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SID 5 Research Project Final Report

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Project identification

1. Defra Project code: SE3029
2. Project title: An investigation of potential badger/cattle interactions including the extent of badger visitations to farm buildings and food stores, and how cattle husbandry methods may limit these.
3. Contractor organisation(s): Central Science Laboratory
4. Total Defra project costs: £ 556666.31
5. Project: start date .... 01 January 2003
   end date .... 31 December 2005

6. It is Defra's intention to publish this form.
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(b) If you have answered NO, please explain why the Final report should not be released into public domain

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.

Bovine tuberculosis, caused by infection with *Mycobacterium bovis* is a serious disease in British cattle. The European badger (*Meles meles*) is implicated as the main wildlife reservoir for this disease in the UK. Estimates of the risks of disease transmission from badgers to cattle, and advice to reduce these risks have hitherto focussed on cattle contact with badger excretory products (mainly urine and faeces) at pasture. However, badger visits to farm buildings were identified as posing a potentially substantial risk to cattle during a study at Woodchester Park.

The current study aimed to investigate the extent of badger visits to farm buildings in TB hotspots in the southwest of England and to identify reasons why these occur. Surveys of 36 farms over eight seasons between July 2003 and June 2005 revealed generally low standards of biosecurity among farms. The majority of cattle housing and feed stores were judged as accessible by badgers and other wildlife and few troughs were raised above the minimum recommended height (80cm) to prevent badgers from gaining access to them. Signs of badger activity (droppings, carcasses, hair, runs, setts) were detected on 39% of farms surveyed. On 29% of these material was identified as infected with *M. bovis* by culture. Logistic regressions to identify some factors associated with the presence/absence of signs of badger activity identified the total number of badger setts and number of active setts as significant predictors ($P = 0.02$).

Six farms, which badgers were known to frequent, were studied more intensively to gain a deeper understanding of badger visits to farm buildings. Video and still camera surveillance identified that the frequency of badger visits peaked in the late spring/summer and were more frequent during times of warmer weather. A negative association between rainfall in the previous 24 hours and the frequency of badger visits was of borderline significance ($P = 0.051$). Warm, dry weather results in few earthworms (*Lumbricus terrestris*) being available at the soil surface and this limitation of badgers' primary prey may be the main causative factor behind their visits to farm buildings.

Badger visits were associated with feeding activities in the majority of cases. They fed on all stored feeds available and at all times of the year but foraged on cattle cake more frequently than expected. Feed stores were the most frequently visited facility within farmyards although badgers entered every building type monitored. Whilst within farmyards, direct contact between badgers and cattle was rare, but physical contact was observed on four occasions. In contrast, during observations on 41 badgers at pasture, a minimum distance between badgers and cattle of 4m was maintained at all times and direct contact was not observed.

An experiment to exclude badgers from farm buildings and facilities indicated that electric fencing was

highly successful. Badgers challenged the fence, and received a shock, on 25 occasions. While fencing was active badgers continued to pass through the farmyard but foraged more and more widely in fields. After the fencing was removed badgers quickly returned to foraging within farmyards and with greater frequency. Hence, whilst effective at excluding badgers, barrier methods, such as electric fencing, should be maintained throughout the year.

The risks of cattle contact with badger excretory products within farmyards was compared with those at pasture by calculating the infectious probability of each event type. This indicated that badger contamination of stored farm feeds was far more risky than badger urine at pasture but was assessed as less risky than badger faeces at pasture. Nonetheless, the magnitude of the risk of indirect infection posed by badger contamination of feed stores was high.

The risks to cattle of indirect infection posed by badger visits to farmyards and buildings clearly have the potential to be considerable. At present few farmers appear to invest in measures to prevent badgers from accessing vulnerable facilities or stored feeds. Barrier methods could successfully be used to prevent badger access and reduce risks.

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).

1. Introduction.

Bovine tuberculosis (TB) caused by *Mycobacterium bovis* is a serious disease in British cattle. In the early 1970s, the persistence of herd breakdowns in the south west of England was associated with a relatively high prevalence of infection in badgers (Muirhead *et al.* 1974). Infectious badgers may excrete bacilli in faeces, urine, sputum and/or exudate from wounds and abcesses (Clifton-Hadley *et al*., 1993) and their contamination of the environment may constitute a source of infection for cattle (Muirhead *et al.* 1974; MAFF 1979). However, cattle may also be at risk from direct contact with dead and moribund badgers (Dolan 1993; Flanagan 1993). It has been widely believed that transmission to cattle is most likely to occur via grazing on contaminated pasture (Muirhead *et al*., 1974; MAFF, 1979; Wilesmith *et al*., 1982) although the precise mechanism involved is not yet known. Current advice to farmers (MAFF, 1999) and research into transmission from badgers to cattle (Brown *et al*., 1994; Hutchings & Harris, 1997; Hutchings & Harris, 1999) has therefore focused on the risks associated with contamination of pasture. However, several workers have recorded the use of farm buildings and the exploitation of livestock feed by badgers (Benham, 1985; Brown, 1993; Cheeseman & Mallinson, 1981; Sleeman & Mulcahy, 1993). Clearly, where badgers are able to enter buildings and/or contaminate feed used by cattle (by the deposition of excretory products (faeces, urine), sputum and/or exudate from wounds and abcesses), the potential risks of disease transmission are likely to be far greater than in the wider environment. Nevertheless, there has been relatively little systematic research in this area. Cheeseman & Mallinson (1981) found that the prevalence of disease was significantly greater amongst badgers recovered from farm buildings than from a sample of animals killed on the roads in the same area. This suggests that there may be some differences in the behaviour of infected and uninfected badgers that make the former more likely to come into the close proximity of cattle, their feed and bedding. In other studies badgers have been observed to visit cattle troughs to feed (Sleeman & Mulcahy, 1993; Hahesy *et al*., 1997). A questionnaire-based study funded by the Milk Development Council revealed that occupiers of farms with a recent history of bovine TB in cattle were significantly more likely to have seen signs of badgers in farm buildings, feed stores and at troughs, than those on uninfected control farms (Christiansen & Clifton-Hadley, 2000).

Recent BBSRC funded work (a collaborative PhD studentship with Prof. Tim Roper of Sussex University) at CSL's Woodchester Park study area, constitutes the most detailed scientific study so far conducted on the use of farm buildings by badgers. With the use of radio-tracking and video surveillance the study identified relatively high levels of farm building-use by badgers, including known infected animals. Badgers were observed habitually consuming cattle feed cake (maize, soya and wheat based) stored on the ground in an open-sided shed and from around a storage silo. Badgers also fed on grass and maize silage in cowsheds, rat-tailed maggots (*Eristalis* spp.) from slurry pits, a variety of invertebrates from farmyards and foraged for rodents in barns and haystacks. They were also observed taking hay back to the sett from farm buildings to use as bedding material. These activities brought badgers into much closer contact with cattle than on pasture where they were observed to maintain a distance of at least 10m. In addition, cattle feed in facilities visited by badgers was found to contain badger excretory products on several occasions.

Intensive nocturnal field observations revealed that infected badgers might be more likely to enter buildings than their uninfected counterparts (Garnett *et al*. 2002). This greater dependence on anthropogenic food sources may be a consequence of nutritional stresses imposed by the infection. The frequency of visits to buildings by all badgers increased immediately following periods of low rainfall, when natural foods may have been in short supply (Roper *et al*. 2003). Badgers were also observed to exploit cattle feed in troughs on pasture, where they were able to gain access even when they were set above the height specified in current DEFRA guidelines (80 cm; see MAFF, 1999) for excluding badgers (Garnett *et al*. 2003). On several occasions cattle feed in troughs was contaminated with badger faeces. The ends of two troughs were habitually used as latrines suggesting that visiting badgers were scent-marking this food source.

However, although the results from the study at Woodchester Park provide compelling evidence that badger visitations to farm buildings and cattle troughs could be a potentially important source of infection for badgers, the extent of this phenomenon is as yet not known. This study focused on only two farms (one with beef and the other with dairy cattle) so it is not yet clear to what extent the observed behaviour is typical of badger populations or farms elsewhere. Also, further intensive monitoring of other farms is necessary to provide information on badger visits to a variety of facilities, seasonal and weather related variations in the frequency of visits and preferred food types.

On some farms the presence of badgers and their excretory products in buildings has the potential to be the single most important risk factor for resident cattle. The potential importance of these phenomena was reiterated in the report of the independent Husbandry Panel (Phillips *et al*., 2000) in which the current state of knowledge on the impact of farm management practices on the risks of bovine TB in cattle was reviewed. They concluded that measures to reduce the risks associated with badgers contaminating farm buildings and cattle troughs should form part of 'an integrated disease management strategy based on good practice', and identified further research in this area as a high priority.

2. Objectives.

This project sought to answer several fundamental questions about the use of farm buildings by badgers.

1) The extensive part of the study sought to answer the following principal question:
   a) What is the extent of badger visits to farm buildings in TB hotspot areas?

In addition, preliminary analyses were undertaken to answer the following question:
   b) What factors may make some farms more attractive to badgers than others?

2) The intensive part of the study sought to answer the following principal questions:
   a) What is the seasonal and weather related frequency of badger visits to farm buildings and troughs?
   b) What food types are exploited during visits to farms?
   c) What types of facility are most vulnerable to access by badgers?

d) Do badgers and cattle come into closer contact on pasture or in buildings?
e) Can electric fencing deter visits to buildings and where do excluded badgers go?
f) What are the main risks to cattle associated with badger excretory products/behaviour?

All of these objectives were fully met using a diversity of techniques (Table 1).

Table 1. Methods used to achieve objectives.

Objective number	Methods used
1a	Extensive surveys of farmyards, farm buildings and surrounding land for signs of badger activity on 36 farms in TB hotspot areas.
1b	Extensive surveys of farmyards, farm buildings and surrounding land for signs of badger activity on 36 farms in TB hotspot areas.
2a	Monthly video and still camera surveillance of farm facilities and radio tracking of 10 badgers on 6 farms in TB hotspot areas, collection of weather data.
2b	Video and still camera surveillance of feed stores and dietary analysis of badger faecal samples from 3 farms, and field examination of badger faeces from 11 farms in TB hotspots.
2c	Extensive surveys of farmyards and farm buildings to estimate accessibility on 36 farms in TB hotspot areas, and video and still camera surveillance of farm facilities.
2d	Nocturnal direct observations of badger incursions onto grazing land for17 farms, radio tracking of 10 badgers on 6 farms and video and still camera surveillance of farm facilities on 6 farms in TB hotspots.
2e	Electric fencing experiment, monitored using video and still camera surveillance of fenced and unfenced facilities and radio tracking of 7 badgers on 3 farms in TB hotspots.
2f	A comparison between the infectious probabilities of badger excretory products at different locations.

3. Methods

The study was conducted in two phases; an extensive phase to address objectives 1a and b and an intensive phase to address objectives 2a to f.

3.1 Extensive study

Using data extracted from the VETNET, hotspot parishes in the southwest of England were identified. A hotspot parish was defined as a parish that had experienced more than one cattle herd TB breakdowns between 1996 and 2002, giving a total of 4093 farms from which to sample. Farms with fewer than 40 cattle and those with more other livestock than cattle were ignored in order to focus specifically on commercial cattle-based enterprises. A random number was assigned to each farm (using Excel's random number generator) and the data were sorted by this number in ascending order. The 100 farms appearing at the top of the spreadsheet were contacted for permission to survey. Of these, 64 replied positively and the first 30 of these were selected for the extensive part of the survey. These represented a mixture of beef and dairy farms.

