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SID 5 Research Project Final Report

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Project identification

1. Defra Project code: WM0310
2. Project title: Monitoring regional changes in badger numbers.
3. Contractor organisation(s): Central Science Laboratory, Sand Hutton, York, YO41 1LZ

54. Total Defra project costs (agreed fixed price): £ 473,963.00

5. Project: start date................ 01 November 2005

   end date................. 31 May 2006

6. It is Defra's intention to publish this form.
Please confirm your agreement to do so.. **YES** ☒ **NO** ☐

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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

- In response to potential changes in government policy towards the management of the badger population in England, Defra identified a requirement for data on the current status of the population. Such baseline data on badger numbers is a vital prerequisite to assessing any change in population status following the implementation of any new management policy.
- The overall objective of this study was to provide baseline data on badger densities in areas likely to be culled (as well as controls), to allow any subsequent changes in badger densities to be assessed.
- Based on the location of farms identified by the Veterinary Laboratory Agency (VLA) as having recent recurrent bovine tuberculosis (bTB) herd breakdowns, four study regions located in south-west England were delineated: Cornwall, Devon, Gloucestershire and Herefordshire/Worcestershire/Staffordshire (henceforth Herefordshire).
- Sampling was based on a series of randomly selected survey areas in each region, each survey area consisting of a circle with a radius of 2.5km (19.6 km^2). Each area was centred on a randomly selected 'central' farm that had two or more bTB breakdowns in four years and/or had been under movement restriction for more than 24 months over that period. In each region a small number of central farms were designated control farms and thus having no bTB problem.
- In each survey area, line transects were established across approximately 20 randomly selected fields. The orientation of each transect line was also selected randomly.
- Distance sampling involving spotlights counts along these transects at night was used to estimate population densities of badgers in each of the four regions. The technique also allowed the simultaneous collection of data on fox, hare and deer.
- Distance sampling along each transect was conducted by a pair of surveyors with transects covered twice during an overall 11-week survey period (13th March to 18th May).
- Overall, the number of survey areas completed was: Cornwall 20 areas (759 transects; total length 174,925 m), Devon 21 areas (793 transects; total length 192,698 m), Gloucestershire 19 areas (640 transects; total length 164,734 m) and Herefordshire 20 areas (659 transects; total length 178,144 m).
- Fewer transects were covered during the second round of surveys due to a number of different reasons, including removal of access permission by landowners (e.g. as a result of change of land use). Total transect length during the second round of surveys represented 59%-74% of the total transect length in the first round of surveys (Cornwall = 74%; Devon = 71%; Gloucestershire = 72%; Herefordshire = 59%).
- For each region, the total numbers of badgers recorded during the second round of surveys was lower than in the first round. Allowing for the shorter total transect length in the second round, however, the rate of detection was actually higher in the second round in Cornwall and Devon: Cornwall 0.48 and 0.53 badgers per km; Devon 0.44 and 0.48 badgers per km (Gloucestershire 0.74 and 0.68 badgers

per km; Hereford/Worcester 0.56 and 0.44 badgers per km) for first and second surveys respectively.

- Using distance analysis, the density of badgers foraging in open pasture was estimated to be: Cornwall 4.5 badgers km^{-2} (95% confidence limits: 3.2 – 6.5); Devon 4.1 badgers km^{-2} (3.0 – 5.6); Gloucestershire 4.4 badgers km^{-2} (3.2 – 6.1); Herefordshire 3.9 badgers km^{-2} (2.9 – 5.4).
- The relative densities of badgers derived from distance sampling in this study do not represent absolute regional abundances. Badgers only spend a proportion of their time in open, surveyable habitat, so absolute abundance will be underestimated. The derived values represent relative population density estimates in open pasture and can be applied to the assessment of potential changes in density over time in the same region.
- Estimates of absolute badger abundance and density are possible to produce through the application of correction factors to the relative density estimates derived in this study. A previous CSL study in Woodchester Park, Gloucester, indicated that badgers, on average, spend 48.5% of their time in open land, and this was used to convert densities observed in open pasture to overall density in the Wodchester site. This figure was derived in one specific area in Woodchester Park, and no information is available on its applicability to other regions and habitat mosaics.
- Estimates for the mean density of other target species in open pasture were: fox - Cornwall 2.6km^{-2} (95% confidence limits: 1.9 – 3.6); Devon 1.9km^{-2} (1.3 – 2.9); Gloucester 2.4km^{-2} (1.8 – 3.3); Herefordshire 2.0km^{-2} (1.4 – 2.7); hare - Cornwall 0.4km^{-2} (0.2 – 0.8); Devon 1.8km^{-2} (1.0 – 3.2); Gloucester 2.6km^{-2} (1.7 – 3.8); Herefordshire 3.9km^{-2} (2.7 – 5.8).
- Deer were recorded on pasture in all regions. Numbers (and encounter rates) were: Cornwall 23 (0.13 deer km^{-1}); Devon 149 (0.77km^{-1}); Gloucester 130 (0.79km^{-1}); Herefordshire 19 (0.11km^{-1}). Roe deer were the species encountered most frequently.
- The project was subject to a number of issues that reduced the overall survey coverage below that initially anticipated. Analysis indicated, however, that the reduced sample size did not significantly affect the confidence limits around the estimates of badger densities.
- Repeating the survey work in autumn will be beneficial. In the present study, in Cornwall and Devon detection rate of badgers was lower in early compared to late spring due to the exceptionally inclement early season weather, and lowered detection rates can result in underestimates of population densities. In addition, recruitment of offspring to the population over summer will result in higher population densities in autumn. Information on the seasonal variation in regional population densities would provide additional data to inform future policy decisions. Most importantly, however, a regular monitoring scheme would optimally be conducted in autumn, as during this season in addition to the population being at its maximum, vegetation remains low (facilitating surveys) for the entire monitoring season (unlike in the spring).
- This project represents a significant contribution to the existing knowledge of regional badger population densities. It is both the geographically most extensive and regionally intensive distance sampling study, using walked lamped transects, that has been undertaken on badgers and other British mammals to date. The project has produced baseline estimates of spring badger densities in open pasture against which any potential future changes can be assessed.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:
   - the scientific objectives as set out in the contract;
   - the extent to which the objectives set out in the contract have been met;
   - details of methods used and the results obtained, including statistical analysis (if appropriate);
   - a discussion of the results and their reliability;
   - the main implications of the findings;
   - possible future work; and
   - any action resulting from the research (e.g. IP, Knowledge Transfer).

2. Introduction

In response to the ongoing issue of the role of badgers *Meles meles* in the transmission of bovine tuberculosis (bTB) in cattle, Defra are considering potential changes to their management policy towards badgers. In order to support any new policy there is a need to monitor the number of badgers. If badgers are to be culled, then monitoring should assess the consequences of culling at a regional scale and assess trends in numbers in culled and non-culled areas. A vital prerequisite to assessing any change in status (and the overall objective of this project) is having baseline data on badger densities in areas likely to be culled (as well as controls). By providing this background assessment, the effectiveness of any possible culling policy carried out under licence can be studied by using similar methods, allowing any subsequent changes in badger densities to be assessed. From consideration of the statistical power necessary to detect a significant change in density, sampling procedures are required that permit the detection of a reduction in the population of 50%. In addition, however, badger density should not be reduced to extremely low levels (i.e. localised disappearance would contravene the Berne convention).

Precision and unbiased estimates of population size are necessary for making reliable decisions in wildlife management and conservation (Ogutu *et al.,* 2006). The application of robust methods and sound statistical analysis will produce more precise estimates of abundance (Hounsome *et al*., 2005). One technique that has been widely used in recent years to estimate the abundance of vertebrates is distance sampling (Buckland, *et al*. 2000; Buckland *et al*. 2001).

Distance sampling is a technique used for estimating population densities without involving any capture, marking or release procedures. It extends the traditional capture, mark and re-capture theory of the population sampling approach by measuring distances from a randomly placed transect line across a habitat to individuals of the study species detected by observers travelling along the line (Buckland *et al.,* 2001). A statistical model (a detection function) is fitted to the distance data which describes the probability of seeing animals given their distance from the transect; the probability decreases with increasing distance. The mean probability of detection can then be estimated from the survey data. Density is estimated from the number of animals encountered per unit area surveyed, divided by the probability of detection. The objective of distance sampling, therefore, is to sample the perpendicular distances to detected animals from the transect line rather than carry out an absolute census of all individuals in an area.

The accuracy of any method for estimating populations can only be quantified when the true abundance is already known. For distance sampling, a number of studies have evaluated the accuracy of the technique using known populations of inanimate objects (e.g. Hone 1988; Anderson *et al*. 2001) or enclosed animal populations (e.g. Southwell 1994; Pelletier & Krebs 1997). In general, these studies indicated close agreement between the distance sampling estimates and the known population size. Recently, the technique has been validated for badgers on a population that has been the subject of a long-term mark-recapture study (Hounsome *et al*. 2005).

Distance sampling, like mark-recapture has the benefit of not requiring the detection of all animals in the population. Estimates of density arising from a number of previous (mark-recapture and radio tracking) studies range from 25.3 adults km^{-2} in Gloucestershire and 16.5 adults km^{-2} in Oxfordshire to 5.7 adults km^{-2} in suburban Bristol and 2.1 adults and cubs km^{-2} in Inverness-shire. Mark-recapture, however, is both labour and resource intensive. Hounsome *et al*. (2005) concluded that, compared to mark-recapture, distance sampling potentially offers a more resource efficient method of estimating populations.

Previous studies estimating badger abundances have, however, largely focused on badger main sett densities. Three national surveys have been conducted to estimate the population of badgers in Britain using counts of main setts. The first summarised the results of the National Badger Survey instituted in 1963, and estimated the population to be 216,000 from 36,000 main setts (Clements *et al*. 1988). During the late 1980s, the population was estimated to be 250,000 adults and 105,000 cubs from 42,891 main setts (Cresswell *et al*. 1990). In the mid 1990s, there was an estimated 50,241 main setts (Wilson *et al.,* 1997). In 1990, Cresswell *et al.* estimated average densities for badgers in various land classes in Britain, e.g. 0.6-0.7 social groups km^{-2} in favourable habitats and 0.3-0.4 social groups km^{-2} in less favourable habitats.

