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# Quantifying the risks of TB infection to cattle posed by badger excreta

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## SUMMARY

Despite strong circumstantial evidence to suggest that the main route of TB transmission from badgers to cattle is via contaminated badger excreta, it is unclear whether the associated risks are high enough to account for the prevalence of the disease in south-west England. To decide whether this was a viable route of transmission, cattle contact with badger excreta was investigated using a deterministic approach to quantify the risks to cattle posed by badger excreta. Levels of investigative and grazing contacts between cattle and badger urine and faeces could each account for the disease prevalence in south-west England. An infection probability of $3{\cdot}7 \times 10^{-4}$ per bite from pasture contaminated with badger urine infected with *Mycobacterium bovis* could account for the prevalence of TB in cattle in south-west England. Infection probabilities of $6{\cdot}9 \times 10^{-7}$ per investigation and $1{\cdot}1 \times 10^{-7}$ per bite from badger latrines could each account for the prevalence of TB in cattle in the south-west. When considering only the high risk areas of south-west England these bounds fell by a factor of eight. However, badger excreta may still constitute a high level of risk to cattle. The levels of cattle contact with badger excreta are far higher than previously thought, suggesting that it is the probability of infection per given contact with infected badger excreta which has the greater influence on the probability of transmission and not the level of contact. The infection probability per cattle contact with infected badger excreta is in all likelihood extremely low.

## INTRODUCTION

Bovine tuberculosis (TB) in cattle remains a problem in parts of south-west England. In 1971 badgers (*Meles meles*) were identified as a wildlife reservoir of the disease, and since 1975 badger control operations have been undertaken to try to reduce the number of herd breakdowns. However, there is no unequivocal evidence that these have reduced the extent of the problem, and in fact the number of herd breakdowns has increased dramatically since the early 1990s. Despite a considerable amount of research into the links between TB in badgers and cattle, the actual mode of transmission remains unclear. So far transmission has only been demonstrated under experimental conditions [1]. In England direct contact between badgers and cattle is not generally believed to be the main route of transmission because badgers either deliberately avoid cattle where at all possible [2] or the two species ignore each other (J. A. Brown, personal communication). However, it is possible that direct contact may occur when infectious badgers enter cattle buildings [3, 4].

Whilst the risk of transmission from badgers to cattle appears to be low and unpredictable [4], most cases of TB in cattle in south-west England are believed to be due to the inspiration or ingestion of bacilli when grazing stock contact grass contaminated

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by infected badger urine, faeces and/or sputum [4–6]. Of these, infected badger urine may pose the greater risk to cattle since it can contain large numbers of bacilli; up to 300000 $ml^{-1}$ [7]. Most badger urinations occur either at latrines or on pasture where a badger path crosses a linear feature such as a fence-line or a hedgerow with restricted access; these 'crossing point' urinations are readily accessible to cattle [8].

Early field studies suggested that grazing cattle strongly avoided badger urine and faeces [9], and so it was concluded that the risks to cattle from badger excreta were negligible. However, more recent work has shown that whilst cattle avoid badger faeces at latrines when there is a suitable long sward to graze, avoidance declines markedly once competition for fresh pasture increases, and that most if not all cattle in a herd will graze at active badger latrines [10]. Badger urine deposited on pasture away from latrines was not avoided by grazing cattle, and so cattle would contact and/or graze pasture contaminated with badger urine soon after they were released into a field for grazing [10]. Thus all types of pasture contamination will eventually be grazed in each grazing regime, and grazing at active badger latrines is more frequent in low-ranking cattle. This one study has shown that there can be high levels of contact between cattle and badger excreta and that the associated risks of disease transmission are therefore high [10].

In this paper we seek to determine whether contact with badger excreta on pasture could account for the pattern of TB in cattle herds in south-west England. To quantify the risks posed by badger excreta to cattle, it is necessary to understand the contact process and the factors that are likely to enhance or reduce this risk.