Each farm was surveyed once per quarter for eight quarters between July 2003 and June 2005. Field maps at a scale of 1:2500 were updated with new buildings, changed boundaries and other geographical features throughout the study. On all farms, farmyards and buildings were thoroughly searched for signs of badger activity, including faeces, latrines, setts, carcasses, hair, footprints and runs during each survey. The locations of any signs of badger activity were recorded on the field maps. Any potentially infectious material (faeces and carcasses) was collected and submitted to CSL York for microbiological culture and spoligotyping of culture positive samples.

Each farmyard was surveyed to determine the state of perimeter fences and walls and the presence of spilled feed. All buildings and facilities (including feed stores and troughs) within the farmyard were surveyed for purpose and content, and were scored for accessibility (where 1 = no access, store completely and effectively sealed; 2 = some access possible e.g. by forcing doors/gates, squeezing through small gaps; 3 = easy access). In addition, the height of each trough, from the highest point on the ground to the lip of the trough, was measured to the nearest 1cm.

On 1:5000 field maps with the farm at the centre, a circle of radius 500m was drawn around the farm. This radius was chosen since it was slightly larger than the largest estimates of badger territory sizes in the southwest of England (Krebs 1997). All land within the circle was surveyed. Field/land use and the presence of latrines, single badger faeces and setts were recorded on the maps to indicate local exposure to badgers. In addition, badger faeces were destructively investigated in the field using a stick, to determine the approximate food content of each one by identifying major components such as cereal grains and fruit seeds. Content was reported as 'worms' if the sample contained no obvious signs of other foods.

Any badger setts found during the surveys were marked on the field maps and surveyed for signs of activity using a weighted scoring system adapted from Wilson *et al.* (2003). The condition of the tunnel floor was scored as 0 = obstructed (entrance is partially or completely filled in with leaves, twigs or earth), 1 = loose (little sign of trampling, floor covered in loose soil/lumps of earth/other debris) or 2 = compacted (soil and other debris either flattened or freshly churned up). The tunnel side walls were scored as either 0 (unpolished) or 2 (polished = smooth, polished areas on side wall/tree roots). Badger footprints at a hole entrance or nearby were scored as 0 (absent) or 3 (present). Recent excavations were scored as 0 (absent) or 3 (signs of recent digging in the tunnel or on the spoil heap). Bedding was scored 0 (absent) or 3 (evidence of material being dragged in or out of the tunnel e.g. tufts of grass). The presence of rabbit droppings at hole entrances or nearby was recorded to aid the surveyor's decision as to whether activity signs were attributable to badgers or rabbits. If rabbit droppings were present, activity scores were reduced to 0 for that hole. The number of latrines found within 5m of the outermost holes was recorded for each sett and the number of fresh faeces within each latrine was also counted. In addition, faeces were destructively investigated for food content as before. The scores for each category and each hole, the number of latrines and number of fresh faeces present were summed to produce an activity score. All data were entered into Excel spreadsheets, and analysed using SPSS 13.0 (SPSS inc., Chicago).

Data on farm practices and features were entered into a binary logistic regression in order to identify factors associated with the presence/absence of signs of badger activity within farmyards (as a dichotomous response variable). For this initial, exploratory analysis data from a single season were used. Autumn 2003 was selected as the appropriate season since it was after the first survey, so reducing the likelihood of recording errors, was sufficiently early in the project to maximise the likelihood of all features being recorded and came at the end of the summer, when most signs of badger activity were expected to have accumulated within farmyards. Explanatory variables tested were: farmyard perimeter permeability (1-5), waste feed on the ground (0, 1), number of setts within 500m of the farmyard, number of active setts within 500m of the farmyard, cattle cake stored on farm (0,1), cereal silage stored on farm (0,1), cereal grains stored on farm (0,1), building accessibility (1-3), feed storage condition (1-3), number of cattle in buildings, method of cattle feeding (1-3) and mean trough lip height. To reduce the number of explanatory variables, each one was regressed against the presence/absence of signs of badger activity independently. Those not reaching significance were excluded from further analyses. A final model was constructed by entering explanatory variables under a forwards conditional procedure in order to identify the most parsimonious model.

3.2 Intensive study

Six farms, four of which were close to the Woodchester Park study area, one in Wiltshire and the other towards the north of Gloucestershire were selected for the intensive part of the study (Table 2). These farms were selected because they were known to experience visits by badgers, thus providing the opportunity to study the nature of such visits more closely.

Table 2. Farms within the Intensive study.

Farm	Location	Type	Approximate number of cattle
A	Woodchester area	Beef	250
B	Woodchester area	Beef	250
C	North Gloucestershire	Dairy	500
D	Woodchester area	Dairy	200
E	Woodchester area	Beef	150
F	Wiltshire	Dairy	250

3.2.1 Bait marking

A bait marking exercise was undertaken at each main sett that lay within 500m of five of the six intensive study farms between February and April 2004 in order to determine social group configuration in relation to the farms and to identify which social groups maintained the farmyards within their territories. One farm was not bait-marked since a main sett was present within the farmyard. The method used was as described by Delahay *et al.* (2000). Briefly, this involved feeding of bait (a mix of peanuts, golden syrup and coloured plastic beads; a different colour being used at each sett) at each sett for 12 days prior to the survey. The survey consisted of a systematic search for badger latrines to identify the plastic beads (returns). Returns were plotted on 1:10,000 scale field maps and digitised in ArcGIS 8.1 (ESRI, California). Minimum convex polygons were constructed around the outer-most latrines for each social group (i.e. outer-most latrines with returns of the same colour as fed at the main sett) and these were modified according to the presence of badger runs between two social groups and by excluding outlying latrines. Maps of social group territories were then constructed in ArcGIS 8.1.

3.2.2. Dietary analysis

The occurrence of farm-derived feeds (FDF) in badger diets was assessed by quantifying the contents of badger faecal samples collected in the field. Up to 20 fresh faecal samples were collected from each of three farms each quarter between August 2003 and May 2005. Wherever possible faeces were collected at the same latrines between quarters. Samples were broken-up and washed in two graded sieves of 500µm and 150µm to produce two fractions. The macro-fraction was examined using a binocular microscope under x10 magnification. FDF was identified by comparing with samples derived from captive badgers that had been fed known diets. Food items were scored as present or absent in each sample.

3.2.3 Badger capture and sampling

Trapping exercises were undertaken three times per year at all six farms between May 2003 and May 2005. No trapping was undertaken during the close season (February to April, inclusive). Steel-mesh cage traps were placed at or close to 10 setts and baited with peanuts during the afternoon, for 3-10 days before being set. Traps were set during the late afternoon/early evening for two consecutive nights following pre-baiting and were checked early the following day. Badgers caught in the trap were transferred to a holding cage for transport to the sampling facility.

Before clinical sampling badgers were anaesthetised with a mixture of ketamine, butorphanol and medetomidine as described by de Leeuw *et al*. (2003). On first capture badgers were given a unique indentifying tattoo on the belly and all cubs >3kg and yearling and adult badgers were given a unique, identifying fur-clip on both flanks (Cheeseman & Harris 1982, Stewart *et al*. 1997). The location, sex, body weight and condition, reproductive status and age class (<1 year = cub, >1 year but <2 years = yearling, >2 years = adult) were then recorded. The infection status of captured badgers was determined by bacterial culture of clinical samples (Clifton-Hadley *et al*. 1993) and a serological test for the presence of antibodies to *M. bovis* (indirect ELISA; Goodger *et al*. 1994). Samples of sputum, faeces, urine, pus from abscesses, and bite wound swabs, were taken for bacterial culture and up to 5ml of jugular blood for serology. Wherever possible (for example, in the absence of neck-lesions) adult badgers were fitted with radio-transmitter collars. After a period of recovery all badgers were released at the point of capture.

All badger carcasses found on the study farms were submitted for *post mortem* examination for tuberculous lesions and tissue samples from lymph nodes and major organs were taken for bacterial culture.

3.2.4. Video and still camera surveillance

Remote video and still camera surveillance equipment was deployed on the six farms of the intensive study to monitor the frequency, timing and duration of badger visits to farmyard facilities. Still cameras triggered by either passive infrared (PIR, n = 4) or active infrared (AIR, n = 7) sensors detecting movement were distributed among farmyard facilities (Table 3) on three farms[1]. Sensors were set at a moderate sensitivity so that they could detect movement of medium-sized animals (e.g. badgers and foxes) but not smaller animals and objects (e.g. mice and leaves). Cameras were set with a minimum of 5 minutes between photographs to reduce multiple images of the same animal. Cameras were automated to be active between the hours of 20.00 and 05.00 each night for four nights in any one week of each month between November 2003 and June 2005. When the 36-exposure, 35mm colour films were completely or nearly completely used at the end of a surveillance session they were replaced and developed. Data on the date and time of each recorded event were downloaded onto a PC using the StatPack software (Goodson & Associates, Kansas) and the relevant photograph was assigned to each event.

Custom-built remote video surveillance equipment[2] (n = 8) using black and white video tapes under infrared illumination was deployed under the same regime as the still cameras. However, due to the limited number of sets of video equipment, these were rotated around farms and facilities within months. Videos were set to record constantly in 12-hour time-lapse mode between 20.00 and 05.00 and tapes were watched at a later date to record badger behaviour at farmyard facilities. Observations on the date, time and duration of badger visits, the number of individuals involved and their behaviour at each event were recorded.

[1] Equipment used was TrailMaster TM550 (PIR) and TM1550 (AIR) linked to TM35 camera kit, from Goodson & Associates, Inc., 10614 Widmer, Lenexa, KS 66215, USA.
[2] Designed and built by Highview Electronics, Building 11, The Mews, Mitcheldean, Gloucester, GL17 0SL, UK.

Table 3. Number of camera nights during which remote video and still camera surveillance equipment was deployed at farmyard facilities on the six intensive study farms.

Date	Feed Store	Cattle Housing	Farmyard	Silage Clamp	Troughs	Slurry Pit	Total
Nov-03	10	16	4	4	0	0	34
Dec-03	18	13	8	5	0	1	45
Jan-04	18	12	12	4	0	0	46
Feb-04	12	11	12	15	0	0	50
Mar-04	12	18	13	9	2	0	54
Apr-04	17	19	11	13	6	0	66
May-04	23	17	14	11	9	0	74
Jun-04	10	13	13	4	2	0	42
Jul-04	13	10	17	4	1	0	45
Aug-04	12	12	16	6	0	0	46
Sep-04	6	16	14	4	2	0	42
Oct-04	12	22	10	5	1	0	50
Nov-04	14	16	12	7	3	1	53
Dec-04	14	15	12	6	0	0	47
Jan-05	16	16	16	9	2	0	59
Feb-05	23	18	16	8	4	0	69
Mar-05	14	17	12	14	2	0	59
Apr-05	8	9	12	3	0	0	32
May-05	15	17	4	13	8	0	57
Jun-05	24	15	16	10	5	0	70
Total	291	302	244	154	47	2	**1040**

3.2.5. Badger-cattle interactions at pasture

The majority of cattle in the southwest of England are housed within the farmyard between October and April, hence this part of the study was undertaken between May and September. Observations of badger movement on pasture were taken from either the roof or interior of a stationary Landrover, depending on the field of view available. Observations were made on 17 half-nights from 20.00 to 01.00 or 01.00 to 05.00 from 30th June to 30th July 2004 at three farms and 30 half-nights from 30th August to 31st September 2005 at 15 farms. A novel piece of equipment was designed for this purpose. The equipment consisted of a generation 2+ night vision monocular (D-121M) with a laser rangefinder (Leica LRF 800) mounted on the side by means of a Weaver rail. These two were zeroed to an infrared laser sight (Corsak-16-I) and extra illumination was provided by an infrared illuminator (HTH-202), both mounted to the monocular by Weaver rails[3]. The equipment was mounted on a camera tripod. The night vision monocular was used to scan pasture for badger presence. On observing a badger the time was recorded and the badger's distance from and angle in relation to the observer were measured using the rangefinder and a hand-held compass to the nearest 1m and 1º respectively. The same measurements were then taken on the nearest cattle. These measurements were repeated at 1-minute intervals until the badger moved out of view. Notes were also taken on the response of badgers and cattle to each other. Direct interaction between a badger and cattle was recorded if the animals were within 2m of each other and responding directly to the each other's presence. Data were uploaded to ArcGIS 8.1 in order to plot badger trajectories across pasture and measure minimum distances between badgers and cattle to the nearest 1m.

