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

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Electronic Supplementary Material

1 Selection of study sites

The numbers of sites and study farms were chosen to achieve representation of varying environmental conditions (which would be maximised by spreading study farms across as many sites as possible) while maintaining logistical practicality (which would be maximised by grouping all study farms at a single site).

Study sites were located within the former treatment areas of the Randomised Badger Culling Trial (RBCT, Bourne et al. 2007), and were named accordingly (C2, F1, F2). An exception is our C4 site, which was chosen after a previous site (C3) was abandoned due to extremely low bait uptake from badger traps over a prolonged period. For this reason, monitoring at C4 commenced later than that at other sites. The primary challenge in selecting study sites was identifying contiguous areas with ≥2 beef farms and ≥2 dairy farms.

Sites C2 and C4 were both located in North Cornwall, in a landscape of rolling hills interspersed with steep wooded valleys. Although cattle farming was the primary enterprise at both sites, sheep were also kept on several of the farms. Site F1, located on the North coast of West Cornwall, was bounded by granite cliffs and moorland; cattle farming was the sole farming enterprise although some forage crops were grown. Site F2, located on the South coast of West Cornwall, included wooded valleys. Several of the study farms were engaged in growing crops such as cauliflowers and daffodils, as well as farming cattle. Summary data on the study populations at each site are presented in Table S8.

2 Detailed observations of GPS-collared badgers using farm buildings

The five GPS-collared badgers which habitually visited building complexes where cattle were housed entered two complexes, on beef farms at our F1 and F2 study sites (Table 2). The building complex visited by two GPS-collared badgers at F2 (shown in Figure 1A) included a building where feed sacks were piled, next to another where cattle were housed. In contrast, the building complex visited by three GPS-collared badgers at F1 contained no stored feed; here cattle were fed silage in a yard with deep litter. All five of these

badgers tested negative to both StatPak and IFNg tests (Table 2), and neither farm experienced a cattle TB incident in the course of the study.

A sixth GPS-collared badger habitually visited a feed store remote from any cattle housing (Table 2). This building (F2-D-a) was an open barn with no door. The badger involved (F2_017) was only tracked for 35 days before he died in a suspected traffic accident, but he was located <25m from the store 27 times over 20 nights during this period. Most of his visits were brief (mean 1.3 consecutive locations per visit, median 1, range 1-2). The visits appeared to have followed a delivery when feed was spilled in the yard outside the store. This badger tested negative for *M. bovis* by StatPak and IFNg while alive, and, at post mortem, by gross pathology and culture. Another GPS-collared badger from the same social group, F2_025, was subsequently tracked for 264 nights but did not enter the environs of this feed store (Table S1, Table S6). She likewise tested negative by StatPak and IFNg (Table S1). This farm experienced a cattle TB breakdown towards the end of the study.

3 Contact-collared badgers

As well as tracking badgers with GPS-collars, we also fitted badgers with UHF contact-collars (Vectronic Aerospace GMbH) detectable by the cattle collars at distances of <2m (Woodroffe et al. 2016). Two badgers wearing such contact-collars, F1_003 and F2_001, are known or suspected to have visited two of the building complexes visited by GPS-collared badgers (buildings F1-B-a and F2-A-a).

F1_003, one of the five GPS-collared animals which regularly visited building complex F1-B-a, wore a contact-collar for 98 days between bouts of GPS-tracking. During this period, four collared cattle spent a total of 26 nights <25m from the F1-B-a building complex but did not record any contacts with F1_003's collar.

Five non-deployed cattle collars stored temporarily in building complex F2-A-a in Feb 2014 recorded contacts with contact-collared badger F2_001 on six of the 23 nights they were present (16 contacts over 115 collar-nights). In contrast, six cattle which spent a combined total of 58 cattle-nights at the same building complex recorded no contacts with badger F2_001. Badger F2_001 was

subsequently found dead in the F2-A farmyard. While alive, F2_001 tested positive to both the StatPak and IFNg tests; at necropsy he was found to have disseminated lung lesions. Thus, this (non GPS-collared) animal was the only test-positive badger known to have frequented farm buildings across the four study sites.

