**Ranging behaviour of badgers *Meles meles* vaccinated with Bacillus Calmette Guerin**

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**SUPPORTING INFORMATION**

**Contents**

# 1 Supplementary Methods

## *1.1 Study site details*

Three of our four 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). The fourth site, C4, 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.

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 F2 study farms were engaged in growing crops such as cauliflowers and daffodils, as well as farming cattle. Summary data on the badger populations at each site are presented in Table S6.

## *1.2 Accounting for GPS-collar accuracy*

As detailed in Woodroffe *et al.* (2016), we developed a method to optimise the accuracy and precision of badger GPS-collar data. Tests conducted with stationary collars indicated that the mean distance from a collar's recorded location to its true location (a measure of accuracy) was 6.1m (median 3.7m), and the mean distance to the centroid of all recorded locations (a measure of precision) was 5.9m (median 3.3m). However, all collars occasionally recorded locations >50m from their true location. Our analyses suggested that the accuracy of recorded locations could be improved by filtering out locations with high horizontal dilution of precision (HDOP, Langley 1999) and low numbers of satellites (Woodroffe *et al.* 2016).

The filtering method that we developed first excluded all locations that were >1,000m from both the preceding and subsequent locations. This filter was derived from published data on badger movement speeds (Do Linh San, Ferrari & Weber 2007), and successfully excluded most locations recorded in improbable places (e.g., far outside the study areas, or in the sea). We then excluded all locations with HDOP >4 or based on contact with fewer than four satellites. Analyses based on Receiver Operating Characteristic (ROC) curves, similar to those used to identify optimal specificity and sensitivity for diagnostic tests (Metz 1978), identified this set of filters as excluding the greatest number of inaccurate locations while retaining the greatest number of accurate locations (Woodroffe *et al.* 2016). Applying these filters led us to exclude 17.6% of all badger GPS-collar locations (Table S1).

We have previously shown that this filtering did not compromise analyses of badger habitat selection (Woodroffe *et al.* 2016). To determine whether it introduced systematic biases which could compromise our analyses of the effects of vaccination on badger behaviour, we constructed a generalised linear mixed model, with normally distributed errors, of the proportion of locations excluded from all 66 GPS-tracking bouts, involving 54 badgers (data in Table S1). This model (summarised in Table S7) showed that the proportions of excluded GPS-collar locations differed between sites, with 21.6% of locations excluded at C2, 15.8% at C4, 14.5% at F1, and 19.1% at F2. This variation is likely to reflect differences in land cover between the four sites. For example site F1, with the smallest proportion of excluded locations, is a relatively open clifftop landscape, with little tree cover to impede GPS-collar contact with satellites, whereas site C2 (with the greatest proportion of excluded locations) includes more woodland. After accounting for this variation between sites, our model of the proportions of GPS-locations excluded by filtering did not differ significantly between the sexes (male *vs* female, estimate -0.0088, SE 0.0119, p=0.461), or between badgers of different infection status (positive *vs* negative, estimate -0.0028, SE 0.0123, p=0.826) or vaccination status (vaccinated *vs* unvaccinated, estimate -0.0162, SE 0.0134, p=0.251). We therefore conclude that our primary analyses – which all accounted for differences between sites – are unlikely to have been biased by filtering to exclude inaccurate GPS-locations.

**Table S1** – Summary data from 66 GPS-collar monitoring periods involving 54 badgers. Shading indicates tracking bouts involving vaccinated badgers.