Sett surveys, however, incorporate a number of assumptions. It is assumed that badgers are organised into social groups throughout their range in Britain, and that each social group inhabits a territory with one main sett. An assumption of, on average, six adult badgers per social group (derived from a number of mark-recapture and radio tracking studies) is then used to derive estimates of densities or absolute population size. These assumptions, however, contain inherent weaknesses. For example, the sizes of badger social groups will vary markedly both between and within different regions as a consequence of variation in, amongst other factors, preferred habitat. If these assumptions do not hold, then estimates of population densities will be unreliable. Sett surveys are also of limited use when monitoring year-to-year changes in badger numbers, or the effects of management.

The present study, in conjunction with the simultaneous work conducted in Wales, represent the first large-scale application of walked distance sampling using spotlights to estimate population densities of any British mammal.

3. Aim

The overall objective of the study was to provide baseline data on regional badger densities foraging on open pasture on selected regions in south-west and west England. Such information would serve as baseline data with which to compare any changes in badger numbers in the event of any future management policy.

4. Study regions

The study was conducted in four regions of south-west and west England – Cornwall (region 1), Devon (region 2), Gloucestershire (region 3) and Hereford/Worcestershire/Staffordshire (henceforth Herefordshire) (region 4). The study regions were based on the location of farms identified by the Veterinary Laboratory Agency (VLA) as having recent recurrent bovine tuberculosis (bTB) herd breakdowns and converted into a shapefile using ArcGIS 9.1.

Regions were based on the distribution of bTB hotspot areas. To identify hotspots the County Parish Holding (CPH) points of all 1024 recurrent bTB farms within England were buffered by 10km, and the resulting circles coalesced where overlapping. This created a series of 12 distinct areas within which between 1 and 490 bTB farms were located, and allowed for identification of three hotspots (Cornwall/Devon, Herefordshire/Worcestershire/Gloucestershire, Staffordshire) that contained between 72 and 490 bTB farms. Only 35 bTB farms lay outside the hotspots, and these were considered outliers, and were not considered for monitoring.

Two of these hotspots (Cornwall/Devon and Herefordshire/Gloucestershire) were split, using major geographical features as the basis for this. Region 1 and 2 were divided using the course of the River Tamar, which following the Cornwall and Devon county boundary virtually dissects from the Irish Sea to English channel, with only a small section of the A3072 running into Bude being used to finish the boundary in the north. Region 3 and 4 were divided using the courses of the Severn and Avon Rivers (Figure 1). The selection of four study regions represented the optimal delineation of bTB hotspots with respect to logistically manageable survey areas having discrete county and topographical boundaries.

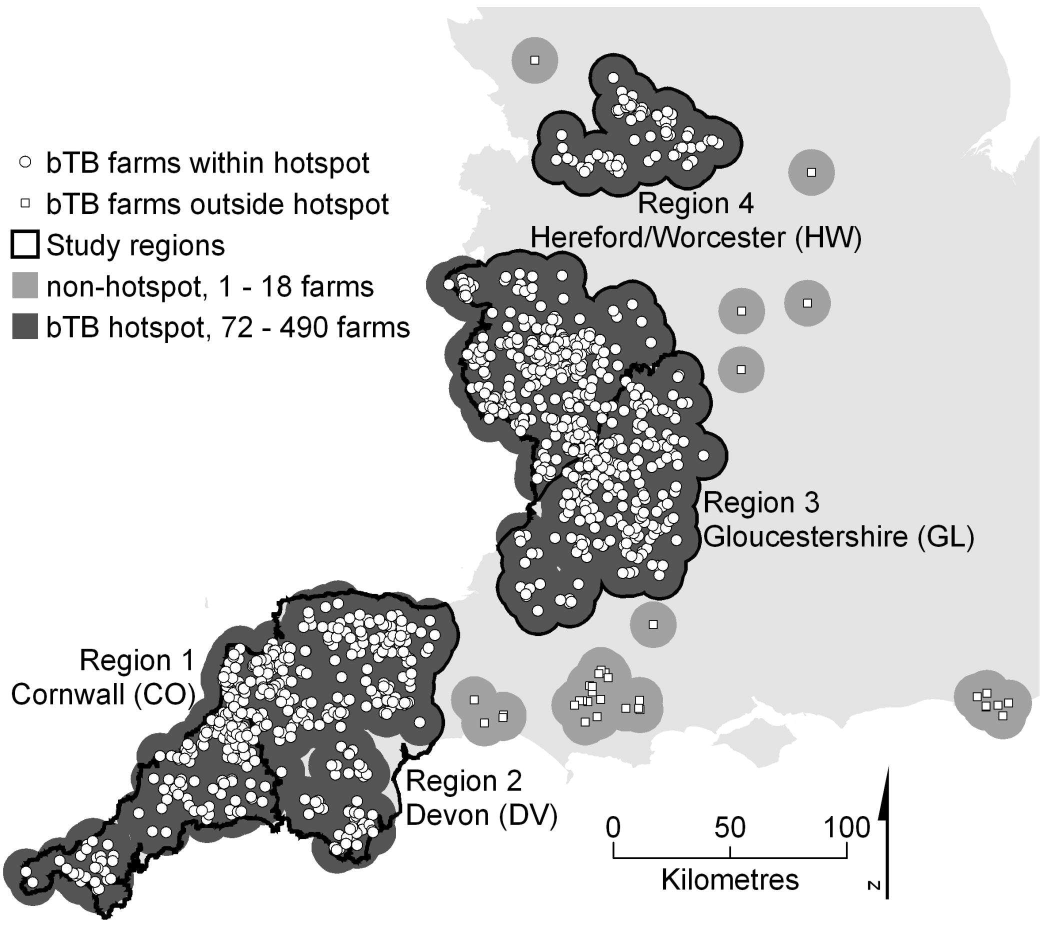

Figure 1. Location of the four study regions in south-west and west England.

5. METHODOLOGY

5.1 Sampling procedure

Sampling was based on a series of survey areas, each consisting of a circle with a radius of 2.5km ($19.6km^2$). Each survey area was centred on a randomly selected 'central' farm that was surrounded by varying numbers of landholdings. Central farms were those that had two or more bTB breakdowns in four years and/or had been under movement restriction for more than 24 months over that period. In each region a small number of central farms were designated control farms and thus had no bTB problem. The former category represented farms that would be eligible for a license in the event of the introduction of a badger cull, whilst control farms would not be eligible.

In order to estimate how many survey areas and how many transects were required the monitoring of badgers was simulated in a region encompassing 25 survey areas by observations along 500 transects in open land, to assess at what level a change in the population could be detected. The simulations indicated that, given a likely badger density of approximately 12 badger km^{-2} (half that of CSL's intensely monitored study population at Woodchester Park, Gloucester), a sampling strategy of 25 survey areas each with 20 transects of 5000m cumulative transect length, and each transect covered twice, should be able to detect a change in density of 15% at the regional level. Should density fall, the percentage difference needed to detect a change increases, such that at 6 badger km^{-2} a decrease in the order of 25% is needed to be statistically significant. Details of the power analysis to determine sample size are in Appendix 2.

In the event of a badger cull, changes in badger densities could be compared between survey areas centred on eligible (culled) and non-eligible (non-culled) farms. A significant unknown, however, was the number of eligible farms that would actually opt to take up a license to cull if such a scheme was introduced; it was expected that not all would and that these would act as controls. Therefore, the target sample of 25 survey areas would contain 'cull' and 'control' (but eligible) survey areas, but with an unknown ratio. As insurance against a high uptake of cull licenses, a number of control areas were included in the survey sample, which were centred on non-bTB farms and so would not be eligible for a cull license.

5.1.1 bTB farms

A random selection of bTB farms within each study region formed the basis for monitoring efforts. However, prior to making this selection, farms that were within two kilometres of the proactive areas of the Randomised Badger Culling Trial (RBCT), or the Woodchester Park and Badger Vaccine Trial study areas, were excluded.

Table 1. Numbers of bTB farms comprising the sample pool in each region.

Study Region	Total number of bTB farms	Excluded bTB farms	Farms available for survey
Region 1	148	22	126
Region 2	279	57	222
Region 3	221	46	175
Region 4	341	43	298
Totals	989	168	821

To ensure randomness, the bTB farms available for monitoring within each region were put into a random order, and farms were considered for survey in this order, omitting those farms for which land access permission was not granted.

5.1.2 Control farms

In addition to surveying bTB farms, a number of control farms were also required for monitoring. A control strip was defined within all study regions, that was no more than 8km and no less than 5km from the nearest bTB farm (Figure 2). Within this area June Census data was used to randomly select 15 farms for each study region that had recorded a cattle entry. Any farm for which contact details could not be acquired (seventeen farms), or which fell within 2km of an exclusion area (one farm) were dismissed. As with the bTB farms, the control farms were put in a random order and were considered for survey in this order, omitting those farms for which land access permission was not granted.

