fever virus by keeping them away from wildebeest (*Connochaetes taurinus*) calving grounds (Mushi & Rurangirwa 1981).

In Britain and Ireland, the control of bovine tuberculosis (TB) is a cause of significant concern to the farming industry and the general public. However, TB control is impeded by uncertainty about where transmission is most likely to occur. Most cattle acquire TB (caused by *Mycobacterium bovis*) from other cattle (Donnelly & Nouvellet 2013), but wild badgers (*Meles meles*) are also an important source of infection (Donnelly et al. 2003, Griffin et al. 2005, Donnelly et al. 2006). Nevertheless, it is unclear how and where badger-to-cattle transmission occurs (Godfray et al. 2013).

In recent years, farm buildings have become a focus for TB management. In TB-affected areas, some farms receive frequent badger visits to feed stores, farmyards, and cattle housing (Garnett et al. 2002, Tolhurst et al. 2009, Judge et al. 2011, Payne et al. 2016), and some badgers making such visits have advanced TB (Cheeseman & Mallinson 1981). Moreover, anecdotal observations of close contact between badgers and housed cattle (Garnett et al. 2002, Tolhurst et al. 2009) contrast with very low rates of direct contact at pasture (Böhm et al. 2009, Drewe et al. 2013, O'Mahony 2014, Woodroffe et al. 2016), leading to the suggestion that farm buildings might be particularly important sites for transmission between the two species (Drewe et al. 2013, O'Mahony 2014). Even if – as seems likely – interspecific *M. bovis* transmission occurs mainly through the shared environment (Kukielka et al. 2013, King et al. 2015, Woodroffe et al. 2016), badgers in farm buildings contaminate cattle feed and bedding (Garnett et al. 2002, Tolhurst et al. 2009), making them potentially infectious to cattle (Palmer et al. 2004). Encouragingly, farms can be managed to effectively prevent badger access to buildings (Tolhurst et al. 2008, Judge et al. 2011), with the potential to reduce cattle TB incidence if a high proportion of transmission does indeed occur indoors. UK farmers are therefore advised to exclude badgers from farm buildings (Agriculture and Horticulture Development Board 2015, Department of Agriculture Environment and Rural Affairs 2015). However, the impact of such management on cattle TB risk has not been tested (Godfray et al. 2013).

Badgers' tendency to visit farm buildings is not universal. High rates of building use in several British study areas (Garnett et al. 2002, Tolhurst et al. 2009, Judge et al. 2011) contrast with low rates in Ireland (Mullen et al. 2015, O'Mahony 2015). Such geographical differences might reflect variation in resource availability, itself related to badger population density. Badgers visit farm buildings more frequently during dry weather (Garnett et al. 2002, Tolhurst et al. 2009, O'Mahony 2015), a time when their natural invertebrate prey are less accessible (Kruuk 1978). High population densities also limit food availability, as indicated by reduced badger bodyweight (Kruuk & Parish 1983, Rogers et al. 1997, Tuyttens et al. 2000) and reproductive success (Woodroffe & Macdonald 1995). Food scarcity in dense populations subjected to intense resource competition might therefore encourage badgers to seek man-made foods in farm buildings. Moreover, chance encounters with farm buildings are more probable at high badger densities.

We explored the potential role of farm buildings in *M. bovis* transmission by characterising badgers' use of buildings at four farmland sites in southwestern Britain. We also combined our own data with those of published studies to test the hypothesis that use of farm buildings reflects local badger population density.

Materials and Methods

Field data collection

We conducted our study between May 2013 and Aug 2015 at four sites in Cornwall (C2; C4; F1; F2), southwestern Britain (Woodroffe et al. 2016). Each site comprised five farms, with 2-3 dairy and 2-3 beef herds at each site, giving 20 farms (10 dairy, 10 beef) in total. Sites were at least 20 km apart. Electronic Supplementary Material provides further details on study site selection.

We used a handheld GPS unit to record the locations of all 133 farm buildings at these four sites. To better represent building shape, we then used these point locations to identify farm buildings on digital maps (https://www.ordnancesurvey.co.uk/business-and-government/products/vectormap-products.html), and aerial photographs (https://www.google.co.uk/intl/en_uk/earth/).