| ID | start of monitoring | end of monitoring | days monitored | first vaccinated | TB test status StatPak | IFNg | filtered locations | total locations | % locations excluded |
|---|---|---|---|---|---|---|---|---|---|
| C2_002 | 23 May 13 | 1 Aug 13 | 70 | – | neg | neg | 648 | 886 | 26.9% |
| C2_003 | 22 May 13 | 24 Sep 13 | 125 | – | pos | pos | 1,592 | 2,038 | 21.9% |
| C2_004 | 22 May 13 | 1 Jul 13 | 40 | – | pos | neg | 477 | 559 | 14.7% |
| C2_005 | 23 May 13 | 15 Sep 13 | 115 | – | neg | neg | 1,189 | 1,499 | 20.7% |
| C2_006 | 23 May 13 | 4 Jul 13 | 42 | – | pos | neg | 294 | 333 | 11.7% |
| C2_008 | 24 May 13 | 2 Sep 13 | 101 | – | neg | neg | 1,401 | 1,837 | 23.7% |
| C2_011 | 11 Jan 14 | 23 Mar 14 | 71 | – | pos | neg | 766 | 935 | 18.1% |
| & | 5 Jun 14 | 5 Oct 14 | 122 | – | pos | neg | 1,758 | 2,304 | 23.7% |
| C2_015 | 10 Jan 14 | 17 Apr 14 | 97 | – | neg | neg | 813 | 979 | 17.0% |
| & | 9 Jun 14 | 9 Oct 14 | 122 | – | neg | neg | 2,232 | 2,840 | 21.4% |
| C2_017 | 11 Jan 14 | 24 Oct 14 | 286 | – | pos | pos | 4,456 | 5,626 | 20.8% |
| C2_019 | 23 Jan 14 | 24 Apr 14 | 91 | – | neg | neg | 1,020 | 1,381 | 26.1% |
| C2_020 | 5 Jun 14 | 12 Jun 14 | 7 | – | neg | neg | 70 | 94 | 25.5% |
| C2_022 | 23 Jan 15 | 11 May 15 | 108 | – | neg | neg | 1,547 | 1,971 | 21.5% |
| C4_001 | 14 Jul 14 | 4 Sep 14 | 52 | – | neg | neg | 796 | 1,001 | 20.5% |
| C4_003 | 17 Jul 14 | 16 Dec 14 | 152 | – | neg | neg | 3,260 | 3,693 | 11.7% |
| C4_004 | 17 Jul 14 | 12 Sep 14 | 57 | – | neg | neg | 883 | 1,180 | 25.2% |
| & | 30 Sep 14 | 3 Feb 15 | 126 | – | neg | neg | 955 | 1,170 | 18.4% |
| C4_005 | 30 Sep 14 | 25 Oct 14 | 25 | – | pos | neg | 405 | 500 | 19.0% |
| C4_006 | 2 Oct 14 | 18 Dec 14 | 77 | – | pos | neg | 1,510 | 1,727 | 12.6% |
| C4_008 | 1 Oct 14 | 23 Oct 14 | 22 | – | neg | neg | 461 | 550 | 16.2% |
| F1_002 | 14 May 13 | 8 Nov 13 | 178 | – | neg | neg | 2,605 | 3,032 | 14.1% |
| F1_003 | 14 May 13 | 14 Sep 13 | 123 | – | neg | neg | 1,759 | 2,063 | 14.7% |
| & | 22 Sep 14 | 10 May 15 | 230 | 22 Sep 14 | neg | neg | 3,089 | 3,465 | 10.9% |
| F1_004 | 13 May 13 | 6 Jun 13 | 24 | – | neg | neg | 168 | 211 | 20.4% |
| F1_005 | 16 May 13 | 28 Aug 13 | 104 | – | neg | neg | 1,497 | 1,745 | 14.2% |
| F1_006 | 16 May 13 | 6 Aug 13 | 82 | – | neg | neg | 1,188 | 1,410 | 15.7% |
| & | 13 Nov 13 | 14 Feb 14 | 93 | – | neg | neg | 856 | 987 | 13.3% |
| & | 22 Sep 14 | 25 Feb 15 | 156 | 22 Sep 14 | neg | neg | 2,094 | 2,424 | 13.6% |
| F1_013 | 17 May 13 | 21 Aug 13 | 96 | – | neg | neg | 1,274 | 1,585 | 19.6% |
| F1_015 | 17 May 13 | 16 Aug 13 | 91 | – | pos | neg | 1,366 | 1,640 | 16.7% |
| & | 26 Oct 13 | 12 Mar 14 | 137 | 26 Oct 13 | neg | neg | 1,329 | 1,605 | 17.2% |