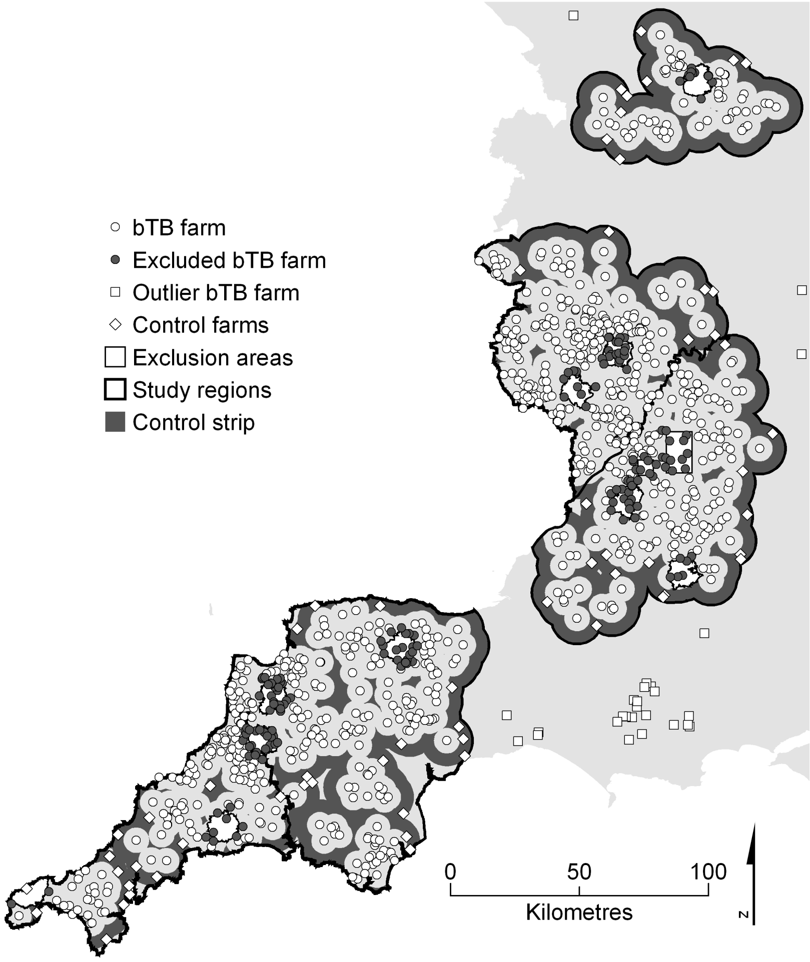

Figure 2. Delineation of buffer zones containing control farms.

5.1.3 Survey areas

Survey areas consisting of circles with a radius of 2.5km were to be positioned around any farms selected for monitoring. At this finer geographic scale, the positional accuracy of the CPH points precludes their use as a basis for defining survey areas. Instead data from the Rural Land Registry (RLR) was used.

Initially RLR data was requested for the first 50 bTB farms, from their random order, in each region, and all control farms in each region. All land parcels for the farms in question was requested, along with any other land parcels within 2.5km of those land parcels. A further set of RLR data was requested for, in their random order, 15 bTB farms in study region 1. Relevant contact information was supplied with these files.

Land parcel data was used to position the 2.5km survey area circles around the central farm, taking into account any confounding factors, such as extensive dispersal of the land parcels of the central farm, or the presence of any significant landscape features likely to influence badger distribution. Examples of positioning survey areas in response to varying factors are in Appendix 3.

Finally survey areas were not permitted to overlap. Therefore farm survey areas were created in their random order. If when considered for monitoring, a farm's survey area would impinge on an existing survey area, this farm was ignored, and the next farm was considered instead. This process was repeated until survey areas had been established for 21 bTB farms, and 4 random control farms in each region (Figure 3).

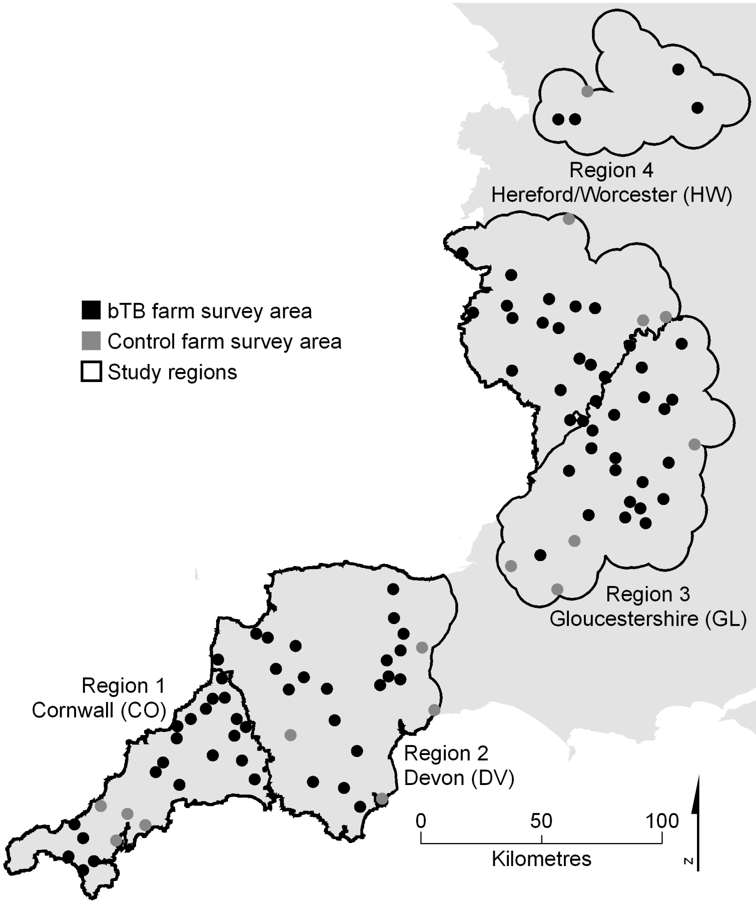

Figure 3. Distribution of randomly selected survey areas in the four study regions in south-west and west England.

5.1.4. Random field selection

Within each survey area a random selection of land parcels was required for distance sampling. All land parcels that had their centre within the survey area were considered, excluding those for which access permission had been refused, no contact information were available, were within another study region, or were on the other side of a major geographic feature such as a major river or motorway from the focal farm's land parcels. In addition land parcels smaller than one hectare were not considered, as these fields were not suitable for distance sampling and formed a very small proportion of the number of fields.

The remaining fields were then put in random order and the top fifty were selected as a pool. Field staff would then consider the fields in order, setting up transects in those fields that were suitable. Fields would be discarded if access was denied, or if the field was unsuitable for distance sampling. If the initial fifty fields did not provide enough land to meet the requirements of a minimum of 20 transects with a total length of 5000m, then a further randomly selected list was considered. Surveys concentrated on pasture fields, but where the availability of pasture within a survey area was low a limited number of arable fields were included in the sample.

5.1.5 Postal land access requests

On receipt of the data on landholdings from Defra Rural Development Service (RDS), letters seeking permission for access to land were sent out. These letters included a *pro forma* reply and stamped addressed envelope. A total of 2704 letters were sent out and replies were received from 1133 (41.9%). There were 792 landowners who gave permission (69.9% of those replying) and 341 who refused permission (30.1%).

5.2 Field surveys

5.2.1 Distance sampling

Distance sampling (Buckland *et al*., 2001) is a well established technique, involving surveys along random lines or points. The perpendicular distances from the lines or points to the study animals detected are used to estimate animal density. The technique, using spotlight counts at night along randomly placed transects, has been validated for badgers in south-west England by CSL staff from Woodchester Park (Hounsome *et al*., 2005).

It was not feasible to use distance sampling methods based on vehicle-mounted spotlight counts as utilised by the Randomised Badger Culling Trials (RBCT), due to the smaller-scale survey units in this study. Vehicle-mounted spotlight surveys have also been limited to areas with reasonable visibility: for example they have proved unsuitable for some areas in Cornwall with small fields and high hedges. Distance sampling in this study was therefore carried out on foot. Surveys are best conducted in the pre-breeding period from late February to the end of April, before large numbers of cubs are above ground and when visibility is good due to low vegetation, and in the autumn (September-November inclusive) when badger breeding is complete. Low badger activity and cold weather in December and January limits the applicability of the method in these months. The influx of cubs and growing crops limits the efficacy of the methodology from early May. Stable estimates depend on obtaining a minimum number of sightings (60-80) of the target species. The distance sampling method also allowed density estimates for other species: foxes *Vulpes vulpes*, hares *Lepus europaeus* and deer spp. to be collected at the same time.

5.2.2 Field transects

Following Hounsome *et al*. (2005), line transects were established across a random sample of fields in each of the 19.6 km^2 survey areas. The orientation of transect lines was at random with respect to the expected distribution of the study population (Buckland *et al*. 2001). In establishing transects, however, it was unrealistic to use completely random start points, as this would have required surveyors to walk along field boundaries from the point of access to the start point, which would have disturbed animals nearby. The start of each transect, therefore, was located at the nearest practical point of access to the field. For each field, a line transect was then established across the field along a random bearing from the start point. The only constraint on the bearing was that the length of individual transects should exceed a minimum distance of 50m. A compass was used to follow the bearing and the end points marked using highly reflective tape placed on a suitable substrate (e.g. fence, tree). The start and end points of the transect were also recorded on GPS.

During night-time surveys, each transect was walked by two field surveyors. Each surveyor carried a red-filtered spotlight (1.2 million candle power), a pair of binoculars, a laser rangefinder and a compass. The orientation of the transect line was indicated by the reflective tape at the end of the line that was visible in the spotlights. One surveyor walked in the lead and scanned the spotlight directly along the transect line and up to angles of 45° either side. The surveyor walking behind scanned all around, concentrating on the wider angles from the transect line. When an animal was spotted, it was identified (using binoculars if necessary) and its distance determined using the rangefinder. The bearing to the animal (from the observer) was measured using the compass. If an animal was moving, the distance and bearing was measured to the point at which it was first seen. For each observation, subsequent calculations derived the perpendicular distance from the line transect to the target species from the sine of the angle between the bearing to the animal and the transect bearing, multiplied by the distance to the animal from the observer.

It was intended that each transect would be surveyed twice during the overall study period. For most survey areas, however, fewer transects were covered during the second round of surveys. Exclusion of transects from the second round occurred for a number of reasons, including removal of access permission by the landowner (e.g. as a result of stock having been turned out between surveys), inability to contact landowners to confirm access permission or the field no longer being suitable for surveying (usually due a marked increase in crop height, e.g. silage grass or arable crop).

5.3 Distance analysis

The survey results were analysed using the distance sampling software Distance 4.1 (Thomas *et al*. 2004). The assumption underlying distance sampling is that the further away a subject is from the observer the less likely it is to be detected. The probability of detection is calculated from the perpendicular distances of the detected subjects from the transect line. From this an observational width is estimated which, in conjunction with the length of transect, provides an estimate of the effective observational area. The estimated number of subjects in the observational area provides the subject density. To avoid the problem of pseudoreplication, repeated transects were entered as single transects of double length (transects were sampled a maximum of twice). The distance fitting was half-normal/cosine. The density of target species in open pasture was estimated as individuals per km^2.