4 Detailed results of monitoring with camera traps

Our camera traps recorded badgers at only two feed stores: the one at the F2-A-a building complex where GPS-collared badgers were repeatedly located (described above), and another on farm C4-D. At the C4-D store, feed was contained within secure hard-sided bins; here the badger sniffed at the bin but did not access any feed and left within a few seconds. Camera traps were not yet in place at the open feed store (building F2-D-a) in Sep-Oct 2013 when GPS-collared badger F2_017 visited it repeatedly (Table 2). However, camera-trap monitoring for 451 nights starting in Nov 2013 detected no visits after F2_017 died in a suspected road traffic accident (Table S5).

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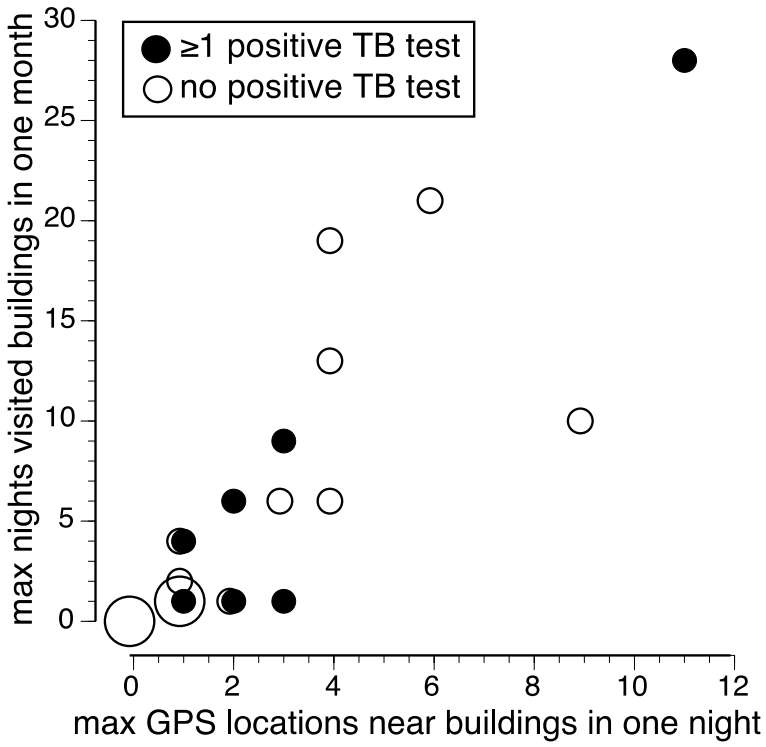

Figure S1 – Characterisation of individual badgers' use of space in and near farm buildings, for 38 GPS-collared badgers with farm buildings in their home range polygons. The graph plots, for each badger, the maximum number of GPS-collar locations falling <25m from a farm building on any one night, against the maximum number of nights in any one month when the badger was located <25m from a building at least once. Incomplete months of monitoring, and badgers without buildings in their home ranges, were excluded. Point size indicates the numbers of badgers represented, with the largest points equivalent to four individuals. Filled circles indicate individuals with at least one positive StatPak or IFNg test.