| & | 16 Jun 14 | 6 Sep 14 | 82 | | neg | neg | 1,413 | 1,734 | 18.5% |
| F1_020 | 16 Jun 14 | 18 Nov 14 | 155 | – | neg | neg | 3,313 | 3,892 | 14.9% |
| F1_021 | 24 Oct 13 | 19 Mar 14 | 146 | – | neg | neg | 2,325 | 2,807 | 17.2% |
| F1_022 | 27 Oct 13 | 31 Jan 14 | 96 | 27 Oct 13 | neg | neg | 1,294 | 1,581 | 18.2% |
| F1_024 | 26 Nov 14 | 3 Mar 15 | 97 | 25 Nov 14 | neg | neg | 966 | 1,111 | 13.1% |
| F1_029 | 22 Sep 14 | 7 Feb 15 | 138 | 22 Sep 14 | neg | neg | 1,942 | 2,252 | 13.8% |
| F1_030 | 24 Sep 14 | 18 Dec 14 | 85 | 24 Sep 14 | neg | neg | 1,328 | 1,563 | 15.0% |
| F1_033 | 16 Jun 14 | 8 Apr 15 | 296 | – | neg | neg | 3,897 | 4,420 | 11.8% |
| F1_036 | 22 Sep 14 | 9 Nov 14 | 48 | 22 Sep 14 | neg | neg | 976 | 1,137 | 14.2% |
| F1_039 | 18 Jun 14 | 24 Oct 14 | 128 | – | neg | pos | 2,847 | 3,243 | 12.2% |
| F2_002 | 10 Sep 13 | 16 Nov 13 | 67 | – | neg | neg | 498 | 632 | 21.2% |
| F2_004 | 10 Sep 13 | 24 Feb 14 | 167 | – | pos | pos | 2,178 | 2,694 | 19.2% |
| F2_005 | 10 Sep 13 | 22 Jan 14 | 134 | – | neg | neg | 1,738 | 2,246 | 22.6% |
| F2_007 | 10 Sep 13 | 14 May 14 | 246 | – | neg | neg | 3,124 | 3,738 | 16.4% |
| F2_012 | 16 Sep 13 | 30 Oct 13 | 44 | – | pos | neg | 807 | 953 | 15.3% |
| F2_015 | 19 Sep 13 | 12 Mar 14 | 174 | – | pos | pos | 2,220 | 2,857 | 22.3% |
| F2_017 | 25 Sep 13 | 30 Oct 13 | 35 | – | neg | neg | 406 | 480 | 15.4% |
| F2_020 | 7 May 14 | 9 Sep 14 | 125 | – | neg | neg | 1,989 | 2,546 | 21.9% |
| F2_023 | 10 Sep 14 | 8 Jun 15 | 271 | 9 Sep 14 | neg | neg | 3,082 | 3,684 | 16.3% |
| F2_024 | 7 May 14 | 21 Jan 15 | 259 | – | pos | neg | 3,402 | 4,259 | 20.1% |
| F2_025 | 8 May 14 | 9 Sep 14 | 264 | – | neg | neg | 1,831 | 2,366 | 22.6% |
| & | 10 Sep 14 | 27 Jan 15 | | 10 Sep 14 | neg | neg | 1,578 | 1,856 | 15.0% |
| F2_026 | 7 May 14 | 14 May 14 | 7 | – | pos | pos | 59 | 92 | 35.9% |
| F2_030 | 13 May 14 | 27 May 14 | 14 | – | pos | pos | 166 | 213 | 22.1% |
| F2_032 | 14 May 14 | 18 May 14 | 4 | – | neg | neg | 38 | 49 | 22.4% |
| & | 30 Jun 14 | 24 Jul 14 | 24 | – | neg | neg | 326 | 425 | 23.3% |
| & | 8 Sep 14 | 21 Oct 14 | 43 | 8 Sep 14 | neg | neg | 1,057 | 1,229 | 14.0% |
| F2_033 | 14 May 14 | 3 Jul 14 | 50 | – | neg | neg | 820 | 1,065 | 23.0% |
| F2_034 | 15 May 14 | 12 Jun 14 | 28 | – | neg | neg | 360 | 485 | 25.8% |
| & | 8 Sep 14 | 27 Apr 15 | 231 | 8 Sep 14 | neg | neg | 3,010 | 3,408 | 11.7% |
| F2_039 | 1 Jul 14 | 27 Jan 15 | 210 | – | pos | pos | 3,439 | 4,121 | 16.5% |
| F2_041 | 9 Sep 14 | 18 Dec 14 | 100 | 8 Sep 14 | neg | neg | 811 | 1,044 | 22.3% |
| F2_043 | 24 Jan 15 | 17 Mar 15 | 52 | 10 Sep 14 | pos | neg | 724 | 940 | 23.0% |
| F2_045 | 28 Jan 15 | 11 Jun 15 | 134 | 11 Sep 14 | pos | neg | 1,422 | 1,996 | 28.8% |
| **Total** | | | 7,176 | | | | 99,144 | 120,388 | 17.6% |

