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Use of cattle farm resources by badgers (*Meles meles*) and risk of bovine tuberculosis (*Mycobacterium bovis*) transmission to cattle

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Nocturnal observations, radio telemetry and time-lapse camera surveillance were used to investigate visits by badgers (*Meles meles* L.) to two cattle farms. During 59 half-nights (*ca.* 295 h) of observation and 17 nights (*ca.* 154 h) of camera surveillance, 139 separate visits to farm buildings, by at least 26 individually identifiable badgers from two social groups, were recorded. The badgers, which included three individuals infected with bovine tuberculosis (*Mycobacterium bovis*), used cowsheds, feedsheds, barns, haystacks, slurry pits, cattle troughs and farmyards to exploit a range of food resources, including cattle feed and silage. Cattle feed was contaminated with badger faeces and badgers also came into close contact with cattle. The minimum number of badgers visiting farm buildings per night was negatively correlated with local 24 h rainfall. We conclude that exploitation by badgers of resources provided by cattle farms constitutes a potentially important mechanism for tuberculosis transmission from badgers to cattle.

Keywords: badgers; cattle; bovine tuberculosis; foraging; farm biosecurity

1. INTRODUCTION

The prevalence of bovine tuberculosis (*Mycobacterium bovis*) in British cattle has risen steadily over the past 20 years, with significant financial and animal-welfare consequences for the farming industry (MAFF 2001). Badgers (*Meles meles* L.) are known to be susceptible to *M. bovis* and have been implicated in the transmission of the bacterium to cattle (for a review, see Krebs *et al.* 1997), but the precise route of infection has yet to be determined. Research into badger–cattle transmission routes has hitherto focused on the possibility of cattle grazing on pasture contaminated with badger excreta (Benham & Broom 1991; Benham 1993; Brown 1993; Hutchings & Harris 1997, 1999). However, the likelihood that the disease is transmitted via contaminated pasture is undermined by the fact that most cattle are averse to grazing in the vicinity of badger excreta (Benham 1993) except at high herd densities (Hutchings & Harris 1997). Furthermore, *M. bovis* bacilli suspended in badger urine only survive for up to 3 days and 14 days on summer and winter pastures, respectively (MAFF 1979).

A few reports have been made of badgers using farm buildings for shelter or to forage on stored cattle feed (Cheeseman & Mallinson 1981; Sleeman & Mulcahy 1993; T. J. Roper, personal observation) and Cheeseman & Mallinson (1981) have suggested that infected badgers may use farm buildings more frequently than uninfected animals. In addition, badgers found dead or *in extremis* on farms have a significantly higher incidence of tuberculosis infection than carcasses found by roads (Cheeseman & Mallinson 1981). Badgers may therefore infect cattle during visits to farm buildings, either because this involves badgers making direct respiratory contact with cattle or through contamination of the premises with badger excreta and secretions. However, the evidence of use of farm buildings by badgers is at present circumstantial or anecdotal.

Our aim was to quantify the use that wild badgers make of farm buildings and other farm-related resources, such as slurry pits and cattle troughs, in order to determine whether this could potentially result in transmission of bovine tuberculosis from badgers to cattle. We also investigated the relationship between use of farm buildings and rainfall, because we suspected that badgers might use the artificial food resources provided by farms more frequently during dry periods, when their staple food of earthworms (*Lumbricus* spp.) is unavailable. Earthworms constitute the single most important food item for badgers in Britain (Neal 1988; Kruuk 1989; Neal & Cheeseman 1996) but their availability to badgers is reduced on dry nights, when worms retreat below ground to avoid desiccation (Darwin 1881; Satchell 1967; Kruuk 1978; Kruuk & Parish 1981).

2. MATERIAL AND METHODS

(a) *Study area*

The study involved two badger social groups (A and B) in Woodchester Park, Gloucestershire, UK. The territory of group A contained a dairy farm (farm A), while that of group B contained a beef cattle farm (farm B). Otherwise, the territories consisted mostly of farmland but also contained an elderflower orchard and several small copses of deciduous woodland and scrub, in two of which the relevant main setts were located. The farmland included in the territories consisted of cattle grazing pasture plus one silage meadow.