3.2.6. Radio tracking

Radio collars were fitted to ten badgers, one from a sett associated with farm A, one from farm B, three from farm D, four from farm E and one from farm F. A Yagi flexible 3-element directional aerial attached to a Telonics TR4 radio receiver was used to detect signals from radio collars[4]. Before each radio tracking session wind speed was estimated using the Beufort scale and cloud cover using the Oktas scale. Radio tracking sessions were undertaken between dusk and 01.00 or 01.00 until dawn on alternate nights on 3-4 nights per week, for two weeks in each month from July 2003 to June 2005. Approximately three location fixes were taken on each badger per session. Fixes were made by obtaining an initial signal from an individual and following the direction on foot and in a down-wind direction if possible, until the animal could be viewed with a generation 2+ image intensifier (Omega II night vision hand viewer system[5]). If a visual observation could not be made a second bearing was taken from another location, as close to 90º from the first as possible. To avoid temporal autocorrelation of fixes,

[3] Equipment built and supplied by Soviet Bazaar, Isle of Barra, Outer Hebrides.
[4] All equipment supplied by Biotrack Ltd. Wareham, Dorset.
[5] Omega Survival Systems Ltd., Milford, Surrey.

these were collected with a minimum of 30 minutes between them. Every effort was made to ensure that badgers were unaware of the presence of the observer. Data were analysed in Ranges 6 (Anatrack Ltd., Wareham).

Range areas were plotted against the incremental number of fixes used to calculate them to indicate range stability for each badger following Kenward (1987). Stability was concluded if the plot reached an asymptote. Home ranges were described by 100%, 95% and core area minimum convex polygons (MCPs). The core area, for each badger range was defined by an inflection point on a plot of range area versus the proportion of fixes used to calculate them (Kenward 1987). If no inflection point was apparent it was concluded that that badger range did not have a well-defined core area. The area of each farmyard, from 1:10,000 Ordnance Survey raster maps, was measured in ArcView 3.2 (ESRI, California). Each badger home range was laid over these maps as an individual theme in order to calculate the proportion of each farmyard contained within each range. Ranges were constructed for each badger from all fixes available (henceforth called annual ranges) and from fixes falling within each quarter year (henceforth called winter [January to March], spring [April to June], summer, [July to September] and autumn [November to December]).

3.2.7. Fencing experiment

To assess whether electric fencing could be used to effectively exclude badgers from facilities an exclusion experiment was undertaken using a modified version of the badger-proof fence described by Poole *et al.* (2002). The experiment was conducted at farms A, B and F (Table 4).

Table 4. Deployment of electric fencing on farms and badgers monitored during the experiment.

Farm	Facilities within electric fencing	Badger radio collar numbers monitored
A	Trough, Feed store	926, 245
B	Feed store	751, 814, 364, 565
F	Feed store	354

The experiment was partitioned into three phases, each of 2-weeks' duration:

a) Phase 1. A pre-treatment phase during which badger use of farm buildings was monitored by video and still camera surveillance of facilities and radio tracking radio collared animals on each farm.
b) Phase 2. The treatment phase, at the start of which electric fencing was deployed at the 3 farms and activated every night for 2 weeks. At one of these farms the fence was disassembled during the day in order to allow farm personnel access to the feed sheds. At the other two farms the fences were simply switched off during the day as daily access was not required. Facilities and badger activity were monitored as in Phase 1.
c) Phase 3. A post treatment phase, at the start of which electric fencing was removed. Facilities and badger activity were monitored as in phases 1 and 2.

Video and still-camera surveillance employed the same equipment as detailed in section 3.2.4. Equipment was deployed at each facility (Table 4) to monitor between dusk and dawn for every night of the 6-week experiment.

An observer was allocated to each farm to radio track badgers during four alternating half-nights per week for the 6-week period. Location fixes were taken as before (section 3.2.6), with four fixes taken on each badger per half-night. Consecutive fixes were separated by a minimum of 20 minutes due to logistical constraints of tracking multiple badgers. Data were analysed in Ranges 6 and Genstat 8 (VSN, Hemel Hempsted).

3.2.8. Calculation of the infectious probability of badger excretory products

As a preliminary step towards identifying the main risks to cattle associated with badger excretory products the infectious probability of these products within feed stores was calculated and compared to that calculated for badger excretory products at pasture by Hutchings & Harris (1999). The equation to calculate the infectious probability was taken directly from Hutchings & Harris (1999) and Daniels *et al.* (2003).

$$P_{inf} = 1\text{-}(1\text{-}P)^{1/Fe.Fi.Ip}$$

Where:
P_{inf} = The infectious probability.
P = Probability of a bovine having a confirmed diagnosis of infection.
F_e = Mean number of faeces likely to be encountered per bovine per year.
F_i = Proportion of faeces ingested per bovine per year.
I_p = Mean prevalence of infection in badgers x proportion of badgers excreting via relevant route.

This simple, deterministic method estimates the probability of infection per bite needed to account for the prevalence of TB in cattle in southwest England.

Cattle herd and TB data from 1993 were used to calculate *P* and data on TB prevalence in badgers were taken from Hutchings & Harris (1999) to calculate I_p in order to provide comparability with their estimate of P_{inf} for pasture contamination. The proportion of badgers excreting bacteria in faeces was not presented in Hutchings & Harris (1999) so was calculated from data in the Woodchester Park database on badger captures and associated *M. bovis* culture results. The prevalence of infection in badgers was divided by this figure to derive I_p. F_e was calculated by entering data from sections 4.1.1 and 4.2.4 into the following equation:

$$F_e = (N/S)T.P_p$$

Where:
N = Total number of faeces in stored farm food.
S = Number of times stored food was surveyed for faeces presence.
T = Time over which cattle are fed concentrates in housing (91 days per year).
P_p = Proportion of farms where feed stores were contaminated with badger faeces.

F_i was assumed = 1. Stored feed may be mixed into 'complete diet', hence mixing any contamination uniformly within the feed, or may be scattered across the top of a trough, also providing some mixing. It is likely that >1 cow will consume contamination at any given feeding, and with up to 75,000 bacilli per gram of badger faeces, sufficient bacteria should be present in a single infected dropping to potentially infect every cow in a herd (i.e. each cow has an equal likelihood of becoming infected).

3.2.9. Costs of biosecurity measures
Costs of proofing buildings and farmyards against badgers were estimated for a farm considered broadly representative of cattle farms in the southwest. Materials and labour costs were estimated at 2005 prices and applied to the areas of the farm that required proofing measures.

4. Results

4.1. Extensive study

4.1.1. Farm surveys

All 36 farms were surveyed eight times, once each quarter, between July 2003 and June 2005. Cattle were housed during the winter on 94% of farms, mainly between October/November to April/May each year. When at pasture, cattle were provided with supplementary feed in troughs on 22% of farms. On all farms fresh water was available to cattle via mains-fed troughs. On only one farm could supplementary feed at pasture be considered out of the reach of badgers or other wild animals. On this farm mineral licks were supplied in large containers with the side cut-out, which were suspended by a rope from the limbs of trees so that the base of the container was approximately 70cm from the ground. Water and feed troughs were present on all farms surveyed. The average height of feed troughs on farms was 47.3cm ± 1.3cm (mean ± SE) (n = 366). The average height of water troughs was 55.4cm ± 0.9cm (n = 534). Only 13% of water troughs and 7% of feed troughs were at or above the Defra recommended height of 80cm. Troughs at pasture had signs of badger activity associated with them in 0.44% of cases and on 2.1% of farms, including footprints in sediment in and beside troughs and latrines at the base of troughs.

Active badger setts were present within 500m of the farm centre on 94% of farms. The average total number of setts per farm was 4.8 ± 0.6 (mean ± standard error) (range = 0 to 14). The average number of active setts per farm was 3.0 ± 0.4 (range = 0 to 11). Badger latrines not associated directly with a sett were found within 500m of 76% of farmyards. Of 125 latrines surveyed during the autumn of 2003, nine were found to contain farm-derived feed. Grains potentially taken from feed stores were identified by the absence of a husk, which was evident on grains potentially taken from growing crops.

No farms deliberately protected the entire yard from incursion by badgers or other wildlife, although 6% of those surveyed were classified impervious to badgers based on the presence and good condition of perimeter walls and gates. In contrast, 69% of farmyards were freely accessible to badgers. Concentrated cattle feed was stored on 56% of farms surveyed, grass silage on 53%, maize silage on 42%, cereal grains on 31%, sugar beet pulp on 11%, and cereal silage on 8%. Spilt feed was present within the yards of 61% of farms surveyed. Two farms demonstrated exceptionally high standards of cleanliness and hygiene, with one having all buildings and yards cleared and steam-cleaned at the end of the cattle-housing season.

Biosecurity of cattle buildings and feed stores was generally of a very low standard, with few farms employing resources to prevent wild animals from entering their buildings. Feed stores were judged to be freely accessible by badgers in 56% of cases and partially accessible in 12% of cases (n_{total} = 94) and the same was true for cattle housing in 43% and 47% of cases (n_{total} = 175). Notable amongst the exceptions were a series of modern feed stores on one farm, with roller shutters that were closed each night and an old, open feed store which had purpose-built, sealable chip-board feed bins installed, on another farm. Feed stores were assessed as impervious to badgers in 29% and cattle housing in 7% of cases. In 85% of cases (n = 356) feed was stored loosely on the ground and in 3% of cases it was stored in open bags or containers to which wild animals could freely gain access. In 12% of cases feed was stored in sealed containers, either inside buildings or in the yard.

Whilst not evaluated during a formal survey, discussions with farmers indicated that few were aware of badger activity within their farmyards. Signs of badger activity were found in farmyards and buildings on 39% of farms, (Table 5). Two badger carcasses and 66 faecal samples were submitted for mycobacterial culture. Both carcasses and two faecal samples tested positive for the presence of *Mycobacterium bovis*.

Table 5. Signs of badger activity observed in farmyards and buildings.

Sign	Faeces	Carcass	Live observation	Foot print	Badger run	Hair	Sett
Number of farms	6	2	4	7	3	1	2

4.1.2. Correlates of badger visits to farm buildings

Initial logistic regressions identified significant associations between the total number of badger setts and number of active setts within 500m of the farmyard and the presence/absence of signs of badger activity within farmyards (total number of setts: β = 0.559, Wald statistic (χ^2) = 9.859, *d.f.* = 1, P = 0.002; number of active setts: β = 0.829, Wald statistic (χ^2) = 9.319, *d.f.* = 1, P = 0.002). An association with cattle cake stored on farm was of border-line significance (β = 1.584, Wald statistic (χ^2) = 3.253, *d.f.* = 1, P = 0.071).