Estimates of absolute badger abundance and density are possible to derive through the application of correction factors to the estimates for density in open pasture. These correction factors include estimates of the total open habitat within the study area, and a factor (habitat multiplier) to account for the proportion of time that badgers spend in open, surveyable land. The only study, to date, that has derived a habitat multiplier was conducted in Woodchester Park, Gloucestershire (Hounsome *et al*. 2005); using radio-tracking data (Garnett 2003). The proportion of time, however, that badgers spend in open land may vary between areas of differing habitat composition. Currently, there is insufficient understanding of how this proportion varies between different habitats, and within the same habitat over time. With significant differences in habitat between Woodchester Park (pasture/woodland mosaic) and the three other study regions (e.g. Cornwall has an arable/pasture mosaic) it was not considered appropriate to apply these extrapolations in this study.

6. Results

6.1 General

The distance sampling survey period extended for 11 weeks from 13th March to 18th May (1st round: start date 13th March; 2nd round: start date 1st May).

The number of survey areas, transects and total transect length in each region are summarised in Table 2.

Table 2. Number of survey areas, transects and total transect length for each region.

Region	No. Survey areas	No. Transects	Total Transect length (m)
Cornwall	20	759	174,925
Devon	21	793	192,698
Gloucestershire	19	640	164,734
Herefordshire	20	659	178,144

For each region, the number of badgers, fox, hare and deer observed during the first and second surveys in each survey area are shown in Tables 3-6. In each region, numbers of each species varied between different survey areas, with each region containing at least one area that had markedly higher numbers of animals than the other areas.

Total transect length during the second round of surveys represented 59%-74% of the total transect length in the first round of surveys (Cornwall = 74%; Devon = 71%; Gloucestershire = 72%; Herefordshire = 59%).

6.2 Encounter rates

The encounter rates (individuals per km transect) for badger, fox, hare and deer in each of the four study regions are presented in Figure 4.

For each region, the total numbers of badgers recorded during the second round of surveys was marginally lower than in the first round. Allowing for the shorter total transect length in the second round, however, the rate of detection was higher in the second round in Cornwall and Devon (Table 7). Conversely, the encounter rate fell in Gloucestershire and Hereford/Worcester in the second round of surveys. In general, encounter rates for fox increased in the second round of surveys, whilst hare decreased.

Table 3. Numbers of target species recorded in Cornwall.

	Individuals							
	Badger		Fox		Hare		Deer	
Area	Survey 1	Survey 2	Survey 1	Survey 2	Survey 1	Survey 2	Survey 1	Survey 2
01	2	2	0	0	2	2	0	0
02	0	3	0	1	0	0	0	0
03	2	0	0	2	0	0	0	0
04	2	0	1	0	0	0	1	2
05	4	2	1	1	0	0	0	0
06	0	0	1	5	1	1	2	2
07	0	0	3	0	0	0	4	0
09	4	3	0	0	0	0	2	1
10	2	5	1	0	0	0	0	0
11	3	0	2	0	0	0	4	1
12	2	2	0	0	2	0	0	1
13	1	1	1	2	0	1	2	1
14	1	3	5	3	0	0	0	0
15	2	0	10	3	0	0	0	0
16	5	0	1	4	0	0	0	0
17	1	0	1	1	0	0	0	0
18	4	10	5	11	0	0	0	0
23[a]	5	3	0	2	0	0	0	0
24[a]	1	0	3	2	0	0	0	0
25[a]	7	5	3	3	0	0	0	0
Total	**48**	**39**	**38**	**40**	**5**	**4**	**15**	**8**
Total	**87**		**78**		**9**		**23**	

Shaded cells indicate that observations included one or more clusters (i.e. groups) of the target species.
[a] Control area

Table 4. Numbers of target species recorded in Devon.

	Individuals							
	Badger		Fox		Hare		Deer	
Area	Survey 1	Survey 2	Survey 1	Survey 2	Survey 1	Survey 2	Survey 1	Survey 2
1	5	1	1	1	6	2	0	0
2	0	0	2	0	0	0	16	5
3	0	2	0	1	0	0	0	1
4	0	3	1	0	5	1	0	0
5	1	0	1	3	1	0	7	0
6	2	1	1	2	0	0	2	0
7	1	0	0	2	0	0	2	16
8	1	2	1	3	0	0	8	6
9	2	6	1	1	0	0	29	0
10	2	5	1	1	0	0	1	0
11	1	1	2	2	2	0	5	2
12	0	0	1	4	3	0	0	0
13	4	2	0	2	0	0	6	0
15	3	0	0	1	0	0	0	0
16	3	1	0	0	0	0	2	0
17	2	1	3	4	3	1	7	1
18	3	ns	1	ns	0	ns	12	ns
21	4	4	3	6	2	5	9	8
22[a]	0	1	1	0	0	0	0	0
23[a]	7	8	1	1	0	0	0	0
24[a]	8	0	2	3	0	0	1	3
Total	**49**	**38**	**23**	**37**	**22**	**9**	**107**	**42**
Total	**87**		**60**		**31**		**149**	

ns not surveyed

Table 5. Numbers of target species recorded in Gloucestershire.

	Individuals							
	Badger		Fox		Hare		Deer	
Area	Survey 1	Survey 2	Survey 1	Survey 2	Survey 1	Survey 2	Survey 1	Survey 2
1	1	3	2	0	1	9	0	6
2	3	1	2	5	0	0	3	12
3	0	1	3	3	4	0	3	0
4	1	0	1	2	8	5	5	0
6	1	0	5	2	0	0	11	2
7	1	1	3	5	1	1	0	0
9	3	4	4	1	3	0	3	0
10	14	1	3	0	4	5	5	9
11	2	2	1	4	0	0	15	6
12	0	1	3	0	0	0	0	0
13	17	9	4	5	0	0	8	8
15	0	0	8	0	5	0	0	0
16	0	1	1	1	13	1	0	0
17	8	0	3	0	0	0	5	0
18	11	3	0	2	0	0	10	2
20	0	9	1	3	2	1	0	0
21	3	7	2	1	5	1	10	3
22[a]	5	0	1	0	0	1	2	0
23[a]	1	4	7	4	4	0	2	0
Total	**71**	**47**	**54**	**38**	**50**	**24**	**82**	**48**
Total	**118**		**92**		**74**		**130**	

Table 6. Numbers of target species recorded in Herefordshire.

	Individuals							
	Badger		Fox		Hare		Deer	
Area	Survey 1	Survey 2	Survey 1	Survey 2	Survey 1	Survey 2	Survey 1	Survey 2
1	1	1	1	2	0	0	0	0
2	3	10	6	1	5	0	0	9
3	2	1	1	3	1	2	0	0
4	0	1	1	0	4	1	0	0
5	3	0	3	1	15	10	0	0
6	0	0	2	0	1	0	0	0
7	6	0	1	2	0	0	0	0
8	2	2	3	10	19	1	0	0
9	0	0	2	4	2	1	0	0
10	2	3	3	3	0	0	0	0
11	17	7	3	3	0	0	7	0
12	2	0	1	0	5	0	0	0
13	2	1	3	1	3	1	0	0
14	1	0	3	3	3	5	0	0
15	1	0	2	3	0	0	0	0
16	1	0	3	3	2	1	1	0
17	3	1	1	0	0	1	0	0
23[a]	13	0	0	0	0	0	0	0
24[a]	2	2	1	1	4	1	0	0
25[a]	2	0	7	4	4	7	2	0
Total	**63**	**29**	**47**	**44**	**68**	**31**	**10**	**9**
Total	**92**		**91**		**99**		**19**	

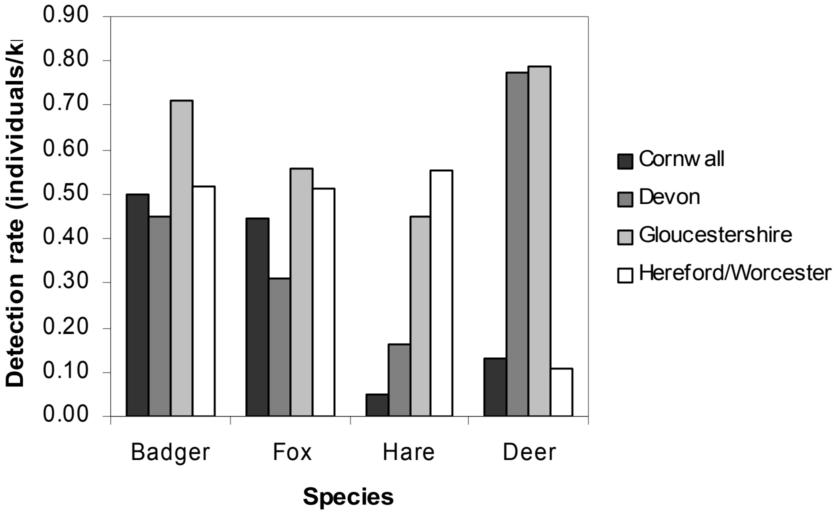

Figure 4. Overall encounter rates (individuals per km of transect) for all target species during transect survey round 1 and 2 combined.

Table 7. Encounter rates of target mammals during distance sampling surveys in England: (a) badger, (b) fox, (c) hare and (d) deer.