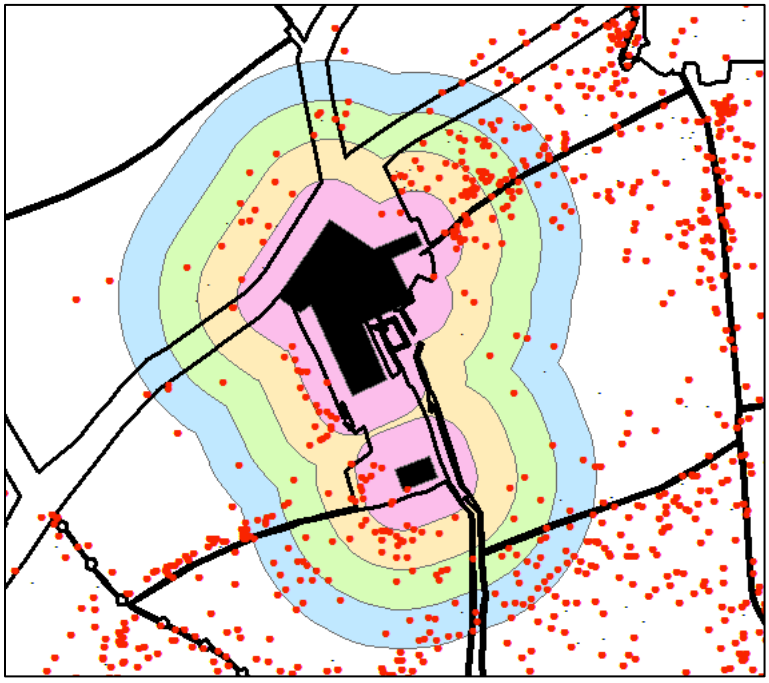

Figure S2 – Example of a GPS-collared badger repeatedly located <25m, but seldom <3m, from a farm building complex. Black shading indicates the building complex, and coloured bands show the buffers <25m, 25-50m, 50-75m and 75-100m from the buildings. There are several GPS-locations (red circles) in the <25m (pink) buffer, but most are on pasture fields outside the building complex. Over 264 nights of monitoring, this animal (F2_025) was recorded 40 times <25m from a building, but only once <3m away (Table S1).

Table S1 – Summary data from 65 GPS-collar monitoring periods involving 54 badgers. Where the same individual was monitored for more than one period, test results and numbers of GPS locations relative to farm buildings are given for all periods combined.