Two final models were derived using each of the two significant explanatory variables in isolation since they were co-linear. Both analyses also included the storage of cattle cake on the farm although this variable did not achieve significance and was not included in either final model, hence statistical values for these models remained as above.

4.2. Intensive study

4.2.1. Bait marking

One intensive study farm (F) was not bait marked because a main sett was present within the farmyard. It was not possible to construct social group territories around main setts on three farms (C, E, F) due to insufficient bait marking returns being detected. However, due to the positions in which returns were found it was possible to deduce that all farmyards were encompassed by at least one badger social group's territory and most were on the boundary of more than one social group (Table 6) and therefore likely to be visited by badgers from more than one group.

Table 6. Badger territory overlap with farmyards.

Farm	No. social groups with latrines on or within farmyard boundary	No. territories overlapping with farmyard
A	3	1
B	4	2
C	2	1
D	0	1
E	2	1
F	1	1

4.2.2. Dietary analysis

Between August 2003 and May 2005 a total of 446 faecal samples were collected from latrines on farms D, E and F for analysis. Of these 134 (30%) contained feed considered to have been obtained from within farmyards. Farm-derived feed (FDF) was present in faeces in every season surveyed (Fig 1).

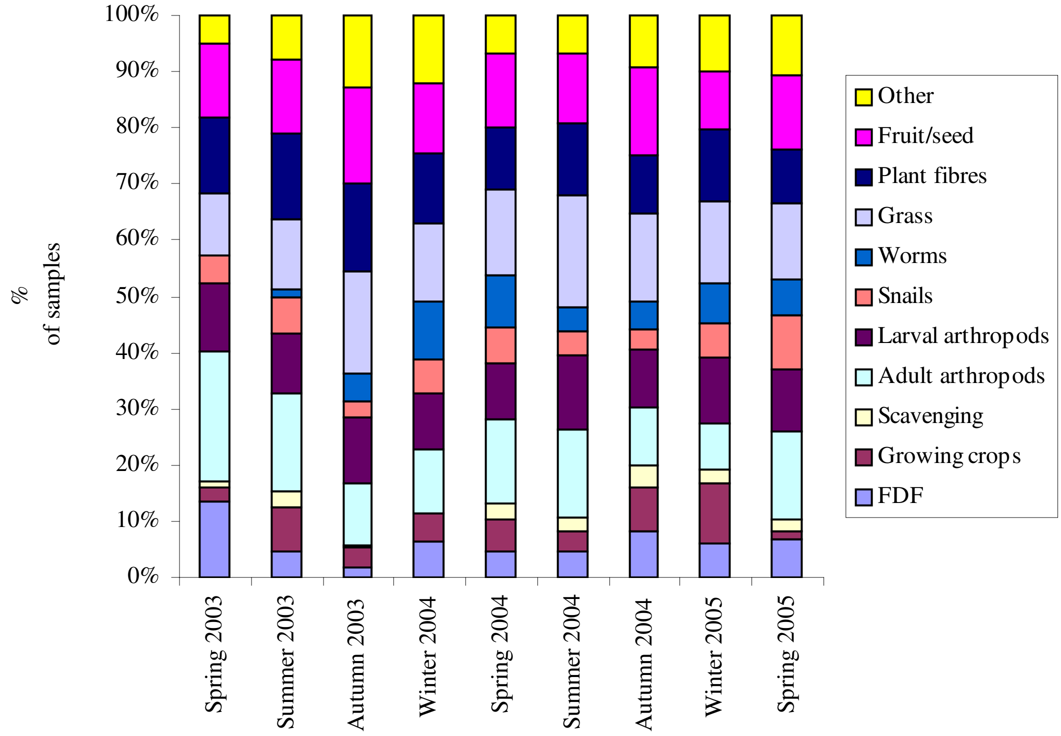

Fig. 1. Variation in composition of faecal samples between seasons.

FDF observed in faecal samples comprised of cattle cake, concentrates, maize silage, wheat silage, barley and wheat. Cattle cake and concentrates together occurred significantly more frequently than all other FDF types (χ^2 = 8.00, *d.f.* = 1, $P = 0.005$). Barley and wheat occurred significantly more frequently than the remaining FDF types, but were not significantly different from each other.

The proportions of samples containing each food item varied between season (Fig. 1) but this variation was only statistically significant for growing crops (χ^2 = 35.26, *d.f.* = 8, $P < 0.001$) adult arthropods (χ^2 = 19.15, *d.f.* = 8, $P < 0.014$), snails (χ^2 = 26.09, *d.f.* = 8, $P = 0.001$), earthworms (χ^2 = 31.77, *d.f.* = 8, $P < 0.001$) and 'other' items (χ^2 = 17.03, *d.f.* = 8, $P < 0.030$). In general terms, growing crops were present in summer and autumn samples at higher frequencies than statistically expected, representing the times of year when these were available. While not statistically significant ($P = 0.096$), FDF was generally present at higher frequencies than expected during the summer and autumn and at lower frequencies during the winter.

The seasonal proportions of samples containing each food item were analysed for parametric correlations (Pearson's) after arcsine transformation. Very few significant temporal correlations existed between food items (Table 7).

Table 7. Temporal correlations between food items.

Food items	Correlation coefficient (*r*)	*P*
Farm-derived feed and grass	-0.718	0.029
Grass and larvae	0.750	0.020
Fruit and other	0.694	0.038
Other and worms	0.647	0.060

Under the assumption that that fresh faecal samples were no more than one week old when collected, the proportion of samples containing FDF (arcsine transformed) was tested for parametric correlations with weather conditions during the preceding 7 days. However, there were no significant correlations between total rainfall (in mm), mean minimum daily temperature (ºC) or mean maximum daily temperature (ºC) and the proportion of samples containing FDF.

The probability of FDF presence in faecal samples varied significantly between farms and seasons (Table 8). Whilst controlling for FDF availability on each farm, the presence/absence in droppings of most types of FDF, except wheat silage and maize silage, varied significantly between farms but not years (Table 8). Cattle cake was more likely to occur in faecal samples during spring than winter, but less likely to occur in summer. This apparently anomalous result could be due to the significant interaction between season and year, which also had a negative regression coefficient (Table 8).

Table 8. Significant results of binary logistic regressions to identify factors associated with the presence/absence of various farm-derived feeds in faecal samples.

Response variable	Explanatory variable	*β*	Wald statistic (χ^2)	*d.f.*	*P*
Farm-derived feed	Season		8.444	3	0.038
	Summer (vs winter)	-1.083	6.856	1	0.009
	Farm		30.649	2	<0.001
	Farm F (vs E)	1.061	14.119	1	<0.001
	Farm D (vs E)	1.514	30.069	1	<0.001
	Season x year		7.930	3	0.047
	Spring x year 2 (vs winter x year 2)	-1.405	5.544	1	0.019
Cattle cake/ concentrates	Farm		19.388	2	<0.001
	Farm F (vs E)	0.891	8.198	1	0.004
	Season		9.125	3	0.028
	Spring (vs winter)	1.068	4.984	1	0.026
	Summer (vs winter)	-1.093	4.096	1	0.043
	Season x year		10.156	3	0.017
	Spring x year 2 (vs winter x year 2)	-2.132	8.140	1	0.004
Barley	Farm		19.388	2	<0.001
	Farm D (vs E)	2.280	22.518	1	<0.001
	Season		8.940	3	0.030
Wheat	Farm		13.506	2	0.001

4.2.3. Badger capture and sampling

A total of 50 badgers were caught and sampled (Table 9). During 122 capture events, 50% of badgers were caught twice, 34% three times, 16% four times, 12% five times, 10% six times, 4% seven times and 2% (one badger) were caught ten times. Of these three were excreting *M. bovis* (one adult male in faeces, one adult female in urine and sputum and one adult female in sputum alone) at least once at sampling. Radio collars were fitted to 24 adult (or apparently fully grown) badgers (Table 10).

Table 9. Age and sex categories of badgers at first capture.

Farm	No. male cubs	No. female cubs	No. adult males	No. adult females
A	1	0	1	2
B	4	9	0	7
C	0	1	1	0
D	2	3	0	0
E	3	2	3	7
F	0	4	0	0

Table 10. Sex and infection status of badgers fitted with radio collars.

Collar Number	Sex	Culture
216	M	Negative
235	F	Negative
245	F	Negative
254	F	Negative
303	F	Negative
336	F	Negative
511	F	Negative
558	F	Positive on urine and sputum
565	F	Negative
603	M	Positive on faeces
638	M	Negative
653	M	Negative
687	F	Negative
702	F	Negative
751	F	Negative
788	F	Negative
814	F	Negative
853	M	Negative
903	F	Negative
926	M	Negative
946	F	Negative
954	F	Negative
965	F	Negative
657/354	F	Negative

4.2.4. Video and still camera surveillance

Between August 2003 and June 2005, 2050 incursions into farmyards and facilities on six farms were recorded from 1040 camera nights of surveillance. A diversity of mammals was observed visiting a number of different facilities, but the majority of visits were made by badgers to feed stores and troughs (Fig. 2).

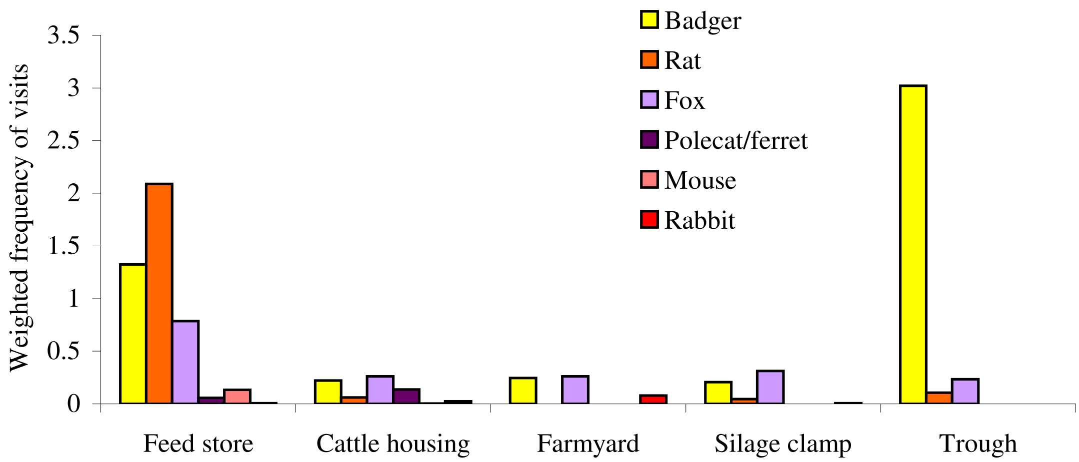

Fig. 2. Relative frequency of visits by wild mammals to farmyards and facilities. Absolute visit frequency was weighted by the number of camera nights over which each facility was monitored.

The frequency of badger visits varied significantly between facility types (χ^2 = 473.91, *d.f.* = 4, $P < 0.001$), with feed stores being visited more frequently than any other. The majority of badger visits to troughs were associated with a single, large, easily accessible trough on one farm.