Both farms included a cattle shed and pen, plus a grass silage clamp. Farm A also contained two slurry pits and a clamp for maize silage, whereas farm B included a barn and haystacks. Both farms stored cattle feed consisting of a maize and soya base

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with wheat, vitamin and mineral additives, mixed on the farms in question. At farm A, the feed was stored in a shed that was completely open on one side, and was fed to cattle in the aisles of a cowshed. At farm B, feed was kept in metal silos and fed to calves and heifers from troughs put out in pasture fields. Visits to all of these farm resources were recorded during direct observation of radio-collared badgers, while camera surveillance equipment was used as an additional method of monitoring visits by marked badgers to the feed shed on farm A.

(b) *Trapping, fur-clipping, radio-collaring and tuberculosis status of badgers*

Badgers from both social groups were live-trapped on eight occasions from spring to autumn 1999. Trapping was suspended from early March to mid-May to avoid separating mothers from young cubs. Cage traps were positioned near setts and pre-baited with peanuts for 7–10 days before setting them on two consecutive nights. Traps were checked each morning and captured animals were anaesthetized with an intramuscular injection (20 mg kg^{-1}) of ketamine hydrochloride (MacKintosh *et al.* 1976). Badgers caught for the first time were given a unique identifying tattoo (Cheeseman & Harris 1982), some individuals were fitted with radio-collars and all were fur-clipped (Stewart & MacDonald 1997) to enable them to be identified by sight or on video. In 1999, nine badgers were radio-collared and fur-clipped (six from group A, three from group B), while a further three were just fur-clipped (one from group A, two from group B). In 2000, no badgers were radio-collared but eight from group A (three of which had been marked in the previous year) were fur-clipped.

At the time of trapping, clinical samples (faeces, urine, sputum and wound swabs) were taken from all badgers for subsequent culture of *M. bovis* (Clifton-Hadley *et al.* 1993). On the basis of these samples, two of the badgers radio-collared in 1999 (one from each group) and one of the animals fur-clipped in 2000 (from group A) were infected.

(c) *Radio-tracking and video surveillance*

Group A badgers were radio-tracked on foot for 34 sessions from March to August 1999 and group B badgers for 25 sessions from May to October 1999. Night-vision equipment was used to make opportunistic observations of badgers in farm buildings and yards. Sessions lasted 4–5 h, starting either from first emergence until 01.00 h (29 sessions), or from 01.00 h until dawn (30 sessions), with visual or radio fixes being taken at 15 min intervals. Badger visits were evenly distributed around 01.00 h, the average time of badger sightings in farm buildings being 01.24 h ± 2 h 18 min.

Time-lapse video surveillance of the feed shed at farm A was carried out on 17 randomly chosen nights from February to April 2000. The camera was mounted on a tripod placed 5 m from the entrance to the shed, with infra-red lights on either side to provide illumination. The equipment was placed in position for several nights before the study period to acclimatize badgers to its presence.

(d) *Rainfall data*

Rainfall was recorded at 09.00 h every morning throughout the study period, using a rain gauge located within 1.5 km of the main setts of the two target groups of badgers.

Table 1. Selection of different food resources by badgers at two farms.
(Figures give the percentage of visits in which the resources in question were exploited. Farm A: $n = 45$ visits, March–August 1999; farm B: $n = 27$ visits, June–October, 1999.)

building/area	food type	farm A	farm B
feed shed	cattle feed	60	—
silo	cattle feed	—	7.4
cattle trough	cattle feed	—	48.1
slurry pit	rat-tailed maggots	15.6	—
cowshed	grass/maize silage	15.6	0
barn and haystacks	rodents	—	33.3
cattle pen/farmyard	invertebrates, water	8.9	11.1

(e) *Data analysis*

Frequency of visits to farm buildings by badgers from both social groups was related to rainfall during the 24 h period (from 09.00 to 09.00 h) that included each observation session, while controlling for between-group variation, using analysis of covariance (ANCOVA). The minimum number of individual badgers observed to visit farm buildings on each night (during either radio-tracking sessions or video surveillance) was regressed against rainfall, after logarithmic transformation of both axes, using the statistical package GLIM (Crawley 1993).