We used GPS-collars (Telemetry Solutions, Concord, CA, USA) to monitor badger movements relative to farm buildings. Badgers were cage-trapped and handled under licence from Natural England (licence 20122772) and the UK Home Office (project licence 70/7482), following ethical review by the Zoological Society of London (project BPE/0631). Badgers were chemically immobilized (de Leeuw et al. 2004) to facilitate collaring; GPS-collars were fitted to 54 individual badgers (Table S1). To conserve battery life, badger GPS-collars did not record locations between 0600h and 1800h UTC, when badgers would normally be in their setts (dens) outside satellite range. Outside this period, locations were attempted at 20-minute intervals, unless an on-board accelerometer indicated that the badger was inactive (usually underground). On average, badger GPS-collars recorded data for 110 days (standard deviation 74, range 4-296 days) before the battery expired, the collar was dropped or replaced, or the badger died or dispersed (Table S1). Trapping sessions were timed to help achieve our aim of maintaining at least one GPS-collar per social group, year-round. GPS-collar monitoring occurred in all months (Woodroffe et al. 2016). Attempts were made to remove all collars at the end of the study.

To further evaluate badgers' use of farm buildings, we deployed motion-sensing camera traps (Bushnell Trophy Cam HD) within all feed stores which we judged to be potentially accessible to badgers. As in other studies (Garnett et al. 2002, Tolhurst et al. 2009, O'Mahony 2015), cameras were positioned to provide a view of potential entry points and as much as possible of the interior of the store. Cameras were placed in 13 feed stores on 10 farms; other farms had either no feed stores, or stores with close-fitting doors preventing badger access.

We also used GPS-collars to monitor cattle presence in or near farm buildings. Cattle collars (GPS-plus, Vectronic Aerospace GmBH, Berlin, Germany) were programmed to record locations at 20-minute intervals, 24 hours a day.

Cattle were briefly restrained in a crush to facilitate collaring. Wherever possible, collars were deployed simultaneously on two members of every cattle group within a herd. Collars were deployed on 421 individual cattle, for an average of 19.3 days (standard deviation 23.1, range 1-213 days) before being removed or falling off. Collars were disinfected before being re-deployed. Badger and cattle tracking data are lodged on Movebank (www.movebank.org; Movebank Project 158275131).

Badgers were blood-sampled on the first capture of each trapping session. To assess *M. bovis* exposure, we transferred heparinised blood samples to a laboratory within seven hours of collection for gamma interferon (IFNg) testing (Dalley et al. 2008). In addition, serum samples were subjected to the BrockTB StatPak test (Chambers et al. 2008). Badgers were considered test-positive if positive results were obtained from the IFNg test, the StatPak test, or both; using these two tests in combination has a positive predictive value of 0.75 and a negative predictive value of 0.97 (Drewe et al. 2010). Badgers found dead at the study sites were frozen and transported to a laboratory for a standardised necropsy and *M. bovis* culture (Crawshaw et al. 2008). We obtained data on the TB status of cattle herds from http://www.ibtb.co.uk.

Analysis of field data

Our analyses took into account the imperfect accuracy of GPS-collar locations. Field tests conducted with stationary collars (Woodroffe et al. 2016), and observations of badger movements (Figure 1A), both confirmed that GPS-collars recorded locations in and around farm buildings as well as outdoors. Tests with stationary collars (described in Woodroffe et al. 2016) showed that median location error was 3.7m for badger collars and 4.3m for cattle collars. To improve location accuracy, following Woodroffe *et al.* (2016), we excluded all GPS-collar locations associated with fewer than four satellites, or with horizontal dilution of precision >4 (Langley 1999). We likewise excluded badger locations which were >1km from locations both 20 minutes previous and 20 minutes subsequent (Woodroffe et al. 2016). Applying these filters led us to exclude 18% of badger locations and 13% of cattle locations (Table S1). We conducted secondary analyses on all GPS-collar data (i.e., without excluding any locations) to determine whether this filtering influenced our findings.

Since GPS-location accuracy was imperfect, our analyses combined locations in and near farm buildings. For primary analyses, we conservatively considered individual badgers or cattle to be present at a farm building when their GPS-location fell within it, or less than 25m from it (together referred to as <25m). We also identified GPS-locations <3m from farm buildings, and checked whether barriers (e.g. walled hedges) separated badger locations from buildings. We used these data, alongside the maximum duration of building visits (maximum number of GPS-locations <25m from farm buildings in a single night), and the maximum frequency of building visits (maximum number of nights with at least one location <25m from a farm building in any one month), to categorise individual GPS-collared badgers according to their use of space in and around farm buildings. We used χ^2 tests to compare badgers' distribution across these categories with their *M. bovis* test-status, and with the herd TB test-status of the farms where they could access buildings.

We used compositional analysis (Aebischer et al. 1993) to test whether GPS-collared badgers used space in and around farm buildings in proportion to its availability. To characterise the observed pattern of space use, we classified each badger GPS-location as <25m from a farm building, ≥25m but <50m (25-50m), ≥50m but <75m (50-75m), ≥75m but <100m (75-100m), or ≥100m away. The width of these categories was based on tests using stationary collars (Woodroffe et al. 2016), which indicated that 95% of locations were accurate to within 17.5m; a category width of 25m was therefore selected to ensure that locations were correctly categorised while still providing fine-grained information on proximity to buildings. We then calculated, for each individual badger, the proportion of locations falling within each distance category; these proportions summed to 1 across all categories. Such an array of proportions is termed a composition (Aebischer et al. 1993).