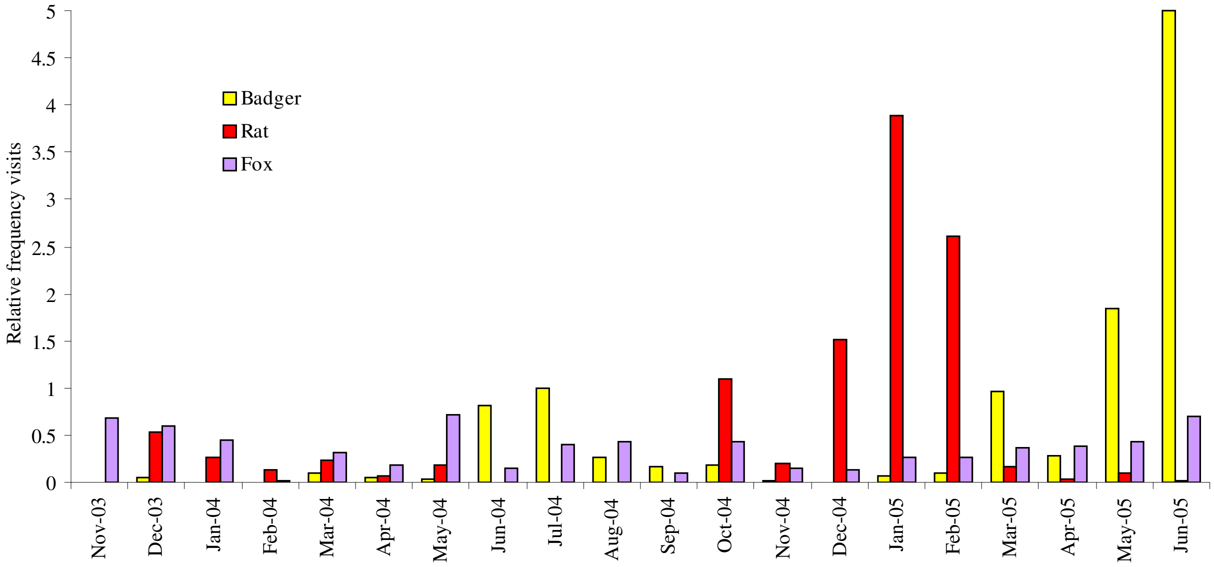

Fig. 3. Temporal variation in the relative frequency of visits to farmyards and facilities.

The temporal pattern of visits varied between species (Fig. 3). Foxes maintained a fairly constant frequency of visits throughout the year ($P = 0.100$), rats tended to visit more frequently during the winter months ($\chi^2 = 36.29$, *d.f.* = 19, $P = 0.010$). Badgers visited more frequently during the spring and summer months ($\chi^2 = 30.63$, *d.f.* = 6, $P = 0.044$), but the magnitude of this effect varied between years.

The earliest that badgers were recorded entering farmyard facilities was 20:05 and the latest was 05:41. Visit frequency peaked between 02:00 and 03:00 (Fig. 4) although this varied between seasons. Visits were significantly earlier during the autumn than at any other time of the year (one-way ANOVA: $F = 5.019$, *d.f.* = 133, $P = 0.003$, *post hoc* least significant difference test: $P_{winter} = 0.002$, $P_{spring} = 0.003$, $P_{summer} < 0.0001$).

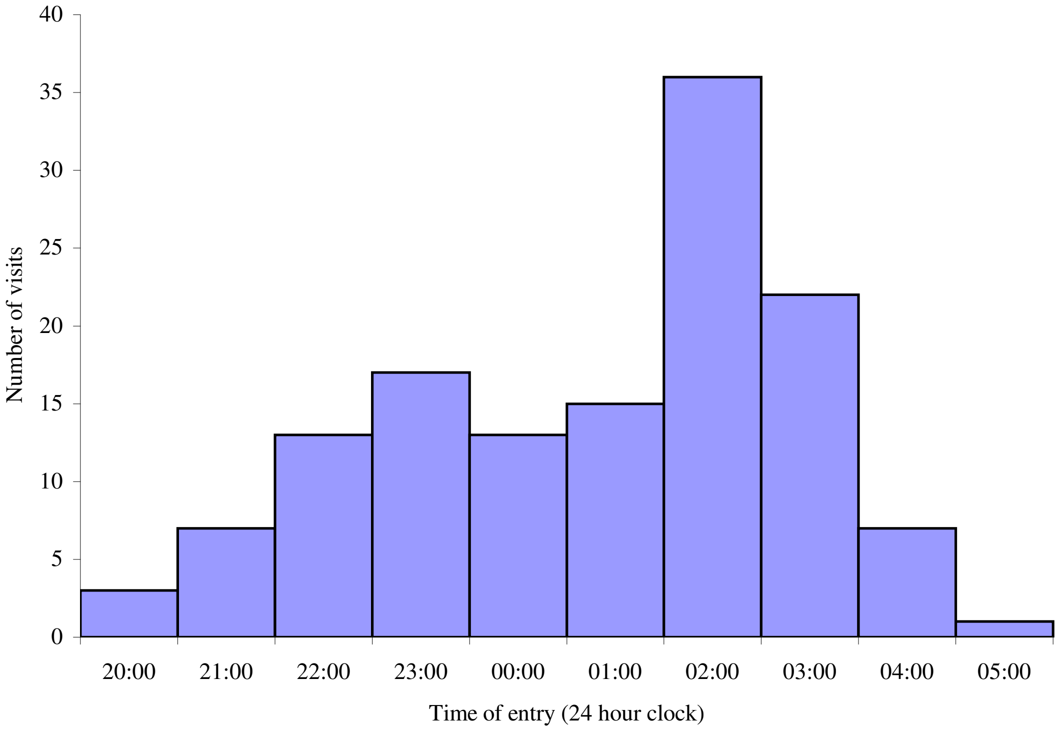

Fig. 4. Times of entry by badgers into farmyard facilities.

The vast majority of behaviours observed (61%) represented feeding activities. Scent marking/excreting was rarely observed (n = 12) but on ten occasions it took place in areas where cattle feed was stored (including one excretion in a silage clamp). However, neither excretion nor scent marking by badgers were ever observed to take place directly onto stored feed. Interspecific interactions involving badgers were not common, being observed on 47 occasions, but 76% of such encounters were with cattle, mainly at troughs but also in housing. Direct interactions between badgers and cattle were observed on 18 occasions, four of these being nose-to-nose contact for several seconds. Contact was most frequently made by cattle investigating badgers (which generally involved sniffing), which usually responded by moving away. However, on three occasions badgers approached cattle and investigated them by close sniffing. The frequency of observed behaviours varied significantly between different farmyard facilities (χ^2 = 267.72, *d.f.* = 44, P < 0.001). Farmyards were mainly used whilst travelling to and from buildings and less so for foraging and feeding. Badgers foraged and fed most frequently in feed stores. Interactions between badgers and cattle were most frequent within feed troughs.

The frequency of visits to facilities varied according to facility type and the feed available therein (χ^2 = 2033.20, *d.f.* = 24, P < 0.001). Visits were more frequent than expected where cattle cake or wheat grains were available in feed stores, hay/straw in cattle housing, maize silage in silage clamps and complete diet (maize silage/concentrate/grass silage mix) in troughs.

The frequency of visits to farmyard facilities varied significantly with the maximum recorded temperature on that day (r_s = 0.242, n = 251, P < 0.001) and during the previous 24 hours (r_s = 0.268, n = 251, P < 0.0001) such that visits were more frequent during periods of warmer weather. Total rainfall in the previous 24 hours followed a negative trend with the frequency of visits, but this association was not quite significant (r_s = -0.139, n = 251, P = 0.051). Binary logistic regressions identified maximum daily temperature as the only significant predictor of variation in the presence/absence of badger visits (on that day: β = 0.093, Wald statistic (χ^2) = 3.836, *d.f.* = 1, P = 0.050; 24-hours previously: β = 0.112, Wald statistic (χ^2) = 10.284, *d.f.* = 1, P = 0.001).

4.2.5. Badger-cattle interactions at pasture

Badgers were observed traversing cattle pasture on 13 of 20 farms surveyed. Badgers were observed on pasture on 37 occasions involving 41 individuals. Most visits were by single badgers but two were by a pair and one by three badgers. The mean minimum distance maintained between badgers and cattle within the same field was 137m ± 27m (range: 4m - 456m). Cattle generally ignored badgers at pasture but occasionally moved towards them. Badgers generally avoided cattle but on two occasions seemed to ignore prostrate cattle despite being only 4m from them. On no occasion was direct contact observed between badgers and cattle. Badgers were observed at pasture for a mean of 15 min. 1 sec. ± 2 min. 21 sec. (range: 1 min. - 62 mins.). The duration of badger visits to pasture did not vary significantly in relation to the presence or absence of cattle (Mann-Whitney test: P = 0.296).

4.2.6. Radiotracking

A total of 810 fixes were obtained from ten radio-collared badgers between 3 November 2003 and 24 June 2005 (Table 11). The mean number of fixes obtained per badger was 81 ± 7 (standard error) fixes (range: 41 - 123 fixes). The mean time span over which fixes were obtained was 10.3 months ± 0.6 months (range: 7 - 12 months).

Table 11. Summary of radio-tracking data collected.

Collar frequency	Number of fixes	Duration
235	58	23 July 04 – 29 April 05
558	85	8 December 03 – 3 June 05
603	41	15 June 04 – 22 December 05
638	85	4 November 03 – 29 September 04
653	77	12 August 03 – 24 June 04
657	123	20 July 04 – 22 June 05
702	103	3 November 03 – 28 September 04
751	93	23 July 04 – 23 June 05
853	76	12 August 03 – 24 June 04
926	69	8 December 04 – 17 June 05

Asymptotes were not reached on incremental plots of range area for any annual home ranges when constructed using kernel estimators and only one home range (for collar 603) when they were constructed using minimum convex polygons (MCPs). MCPs were used during all further analyses.

Home range size was generally consistent between badgers (100%MCP 17.98 ± 2.20 Ha, 95%MCP 13.77 ± 1.59 Ha, MCP core area 3.29 ± 1.30 Ha), with no significant variation between the sexes for any estimate (Mann-Whitney test, P>0.05). Home range sizes varied significantly between seasons (one-way ANOVA 100%MCP: F = 3.020, *d.f.* = 37, P = 0.043; 95%MCP: F = 2.988, *d.f.* = 37, P = 0.045). Autumn home ranges were significantly smaller than spring or summer ranges (*post hoc* least significant difference test, 100%MCP: P_{spring} = 0.025, P_{summer} = 0.009; 95%MCP: P_{spring} = 0.034, P_{summer} = 0.011) but did not differ from winter ranges (P > 0.05) (Table 12).

Table 12. Seasonal home range characteristics. Home range areas are the mean ± one standard error.