A minimum number of badgers was used as the measure of farm visits in order to avoid repeated counting of individuals within any one night, since individuals occasionally made more than one visit to farm buildings in a single night. Visits by different adult badgers to the same farm were considered independent, since adults forage solitarily when away from the sett (Kruuk 1978; Neal & Cheeseman 1996). Young cubs still following their mothers were excluded from the analysis, but older independent cubs were included.

3. RESULTS

(a) *Frequency and nature of visits to farms by badgers*

During 59 radio-tracking sessions from March to October 1999, 72 badger visits to farm facilities were observed, of which 40 were made by marked badgers. At least 19 individual badgers from both social groups visited the two cattle farms. On any one night, the minimum number of individual badgers visiting ranged from zero to seven (group A) or zero to six (group B).

A total of 67 visits to the feed shed in farm A were recorded through camera surveillance from February to April 2000, including 56 visits by eight fur-clipped animals. Single visits ranged from 1 to 77 min in duration (mean: 36 min) and total visit duration, including visits by unmarked badgers, was 22 h 51 min. Badgers visited the feed shed on 53% of surveillance nights.

Badgers visited farms to exploit a wide range of food resources (table 1). Cattle feed cake was the most frequently consumed commodity, accounting for 60% and 55.5% of visits to farms A and B, respectively. Badgers took cattle feed from an open-fronted storage shed at farm A, and from around a silo and two cattle troughs placed in open pastures at farm B. Badgers accessed the troughs by climbing or jumping, gripping the trough rim with their

Figure 1. Badger faeces in a cattle trough on farm B.

foreclaws, and then pulling themselves up with their forelimbs.

In addition, badgers fed on grass and maize silage in cowsheds, rat-tailed maggots (*Eristalis* spp.) from slurry pits (particularly in summer) and invertebrates from under stones and cow dung in farmyards. They also hunted for rodents in barns and haystacks, and drank from farmyard puddles. While feeding in cowsheds or at cattle troughs, badgers came within 2 m of cattle on eight occasions, four of such encounters involving tuberculous badgers.

Thirteen droppings, including one that was known to have been deposited by a tuberculous badger, were found in cattle feed at the two farms. Three of these droppings were in the feedshed on farm A and ten in cattle troughs placed in open pasture on farm B (figure 1). One urination was also found in cattle feed in the feedshed on farm A.

(b) *Effect of rainfall*

Analysis of covariance showed a significant negative relationship between log minimum number of radio-collared individuals visiting farms per night and total rainfall in the previous 24 h ($F_{1,57} = 6.81$, $p = 0.01$; figure 2*a*). There was no significant effect of farm type ($F_{1,56} = 0.41$, $p = 0.52$) and no interaction between rainfall and farm type ($F_{1,55} = 0.063$, $p = 0.80$). No badgers ever visited farms when there had been more than 8 mm of rain during the relevant 24 h period.

Regression analysis of the video surveillance data also revealed a significant negative relationship between log minimum number of fur-clipped individuals visiting the feed shed of farm A each night and log total rainfall in the corresponding 24 h ($F_{1,15}$ $p = 0.03$; figure 2*b*).

There was slight homoscedasticity in the log-transformed data so, as a precaution, Spearman's rank correlations were also applied. A significant negative relationship was again revealed between (i) the minimum number of radio-collared individuals visiting farms per night and total rainfall in the previous 24 h ($r_s = -0.29$, $n = 59$, $p = 0.03$); and (ii) the minimum number of fur-clipped individuals visiting the feedshed of farm A each night and total 24 h rainfall ($r_s = -0.54$, $n = 17$, $p = 0.03$).