To calculate "expected" compositions, we first constructed a home range polygon for each individual badger using the nonparametric Local Convex Hull (*a-LoCoH*) method. We selected this method because it accurately reflects physical barriers such as coastline (Getz et al. 2007), and would be expected also to reflect territorial boundaries. We mapped individual ranges using the *R* package *tlocoh* (Lyons et al. 2015), with the *a* parameter (the cumulative distance between a focal location and its nearest neighbours, used to select the locations to construct each hull) set to 1,800m, using the 95% isopleth to indicate the range boundary. To represent the area likely to be available to each badger, we then added a 100m buffer around each individual home range (conservatively based on a mean of 120m (median 81m) between GPS-locations 20 minutes apart). Within each resulting polygon, we generated 1,000 random locations, and categorised these locations according to the distance categories above; this method accounted for variation in the area falling within each distance category. Finally, we used Compos (Smith 2005) to conduct a compositional analysis (Aebischer et al. 1993) comparing the observed and expected compositions for all badgers.

We explored temporal variation in building visitation by counting, for each badger monitoring-night, the number of locations <25m from any farm building (excluding badgers without buildings inside their home range polygons). We analysed these counts using Poisson regression, including badger identity as a random effect. To account for background factors likely to influence these counts, this analysis also included the natural log of the product of the total number of locations for each night, and the proportion of each individual's home range that fell within or <25m from a farm building. We also assessed the contribution to this model of ecological factors expected to influence the frequency of building use; these were sex, *M. bovis* status (positive to StatPak, IFNg, or both), and season, with the last defined according to badger biology as early spring (lactation; Feb-Apr), summer (cub independence, increasing food scarcity; May-Aug), autumn (weight gain for winter; Sep-Oct), and winter (relative inactivity; Nov-Jan).

Our analyses identified a subset of badgers which habitually visited building complexes where cattle were housed. For these animals, we used Poisson regression to explore whether cattle presence (a binary variable indicating, for each night, whether or not any collared cattle were located <25m from a building) influenced the number of badger locations at the building. Since this subset analysis was based on data from just four badgers, we represented badger identity as a fixed effect rather than a random effect.

Comparison across studies

We used linear regression to compare badgers' use of farm buildings with population density, across our own and others' study sites. This comparison required indices of population density and building use, measured consistently across sites. We based our population density estimates on the "minimum number alive" method, since this was the method used in published studies with which we wished to compare our findings (details in Table S2). We measured building visitation as the proportion of monitoring-nights when badgers were detected at farm buildings, because this was the measure reported by most studies, which used remote cameras to monitor building usage (Garnett et al. 2002, Tolhurst et al. 2009, O'Mahony 2015). We used our own, and others' (Mullen et al. 2015), GPS-collar data to estimate this same proportion (details in Table S2). For consistency with camera-based monitoring studies, we considered each GPS-collared badger to be present at a building if it was located within or <3m from it. In case GPS-collars under-reported building use relative to remote cameras (since only a proportion of the badger population was GPS-collared whereas cameras would be expected to record visits by all badgers), we conducted an alternative analysis based entirely on camera data (Table S2).

Results

Badger use of farm buildings

Badgers in our study areas showed an overall tendency to avoid farm buildings (Figure 1B). Of 99,163 GPS locations from 54 GPS-collared badgers, 98.8% fell ≥25m from any farm building, and only 206 (0.21%) fell <3m from such buildings (Table S1). A similar pattern was observed in the dataset of unfiltered locations (Table S3), suggesting that the low number of locations close to buildings was not an artefact of our filtering method.

Badgers used space close to farm buildings less than would be expected, based on its availability (compositional analysis, p=0.003). Across 38 badgers with farm buildings in their home ranges, space <25m from buildings was used significantly less (relative to its availability) than that at all greater distances; land ≥100m away was significantly preferred (Table 1; Figure 1B). Repeating this analysis using unfiltered GPS-collar data gave similar results (Table S4).

Camera traps deployed in feed stores likewise recorded infrequent badger visits. Across our four study sites, monitoring within 13 feed stores, over a combined total of 3,134 store-nights (8.6 store-years), recorded badger visits on just 12 store-nights (0.38%; Table S5). Cameras regularly recorded the presence of cats, dogs, foxes (*Vulpes vulpes*), and birds.