	Winter	Spring	Summer	Autumn
No. 100%MCP ranges	9	10	9	10
No. 95% MCP ranges	9	10	9	10
No. MCP core area ranges	8	7	7	10
100%MCP (Ha)	5.73 ± 1.51	9.21 ± 2.07	10.08 ± 1.97	4.23 ± 1.54
95% MCP (Ha)	5.03 ± 1.50	8.07 ± 1.96	9.23 ± 1.83	3.36 ± 1.14
MCP core area (Ha)	1.22 ± 0.57	2.51 ± 1.01	1.19 ± 0.32	1.08 ± 0.66

Annual home ranges encompassed considerable proportions of farmyards (Table 13). This overlap with farmyards (as the arcsine transformed proportion of farmyard encompassed within home ranges) varied significantly between seasons (one-way ANOVA 100%MCP: $F = 3.475$, *d.f.* = 38, $P = 0.026$; 95%MCP: $F = 4.168$, *d.f.* = 38, P = 0.013; MCP core area: $F = 4.549$, *d.f.* = 38, $P = 0.009$). During the winter months farmyards were overlapped significantly less than during the spring or summer by 100% and 95% MCPs (*post hoc* least significant difference test: 100%MCP: $P_{spring} = 0.049$, $P_{summer} = 0.017$; 95%MCP: $P_{spring} = 0.031$, and $P_{summer} = 0.017$) and less than during the spring by core area MCPs ($P = 0.004$). Overlap was also significantly greater during spring and summer than it was during the autumn for 100% and 95% MCPs (100%MCP: $P_{spring} = 0.027$, $P_{summer} = 0.017$; 95%MCP: P_{spring} 0.017, $P_{summer} = 0.018$ respectively), and core area MCP overlap was significantly greater during the spring than it was during either the summer ($P = 0.013$) or autumn ($P = 0.003$).

Table 13. Home range overlap with farmyards. Figures for No. ranges overlapping are the number of ranges overlapping divided by the total number of ranges analysed for that season. Figures for % overlap are the mean ± one standard error.

	Annual	Winter	Spring	Summer	Autumn
No. 100%MCP ranges overlapping	9/10	4/9	8/10	7/9	3/10
No. 95% MCP ranges overlapping	8/10	3/9	8/10	7/9	2/10
No. MCP core area ranges overlapping	4/8	1/9	5/7	2/6	1/10
% overlap of 100%MCPs	59.4 ± 14.2	18.8 ± 12.5	45.6 ± 13.1	49.7 ± 12.6	11.0 ± 7.3
% overlap of 95% MCPs	55.7 ± 13.9	10.9 ± 10.4	45.6 ± 13.1	45.2 ± 13.1	10.4 ± 7.4
% overlap of MCP core areas	20.6 ± 10.2	1.0 ± 1.0	40.3 ± 14.7	5.1 ± 3.4	0.7 ± 0.7

4.2.7. Fencing experiment

Approximately 30 fixes were obtained per badger during each phase of the fencing experiment (means ± SE, phase 1 = 29 ± 4, phase 2 = 25 ± 3, phase 3 = 32 ± 2). Minimum convex polygons were constructed to define and compare ranges between phases. No home ranges were stable. Ranges constructed using 100% MCPs were significantly larger during phase 2 than they were during phase 1 (repeat measures analysis: $\beta = 5.31$, $t = 2.60$, *d.f.* = 11, $P = 0.02$) and phase 3 ranges were not significantly different from phase 2 ranges ($P > 0.05$). Neither 95% nor core MCPs varied significantly between phases ($P > 0.05$), but all trends between phases were in the same direction as for 100% MCPs. The area of farmyard falling within home ranges did not vary between phases for any range ($P > 0.05$) and there were no clear patterns in the direction of trends between phases. The number of fixes located within farmyards, in comparison with the total number of fixes, was significantly different between phases (binomial repeat measures analysis: $P = 0.03$). These were higher during phase 1 than phase 2 and lower in phase 2 than phase 3, although comparisons between individual phases were not significant ($P > 0.05$).

A total of 408 observations on badgers were made over 31 camera nights during phase 1. During phase 2, 69 camera nights yielded 176 observations and during phase 3, 49 camera nights yielded 367 observations. During phase 2, when electric fencing was erected, the fence was challenged by badgers on 25 separate occasions. The typical pattern of a challenge was that one or more badgers would approach the fence and one would touch it. This badger received a shock and it and any other badgers in attendance retired away from the fence. On one occasion, the fence was knocked down (not by badgers) and a badger gained access to the feed store. On no other occasion was the fence breached.

Badger behaviours within farmyards varied significantly between phases ($\chi^2 = 262.33$, *d.f.* = 24, $P < 0.001$). Foraging and feeding occurred significantly less frequently than expected during phase 2 and feeding occurred more frequently in phase 3. Badgers moved though farm yards more frequently than expected during phase 2 and more frequently than in phases 1 and 3. Excretion and scent marking were observed more frequently than expected during phases 2 and 3, but only occurred four times during phase 2. No interactions between badgers and cattle were observed during phase 1 and fewer than expected were observed during phase 2. Interactions with cattle were more frequent than expected during phase 3, occurring 33 times.

4.2.8. Calculation of the infectious probability of badger excretory products

A total of 66 individual faecal droppings were found inside farmyards, 44 of these being in the yard itself as opposed to inside buildings. It was assumed that faeces in the yard would persist for longer than those in feed sheds and cattle houses, which may quickly be moved into troughs or trampled, respectively, and would therefore be more detectable by surveyors. Hence the number of droppings within the yard (A in Table 14) was used to calibrate data collected during video surveillance. These data were considered to provide a more accurate and comparable measure of the frequency of excretion at different locations but did not necessarily result in the collection of a faecal sample the following day. The number of droppings per facility type were weighted by dividing by the number of camera nights of surveillance at each facility (B in Table 14). The results were then expressed as the proportions of the total weighted number of observations for each facility type (Table 14). The baseline of 44 droppings from the farm surveys was divided by the proportion of video observations within farmyards (0.27) to extrapolate to the total number of droppings that should have been collected from yards and buildings if they all had an equal probability of detection ($\overline{n} = 163$). This extrapolated total number of droppings was multiplied by the weighted proportion of observations of badgers excreting, from video surveillance, for each facility type (Table 14).

Table 14. Extrapolation of the number of droppings that should have been found at each facility type given equal probability of detection.

Facility	No. droppings (A)	No. camera nights (B)	Weighted proportion of samples $\frac{A/B}{(A/B)_{total}}$	Extrapolated no. droppings
Feed store	10	116	0.47	77
Cattle house	2	120	0.09	15
Silage clamp	2	67	0.16	26
Yard	1	20	0.27	44

The number of cattle herd breakdowns in 1993 was 320. Dividing this by the total number of cattle holdings in the southwest at the same time (n = 18,283) and then dividing by the mean cattle herd size at the same time (mean = 46.24) gives an estimate of $P = 3.79 \times 10^{-4}$. F_i was assumed = 1. I_p = disease prevalence in badgers (0.057) divided by the proportion of badgers excreting bacteria in faeces (62/192 = 0.32) = 0.0184. F_e = 77 faeces in feed stores, divided by 8 surveys per farm, multiplied by 0.28 of farms on which badger faeces were detected = 243.32. Thus:

$$P_{inf} = 1 - (1 - 3.79 \times 10^{-4})^{1/(243.32 \times 1 \times 0.0184)} = \underline{8.45 \times 10^{-5}}$$

Comparing this with the results of Hutchings & Harris (1999) (Table 15), indicates that the presence of badger faeces in feed stores presented more of a risk to cattle than badger urine at pasture and less of a risk than badger faeces at pasture.

Table 15. Comparison of infectious probabilities of contaminants at different locations.

Source	P_{inf}
Faeces at pasture (Hutchings & Harris 1999)	9.3×10^{-8}
Urine at pasture (Hutchings & Harris 1999)	3.7×10^{-4}
Faeces in feed stores (current study)	8.45×10^{-5}

4.2.9. Costs of biosecurity measures

The farm surveyed to estimate potential costs of measures to exclude badgers had a total boundary length of 444m and contained three cattle houses, each of approximately 580m^2, a feed store of approximately 580m^2, two troughs of 40m long and 1m wide and a silage clamp of 130m^2. Costs of materials and labour are presented in Appendices 1 - 4. Total exclusion of badgers from the farmyard was estimated to be £11,700 more expensive than protecting each facility within the farmyard (Table 16).

Table 16. Representative costs of badger exclusion methods on a farm in Gloucestershire. Labour costs and VAT are not included.

Feature to be protected	Linear length (m)	Protection measure	Cost (£m^{-1})	Total cost (£)
Farmyard	444	1m x 150mm block wall	40.30	17,893.20
Cattle housing	3 x 96	1.2m Steel sheeting of walls and gates	10.74	3093.12
Feed store walls	96	1.2m Steel sheeting of walls and gates	10.74	1031.04
Feed store gates	8	Steel gates	17.5	140.00
Troughs	2 x 82	12mm Plywood sheet	10.72	1758.08
Silage clamp	46	Electric fencing	3.70	170.20

5. Discussion

This study has identified that badger visits to farmyards and buildings were a widespread and common problem among the farms surveyed within TB hotspots in the southwest of England. Indeed, badgers visited 39% of farms and infectious products were deposited on 29% of these during this study. In some areas badger visits may be particularly common and frequent. The six farms studied during the intensive part of the project were chosen for this reason.

Badgers used farmyards and buildings consistently more frequently during the spring and summer months than during the autumn and winter. The frequency of badger visits was significantly positively correlated with maximum air temperature both on the day of the visits and during the previous day. Visit frequency followed a negative trend with total rainfall during the previous 24 hours, although this correlation was not quite significant. These results are consistent with previous studies (Roper *et al*. 2003) and with the hypothesis that earthworm (*Lumbricus terrestri*s) availability is likely to strongly influence the occurrence and frequency of badger visits to farmyards. Earthworms are the primary food source for badgers in the southwest of England (Kruuk 1978) and their presence at the soil surface (where badgers prey upon them) is dependent on sufficient rainfall (Kruuk & Parish 1985). Dry periods, on the other hand, result in low earthworm availability and badgers are likely to seek alternative food sources, such as those stored on farms.

When badgers visited farmyards and buildings they spent most of their time foraging and feeding. All available food resources were exploited by badgers during visits to farmyards. Even hay and straw were observed to be taken, although these were most probably intended for use as bedding material (Garnett *et al*. 2002). Cattle cake was the most frequently occurring farm-derived food and appeared in badger diets during every season. Cattle cake typically contains a mixture of cereals and minerals, is bound with molasses and coated in fats. It is likely to be highly palatable and nutritious for badgers. Wherever cattle cake, and/or other feeds are stored in accessible conditions, as was typically the case during the present study, badgers are likely to exploit them and may contaminate the feed store with faeces, urine and anal gland secretion as was observed several times during this study. Indeed, while all types of facility monitored experienced visits by badgers, feed stores were visited particularly frequently and should be considered as particularly vulnerable.

Stored feeds are usually destined for cattle troughs, which many cattle share. Cattle are typically fed sufficient rations to provide good nutrition whilst limiting wastage (Phillips 2001). The tendency for cattle to avoid contaminants in feed has been demonstrated to be much lower when large numbers are fed from the same trough and where food is limited, due to competition (Daniels *et al*. 2003). Therefore, contamination of feed stores by badgers poses a considerable risk to cattle. In contrast, at pasture cattle have the choice to avoid contaminants and display greater selectivity (Benham & Broom 1989). Hutchings & Harris (1999) considered that indirect contact between badgers and cattle was likely to pose a far greater risk to cattle at pasture than direct contact. During the present study, direct contact between badgers and cattle at pasture was not observed, although it has been recorded previously (Benham 1985). Direct contact was observed within cattle housing in farmyards. However, it was a sufficiently rare occurrence, in comparison to indirect contact in farmyards, that it was also assessed as posing a lower risk. It is clear that direct and indirect contact between badgers and cattle occur both at pasture and within farmyards. The current analysis indicated that indirect contact within farmyards, as contamination of stored feeds, poses a greater risk than the contamination of pasture with badger urine and a lower risk than contamination of pasture with badger faeces.