**Table S2** – Base model of ln-transformed monthly badger home range size (in $km^2$). This is a generalised linear mixed-effects model with normally distributed errors, based on 290 home range size estimates from 54 GPS-collared badgers across four sites, including badger identity as a random effect. The site variable was included in all analyses, irrespective of whether its effect was statistically significant. After accounting for the covariates in this model, there were no significant effects of badger sex (male *vs* female, estimate 0.133, SE 0.165, p=0.423), infection status (positive *vs* negative, estimate 0.020, SE 0.170, p=0.906), or vaccination status (vaccinated *vs* unvaccinated, estimate -0.023, SE 0.092, p=0.805).

| **Variable** | **Estimate** | **SE** | **p** |
|---|---|---|---|
| Month | | | |
| jan *vs* feb | -0.199 | 0.097 | 0.041 |
| mar *vs* feb | -0.199 | 0.109 | 0.071 |
| apr *vs* feb | -0.179 | 0.126 | 0.157 |
| may *vs* feb | -0.081 | 0.105 | 0.442 |
| jun *vs* feb | -0.176 | 0.101 | 0.083 |
| jul *vs* feb | -0.065 | 0.102 | 0.525 |
| aug *vs* feb | -0.195 | 0.104 | 0.063 |
| sep *vs* feb | -0.198 | 0.097 | 0.041 |
| oct *vs* feb | -0.395 | 0.096 | <0.001 |
| nov *vs* feb | -0.669 | 0.098 | <0.001 |
| dec *vs* feb | -0.636 | 0.101 | <0.001 |
| Site | | | |
| C4 *vs* C2 | -0.341 | 0.285 | 0.237 |
| F1 *vs* C2 | 0.037 | 0.212 | 0.862 |
| F2 *vs* C2 | -0.257 | 0.204 | 0.213 |
| Nights tracked | 0.015 | 0.003 | <0.001 |

**Table S3 –** Base model of nightly distance travelled (in m). This is a generalised linear mixed-effects model with normally distributed errors, based on 585 complete nights of tracking GPS-collared badgers across four sites, including badger identity as a random effect. The site variable was included in all analyses, irrespective of whether its effect was statistically significant. After accounting for the covariates in this model, there were no significant effects of badger sex (male *vs* female, estimate -20.77, SE 108.41, p=0.849), infection status (positive *vs* negative, estimate 168.50, SE 107.50, p=0.125), vaccination status (vaccinated *vs* unvaccinated, estimate 17.07, SE 100.90, p=0.866), or nights since capture (whether represented as a continuous variable [estimate 0.702, SE 0.687, p=0.307] or as a categorical variable [first *vs* subsequent night, estimate -175.24, SE 174.65, p=0.316]).

| **Variable** | **Estimate** | **SE** | **p** |
|---|---|---|---|
| Month | | | |
| jan *vs* feb | -90.91 | 106.57 | 0.394 |
| mar *vs* feb | -73.36 | 183.65 | 0.690 |
| apr *vs* feb | 540.77 | 247.19 | 0.029 |
| may *vs* feb | 546.27 | 133.32 | <0.001 |
| jun *vs* feb | 526.05 | 131.65 | <0.001 |
| jul *vs* feb | 896.27 | 140.04 | <0.001 |
| aug *vs* feb | 1,073.84 | 173.42 | <0.001 |
| sep *vs* feb | 297.89 | 248.39 | 0.231 |
| oct *vs* feb | 229.11 | 200.64 | 0.254 |
| nov *vs* feb | -2.33 | 124.56 | 0.985 |
| dec *vs* feb | -137.88 | 110.84 | 0.214 |
| Site | | | |
| C4 *vs* C2 | 88.26 | 226.06 | 0.698 |
| F1 *vs* C2 | 308.87 | 131.27 | 0.023 |
| F2 *vs* C2 | 110.06 | 133.60 | 0.415 |

**Table S4** – Base model of nightly trespassing probability. This is a generalised linear mixed-effects model, with binomially distributed errors (logistic regression), based on 6,768 badger-nights of GPS-monitoring at four sites, including badger identity as a random effect. The site variable was included in all analyses, irrespective of whether its effect was statistically significant. The number of neighbouring territories with GPS-collared group members was likewise forced into this model. After accounting for these covariates, there were no significant effects of badger sex (male *vs* female, estimate 0.267, SE 0.601, p=0.657), infection status (positive *vs* negative, estimate -0.411, SE 0.627, p=0.512), vaccination status (vaccinated *vs* unvaccinated, estimate 0.221, SE 0.242, p=0.362), or trapping (trapping *vs* no trapping on the night concerned, estimate 0.306, SE 0.248, p=0.217).