Despite this general pattern, some badgers habitually used space in and around farm buildings. Across 38 badgers with farm buildings in their home range polygons, the maximum duration of building visitation (the maximum number of GPS-locations <25m from farm buildings in a single night, for each individual) was positively correlated with the maximum frequency of building visitation (the maximum number of nights with one or more locations <25m from a farm building in any one month, for each individual; Figure S1; $r=0.845$, $p<0.001$), indicating that badgers which repeatedly visited farm buildings also tended to make prolonged visits. Based on this observation, we classified the 54 GPS-collared badgers into five categories, according to their use of space in and around farm buildings (Figure 2, Table S6). We considered six badgers (11%) to be habitual users of farm buildings (category 1); that is, they had a maximum nightly duration of ≥3 locations, a maximum monthly frequency of ≥3 nights, and were located within farm building complexes at least twice (Figure 1A; Table 2; Table S6). The behaviour of these six "category 1" badgers is detailed in Electronic Supplementary Material. Another eight badgers (15%; category 2) habitually approached farm buildings (maximum duration and maximum frequency both ≥3) but never entered them (Table S6); in many cases walled hedges separated GPS-locations of these animals from buildings (Figure S2). Sixteen badgers (30%; category 3) were occasionally located <25m from farm buildings (maximum visit duration and/or frequency <3; Figure 1B; Table S6), while eight badgers (15%; category 4) were never located <25m from a farm building, despite having such buildings in their home ranges (Table S6). A further 16 badgers (30%; category 5) inhabited farmland home ranges which nevertheless excluded farm buildings; these animals' home ranges were on average 220m from the nearest farm building (Table S7).

Badgers' use of space near farm buildings varied over time. GPS-collared badgers were located <25m from farm buildings most frequently in the late summer and early autumn (Figure 3A; Table 3), contrasting with the pattern observed among cattle, which were seldom housed in summer (Figure 3B). Four "category 1" badgers which habitually visited building complexes where cattle were housed (Table 2; Table S6) were tracked simultaneously with 17 collared cattle. After adjusting for the effects of season, these four badgers' GPS-collars recorded 35.5% fewer locations <25m from cattle housing on nights when collared cattle were present in the housing than on nights when the cattle were located elsewhere (Poisson regression including season and badger identity as fixed effects, effect of cattle presence p=0.010).

There was no positive association between badgers' use of farm buildings and either their infection status (reported in Table S1), or that of sympatric cattle herds. The distribution of individual badgers across building use categories was not significantly different between test-positive and test-negative individuals (Figure 2A; χ^2=4.94, d.f.=4, p=0.29). Likewise, the lowest (i.e., most intense) building use category recorded on each study farm was not significantly different between farms which experienced cattle TB in the course of the study, and those which did not (Figure 2B; χ^2=6.44, d.f.=4, p=0.17). After adjusting for sex and season, GPS-collared badgers which tested positive for *M. bovis* (by the IFNg test, the StatPak test, or both), spent significantly less time close to farm buildings than did test-negative badgers (Table 3).

Comparison across studies

In Figure 4, we compare badgers' use of farm buildings in this study with that from four published studies (Table S2). This comparison suggests that farm buildings received more frequent badger visits where badger densities were higher (linear regression; slope=0.020 indicating that, for every 1 badger/km^2 increase in density, there was an absolute increase of 2% in the percentage of farm-nights with badger visits, p<0.001; an alternative analysis using only camera-trap data gave slope=0.021, p<0.001).

Discussion

At our four study sites, badger visits to farm buildings were infrequent: 99.8% of all badger GPS-locations were ≥3m from any farm building (Table S1). Four lines of evidence indicate that this observation reflects genuinely infrequent badger use of farm buildings, rather than a failure to detect building use. First, field tests showed that stationary GPS-collars placed in buildings successfully recorded locations (Woodroffe et al. 2016). Second, several GPS-collared badgers were repeatedly located in and around buildings (Table S1; Figure 1A). Third, locations <25m from buildings were not more likely to be excluded by filtering than locations at greater distances (Table S3). Fourth, parallel monitoring using remote cameras also recorded few building visits (Table S5). Overall, badgers avoided using space in and around buildings, with land <25m from buildings used significantly less than would be expected assuming random movement (Table 1).

Although a number of badgers habitually visited farm buildings, our parallel work in the same areas detected no direct contacts with cattle (Woodroffe et al. 2016). Badgers tended to avoid visiting building complexes on nights when cattle were present, a pattern consistent with published evidence of badgers avoiding cattle at pasture (Benham & Broom 1989, Mullen et al. 2013, Woodroffe et al. 2016).