(a)

Region	Survey	Badger	Total Transect Length (m)	Badger/km
Cornwall	1	48	100831	0.48
	2	39	74094	0.53
Devon	1	49	112644	0.44
	2	38	80054	0.48
Gloucestershire	1	71	95615	0.74
	2	47	69119	0.68
Herefordshire	1	63	112183	0.56
	2	29	65961	0.44

(b)

Region	Survey	Fox	Total Transect Length (m)	Fox/km
Cornwall	1	38	100802	0.38
	2	40	74094	0.54
Devon	1	23	112639	0.20
	2	37	80054	0.46
Gloucestershire	1	54	95615	0.57
	2	38	69019	0.55
Herefordshire	1	47	112183	0.42
	2	44	65951	0.67

(c)

Region	Survey	Hare	Total Transect Length (m)	Hare/km
Cornwall	1	5	100802	0.05
	2	4	74094	0.05
Devon	1	22	112639	0.20
	2	9	80054	0.11
Gloucestershire	1	50	95615	0.52
	2	24	69019	0.35
Herefordshire	1	68	112183	0.61
	2	31	65951	0.47

(d)

Region	Survey	Deer	Total Transect Length (m)	Deer/km
Cornwall	1	15	100802	0.15
	2	8	74094	0.11
Devon	1	107	112639	0.95
	2	42	80054	0.53
Gloucestershire	1	82	95615	0.86

	2	48	69019	0.70
Herefordshire	1	10	112183	0.09
	2	9	65951	0.14

6.3 Population densities in open pasture

Detection functions were successfully fitted to the perpendicular distance data for badgers (and other species) in all regions. Chisquare goodness-of-fit tests showed no significant differences between the observed and expected values indicating a good fit of the detection functions (badger - Table 8).

Table 8. Goodness-of-fit tests for probability of detection function (with some adjacent values pooled to avoid expected values less than 5) for badgers in each of the regions.

Region	Chi-square	df	p
Cornwall	5.927	7	0.55
Devon	9.552	8	0.30
Gloucestershire	10.641	6	0.10
Herefordshire	2.558	7	0.92

6.4.1 Badger

Distance analysis derived mean estimates for badger density in open habitat of 3.9 to 4.5 badgers km^{-2} (Table 9). From the confidence intervals there was no statistically significant difference between the densities of the four English regions.

Table 9. Regional population densities of badgers in open pasture.

Region	Population density (badgers km^{-2})	%CV	95% Confidence limits	
			Lower	Upper
Cornwall	4.52	18.5	3.15	6.49
Devon	4.12	16.0	3.01	5.63
Gloucestershire	4.42	16.9	3.18	6.14
Herefordshire	3.91	16.2	2.85	5.36

6.4.2 Fox

Estimates for mean fox density in open pasture ranged from 1.9 to 2.6 fox km^{-2} (Table 10). From the confidence intervals there was no statistically significant difference between the densities in the four English regions.

Table 10. Regional population densities of fox in open pasture.

Region	Population density (fox km^{-2})	%CV	95% Confidence limits	
			Lower	Upper
Cornwall	2.60	16.2	1.90	3.57
Devon	1.94	19.9	1.32	2.86
Gloucestershire	2.41	15.6	1.77	3.26
Herefordshire	1.96	16.8	1.42	2.72

6.4.3 Hare

Estimates for mean hare density in open pasture ranged from 0.4 to 3.9 hare km^{-2} (Table 11). From the confidence intervals Herefordshire had a higher density than Gloucestershire and Devon, which in turn both had higher densities than Cornwall.

Table 11. Regional population densities of hare in open pasture.

Region	Population density (hare km^{-2})	%CV	95% Confidence limits	
			Lower	Upper
Cornwall	0.38	41.0	0.17	0.83
Devon	1.82	29.4	1.03	3.21
Gloucestershire	2.55	20.2	1.72	3.77
Herefordshire	3.92	19.7	2.67	5.75

6.4.4 Deer

The numbers of individuals of each species of deer recorded are illustrated in Table 12. The majority of deer recorded in any region were identified to species, except for Herefordshire where none of the 19 deer observed were differentiated to species (due to sighting conditions). In order to control for different overall transect lengths between the four regions, the relative encounter rates are illustrated in Figure 5.

Due to generally low numbers and frequent clustering of animals, distance analysis was not carried out on the deer data.

Table12. Numbers of individuals of different species of deer recorded during distance sampling transects in the four study regions.

	Roe	Red	Fallow	Muntjac	Deer?	All	Transect (km)
Cornwall	18	2	2	0	1	23	174.9
Devon	56	43	23	0	27	149	192.7
Gloucester	109	0	12	3	6	130	164.7
Herefordshire	nr	nr	nr	nr	19	19	178.1
All	183	45	37	3	53	321	

nr = species not recorded

Deer (all species) were more prevalent in Gloucestershire and Devon than in Cornwall and Herefordshire, with roe deer recorded most frequently in each of the regions (excluding Herefordshire).

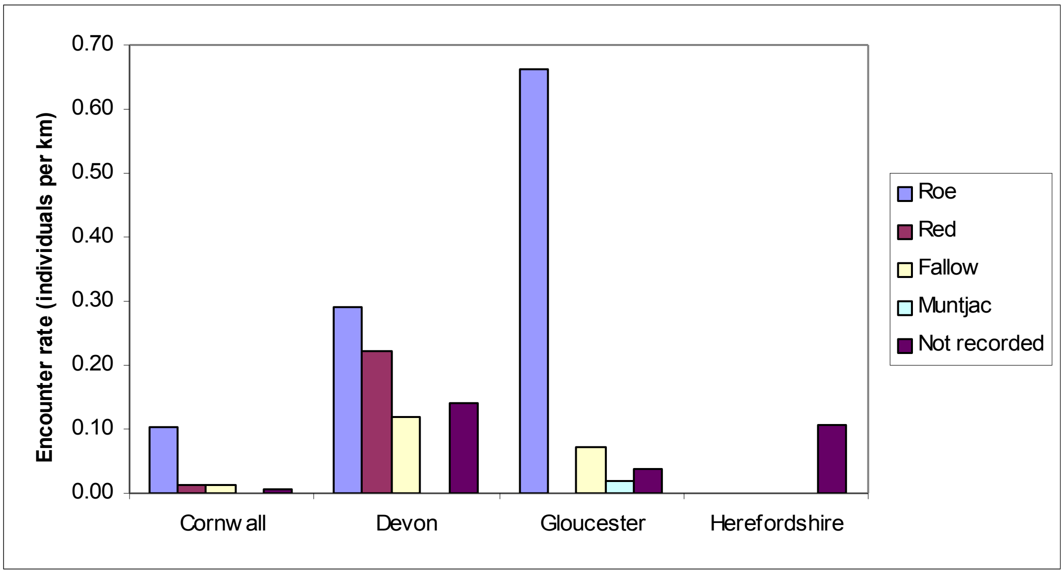

Figure 5. Encounter rates (individuals per km) for each species of deer recorded during distance sampling transects in the four study regions

6.4.5 Sample size

The initial power analysis for the study predicted that if 25 areas were surveyed, the coefficient of variation (%CV) around estimates of badger density would increase as the density decreased and that for densities of 2, 3, 5 and 12 animals km^{-2} the expected %CV was 25%, 16%, 13% and 8% respectively. Additional power analyses to estimate the likely impact of a reduction in the number of areas from 25 to 20 indicated that, at a density of 6 animals km^{-2}, the %CV would be expected to increase from 11.9 to 13.6 (a 14% increase) and at a density of 12 the %CV would increase from 8.6 to 9.2 (a 6% increase).

The %CV of the actual density estimates for badgers of 4.5, 4.1, 4.4, and 3.9 for the four English regions were 19%, 16%, 17% and 16% (Table 8), for 20, 21, 19 and 20 areas surveyed respectively. In comparison, power analysis predicted %CV values of 13% to 16% for these densities of badgers (i.e. 3 and 5 animals km^{-2}, as above). The reduction in the intended number of survey areas covered, therefore, was associated with a very small increase in the variation and confidence limits around the mean density estimates. Although part of this increased variation may be ascribed to the reduction in the number of areas surveyed, a major part of it is probably due to the “patchiness” of badger occurrence between transects inflating the variance beyond that assumed in the modelling.

7. DISCUSSION

7.1 Badger

Estimated densities of badgers in open pasture were similar between all four survey regions: Cornwall (4.5 badgers km^{-2}; %CV 18.5), Devon (4.1 badgers km^{-2}; %CV 16.0), Gloucestershire (4.4 badgers km^{-2}; %CV 16.9), Herefordshire (3.9 badgers km^{-2}; %CV 16.2). This contrasts with data from national sett surveys conducted during the 1980s (Cresswell *et al*. 1990) and 1990s (Wilson *et al*. 1997). In the present study, the Cornwall and Devon regions corresponded to the south-west England survey region in the national sett surveys; Herefordshire corresponded to west Midlands and Gloucestershire fell mainly into west Midlands (around 68% of survey areas) with a few survey areas within south-west England (around 11% survey areas) and southern England (around 21% areas). In the 1980s national survey, main sett densities were higher in south-west England (0.57 main setts km^{-2}) than in the west Midlands (0.25 main setts km^{-2}). This pattern was also found in the 1990s survey, but with higher densities in both regions: south-west England 0.70 main setts km^{-2}; west Midlands 0.46 main setts km^{2}. The variation between regions in relative densities as estimated from distance sampling and sett counts are not necessarily contradictory. It is possible that numbers of badgers per sett varies between regions, although there is insufficient data to support or contradict this, whilst the 1980s survey assumed a mean number per sett across all setts.

In comparison with concurrent, identical, surveys conducted in Wales, estimates of badger densities in the four English regions were comparable with the density estimate for Pembrokeshire and higher than the estimates for Welsh Borders and North Wales.

National sett surveys derive estimates for badger populations by assuming an average number of adult badgers per social group (or main sett). In the 1980s national sett survey, Cresswell *et al*. (1990) used a mean figure of 5.9 adult badgers per social group. From the 1980s national survey, regional sett densities were 0.566 per km^{-2} and 0.249 per km^{-2} in south-west England and west Midlands respectively (Krebs *et al*. 1997). Assuming 5.9 badgers per main sett provides badger densities of 3.34 and 1.47 badgers per km^{-2} respectively. During the 1990s survey, comparable figures were sett densities of 0.698 and 0.463 setts per km^{-2} (Krebs *et al*. 1997) and 4.12 and 2.73 badgers per km^{-2} in south-west England and west Midlands respectively.

In comparison, the present study provided estimates population densities of 4.5 badgers per km^{-2} (%CV 18.5) and 4.1 (%CV 16.0) badgers km^{-2} in open pasture in Cornwall and Devon (south-west England) respectively. Equivalent estimates for Gloucestershire and Herefordshire were 4.4 badgers km^{-2} (%CV 16.9) and 3.9 badgers km^{-2} (%CV 16.2) respectively. Whereas, the estimates in the present study represent densities in open pasture, values derived from sett surveys represent estimates of absolute badger densities.