| **Variable** | **Estimate** | **SE** | **p** |
|---|---:|---:|---:|
| Month | | | |
| jan *vs* feb | -0.732 | 0.199 | <0.001 |
| mar *vs* feb | -0.383 | 0.226 | 0.091 |
| apr *vs* feb | -0.414 | 0.280 | 0.140 |
| may *vs* feb | -0.494 | 0.255 | 0.053 |
| jun *vs* feb | -0.605 | 0.238 | 0.011 |
| jul *vs* feb | -0.322 | 0.221 | 0.146 |
| aug *vs* feb | 0.027 | 0.226 | 0.905 |
| sep *vs* feb | 0.645 | 0.198 | 0.001 |
| oct *vs* feb | -0.272 | 0.204 | 0.182 |
| nov *vs* feb | -0.577 | 0.207 | 0.005 |
| dec *vs* feb | -1.195 | 0.226 | <0.001 |
| Site | | | |
| C4 *vs* C2 | -2.505 | 1.260 | 0.047 |
| F1 *vs* C2 | 0.744 | 0.764 | 0.330 |
| F2 *vs* C2 | -0.433 | 0.741 | 0.559 |
| Neighbouring territories | 0.595 | 0.360 | 0.098 |

**Table S5** – Model of ln-transformed badger home range size (in $km^2$), measured by bait marking in the Randomised Badger Culling Trial (RBCT). This is a generalised linear model with normally distributed errors. The triplet variable was included in all RBCT analyses, irrespective of its contribution to model fit.

| **Variable** | **Estimate** | **SE** | **p** |
|---|---|---|---|
| Triplet | | | |
| C *vs* B | -0.306 | 0.334 | 0.372 |
| D *vs* B | -0.279 | 0.262 | 0.296 |
| G *vs* B | -0.014 | 0.272 | 0.960 |
| H *vs* B | -0.538 | 0.262 | 0.050 |
| Treatment | | | |
| inside proactive *vs* survey-only | 1.029 | 0.255 | <0.001 |
| outside proactive *vs* survey-only | -0.063 | 0.264 | 0.813 |
| reactive *vs* survey-only | 0.554 | 0.262 | 0.044 |