Badgers spent more time close to farm buildings in late summer, broadly comparable with other studies which found higher visitation rates in dry weather (Garnett et al. 2002, Tolhurst et al. 2009, O'Mahony 2015), when natural food is less abundant (Kruuk 1978). However, most other studies have found higher visitation rates in spring (Tolhurst et al. 2009, Judge et al. 2011, O'Mahony 2015).

Badgers visited farm buildings more frequently in areas of higher population density (Figure 4), providing a consistent explanation for previous observations that building use was common in England (Garnett et al. 2002, Ward et al. 2008, Tolhurst et al. 2009, Judge et al. 2011) but rare in Ireland (Mullen et al. 2015, O'Mahony 2015). Frequent building visits recorded in England might reflect a preponderance of studies in Gloucestershire, where badger density is high (Neal & Cheeseman 1996); indeed one study explicitly selected farms based on high badger density (Tolhurst et al. 2009). Since the densities in our four study areas (4.2-6.3 badgers/km^2 by the minimum number alive method; Table S8) are fairly typical of TB-affected farmland in Britain (Bourne et al. 2007, Parrott et al. 2012), the relatively low rates of building use that we detected might also be representative.

Our findings suggest that building visits may not be a prerequisite for *M. bovis* transmission between badgers and cattle. Although *M. bovis* was detected in both badgers and cattle at our study sites, badgers' use of buildings was not related to infection status in either species (Figure 2); indeed, test-positive badgers appeared to spend less time near buildings than did test-negative individuals (Table 3). Moreover, despite a clear relationship between badger density and building use (Figure 4), links between badger density and cattle TB incidence are far from clear (Godfray et al. 2013). Transmission from badgers to cattle has been documented across a range of badger densities (Griffin et al. 2005, Bourne et al. 2007, Judge et al. 2014), including areas where baseline badger density is low (Griffin et al. 2005), and building use is likely to be correspondingly infrequent (Mullen et al. 2015). Hence, while buildings can undoubtedly offer important opportunities for *M. bovis* transmission between badgers and cattle (see Supplementary Material, and Cheeseman & Mallinson 1981), our findings suggest that interspecific transmission may occur without building use. In our study areas, cattle divided their time between pasture and buildings; cattle pasture is a preferred foraging habitat for badgers (Kruuk et al. 1979, Woodroffe et al. 2016) and hence a likely location for *M. bovis* transmission.

Our findings suggest that measures to exclude badgers from farm buildings should be applied strategically. Such measures successfully exclude badgers (Tolhurst et al. 2008, Judge et al. 2011), and would be expected to help reduce cattle TB risks on those farms where infected badgers regularly visit farm buildings. However, such management may not be warranted on all farms, especially where badger density is low. Since pasture may also play a key role in *M. bovis* transmission, measures to minimise infectious contact between badgers and cattle at pasture would be well worth investigating.

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Compliance with Ethical Standards:

Ethical approval: All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. All procedures performed in studies involving animals were in accordance with the ethical standards of the institution or practice at which the studies were conducted.