Few farmers invested in measures to exclude badgers from specific buildings or the whole farmyard, but some did. Furthermore, only two of 36 farmers maintained clean, tidy farmyards. This is consistent with the results of a survey into farmers' attitudes towards TB control measures, where biosecurity measures ranked poorly (Bennett & Cooke 2005). This may partly be due to current advice (e.g. MAFF 1999) containing flaws, such as recommended trough heights, which are now known to be inadequate (Garnett *et al*. 2003). There is a clear need for evidence-based advice. This study has identified the extent of risks posed by badgers to cattle in farmyards in TB hotspots in southwest England and some of the reasons why these risks occur. It has also identified at least one method that can effectively reduce these risks.

5.1. Reliability of results.

Farms within the extensive study were randomly selected from a subset of data from the VETNET system, which contains data on farms in TB hotspots throughout the southwest of England. The reasonably large sample size (n = 36) and random nature of farm selection should have resulted in farms and observations made upon them being representative of farms in TB hotspots in the southwest. Observations on badger activity within these farmyards relied on detection of ephemeral signs of activity, such as faeces, carcasses and footprints. Since such signs are likely to be rapidly destroyed within an active farmyard it is considered likely that estimates of badger activity in the present study were very conservative. Indeed, while signs of activity were detected on four of the intensive study farms, video and still camera images of badgers were recorded within the farmyards of all six.

The factors identified as correlates of signs of badger activity represent fairly coarse measures, which were likely to yield conservative results, especially considering the low likelihood of detecting signs of badger activity within farmyards. Nevertheless, key measures, such as building accessibility and feed types stored are likely to be biologically meaningful with respect to badgers. While exploratory studies, such as this part of the project provide only weak evidence to explain why badgers visited farmyards and buildings, it has provided additional evidence that supports the general conclusions drawn from other parts of the study. Specifically, identification of cattle cake storage as a border-line correlate supports the conclusion that badger visits to farmyards and buildings are primarily undertaken in search of food, and stored feeds (especially cattle cake) are particularly attractive to badgers.

The bait marking results were insufficient to construct badger social group territories with any degree of reliability. However, since latrines with returns were found associated with farmyards it was possible to conclude that each farmyard fell within a territory. Furthermore, more than one colour of return in some of the latrines suggested a territory boundary and supported the idea that some farms were likely to be visited by badgers from more than one social group. Indeed, where food is super-abundant badgers from different social groups may tolerate each others' presence (Macdonald *et al*. 2002). This may have been the situation behind the observation of up to 12 badgers feeding from the same bag of grain within a farmyard at the same time during the present study.

Assessment of diet through faecal analysis is fraught with problems, such as variation in digestibility between food items and variability in particle sizes (Putman 1984). Indeed, due to the sieve mesh size and sampling method used during the present study the relative abundance of earthworms was considerably underestimated. Consequently, the results from the dietary analysis must be interpreted with caution. However, since samples collected in the field were compared with standard reference samples collected during feeding trials, biases will have been consistent between seasons and locations, allowing valid spatial and temporal comparisons of the food items listed.

It was not possible to carry out video or still camera surveillance at every farm facility at all times or to run cameras continuously during the study. Hence the remote surveillance data must be interpreted as representing a series of snapshots at a sample of facilities. It was not possible to control for facility availability during analysis in order to determine facility selection, so the data must be interpreted as a relatively coarse measure of badger selection of different facilities. However, during analysis the data were weighted by the number of camera nights per facility thus allowing valid comparisons between facility types and periods of time.

In comparison with the remote surveillance work, the effort invested in direct surveillance of badgers at pasture was fairly small. Nevertheless, a considerable number of badgers (n = 41) were observed on cattle pasture and detailed observations were made on their behaviour. Farms were randomly-selected and there is no reason to expect the observed behaviours to have been different from those on farms throughout the southwest of England. However, badgers and cattle were observed interacting at pasture during previous studies (Benham 1985; Benham & Broom 1989) so the observations presented here should be considered indicative of the general pattern of behaviours that could be expected to be observed at cattle pasture and not as a catalogue of all behaviours that may occur.

It is considered likely that the animals fitted with radio collars moved and behaved in ways that were representative of the wider population. However, few range estimates achieved stability due to the relatively small number of fixes per badger per year. Consequently, it cannot be concluded that the areas reported are indicative of home range sizes of the badgers studied. Nevertheless, the times at which fixes were obtained were not selected to coincide with badger visits to farm buildings and were intended to represent the general pattern of badger activity. Furthermore, comparisons between seasons were devoid of systematic bias. Hence the overlap of ranges with farmyards, whether on an annual basis or comparatively between seasons, can be concluded to provide a measure of the relative importance of farmyards to the badgers.

The electric fencing experiment was conducted on three farms and at four facilities. Neither whole farmyards nor all vulnerable facilities within a farmyard were enclosed within electric fencing, so the effects of complete badger exclusion could not be assessed. However, three important points were identified by this limited experiment.

Firstly, as proof-of-principle, electric fencing was successfully used to prevent badgers from accessing vulnerable farmyard resources. Secondly, limited evidence suggested that badgers altered their movement patterns, by increasing their ranges to account for exclusion from vulnerable resources. Finally, removal of electric fencing resulted in badgers quickly coming back to exploit the formerly protected farmyard resources, with increased frequency than before and whilst maintaining larger home ranges. Thus, facilities can be protected by electric fencing, but this should be maintained permanently once in place.

The calculation of the infectious probability of badger visits to farmyard facilities represents a crude method of risk assessment. It also underestimated the disease transmission risk of badger visits to farmyards and buildings in comparison to the estimates for pasture by Hutchings & Harris (1999) since the cumulative infectious probabilities of contamination of silage clamps, cattle housing and yards and direct contact with cattle in housing were not taken into account. Under this method there is no characterisation of parameter variability or uncertainty making assessment of estimate precision, error and bias impossible. Furthermore, it was assumed that exposure to potentially infective material via consumption equated to bacterial transmission. This overly simplified the route-specific dose-response of cattle to challenge by *M. bovis*. Consequently, the results of this analysis should be viewed with caution and considered a comparative indication of the likely magnitude of risk only. The only peer-reviewed study that attempted to quantify risks in space posed by badgers to cattle used this same method for badger contaminants at pasture (Hutchings & Harris 1999). Use of this method, and use of cattle data from the same period used in that study during the current analysis represents the first direct comparison of the magnitude of risks to cattle between pasture and the farmyard. This provides a preliminary means to objectively identify the appropriate areas to which limited funds could be directed by the farmer to reduce such risks. However, a more thorough and robust risk assessment would be required to provide more reliable estimates of risks posed to cattle by badgers.

A formal cost –benefit analysis, incorporating the full market and non-market costs of cattle herd breakdowns, and the costs and benefits of appropriate badger exclusion methods has yet to be undertaken. Such an analysis should incorporate characterisation of uncertainty and variability within the data, and would be more likely to produce information pertinent to the provision of more detailed advice to farmers on how best to invest limited resources in risk reduction.

6. Conclusion

Badger visits to farm buildings are probably common and widespread across the southwest of England and pose a considerable disease transmission risk to cattle. Few farmers appear either aware of the problem or willing to deal with it by investing in husbandry and biosecurity best-practice. This may partly be due to the perceived low quality of advice available.

Badger visits to farmyards peaked in late spring/summer, at which time most cattle were at pasture. However, typically, some cattle remained in buildings and badgers continued to contaminate cattle housing and feed stores. Unless uninhabited cattle housing and empty feed stores and troughs are to be thoroughly cleaned and disinfected before the next use, badgers should be excluded from them throughout the year.

Barrier methods, such as electric fencing, could be successfully employed to exclude badgers from key resources. Some methods of badger exclusion may also provide benefits for the control of diseases in which wildlife may act as reservoirs by excluding other wild animals. However, further studies are required to evaluate the costs and benefits associated with different methods of badger exclusion.

Appendix 1. Badger proofing building costs

1.0 Summary

1.1 TB is an increasing risk for cattle keepers as a result of the Foot and Mouth outbreak that led to a suspension of testing and increase in animal movement during restocking. The first action in response to risk is to take action to minimise that risk. The developing understanding, through the work of CSL, of the interaction between badgers and cattle provides an opportunity to look at minimising the contact between the 2 species and so reduce disease transference. This paper looks at the costs of various potential solutions.

1.2 In some circumstances erecting a badger proof perimeter fence will be most appropriate and cost effective. The cost of the various fencing materials is as follows:

	Height (m)	Cost per m run
Galvanised Netting	1.2	£1.56
Galvanised Mesh Fencing	1.2	£2.53
Plastic Netting	1.2	£3.07
Electric Fence	1.0, 5 lines	£1.69
Electric Netting	1.05	£1.54

1.3 Where buildings or yards are gated then sheeting the gates to make a solid barrier will badger proof the building. The cost of the various sheeting materials is as follows:

	Height (m)	Cost per m run
PVC~steel sheeting	1.2, 2nds	£7.16
	1.2, 1st quality	£10.74
Polycarbonate	1.0	£30.07
Plywood	1.22, 9mm	£9.54
	1.22, 12mm	£10.72

1.4 Where the boundary has stock, dung or other material containment requirements the need is for a solid boundary. The cost of the various solid barrier materials is as follows:

	Height (m)	Cost per m run
Pre-cast Concrete Panels	1.0	£28.72
	1.2	£34.32
	1.5	£47.72
Tanalised Dung Boards	1.05, 25mm	£17.93
	1.05, 38mm	£23.72
Plywood Boards	1.22, 12mm	£13.89
	1.22, 18mm	£17.28
Block Walling	1.0, 150mm	£40.30
	1.0, 215mm	£56.80

1.5 The costs quoted exclude VAT and labour except bricklaying is included in the cost of block walling. Agricultural wages start from £5.05/hr (Oct 2005) whereas hired building labour will be 1.5-2 times more expensive.

1.6 The proofing of a specific site will involve a mix of materials to provide the most cost-effective solution. In some instances where buildings are complex or particularly open a perimeter fence may be the only option but if the points of contact are few then sheeting gates may be more cost effective. Solid barriers are twice as expensive as sheeting gates which are 5 times more expensive than fencing but will offer additional attributes which may be desirable.

2.0 Aim

2.1 This report sets out to examine the cost of badger-proofing existing buildings to restrict the potential contact opportunities. Reducing contact should restrict the level of risk of TB transmission in either direction.

3.0 Fencing solutions

3.1 For some farmsteads the solution will be to permanently fence the perimeter or the area around the specific cattle buildings instead of badger proofing individual buildings. Each set of buildings will be unique with considerations given to frequency of access, type of access and existing boundary conditions. In this section consideration is given for 5 differing types of fencing in isolation although a particular site solution may include more than 1 type and/or a combination of types to provide the most cost-effective solution.

3.2 Galvanised wire netting. 50mm hexagonal netting to 1.20m height with standard 1.8m posts every 4m. Cost for 100m perimeter £155.74, £1.56/m. Integrity on undulating ground and over time may be an issue. Could be enhanced by rebating into ground on external side, a single strand of electrified wire or a plastic section for below ground. There would be a maintenance cost to control vegetation and to check fence integrity.

3.3 Galvanised mesh fencing. 50mm diamond woven mesh fence to 1.20m height and 1.8m uprights every 4m. Cost for 100m perimeter £253.24, £2.53/m. Similar problems to wire netting on undulating ground with regards fence integrity. Would need additional measures such as electrified strand or plastic mesh at ground level to be secure.