4. DISCUSSION

Given that badgers are opportunistic omnivores (Roper 1994), it is not surprising that badgers visit farms in the course of foraging. However, previous accounts of farm use by badgers have been infrequent and anecdotal (Cheeseman & Mallinson 1981; Sleeman & Mulcahy 1993); we therefore expected that visits to farms by badgers would be relatively rare. In fact, both of the farms that we monitored were visited regularly by badgers: in about 450 h of observation, we recorded 139 visits by at least 26 individual badgers from the two target social groups. Three of these badgers were known to be tuberculous and excreting *M. bovis* bacilli, having already tested culture positive on urine, faeces, sputum or bite-wound samples. During these visits, badgers took cattle feed from feedsheds, cattlesheds, silo yards and cattle troughs, foraged for other food resources in slurry pits, barns, haystacks, silage clamps and farmyards, and drank from farmyard puddles. Previous studies, by contrast, have merely reported the use of cowsheds, cattle troughs and milking parlours (Cheeseman & Mallinson 1981; Sleeman & Mulcahy 1993). At the most attractive single resource, an open feedshed on farm A, we recorded, in 17 randomly chosen nights, badger visits totalling almost 23 h in duration; in total, *ca.* 154 nocturnal hours were filmed.

While exploiting farm-based resources, badgers defecated and urinated directly onto cattle feed and they may also have contaminated the farm environment with sputum and with exudates from bite wounds and abscesses. All of these constitute potential sources of transmission of bovine tuberculosis from badgers to cattle. For example, faeces can contain up to 75 000 tuberculosis bacilli g^{-1}, while urine and pus can contain 300 000 and 200 000 bacilli ml^{-1}, respectively (MAFF 1979; Gallagher & Clifton-Hadley 2000). Cattle are averse to grazing on pasture that is contaminated with badger faeces or urine (Benham 1993) but they may be less discriminating when feeding from feed troughs, where the food in question is highly palatable and its spatial distribution is severely constrained. Indeed, we observed calves and heifers regularly