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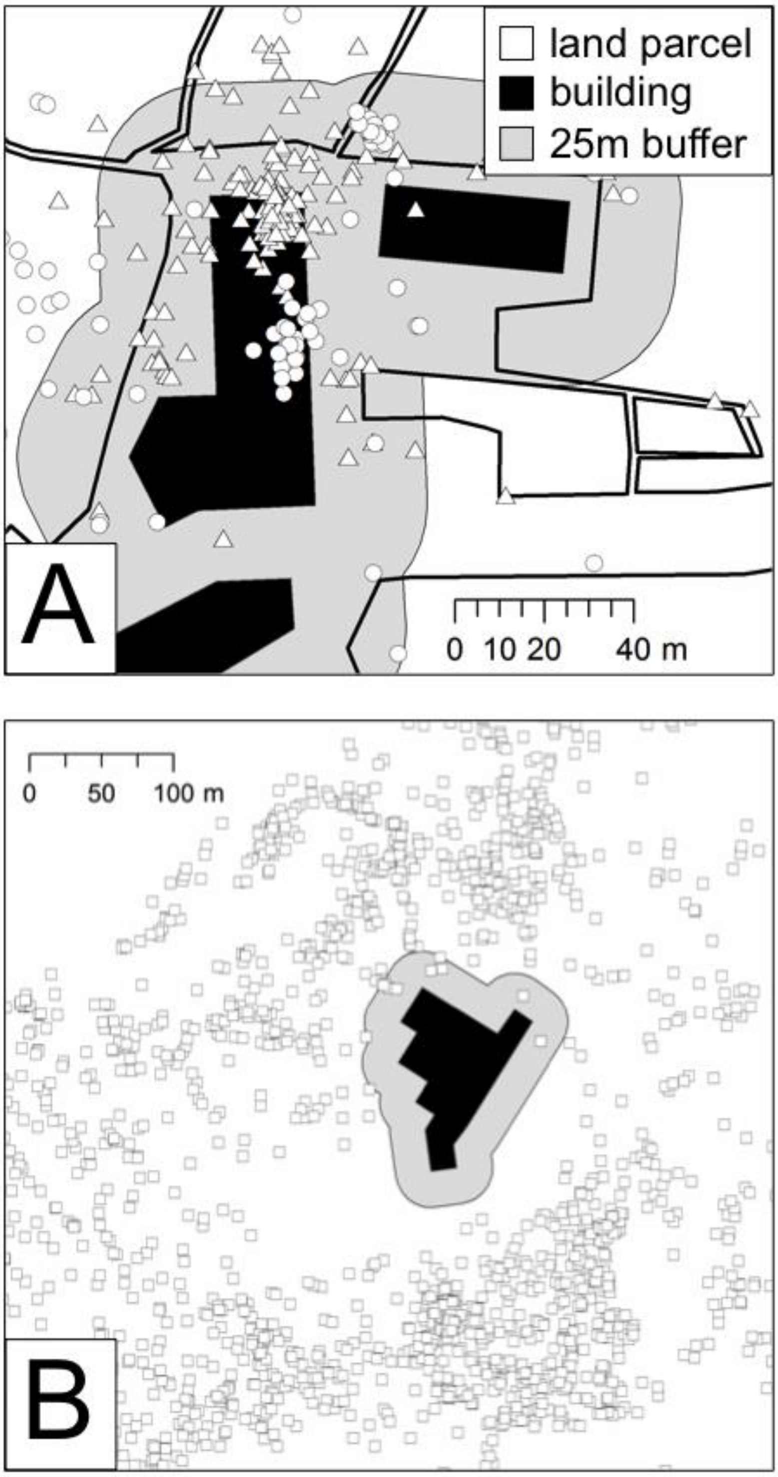

Figure 1 – Contrasting examples of GPS-collared badgers' use of space in and around farm buildings. Panel A shows GPS-locations of badgers F2_002 (open circles) and F2_033 (open triangles), both habitual visitors to a building on farm F2-A. Panel B shows many GPS-locations of badger F1_015 around a farm building complex at farm F1-C, but few close to the buildings themselves. Both building complexes included cattle housing.