Previous estimates of badger density using distance sampling have been conducted using both driven (Heydon *et al*. 2000) and walked transects (Hounsome *et al*. 2005). Using a customised vehicle along road transects, Heydon *et al.* (2000) estimated mean autumn badger densities (1995 and 1996) of 1.3 badgers km^{-2} in east-Midlands. This region, however, is comprised of a predominantly different land classification and has a lower density of mains setts compared to the four survey regions in the current study (Wilson *et al*. 1997). Hounsome *et al*. (2005), using walked transects, estimated an autumn density of 24 badgers km^{-2} in Woodchester Park, Gloucestershire. Badger density at Woodchester Park is amongst the highest recorded in the UK (Rogers *et al*. 1997). Both studies were conducted on post-breeding autumn populations, rather than smaller pre-breeding spring populations as in the present study.

Population densities, whether national or regional, derived from sett surveys suffer from a major inherent weakness, that is the assumption of a mean number of badgers per social group or main sett. As stated, Cresswell *et al*. (1990) assumed an average of 5.9 adults per social group - derived from the available literature. Neal & Cheeseman (1996), however, derived an average of 5.1 using the same literature sources. More recently, further studies across a greater range of habitat types have indicated that this figure may be an overestimate (Wilson *et al*. 1997). With records of social group size ranging by up to 10-fold (e.g. 3.3 to 30 – data in Neal & Cheeseman 1996), it is very difficult to assign a mean group size that is representative across all regions or indeed within individual regions. Wilson *et al*. (1997) concluded that there was insufficient information on which to quantify the variation in badger group size in different habitats or regions, and did not attempt to estimate the total number of badgers in Britain.

Other indirect methods, e.g. those involving indices of field signs, although providing some useful data, possess inherent uncertainty in the extent to which field signs relate to the numbers of badgers (e.g. Wilson *et al*. 2001). The correlation can vary between seasons, weather conditions and habitat.

The principal advantage of distance sampling for monitoring badger populations is that it records badgers directly (compared to indirect methods such as surveys of setts or field signs) whilst allowing for numerous animals to go undetected. The technique used in the present study of walked spotlight transect surveys has been validated against a badger population of known size (Hounsome *et al*. 2005). Although large-scale regional surveys are relatively labour intensive, the techniques is no more so than regional sett surveys.

Distance sampling does have its own limitations. Clearly for a technique that relies on direct observation, surveys can only be conducted on open land. As badgers spend only a proportion of their time in open habitat, density derived from such surveys will not necessarily represent overall densities across all habitats. Distance sampling, therefore provides an absolute density of badgers on open ground, but only a relative measure of overall density. Estimates from distance sampling can also be influenced by season or weather. The proportion of time that badgers spend foraging on pasture may decrease both in very hot, or freezing conditions, due to the ground becoming difficult to dig for earthworms. Differences in the estimates of density under the two conditions could be a reflection of changes in habitat use and/or differences in population size. It would not be possible to ascertain what proportion of the change is attributable to each factor. Changes in habitat use may also be caused by other factors such as human disturbance. For example, if badgers were to be culled by shooting this may for practical reasons be carried out on open ground. Badgers in areas where this occurred may learn to associate open ground with increased danger and so change their behaviour and spend less time on open ground. Thus this method would be unsuitable for monitoring changes in overall badger abundance where factors are likely to cause badgers to change the amount of time they spend on open ground. It cannot be assumed, however, that badgers would reduce their use of pasture in response to culling by shooting. The single most important item of food in the diet of badgers is earthworms, which are found in highest densities in pasture. Pasture would, therefore, remain the most profitable foraging sites for badgers. In the event that badgers did reduce the amount of time in the open in response to shooting, distance sampling would still provide useful information on badger densities. Pasture represents a principal location in which badgers and cattle can interact, and is likely to be a primary arena for potential transmission of disease. Distance sampling would detect changes in the densities of badgers on open pasture, irrespective of whether this change occurred as a result of population change or due to change in behaviour/habitat use. In either case, distance sampling would detect changes in badger density on pasture that would have important implications for the bTB/badger issue.

In theory, estimates of absolute badger abundance and density can be derived from the relative densities in open pasture, through the application of correction factors. These correction factors include estimates of the total open habitat within the study area, and a factor (habitat multiplier) to account for the proportion of time that badgers spend in open, surveyable land. Currently, however, there is relatively little understanding of how the proportion of time spent by badgers in the open may vary between areas with differing habitat composition. Time spent in the open may also vary in the same site due to differences in season or weather. Ideally, a radio-tracking study carried out concurrently in the survey region would provide the best data for generating a habitat multiplier. To date, the only study that has derived a habitat multiplier was conducted in Woodchester Park, Gloucestershire (Hounsome *et al*. 2005), using radio-tracking data from the same area (Garnett 2003). The study concluded that, on average, through all seasons and all periods of the night, badgers spent 48.5% of their time in open habitat. How this figure relates to the habitats in the areas surveyed in the present study remains unknown.

7.2 Fox

Estimated mean densities of fox in open pasture were similar between the four English regions: Cornwall (2.6 fox km^{-2}; %CV 16.2), Devon (1.9 fox km^{-2}; %CV 19.9), Gloucestershire (2.4 fox km^{-2}; %CV 15.6), Herefordshire (2.0 fox km^{-2}; %CV 16.8).

Rural populations of fox have remained largely unquantified (Harris *et al*. 1995). Two recent studies, however, have investigated regional variation in abundance using different techniques: distance sampling (Heydon *et al*. 2000) and faecal counts (Webbon *et al*. (2004).

During 1995-97, (Heydon *et al*. 2000) used vehicle-based distance sampling to estimate post-breeding (autumn) and pre-breeding (spring) densities in mid-Wales, the east Midlands and East Anglia. The study represented the first attempt in Britain to measure and compare fox densities over large geographic areas. The relative spring densities in the three study regions estimated from distance sampling (east Midlands 1.0 fox km^{-2} > mid-Wales 0.4 > East Anglia 0.2) were supported by alternative independent indices of fox abundance (counts of fox breeding earths and gamekeeper lamping index). Each study site was based on the area used by a single fox hunt.

Heydon *et al.* (2000) conducted their study in different regions of England to those in the current study. The distance sampling technique used by Heydon *et al.* (2000) also differed from that used in the current study in a number of ways. Heydon *et al*. (2000) conducted surveys using a vehicle along minor public roads rather than walked transects across open countryside, estimated perpendicular distances by eye rather than using a laser rangefinder, and used spotlights with white light rather than red-filtered light - each of these features posing potential drawbacks. Potential bias associated with distance sampling along roads is well recognised (Buckland 2001, Heydon *et al*. 2000, Ruette *et al*. 2003) - the route of driven road transects is constrained by the availability of roads, the habitat adjacent to roads may be unrepresentative of the wider landscape, and animals may exhibit a density gradient perpendicular to roads (contravening an assumption of distance sampling). The use of spotlights with white light imposes a further risk in that foxes with previous exposure to lamped culling activities may exhibit lamp-shyness and move away from oncoming lights (again contravening an assumption of distance sampling).

During February to March, 1999 and 2000, Webbon *et al*. (2004) estimated fox densities using faecal counts, and represented the first attempt to quantify fox density on a national scale. The technique involved surveying for fox scats along transects within a sample of 1-km squares stratified according to habitat type. Densities were relatively high in pastoral landscapes (1.4 to 1.9 fox km^{-2}). In England, densities were higher in Cornwall, Devon, Gloucestershire and Herefordshire (predominantly 1.0 to 2.4 fox km^{-2}) compared to east-Midlands and East Anglia (both predominantly 0.5 to 1.0 fox km^{-2}).

7.3 Hare

The variation in estimated densities of hare between regions was greater than for badger and fox, ranging from 0.4 hare km^{-2} in Cornwall to 3.9 hare km^{-2} in Herefordshire.

Previously, using vehicle-based distance sampling, Heydon *et al*. (2000) estimated spring densities of hare in east-Midlands of 7.9 hare km^{-2} and 14.7 hare km^{-2} during 1996 and 1997 respectively; similar estimates for mid-Wales were 1.4 hare km^{-2} and 1.8 hare km^{-2} respectively. East-Midlands and Mid-Wales, however, are characterised by predominantly different land classes, arable and marginal upland respectively, compared to the four regions in the current study which are predominantly pastoral.

Harris *et al*. (1995) concluded that, even in comparable habitats, populations of hares can be very different due to clumping as a consequence of anthropogenic factors, particularly the degree of landowner tolerance of the presence of hares.

The difference in the relative magnitude of observations of hare between regions, i.e. higher numbers recorded in Herefordshire and Gloucestershire than in Cornwall and Devon, reflected data on the national distribution and abundance of hares (Battersby, J. [ed.] & Tracking Mammals Partnership 2005).

7.4 Deer

The monitoring of deer numbers was incidental to that of badgers, fox and hare, since many deer prefer habitat such as copses and plantations and would have been unavailable for detection from field transects. Recognising that the majority of the individuals in any survey area were unlikely to be detected, estimates of population density were not calculated for deer.

A number of observations concerning deer, however, can be drawn from the surveys. In all regions deer were recorded on pasture. Encounter rates of deer were markedly higher in Gloucestershire and Devon than in Cornwall and Herefordshire. In Gloucestershire and Devon, encounter rates for deer were the highest of all four of the target species. Although, a greater overall number of deer were observed than badgers in Devon and Cornwall, deer were recorded on fewer pasture fields than badger due to deer more frequently occurring in groups than badgers.

The variation in observations of deer, with respect to different species and regions, reflects trends in the national distribution and abundance of deer (Battersby, J. [ed.] & Tracking Mammals Partnership 2005). In England, roe deer are more abundant than fallow, which in turn are more abundant than red. This relative order of magnitude for these species was observed in respect to total numbers of deer recorded in the present study. Regionally, deer were recorded in higher numbers in Gloucestershire and Devon, with relatively few observed in Cornwall and Herefordshire. In respect to the four regions in the present study, national deer distribution data (Battersby, J. [ed.] & Tracking Mammals Partnership 2005) indicates relatively low abundance of deer in Herefordshire compared to the other three study regions; with red deer confined to Devon and Cornwall. In the present study observations of red deer were also confined to Devon and Cornwall.