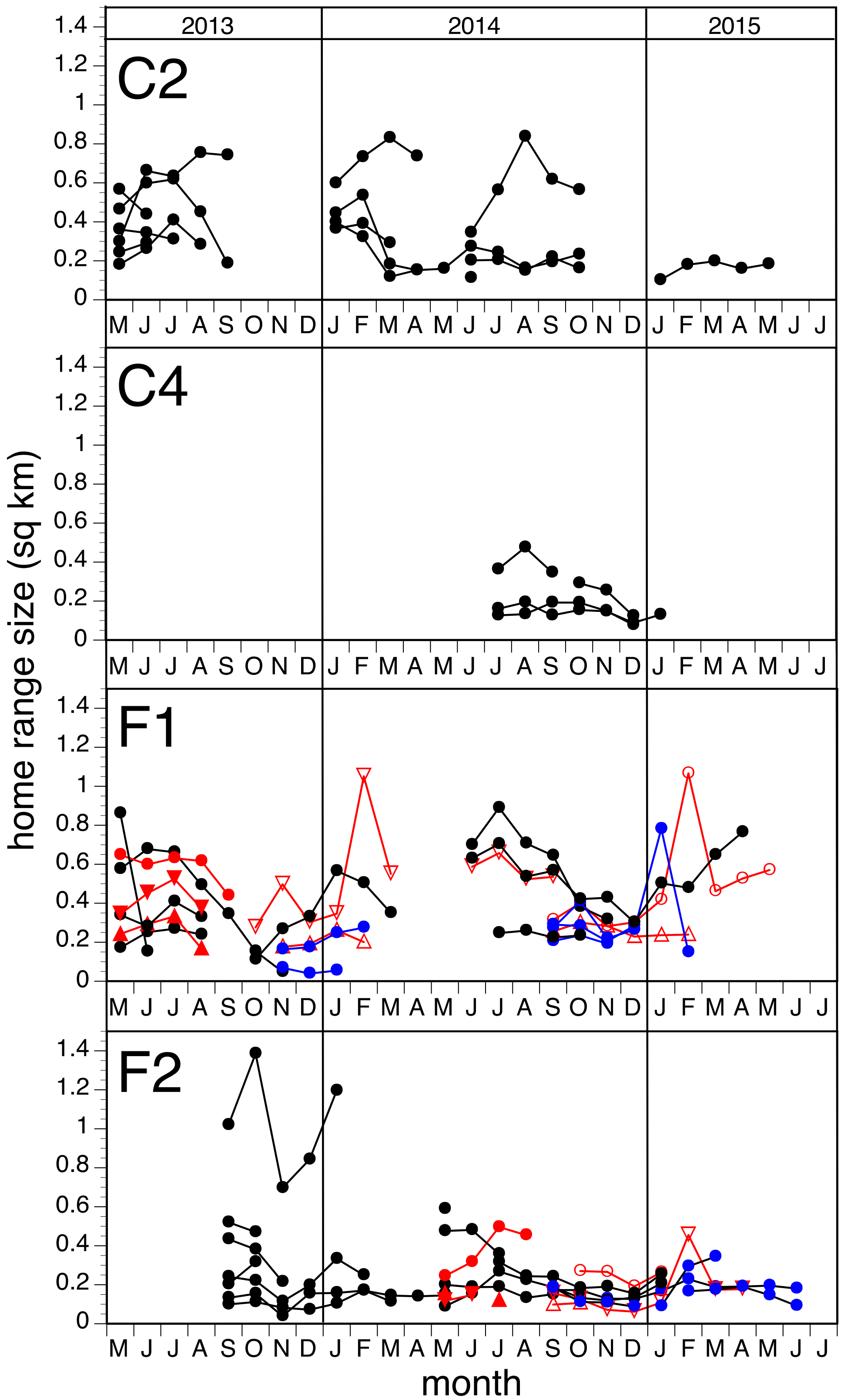
**Table S6** – Summary data on the badger populations at four study sites. Mean territory size was estimated using the Local Convex Hull (*a-LoCoH*) method (Getz *et al.* 2007). Population density was estimated by the Minimum Number Alive method (Cheeseman *et al.* 1987). This table is modified from the Supporting Information of Woodroffe *et al.* (2016).

| **Study site:** | **C2** | **C4** | **F1** | **F2** |
|---|---|---|---|---|
| social groups tracked | 6 | 5 | 7 | 10 |
| mean social group territory size ($km^2$) | 0.56 | 0.29 | 0.51 | 0.44 |
| mean badgers trapped per social group per year | 2.3 | 2.4 | 5.6 | 3.4 |
| population density (badgers per $km^2$) | 4.2 | 5.5 | 6.3 | 6.3 |
| years vaccinated | – | – | 2013-5 | 2014-5 |
| badgers vaccinated | 0 | 0 | 45 | 38 |

**Table S7** – Model of the proportion of GPS-collar locations excluded by filtering. This is a generalised linear mixed-effects model with normally distributed errors, based on 66 monitoring bouts involving 54 badgers. Badger identity is included as a random effect. After adjusting for site, there were no significant effects of badger sex (male *vs* female, estimate -0.0088, SE 0.0119, p=0.461), infection status (positive *vs* negative, estimate -0.0028, SE 0.0123, p=0.826), or vaccination status (vaccinated *vs* unvaccinated, estimate -0.0162, SE 0.0134, p=0.251).

| **Variable** | **Estimate** | **SE** | **p** |
|---|---|---|---|
| Site | | | |
| C4 *vs* C2 | -0.0332 | 0.0199 | 0.101 |
| F1 *vs* C2 | -0.0577 | 0.0148 | <0.001 |
| F2 *vs* C2 | -0.0027 | 0.0144 | 0.855 |

**Figure S1** – Individual variation in monthly home range size across four study sites. Black points represent individuals that were never vaccinated, blue points indicate animals that were tracked with GPS-collars only after vaccination. Red points denote the six individuals which were tracked both before (closed symbols) and after (open symbols) vaccination. No animals were vaccinated at sites C2 and C4. Statistical analyses of these data included the number of nights tracked, which is not accounted for in these plots.



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