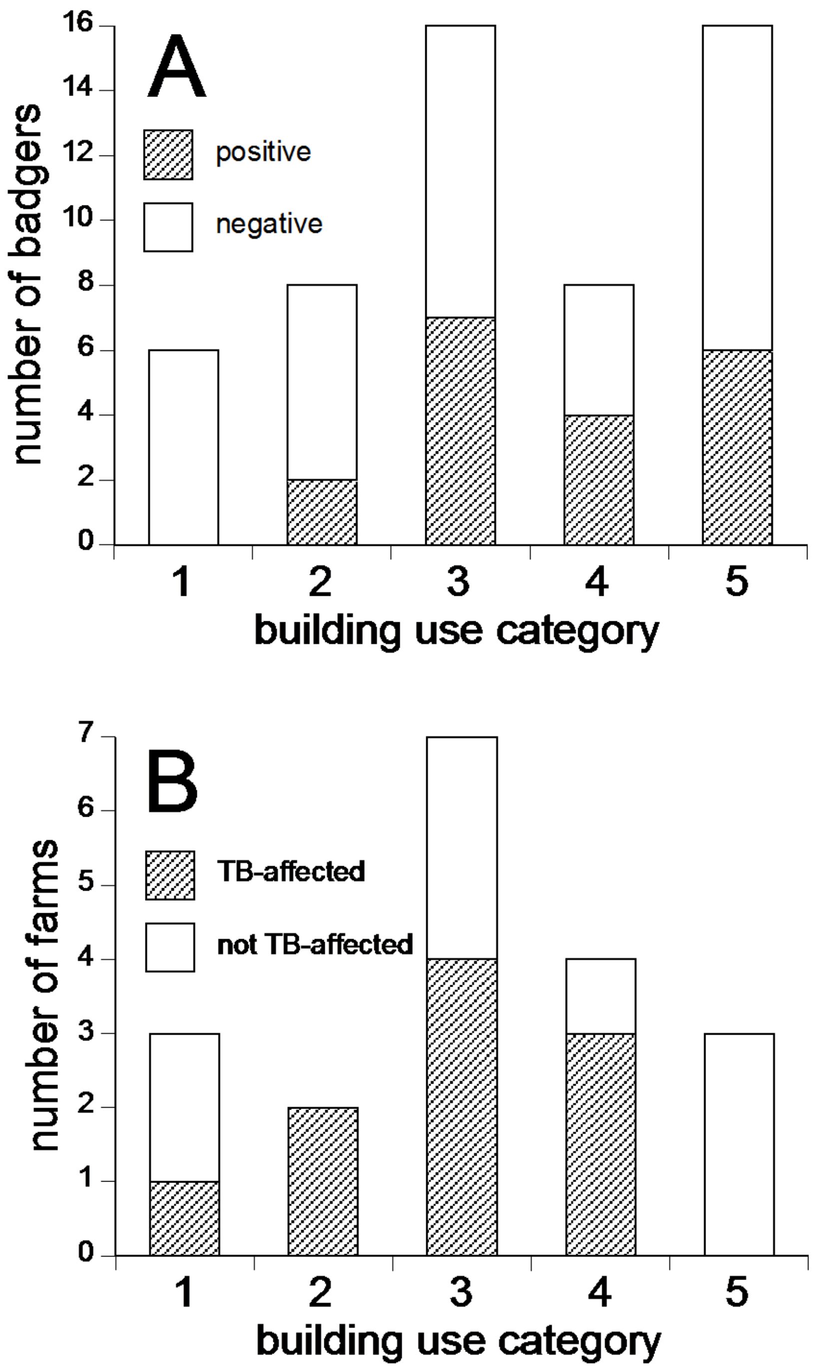

Figure 2 – Categories of badger building use across (A) badgers and (B) farms. Panel A shows the numbers of GPS-collared badgers (n=54) falling into each of five categories of building use, ranging from 1 (habitual use) to 4 (always ≥25m away) and 5 (no farm building in home range). Badgers are divided into those which tested positive to the StatPak and/or IFNg tests, or tested negative to both tests. Panel B classifies 19 study farms (no GPS-collared badgers used farm C4-B) according to the most intense category of building use recorded among resident badgers.

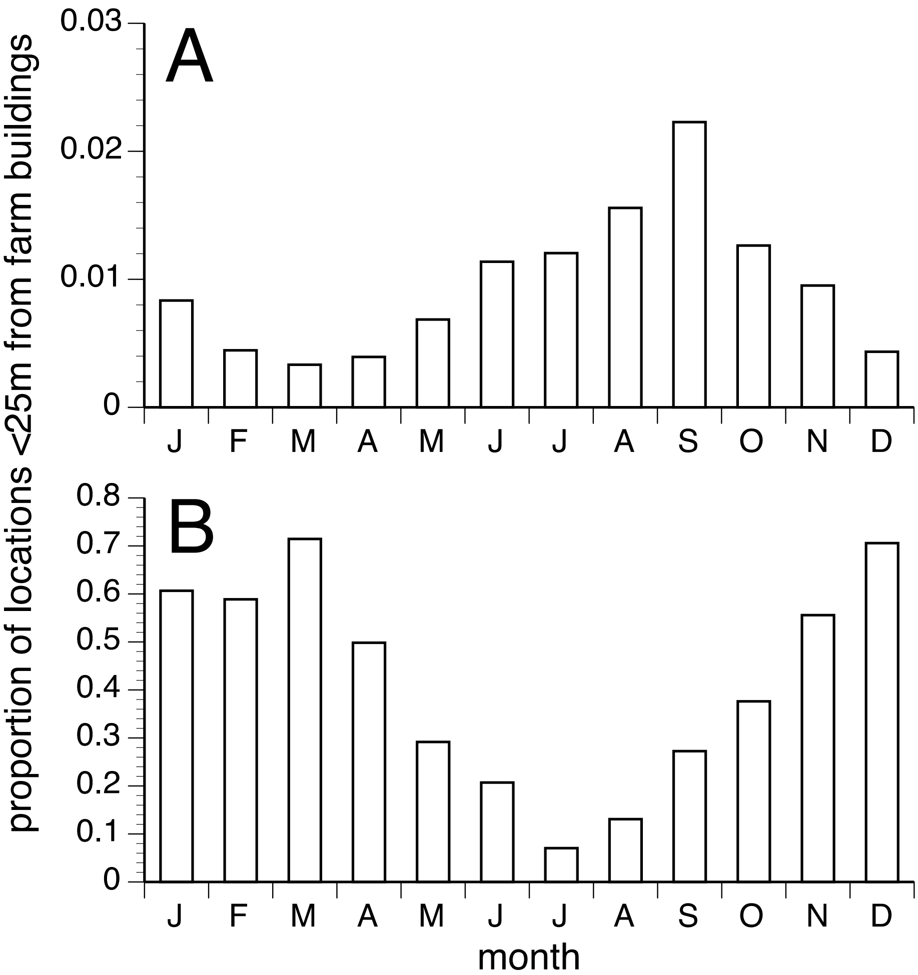

Figure 3 – Seasonal variation in the proportions of night-time GPS-collar locations falling <25m from farm buildings for (A) badgers and (B) cattle. Data come from 54 GPS-collared badgers (n=99,163 locations) and 421 collared cattle, with night-time defined as 1800-0600h (n=259,540 locations). Note the different scales on the two y-axes.