7.5 Constraints

During the project a number of delays and obstacles to the original planned schedule were encountered, including delays in being able to collate all of the necessary data on landholdings, slow and limited receipt of access permissions from landowners and the cold and wet spring limiting the number of suitable nights for surveying. The most problematical issue, throughout the study, was the overall slow (and often negative) response from landowners in responding to requests for access to land. The overall effect of these issues was a reduction in the number of areas per region that were surveyed relative to the original schedule. The reduction in the planned sample size, however, did not have a significant impact on the estimates of population densities or associated coefficient of variation.

8. CONCLUSIONS AND RECOMMENDATIONS

Overall this project represents a significant contribution to the existing knowledge of regional badger population densities. It is both the most geographically extensive and regionally intensive study using walked distance sampling that has been undertaken on badgers and other British mammals to date. It has provided significant additional benefits over previous distance sampling surveys of these species, which have invariably involved sampling from vehicles, in that the surveys included large areas of the landscape in open countryside and so removed any potential effect of roads on the detectability of the target species. The project has produced reliable baseline estimates of spring badger densities on open pasture against which any future equivalent surveys can be assessed.

The study derived population density estimates for badgers on open pasture for four regions in England: Cornwall, Devon, Gloucestershire and Herefordshire. These estimates ranged from 3.9 badgers per km^{-2} (95% confidence limits: 2.85 – 5.36) to 4.5 badgers per km^{-2} (95% confidence limits: 3.15 – 6.49).

Although badger densities were lower than anticipated, the confidence intervals indicate that a 50% reduction should still be detectable. In light of the results, further simulations were conducted (with means of 2 to 5 badgers per km^{-2}) which included a reduction in sample size from 25 to 20 survey areas. Subsequent surveys will involve 25 rather than 20 survey areas and, if a reduction in badger numbers is so large that the number of badgers observed after two walks of the transects are too few to fit a detection curve, then observations could be increased by walking the transects more than twice.

Estimates of absolute badger density and abundance could be derived from the estimates of relative density in open pasture produced in this study, through extrapolation using a number of correction factors. A correction factor for the amount of time that badgers spend in open habitat (habitat multiplier) has been derived, in a previous study, in one specific area (woodland/pasture mosaic) in Woodchester Park, Gloucester. The applicability of this factor to other regions and habitat mosaics, however, is unknown. Investigation of habitat multipliers would entail radio-tracking studies to evaluate habitat use in a range of alternative landscapes.

It is not possible to draw any firm conclusions from comparing densities derived from distance sampling surveys in the current study with those derived from previous studies or national surveys. Comparisons are confounded by differences in methodologies, survey sites and year between the current study and other surveys. In order to reliably calibrate or inform across studies, distance sampling surveys and species national surveys would need to be validated against each other, by conducting each survey method concurrently in a sample of the same sites.

It is recommended that the survey work is repeated in autumn. A regular monitoring scheme for badgers would ideally be based on distance sampling surveys conducted in the autumn, rather than the spring. During autumn, in addition to the population being at its annual maximum, practical issues are more favourable - vegetation is dying down rather than growing up, and farming practices are less focussed on pasture, e.g. no lambing. Following a preliminary autumn survey in 2006, it would be worthwhile to repeat monitoring the following year (2007) to see what year-on-year differences there are. If a badger cull is introduced then a further survey should be conducted in the autumn following introduction of the cull. Subsequently, biennial surveys should be sufficient, although annual monitoring would provide a more immediate feedback. If no cull is introduced, then after an autumn 2007 survey, re-surveying every three years should give an indication as to any changes in the regional badger densities. Comparisons can be made between the current survey and both the baseline and previous survey.

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Appendix 1: Overall transect length and number of transects in each survey area within: (a) Cornwall and Devon, (b) Gloucestershire and Herefordshire.

(a)

	CORNWALL				DEVON			
	Survey 1		Survey 2		Survey 1		Survey 2	
Survey Area	Length (m)	No.	Length (m)	No.	Length (m)	No.	Length (m)	No.
1	5076	25	3763	18	4993	22	4993	22
2	5516	20	3809	14	5420	30	5059	28
3	5010	20	3458	12	5101	29	4866	28
4	5160	21	4040	16	5411	26	4314	20
5	5005	21	4131	17	6594	20	3620	11
6	5022	23	2652	11	5866	20	2902	13
7	5016	24	3770	17	5362	20	4742	17
8	ns	ns	ns	ns	5005	20	3656	15
9	5065	24	3211	14	5553	20	4364	16
10	5006	21	3601	15	5100	22	3287	14
11	5053	21	4253	19	5310	21	4064	16
12	4571	21	3696	18	6124	21	4092	14
13	5144	21	4884	20	5231	21	3880	17
14	5024	20	2774	11	ns	ns	ns	ns
15	5008	25	3778	20	4957	19	3178	12
16	5028	21	4852	20	5302	20	3327	13
17	5029	23	2617	14	5164	20	4234	16
18	5025	22	4321	19	4364	20	ns	ns
19	ns	ns	ns	ns	ns	ns	ns	ns
20	ns	ns	ns	ns	ns	ns	ns	ns
21	ns	ns	ns	ns	5071	22	3294	14
22	ns	ns	ns	ns	5015	26	3557	19
23	5015	24	3470	17	6588	20	5261	16
24	5009	20	3063	14	5113	20	3364	13
25	5049	20	3951	16	ns	ns	ns	ns
Total	100831	437	74094	322	112644	459	80054	334
Mean	5042	22	3705	16	5364	22	4003	17

ns = not surveyed

(b)

	GLOUCESTERSHIRE				HEREFORD/WORCESTER			
	Survey 1		Survey 2		Survey 1		Survey 2	
Survey Area	Length (m)	No.	Length (m)	No.	Length (m)	No.	Length (m)	No.
1	5863	20	5004	17	5224	20	4581	17
2	6005	21	5140	18	6106	20	4523	16
3	5608	20	3273	11	5197	21	4447	19
4	5647	20	2943	10	5048	22	2920	12
5	ns	ns	ns	ns	5260	20	4091	16
6	5239	20	2650	12	5739	20	2182	9
7	5127	23	4972	22	5473	20	2890	12
8	ns	ns	ns	ns	5422	20	2522	11
9	4509	20	3289	14	5470	20	5470	20
10	5809	20	4721	16	5925	20	3767	13
11	3237	14	3085	13	5340	22	4856	20
12	4912	18	3568	12	5287	20	2810	12
13	4863	20	2968	14	6259	20	3627	12
14	ns	ns	ns	ns	6292	20	2192	9
15	4311	19	2494	10	5071	20	2002	8
16	5447	20	3709	15	5114	20	2959	12
17	4700	20	2589	12	5560	21	1474	6
18	3463	16	2529	11	ns	ns	ns	ns
19	ns	ns	ns	ns	ns	ns	ns	ns
20	5029	20	4111	16	ns	ns	ns	ns
21	5662	20	5182	18	ns	ns	ns	ns
22	5202	20	4315	16	ns	ns	ns	ns
23	4982	20	2577	12	5962	20	2274	7
24	ns	ns	ns	ns	5690	20	3558	14
25	ns	ns	ns	ns	6744	21	2816	7
Total	95615	371	69119	269	112183	407	65961	252
Mean	5032	20	3638	14	5609	20	3298	13

Appendix 2: Details of the power analysis to determine sample size.

Introduction

Uncertainty associated with estimates of badger density derived by distance sampling depends upon two components. The first is the error associated with the determination of the relationship between the probability of an observer spotting a badger from a line transect and the perpendicular distance of that badger from the transect. The second is the variability in encounter rate between transects. The recommended minimum sampling effort for distance sampling is to observe a total of 60 to 80 animals along 20 transects. If necessary, the transects may be re-walked on subsequent occasions until sufficient animals have been observed.

Method

To obtain a relationship between the probability of detection and the distance of a badger from a transect, data used in the Hounsome *et al* (2005) paper on distance sampling of badgers at Woodchester Park were obtained as an Excel file from the authors. These data were from 19 transects totalling 4,869 metres which were walked 8 or 9 times to give a total transect length of 4.2km and 87 badgers observed. The data were re-analysed using the software DISTANCE 4.1. The estimated badger density was 24.2/km^2 with a 95% confidence interval of 15.4 to 37.9 (percentage coefficient of variation was 21.9). This was in full agreement with the published paper. The resultant probabilities of detection were used for modelling.

One region of 25 farms, each with 20 fields, was modelled using Genstat 8.1. Each farm had the same mean badger density. The density for each field within a farm was generated as a Poisson distribution around the mean. Badger locations were then generated for each field. Two 250m transects were generated for each field, to mimic a single transect being counted twice. Thus there were 500 transects counted twice, giving a total length of 250km. The probability of each modelled badger being spotted from each transect was calculated according to the relationship derived from the Woodchester data. The resultant model data were then analysed with DISTANCE 4.1. (see Table 1 and Fig 1.) The effect of differing densities across farms was modelled as above but with each farm density as a Poisson distribution around the overall mean and each field as a Poisson distribution around the individual farm mean. The results are given in Table 2. Finally, to mimic the Woodchester situation, one farm of 20 fields was modelled, with each field being sampled 9 times (Table 3.)

Results

For 25 farms each with a badger density of 24 km^{-2}, the percentage coefficient of variation (%CV) for overall badger density was 8%, compared to 22% for the Woodchester data. This value increased as the density decreased until it was approximately 50% at a density of 1 (Table 1.) and the confidence intervals widened accordingly (Fig.1.). When farms had differing densities around the mean, the %CV was little different from the above (Table 2). The simulation intended to mimic Woodchester produced a mean %CV of 19.8, very similar to the 21.9% for the actual data (Table 3).