	monitoring period					farm building	GPS locations			% locations
ID	*start*	*end*	*days*	**StatPak**	**IFNg**	**in home range?**	*<3m*	*<25m*	*total*	**excluded**
C2_002	23 May 13	1 Aug 13	70	neg x1	neg x1	yes	0	0	651	26.9%
C2_003	22 May 13	24 Sep 13	125	pos x3	pos x3	yes	3	3	1592	21.9%
C2_004	22 May 13	1 Jul 13	40	pos x1	neg x1	yes	0	1	477	14.7%
C2_005	23 May 13	15 Sep 13	115	neg x1	neg x1	yes	0	34	1189	20.7%
C2_006	23 May 13	4 Jul 13	42	pos x1	neg x1	yes	0	0	294	11.7%
C2_008	24 May 13	2 Sep 13	101	neg x2 pos x1	neg x2	no	0	0	1401	23.7%
C2_011	11 Jan 14	23 Mar 14	71	pos x4	neg x2	yes	0	2	2524	18.1%
&	5 Jun 14	5 Oct 14	122							23.7%
C2_015	10 Jan 14	17 Apr 14	97	neg x3	neg x2	no	0	0	3046	17.0%
&	9 Jun 14	9 Oct 14	122							21.4%
C2_017	11 Jan 14	24 Oct 14	286	neg x1 pos x1	pos x1	yes	2	5	4456	20.8%
C2_019	23 Jan 14	24 Apr 14	91	neg x1	neg x1	yes	0	4	1020	26.1%
C2_020	5 Jun 14	12 Jun 14	7	neg x1	neg x1	no	0	0	70	25.5%
C2_022	23 Jan 15	11 May 15	108	neg x2	neg x2	no	0	0	1547	21.5%
C4_001	14 Jul 14	4 Sep 14	52	neg x1	neg x1	no	0	0	796	20.5%
C4_003	17 Jul 14	16 Dec 14	152	neg x1	neg x1	yes	0	1	3260	11.7%
C4_004	17 Jul 14	12 Sep 14	57	neg x1	neg x2	yes	0	5	1838	25.2%
&	30 Sep 14	3 Feb 15	126							18.4%
C4_005	30 Sep 14	25 Oct 14	25	pos x1	neg x2	yes	0	0	405	19.0%
C4_006	2 Oct 14	18 Dec 14	77	pos x1	neg x1	yes	0	1	1510	12.6%
C4_008	1 Oct 14	23 Oct 14	22	neg x1	neg x1	yes	0	0	461	16.2%
F1_002	14 May 13	8 Nov 13	178	neg x1	neg x1	yes	2	43	2605	14.1%
F1_003	14 May 13	14 Sep 13	123	neg x4	neg x4	yes	8	102	4848	14.7%
&	22 Sep 14	10 May 15	230							10.9%
F1_004	13 May 13	6 Jun 13	24	neg x3	neg x3	yes	0	1	168	20.4%
F1_005	16 May 13	28 Aug 13	104	neg x3	neg x3	no	0	0	1497	14.2%
F1_006	16 May 13	6 Aug 13	82	neg x4	neg x4	yes	0	0	4139	15.7%
&	13 Nov 13	14 Feb 14	93							13.3%
&	22 Sep 14	25 Feb 15	156							13.6%
F1_013	17 May 13	21 Aug 13	96	neg x1	–	yes	0	8	1274	19.6%
F1_015	17 May 13	16 Aug 13	91	neg x2 pos x2	neg x2	yes	0	11	4109	16.7%
&	26 Oct 13	12 Mar 14	137							17.2%
&	16 Jun 14	6 Sep 14	82							18.5%
F1_020	16 Jun 14	18 Nov 14	155	neg x3	negx1	yes	0	0	3313	14.9%
F1_021	24 Oct 13	19 Mar 14	146	neg x1	neg x1	yes	0	1	2326	17.2%
F1_022	27 Oct 13	31 Jan 14	96	neg x3	neg x2	no	0	0	1294	18.2%
F1_024	26 Nov 14	3 Mar 15	97	neg x1	neg x1	yes	1	3	966	13.1%
F1_029	22 Sep 14	7 Feb 15	138	neg x5	neg x3	no	0	0	1942	13.8%
F1_030	24 Sep 14	18 Dec 14	85	neg x3	neg x2	yes	0	3	1328	15.0%
F1_033	16 Jun 14	8 Apr 15	296	neg x2	neg x2	yes	14	83	3897	11.8%
F1_036	22 Sep 14	9 Nov 14	48	neg x2	neg x1	yes	0	3	976	14.2%
F1_039	18 Jun 14	24 Oct 14	128	neg x2	neg x1 pos x1	no	0	0	2847	12.2%
F2_002	10 Sep 13	16 Nov 13	67	neg x1	neg x1	yes	80	154	498	21.2%
F2_004	10 Sep 13	24 Feb 14	167	pos x2	neg x1 pos x1	yes	2	75	2179	19.2%
F2_005	10 Sep 13	22 Jan 14	134	neg x2	neg x2	yes	0	1	1741	22.6%
F2_007	10 Sep 13	14 May 14	246	neg x4	neg x4	yes	5	31	3124	16.4%
F2_012	16 Sep 13	30 Oct 13	44	pos x1	neg x1	yes	0	0	807	15.3%
F2_015	19 Sep 13	12 Mar 14	174	pos x1	pos x1	no	0	0	2220	22.3%
F2_017	25 Sep 13	30 Oct 13	35	neg x1	neg x1	yes	32	37	406	15.4%
F2_020	7 May 14	9 Sep 14	125	neg x2	neg x2	no	0	0	1989	21.9%
F2_023	10 Sep 14	8 Jun 15	271	neg x4	neg x4	no	0	0	3082	16.3%
F2_024	7 May 14	21 Jan 15	259	pos x1	neg x1	no	0	0	3405	20.1%
F2_025	8 May 14	27 Jan 15	264	neg x4	neg x4	yes	1	40	3409	19.3%
F2_026	7 May 14	14 May 14	7	pos x2	neg x1 pos x1	no	0	0	59	35.9%
F2_030	13 May 14	27 May 14	14	pos x1	pos x1	yes	0	0	166	22.1%
F2_032	14 May 14	18 May 14	4	neg x4	neg x4	yes	0	20	1421	22.4%
&	30 Jun 14	24 Jul 14	24							23.3%
&	8 Sep 14	21 Oct 14	43							14.0%
F2_033	14 May 14	3 Jul 14	50	neg x1	neg x1	yes	28	76	821	23.0%
F2_034	15 May 14	12 Jun 14	28	neg x3	neg x3	yes	0	10	3370	25.8%
&	8 Sep 14	27 Apr 15	231							11.7%
F2_039	1 Jul 14	27 Jan 15	210	pos x2	neg x1 pos x1	yes	28	379	3441	16.5%
F2_041	9 Sep 14	18 Dec 14	100	neg x2	neg x2	no	0	0	811	22.3%
F2_043	24 Jan 15	17 Mar 15	52	neg x2 pos x1	neg x2	yes	0	11	724	23.0%
F2_045	28 Jan 15	11 Jun 15	134	neg x1 pos x2	neg x3	no	0	0	1424	28.8%
Total			7,176				206	1148	99163	17.6%

Table S2 – Estimates of badger' farm building use across studies. To allow comparison across studies, estimates of building use are shown as the percentages of nights that each farm building complex received one or more badger visits, and badger population density estimates are based on minimum numbers alive. Data sources: [1]Tolhurst et al. (2009); [2]Garnett et al. (2002); [3]Garnett et al. (2005); [4]O'Mahony (2014); [5]O'Mahony (2015); [6]Mullen et al. (2015); [7]This study.