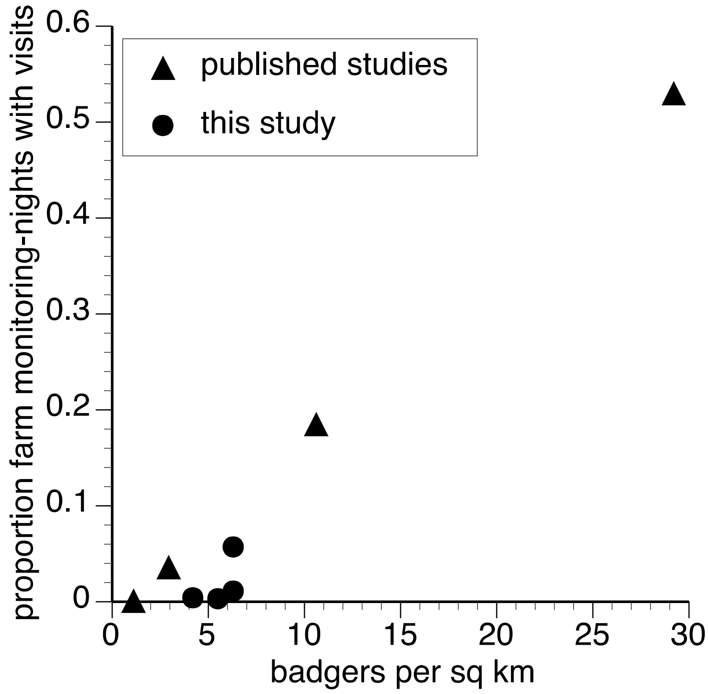

Figure 4 – Badger visits to farm buildings and local badger population densities at eight sites in Britain and Ireland. Details of data sources are given in Table S2.

Table 1 –Badgers' use of space at varying distances from farm buildings, based on compositional analysis of data from 38 GPS-collared badgers with farm buildings in their individual home range polygons. P-values refer to pairwise tests comparing the observed and expected distribution of GPS-locations; significant differences are shown in bold type. Land close to farm buildings was significantly avoided.

Distance category	**Pairwise p-values**					**Preference rank**
	<25m	*25-50m*	*50-75m*	*75-100m*	*≥100m*	
<25m						5
25-50m	**0.010**					4
50-75m	**0.009**	0.629				3
75-100m	**0.003**	0.215	0.263			2
≥100m	**0.001**	**0.010**	**0.014**	0.065		1

Table 2 – Characteristics of six "category 1" GPS-collared badgers which entered farm building complexes, and habitually used the space in and around them. Habitual use is defined as being located <25m away from any farm buildings for ≥3 locations on any one night and ≥3 nights in any one month. StatPak and IFNg are blood tests for *M. bovis* infection; figures indicate the numbers of times each animal was tested in the course of the project. Table S6 presents similar data for all GPS-collared badgers.

badger identity *(site-number)*	**sex**	**StatPak**	**IFNg**	**building identity** *(site-farm-building)*	**cattle present?**	**farm TB-affected during study?**
F1_002	M	neg x1	neg x1	F1-B-a	yes	
F1_003	M	neg x4	neg x4	F1-B-a	yes	no
F1_033	F	neg x2	neg x2	F1-B-a	yes	
F2_002	M	neg x1	neg x1	F2-A-a	yes	no
F2_033	F	neg x1	neg x1	F2-A-a	yes	
F2_017	M	neg x1	neg x1	F2-D-a	no	yes

Table 3 – Factors affecting badgers' use of space <25m from farm buildings. The table shows the results from a multivariable Poisson regression model of the numbers of locations recorded in or near farm buildings for 38 GPS-collared badgers with farm buildings in their home ranges. This model also included badger identity as a random effect.

Variable		**estimate**	**p-value**
Site	C4 *vs* C2	-0.541	<0.001*
	F1 *vs* C2	0.904	
	F2 *vs* C2	2.355	
Season	spring *vs* winter	-0.005	<0.001*
	summer *vs* winter	0.812	
	autumn *vs* winter	0.498	
Sex	male *vs* female	1.230	0.006
Any positive TB test	yes *vs* no	-0.978	0.041
Ln (number locations x proportion of home range <25m from farm buildings)		0.873	<0.001

*These p-values for three degree of freedom test for no effect of site and for no effect of season. They are not testing a particular pairwise comparison.