Fig.1. Results of modelling 25 same-density farms with 20 fields each. Estimated densities and 95% confidence intervals. (Replicate results offset by 0.1 on x axis).

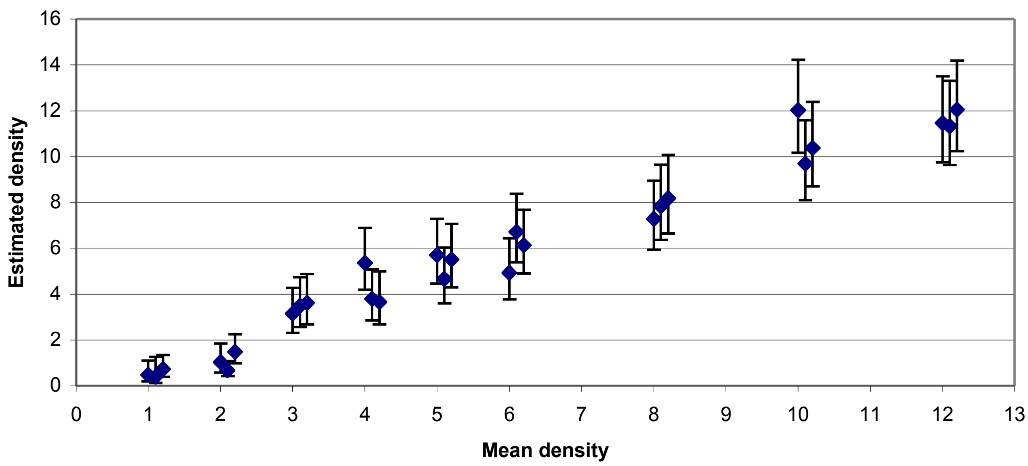


Table 1. Results for a region of 25 farms of equal mean density

Mean density	Rep.	Total count	Estimated density	%CV	95% Confidence Interval	
24	1	489	23.662	6.06	21.009	26.651
24	2	497	23.482	5.69	21.004	26.254
24	3	512	24.514	5.86	21.853	27.500
12	1	233	11.468	8.30	9.7454	13.495
12	2	231	11.317	8.23	9.6299	13.299
12	3	254	12.047	8.33	10.233	14.182
10	1	244	12.024	8.59	10.161	14.230
10	2	214	9.6887	9.14	8.1008	11.588
10	3	208	10.379	8.99	8.7031	12.378
8	1	152	7.2874	10.47	5.9363	8.9460
8	2	165	7.8371	10.63	6.3649	9.6498
8	3	167	8.1848	10.59	6.6516	10.071
6	1	104	4.9311	13.68	3.7742	6.4426
6	2	131	6.7220	11.26	5.3927	8.3791
6	3	119	6.1314	11.52	4.8939	7.6817
5	1	130	5.6981	12.54	4.4582	7.2827
5	2	95	4.6590	13.20	3.5993	6.0308
5	3	109	5.5129	12.67	4.3024	7.0641
4	1	116	5.3633	12.71	4.1827	6.8770
4	2	73	3.7937	14.80	2.8414	5.0650
4	3	70	3.6558	16.03	2.6737	4.9987
3	1	65	3.1385	15.74	2.3082	4.2675
3	2	68	3.4910	15.58	2.5757	4.7317
3	3	78	3.6159	15.27	2.6835	4.8722
2	1	24	1.0278	30.09	0.57450	1.8389
2	2	24	0.66574	24.62	0.41334	1.0723
2	3	28	1.4864	21.42	0.98043	2.2533
1	1	9	0.47255	45.14	0.20165	1.1074
1	2	7	0.38835	63.00	0.11937	1.2635
1	3	13	0.72122	32.18	0.38881	1.3378

Table 2. Results for a region of 25 farms with varying mean density

Mean density	Rep.	Total count	Estimated density	%CV	95% Confidence Interval	
24	1	485	24.684	5.60	22.116	27.550
24	2	494	23.547	5.83	21.001	26.402
24	3	521	23.221	8.02	19.847	27.170
12	1	222	10.750	8.88	9.0326	12.794
12	2	236	11.116	8.73	9.3683	13.191
12	3	231	11.828	8.28	10.056	13.913
6	1	96	4.9949	13.01	3.8729	6.4421
6	2	134	6.5758	11.09	5.2926	8.1701
6	3	140	6.3273	11.63	5.0390	7.9451

Table 3. Results for 1 farm with 20 transects counted 9 times (Woodchester mimic)

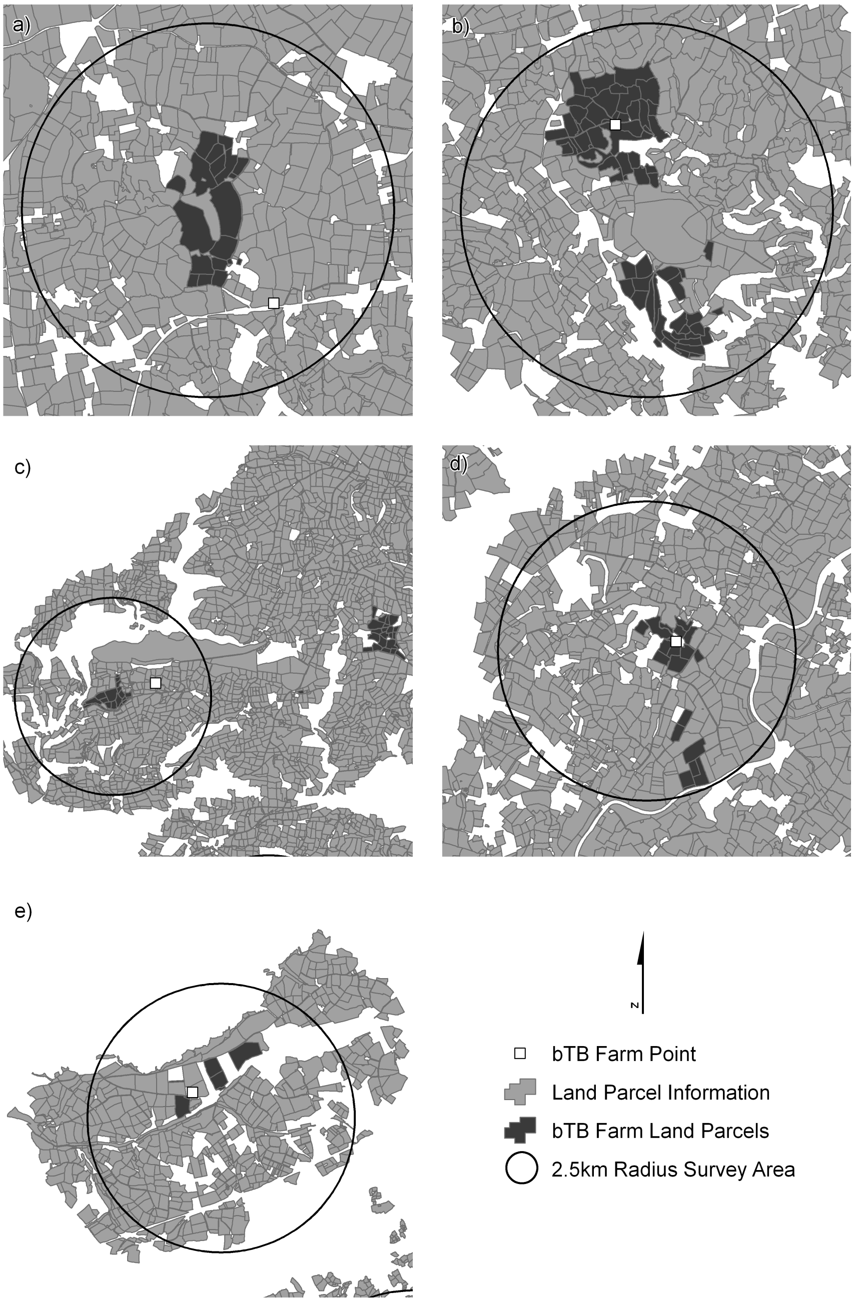
Mean density	Rep.	Total count	Estimated density	%CV	95% Confidence Interval	
24	1	79	22.466	20.30	14.791	34.125
24	2	91	25.278	21.36	16.293	39.216
24	3	115	30.854	17.73	21.430	44.423

Conclusions

The similarity between actual %CV for Woodchester and that of the mimic indicates that the modelling method is a reasonable reflection of reality. The simulations indicate that, given a likely badger density of approximately 12km^{-2} (half that of Woodchester), the proposed sampling strategy should be able to detect a decrease in density of 15%. At initial densities <12km^{-2}, the percentage change in density would need to be greater to be statistically significant, such that at 6km^{-2} the change would need to be at least 25% to be statistically significant. At 3km^{-2} or below it is unlikely that sufficient numbers of badgers will be observed to reliably estimate their density. Thus we will be able to detect approximately a 15% decline in population density at the regional level and should easily be able to detect a 50% decline.

APPENDIX 3: POSITIONING OF SURVEY AREAS

Even with land parcel information, exact positioning of individual survey areas was not straightforward. Ideally an area would be located so that the land parcels belonging to the relevant farm were at the centre of the circle (Figure a), or if the land parcels were not in one contiguous block the survey area was centred so as to contain all the land parcels (Figure b).



However there were several other factors that had impacts on this process. For example, there were occasions where the farm's land parcels were dispersed such that they could not all be contained within one survey area. In this situation the survey area was centred based on the land parcels nearest the farm itself, as in (Figure c), which also usually consisted of the larger proportion of land parcels. Any significant landscape features such as rivers and motorways, which could potentially divide badger populations, also dictated locations of survey areas. Where possible survey areas were positioned in an attempt to avoid having a survey area split by such a potential barrier as the river in (Figure d), as these areas may not be representative of land used by the badger population being surveyed on the targeted area. Another restriction was the availability of land parcel information. In coastal, forested and urban areas, or where agricultural land had simply not yet been recorded, land parcel information could be fairly scarce. Therefore, survey areas were also placed such that a feasible amount of land parcel information would be available for monitoring purposes (Figure 4e). If there was so little land parcel information for a particular farm and it's surrounds, that farm was not considered for monitoring.

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9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

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