3.4 Plastic netting. Double run of 4mm diamond HDPE to 0.61m height (total height 1.2m) and uprights every 4m. Cost for 100m £306.60, £ 3.07/m. Could be rebated into ground to prevent burrowing and incorporate electrified strand.

3.5 Electric fencing. 5 line permanent 2.5mm tensile steel wire, uprights every 7m and fence height of 1.0m. Cost for 100m £168.69, £1.69/m. Maintenance required to prevent undergrowth shorting current and checks made on fence integrity.

3.6 Electric Netting. Stock control netting with steel/plastic woven horizontal with solid plastic uprights. Self-supporting fence in 50m lengths to 1.05m height. Cost for 100m £154.80, £1.54/m.

3.7 Electric fencer units. 3 basic types based on power supply. Dry cell battery fencers start at £79 with batteries at £2.25 each, mains fencers from £74 and rechargeable fencers at £99 with lead/acid battery at £61.20 and charger at £38. Solar powered fencers are becoming more available with fully integrated solar/battery units from £198.

3.8 Summary of fencing options

	Height (m)	Cost per m run
Galvanised Netting	1.2	£1.56
Galvanised Mesh Fencing	1.2	£2.53
Plastic Netting	1.2	£3.07
Electric Fence	1.0, 5 lines	£1.69
Electric Netting	1.05	£1.54

4.0 Sheeting solutions for gates

4.1 Many farm buildings have open, gated fronts that form a low cost boundary to the building where no feeding but possibly access is required. These types of boundaries allow maximum ventilation as recommended to minimise respiratory diseases. Unfortunately these also allow ready access for badgers to come into direct contact with cattle. In these costings there is an assumption that there is a gate or similar barrier that would be modifiable using basic materials and farm based labour. Where solid barriers are acceptable the options include:

4.2 Sheeting gates with PVC coated sheet steel. 3m(9’10”) x 1.2m (4’) x 0.7mm sheets cost £18 1st quality or £12 2nd quality. Fixings are by self-tapping screws costing £12 per 50. To sheet a 6.10m (20’) opening costs £43.68-65.52 excluding labour and VAT. This averages £7.16-10.74/m of opening.

4.3 Polycarbonate sheets are available if light is required but this comes at a premium. The cost of sheeting a 6.10m (20’) opening would be £183.51, £30.07/m excluding labour and VAT.

4.4 Plywood sheeting is an alternative with standard 2.44m x 1.22m sheets costing £15.80-18.20 for either 9mm or 12mm thickness. Fixing is by clamping an angle iron plate against the opposite side of the gate/barrier with bolts. To sheet a 6.10m (20') opening would cost £58.20-65.40, £9.54-10.72/m of opening.

4.5 Where cattle are directly in contact with the barrier, a solid barrier is required to prevent respiratory contact with badgers. Consideration would need to be given to the hinge and catch area of the gate if access was required. Netting is not considered suitable to prevent respiratory contact.

4.6 Summary of gate sheeting solutions.

	Height (m)	Cost per m run
PVC~steel sheeting	1.2, 2nds	£7.16
	1.2, 1st quality	£10.74
Polycarbonate	1.0	£30.07
Plywood	1.22, 9mm	£9.54
	1.22, 12mm	£10.72

5.0 Solid barriers for buildings and yards

5.1 As in section 4 many farm buildings have open, gated boundaries to the building where no feeding or access is required. In these circumstances a more substantial boundary providing stock/dung containment and badger proofing may be required. The options include:

5.2 Pre-cast concrete panels come in heights of 1.0m, 1.2m or 1.5m in standard bay widths of 4.6m or 6.1m. To cover a 6.10m (20') opening would cost £175.26, £209.43, £260.69 or £28.72, £34.32 and £42.72/m of opening respectively.

5.3 Tanalised dung boards. Boards are a standard length of 3.6 m, 150mm width, uprights are every 1.8m and either 25mm or 38mm thick. To cover a 6.10m (20') opening would cost £109.44, £144.77 or £17.93 and £23.72/m of opening respectively.

5.4 Plywood boards. Boards are a standard length of 2.44 m, 1.22m width, uprights are every 1.8m and either 12mm or 18mm thick. To cover a 6.10m (20') opening would cost £84.78, £105.43 or £13.89and £17.28 /m of opening respectively.

5.5 Concrete block walling. Blocks are footed on foundations of hardcore and concrete and either 150mm or 215mm thick. To cover a 6.10m (20') opening would cost £245.92, £346.61 or £40.30 and £56.80/m of opening respectively.

5.6 Summary of solid barrier options.

	Height (m)	Cost per m run
Pre-cast Concrete Panels	1.0	£28.72
	1.2	£34.32
	1.5	£47.72
Tanalised Dung Boards	1.05, 25mm	£17.93
	1.05, 38mm	£23.72
Plywood Boards	1.22, 12mm	£13.89
	1.22, 18mm	£17.28
Block Walling	1.0, 150mm	£40.30
	1.0, 215mm	£56.80

6.0 Labour costs

6.1 All costs are excluding VAT and involve farm labour for erection or installation. The block-walling figure includes bricklaying costs. The Agricultural Wages Board Statutory Minimum Wages are as follows:

Grade	Basic trainee	Standard	Lead worker	Craftsman
Standard rate	£5.05	£5.58	£5.91	£6.58
Overtime rate	£7.58	£8.37	£8.87	£9.87

6.2 If labour has to be hired then the cost will be 1.5-2 times the agricultural rates above. Most farms will have sufficient building expertise to carryout the tasks required with the exception of bricklaying where the cost is included.

7.0 Conclusions

7.1 For a given site there will be a range of solutions depending on the principle use of the boundary. Where it is simply a perimeter, a fence would be indicated however the length of boundary might be less if a solid sheet was used on the building itself. The cost differentials between fence, gate sheeting and simple plywood boarding are as follows:

	Min cost/m	**Relative to fencing**	**Relative to sheeting gates**
Fencing	£1.54	1	0.2
Sheeting gates	£7.16	5	1
Solid barriers	£13.89	10	2

7.2 If the fence solution is more than 5 times the length of the opening then addressing the opening with a sheeting solution will be more cost effective. Similarly, the additional functionality of a solid barrier for retaining materials may be more cost effective than a fence 10 times longer.

All farm sites are different with often building development spanning more than 100 years so the solution to badger proofing the site will be unique to each site. Additional functionality will also affect the choice of boundary.

Appendix 2. Fencing options

Galvanised Wire Netting												**£/m**
					Price	Fixings						
		Length	50.0	50mm	47.75	12.00	56	per roll				
		Height	1.20			100						
		Uprights	1.80		1.80							
Opening Width												
Height	m		No of rolls	Fixings			Netting	Uprights	Fixings	Total		
1	100.00		2.0	112			95.50	46.80	13.44	155.74		1.56
Galvanised Mesh Fencing												
					Price	Fixings						
		Length	25.0	50mm	48.25	12.00	28	per roll				
		Height	1.20			100						
		Uprights	1.80		1.80							
Opening Width												
Height	m		No. rolls	Fixings			Mesh	Uprights	Fixings	Total		
1	100.00		4.0	112			193.00	46.80	13.44	253.24		2.53
Plastic Netting												
					Price	Fixings						
		Length	100.0	4mm	123.90	12.00	100	per roll				
		Height	0.61			100						
		Uprights	1.80		1.80							
Opening Width												
Height	m		No. rolls	Fixings			Mesh	Uprights	Fixings	Total		
1.2	100.00		2.0	100			247.80	46.80	12.00	**306.60**		**3.07**
Electric Fencing				**5 line Permanent**								
					Price	Fixings			Insulators	10	0.211	2.11
		Length	625.0	2.5mm	48.00	20.06	1	per 50m	Corners	10	0.245	2.45
		Height	1.00						Strainer	5	3.10	15.50
		Uprights	2.00		2.15	15.90						20.06
Opening Width												
Height	m		No. rolls	Fixings			Wire	Uprights	Fixings	Total		
1	100.00		1.0	2.0			48.00	80.56	40.12	168.69		1.69
Electric Netting												
					Price	Fixings						
		Length	50.0	2.5mm	73.00	0.00	0	per 50m				
		Height	1.05									
		Uprights	1.00		2.00	2.20						
Opening Width												
Height	m		No. rolls	Fixings			Wire	Uprights	Fixings	Total		
1	100.00		2.0	0.0			146.00	8.80	0.00	154.80		1.55

Appendix 3. Sheeting options

Steel PVC coated Sheets											
3.2775			Sheet		Price	Fixings					
		Length	3.0	1st	18.00	12.00	16	per sheet			
		Height	1.2	2nd	12.00	8.00	50				
Opening Width											
ft		m	No of Sheets	Fixings		1st	2nd	Fixings		Total	
20		6.10	3.0	48		54.00	36.00	11.52	7.68	65.52	43.68
										10.74	7.16
	3.0	99.95	Gate	63.90		203.31				267.21	267.21
										332.73	310.89
Polycarbonate Sheets											
3.2775			Sheet		Price	Fixings					
		Length	3.0	1st	59.25	12.00	16	per sheet			
		Height	1.0			8.00	50				
Opening Width											
ft		m	No of Sheets	Fixings		1st		Fixings		Total	
20		6.10	3.0	48		177.75		11.52		189.27	
										31.02	
Plywood Sheets		(Exterior)									
3.2775			Sheet		Price	Fixings					
		Length	2.44	12mm	18.20	12.00	6	per sheet			
		Height	1.22	9mm	15.80		20				
Opening Width											
ft		m	No of Sheets	Fixings		12mm	9mm	Fixings		Total	
20		6.10	3.0	18		54.60	47.40	10.8		65.40	58.20
										10.72	9.54
	3.0	99.95	Gate	63.90		203.31				267.21	267.21
										332.61	325.41

Appendix 4. Solid barrier options

Pre-cast Concrete Panel												
3.2775			Sheet				Price		Fixings			
		Length	1			1.0	1.2	1.5	12.00	6	per sheet	
		Height	1			28.00	33.60	42.00	8.00	100		
Opening Width												
ft		m	No of Sheets	Fixings	1.0	1.2	1.5	Fixings	Total			
20		6.10	6.1	37	170.86	205.03	256.29	4.39	175.26	209.43	260.69	
									28.72	34.32	42.72	£/m2
Dung Walling		**Tanalised Boards**										
3.2775			Boards		Price	Fixings						
		Length	3.6	38mm	7.80	12.00	6	per sheet				
		Height	0.15	25mm	5.15	8.00	100					
		Uprights	2.10		7.10							
Opening Width												
ft		m	No of boards	Fixings	38mm	25mm		Uprights	Fixings	Total		
20	1	6.10	13.3	80	104.00	68.67		31.17	9.6	144.77	109.44	
										23.72	17.93	£/m2
Dung Walling		**Plywood**										
3.2775			Boards		Price	Fixings						
		Length	2.44	18mm	26.60	12.00	6	per sheet				
		Height	1.22	12mm	18.20	8.00	20					
		Uprights	2.10		7.10							
Opening Width												
ft		m	No of boards	Fixings	18mm	12mm		Uprights	Fixings	Total		
20	1	6.10	2.5	15	65.41	44.75		31.17	8.85	105.43	84.78	
										17.28	13.89	£/m2
Block Walling		**Concrete**										
3.2775			Blocks		Price							
		Length	1.0	150mm	40.30	m2	includes footings					
		Height	1.0	215mm	56.80	m2						
Opening Width												
ft		m			150mm	215mm				Total		
20	1	6.10			245.92	346.61				245.92	346.61	
										40.30	56.80	£/m2

References to published material

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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