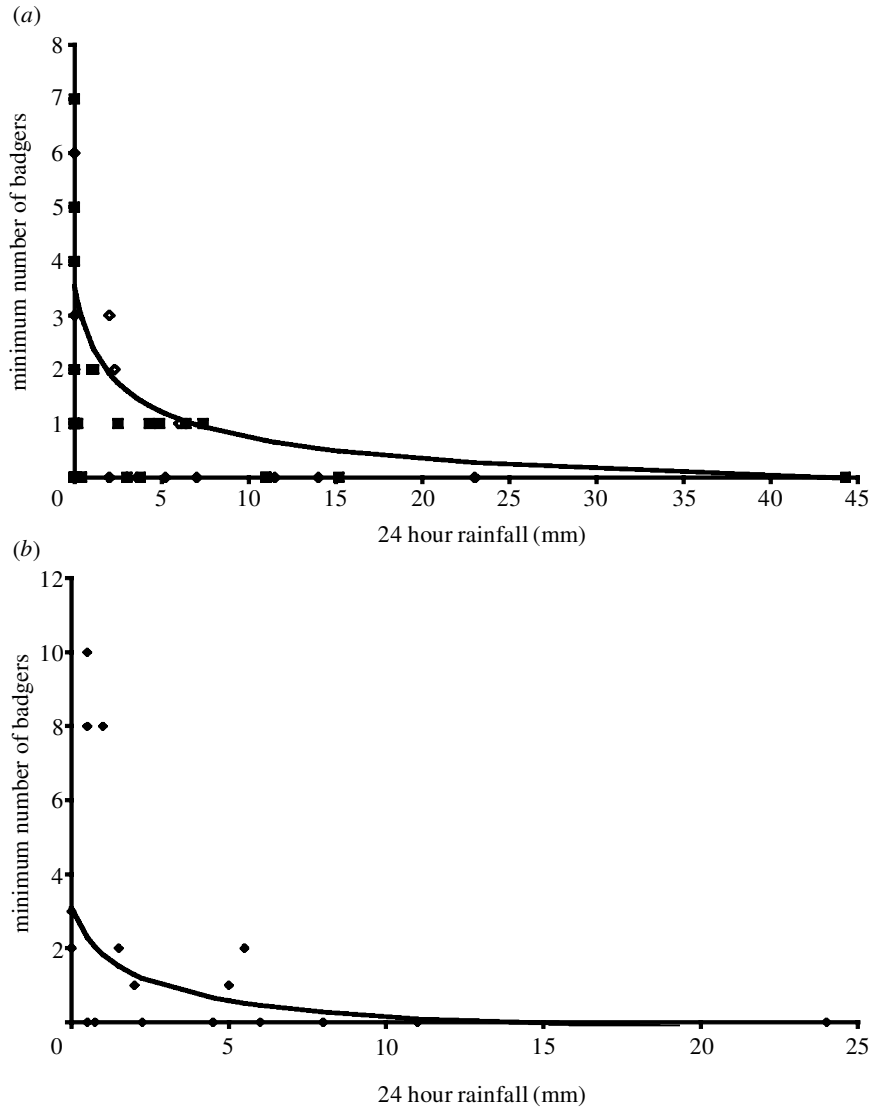

Figure 2. (*a*) Minimum number of marked badgers visiting farms A and B (hollow diamond and solid squares, respectively) versus rainfall during the previous 24 h. The fitted line was back-transformed from a log–log regression. (*b*) Minimum number of individual badgers visiting farm A's feedshed during camera surveillance versus rainfall during the previous 24 h. The fitted line was back-transformed from a log–log regression.

feeding from troughs that were contaminated with badger excretory products.

In addition, badgers sometimes came within 2 m of cattle being held in farm buildings or feeding from troughs, whereas they rarely approach closer than 10 m to cattle on open pasture (Benham 1993). These encounters with cattle could enable direct respiratory transmission of tuberculosis via aerosolized bacilli. Transmission of respiratory diseases such as tuberculosis within farm buildings is likely to be exacerbated by poor ventilation (Robertson 2000). Furthermore, the cattle that were housed in sheds overnight were individuals that were unfit to be let out onto pasture, i.e. sick, injured and heavily pregnant adults, and young calves. Such animals would be particularly vulnerable to infection.

Besides showing that both tuberculous and healthy badgers regularly visit, and contaminate, farms and cattle feeding troughs, the results show a strong negative correlation between the use of farm-based resources by badgers and rainfall. On dry nights, farm visits could be very frequent: on one occasion, at least ten individual badgers visited a single building in the space of 5 h. Following 1 mm or more of rainfall, however, the frequency of visits decreased exponentially and no farm visits were recorded when there had been more than 8 mm of rain. Instead, on wet nights, badgers were observed foraging for earthworms on pasture, often passing by farm buildings in order to reach suitable pastures. Thus, it seems that the artificial foods provided by farms are mainly exploited when climatic conditions are such that the preferred diet of earthworms is unavailable (cf. Satchell 1967; Kruuk 1978; Kruuk & Parish 1981). Earthworms might be preferred because they are a more nutritious food resource (Lawrence & Millar 1945; Durchon & Lafon 1951; Sabine 1983) or because badgers may be reluctant to approach farm buildings due to a fear of humans, which is only overcome by hunger on dry nights when earthworms are scarce or unavailable.

The inverse correlation between farm visits and rainfall is consistent with the fact that the incidence of positive tests for bovine tuberculosis in UK cattle herds peaks in August and September (MAFF 2001). Given that the

incubation period between transmission and skin-test sensitivity is 45–50 days (Little *et al.* 1975), an August and September peak in tuberculosis incidence is compatible with a peak in transmission in July, which is when we observed the exploitation of farm-based resources by badgers to be most frequent and when the weather, nationally, is most often dry (Hulme & Barrow 1997). A thorough analysis of the relative timing of badger visits and herd breakdowns is beyond the scope of the present paper, but worthy of further research.

To summarize, we suggest that the practice of storing farm animal feeds in facilities that are accessible to badgers, and the resultant direct or indirect contact that occurs between badgers and cattle, could be an important source of tuberculosis transmission between the two species, especially in periods of dry weather. This view is supported by the fact that cattle on both of our target farms suffered outbreaks of bovine tuberculosis during the course of our study. Furthermore, of two cattle herds on farm B, tuberculosis only occurred in a herd that had fed from troughs known to be used by badgers. Previously, attempts to control the spread of tuberculosis from badgers to cattle have involved the culling of badgers (Krebs *et al.* 1997) but this policy has not been notably effective (Delahay *et al.* 2002). Our observations suggest that an alternative approach, based on improvements to farm biosecurity, could form part of a long-term strategy for the management of bovine tuberculosis in the UK.

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