	Rate of badger visitation to farm buildings			**Local badger density**		
Site	*% nights with badger visits*	*estimation method*	*source*	*badgers per km²*	*estimation method*	*source*
SW England	18.5%	remote cameras; averaged across seasons from Fig 1(a)	1	10.6	minimum number alive (50 badgers caught in 4.7 km²)	1
Gloucestershire	53%	remote cameras; reported in text	2	29.2	minimum number alive (237-289 badgers in 9km²)	3
County Down	3.6%	remote cameras: averaged across farms from Fig 4.2 in ref 4	4,5	2.93	minimum number alive; cited in ref 4	4
County Wicklow	0.1%	GPS collars: min 34 and max 58 independent visits to farms (from Table 1 & text); use median (46). Eleven social groups monitored for 8.45 quarters (760 nights) on average. Assume each of 58 farmyards within single badger group range, giving 58*760=44,080 farm-nights of monitoring.	6	1.1	minimum number alive; cited in ref 6	6
Cornwall, C2	0.3%	GPS collars; 4 nights with badgers <3m from buildings in 1,576 farm-nights. Alternatively 0/1,275 camera nights (Table S3)	7	4.2	minimum number alive (14 badgers in 3.3km²)	7
Cornwall, C4	0%	GPS collars; 0 nights with badgers <3m from buildings in 848 farm-nights. Alternatively 2/117 camera nights (Table S3)	7	5.5	minimum number alive (12 badgers in 2.2km²)	7
Cornwall, F1	1.0%	GPS collars; 22 nights with badgers <3m from buildings in 2,151 farm-nights. Alternatively 0/401 camera nights (Table S3)	7	6.3	minimum number alive (39 badgers in 6.2km²)	7
Cornwall, F2	5.6%	GPS collars; 110 nights with badgers <3m from buildings in 1,960 farm-nights. Alternatively 10/1,224 camera nights (Table S3)	7	6.3	minimum number alive (34 badgers in 5.4km²)	7

Table S3 – Numbers of badger GPS-locations at different distances from farm buildings, comparing the filtered dataset used in the primary analyses, with the unfiltered dataset used in secondary analyses.

		Distance from farm buildings					
Site		*<25m*	*25-50m*	*50-75m*	*75-100m*	*>100m*	Total
C2	unfiltered	60	152	111	162	22,797	23,282
	filtered	49	127	83	124	17,884	18,267
	% excluded	18.3%	16.4%	25.2%	23.5%	21.6%	21.5%
C4	unfiltered	11	35	55	165	9,555	9,821
	filtered	7	27	48	134	8,054	8,270
	% excluded	36.4%	22.9%	12.7%	18.8%	15.7%	15.8%
F1	unfiltered	307	592	816	1,209	40,983	43,907
	filtered	258	503	702	1,056	35,010	37,529
	% excluded	16.0%	15.0%	14.0%	12.7%	14.6%	14.5%
F2	unfiltered	1,002	886	984	1,317	39,189	43,378
	filtered	834	717	827	1,102	31,617	35,097
	% excluded	16.8%	19.1%	16.0%	16.3%	19.3%	19.1%
Total	unfiltered	1,380	1,665	1,966	2,853	112,524	120,388
	filtered	1,148	1,374	1,660	2,416	92,565	99,163
	% excluded	16.8%	17.5%	15.6%	15.3%	17.7%	17.6%

Table S4 – Intensity of GPS-collared badgers' space use at varying distances from farm buildings, based on compositional analysis of unfiltered data. The analysis is based on data from 38 GPS-collared badgers with farm buildings in their individual home ranges. P-values refer to pairwise tests comparing the observed and expected distribution of GPS-locations; significant differences are shown in bold type. Just as in the analysis of filtered data, this analysis indicated that badgers did not use land close to farm buildings in proportion to its availability (p=0.003), with land <25m from farm buildings significantly avoided relative to all other distances.

Distance	**Pairwise p-values**					**Preference**
category	*<25m*	*25-50m*	*50-75m*	*75-100m*	*≥100m*	**rank**
<25m						5
25-50m	**0.004**					3
50-75m	**0.017**	0.838				4
75-100m	**0.003**	0.248	0.088			2
≥100m	**0.002**	**0.013**	**0.010**	0.085		1

Table S5 – Outcomes of monitoring 13 feed stores with camera traps.

Site	**Building identity** *(site-farm-building)*	**Nights monitored**	**Nights badgers detected**
C2	C2-A-a	243	0
C2	C2-A-b	139	0
C2	C2-C-a	210	0
C2	C2-D-a	353	0
C2	C2-E-c	330	0
C4	C4-D-a	117	2
F1	F1-A-a	193	0
F1	F1-D-a	41	0
F1	F1-D-a	167	0
F2	F2-A-a	172	10
F2	F2-C-a	150	0
F2	F2-D-a	451	0
F2	F2-D-b	451	0
Grand total:		***3,134***	***12***

Table S6 – Characterisation of space use in and around farm buildings, for 38 GPS-collared badgers with farm buildings in their home ranges. Duration refers to the maximum number of locations <25m from farm buildings in any one night. Frequency refers to the maximum number of nights with a location <25m from farm buildings in any one month. Building use categories are (1) habitually entered farm buildings; (2) habitually approached farm buildings but did not enter; (3) occasionally approached farm buildings, may have entered; (4) never approached farm buildings.

badger ID	**farm ID** *(site-farm)*	**duration category**	**frequency category**	**entered building complex?**	**cattle housing?**	**building use category**
F1_002	F1-B	≥3	≥3	yes	yes	1
F1_003	F1-B	≥3	≥3	yes	yes	1
F1_033	F1-B	≥3	≥3	yes	yes	1
F2_002	F2-A	≥3	≥3	yes	yes	1
F2_033	F2-A	≥3	≥3	yes	yes	1
F2_017	F2-D	≥3	≥3	yes	no	1
F2_007	F2-B	≥3	≥3	no	yes	2
F2_034	F2-B	≥3	≥3	no	yes	2
F2_025	F2-D	≥3	≥3	no	yes	2
C2_005	C2-E	≥3	≥3	no	yes	2
F2_004	F2-B	≥3	≥3	no	no	2
F2_032	F2-B	≥3	≥3	no	no	2
F2_039	F2-B	≥3	≥3	yard only	no	2
F1_013	F1-B	≥3	≥3	no	no	2
C2_017	C2-D	≥3	1	yes	yes	3
F1_015	F1-C	2	≥3	no	yes	3
C4_004	C4-C	2	2	no	no	3
C2_011	C2-A	2	1	no	yes	3
C2_019	C2-E	1	≥3	no	no	3
F2_043	F2-B	1	≥3	no	no	3
F1_024	F1-D	1	2	yes	no	3
F1_030	F1-D	1	2	no	yes	3
F1_036	F1-D	1	2	no	no	3
C2_003	C2-A	1	1	yes	no	3
C2_004	C2-A	1	1	no	no	3
C4_003	C4-D	1	1	no	no	3
C4_006	C4-A	1	1	no	yes	3
F1_004	F1-D	1	1	no	yes	3
F1_021	F1-D	1	1	no	no	3
F2_005	F2-B	1	1	no	no	3
C2_002	–	0	0	no	–	4
C2_006	–	0	0	no	–	4
C4_005	–	0	0	no	–	4
C4_008	–	0	0	no	–	4
F1_006	–	0	0	no	–	4
F1_020	–	0	0	no	–	4
F2_012	–	0	0	no	–	4
F2_030	–	0	0	no	–	4

badger	metres to nearest farm building
C2_008	175
C2_015	145
C2_020	331
C2_022	227
C4_001	202
F1_005	129
F1_022	157
F1_029	223
F1_039	91
F2_015	422
F2_020	205
F2_023	169
F2_024	402
F2_026	161
F2_041	248
F2_045	225
mean	220
minimum	91
maximum	422

Table S7 – Proximity to farm buildings for badgers without such buildings inside their individual home range polygons.

Table S8 – Summary data on the badger and cattle study populations. Mean territory size was estimated using the Local Convex Hull (*a-LoCoH*) method (Getz et al. 2007). Population density was estimated by the Minimum Number Alive method (Cheeseman et al. 1987).

Study site:	C2	C4	F1	F2
Badgers				
social groups tracked	6	5	7	10
mean territory size	55.6 ha	28.5 ha	51.0 ha	44.2 ha
mean badgers trapped per social group per year	2.3	2.4	5.6	3.4
population density	4.2 km^{-2}	5.5 km^{-2}	6.3 km^{-2}	6.3 km^{-2}
Cattle				
Herds studied				
beef	3	2	3	2
dairy	2	3	2	3
Total	5	5	5	5
TB-affected herds	5	2	1	2