## METHODS

Cattle may contract TB from badger excreta in two ways. Cattle can ingest *Mycobacterium bovis* from grazing infected pasture. Eructation of rumen gasses can transfer this infection to the lungs [11]. Also, during grazing and investigative contact with infected pasture, explosive inhalation of aerosolised *M. bovis* may take place. These two modes of contact between cattle and contaminated pasture were estimated separately.

We used a deterministic approach to quantify the amount of grazing and investigatory contact cattle have with badger urine and faeces. Here we define grazing contact as bites taken from the sward, investigative contact as close muzzle to sward contact but no bites taken from the sward, and total contact as grazing contact plus investigative contact.

### Quantifying the risks posed to cattle from grazing infected pasture

Cattle do not avoid grazing pasture contaminated with badger urine. Cattle do avoid grazing pasture contaminated with badger faeces whilst non-contaminated, fresh pasture is present. However, once competition for fresh pasture increases, the contaminated pasture is grazed. This leads to all areas of pasture contaminated with badger excreta being grazed by the end of a field rotation [10]. The amount of grazing contact cattle have with contaminated pasture could therefore be calculated by calculating the area of contaminated pasture encountered per herd per year and the risks posed to cattle from these contacts estimated. The following calculations concentrate on estimating the area of contaminated pasture an average herd grazes in a year.

Using 1993 figures we calculated an estimated probability of infection per cow bite of contaminated sward to cattle which would account for the level of herd breakdowns in south-west England. Three hundred and twenty herd breakdowns occurred in this region in 1993 [12] out of a total of 18283 herds, made up of 8908 dairy and 9375 beef herds [13]. This gave a probability of a herd breakdown of 0·0175. In the south-west at this time there were more dairy cows than beef cattle with 660516 dairy and 184923 beef cattle. This equates to an average dairy herd of 74·15 animals and an average beef herd of 19·73 animals. Using the dairy figures and a mean stocking density in the south west of 1·90 cows $ha^{-1}$ [14] the average herd would need 39 ha. Using the cattle grazing figures described below, it would take a herd of 74·15 cows 12·49 days to graze a field of 39 ha once over. Assuming that herds are over-wintered in-doors and are therefore not at risk from badger excreta on pasture, in the remaining 274 grazing days per year the average herd would go through 21·94 field rotations.

### *Area of pasture infected with badger urine*

The area of infectious sward encountered by cattle was calculated. The mean size of territory used by a social group of badgers in three control areas in south-west England was 0·573 $km^2$ [15], and this can be used as a mean for the south-west area. In a

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Gloucestershire study site, badger home ranges averaged 0·372 km², and of this an average of 0·254 km² was pasture (68·3 %) [16]. The total number of urinations on pasture per badger per night on the Gloucestershire study site were as follows: spring, 0·53; summer, 0·44; autumn, 0·12 [16]. The average size of a urine trail was 0·75 m by 0·05 m, and the average diameter of a urine patch was 0·13 m [16]. The average trail therefore covered 0·038 m², and the average patch 0·013 m². Since trails and patches accounted for 61 and 39 % of urinations respectively [16], the average urination measured 0·028 m².

Using a mean group size of six adults [17] and disregarding cubs since these do not contribute significantly to total urine production above ground [18], the mean area of pasture within a territory covered by badger urine on any one night can be calculated as follows.

Within the 0·573 km² territory of the average social group in the south-west, the total area of pasture will be 0·4 km² (70 %) which is similar to the area of pasture necessary to hold a herd of average size at average stocking density. Assuming a prevalence rate of 5·7 % [19], on average 0·34 adult badgers per group will be infected. However, only 16·7 % of a sample of 36 tuberculous badgers had kidney lesions and were excreting bacteria in their urine [20], so an average of only 0·06 badgers per group (1·0 %) will actually be passing infected urine. If it is assumed that badgers living on average size territories exhibit the same urinatory behaviour as those monitored in the Gloucestershire field study and that all urinations occur on different sites, the area of pasture (m²) covered by badger urine on any one night (AUN) can be calculated as:

$$AU \times UB \times IB,$$

where AU = the average area of urination, UB = the average number of urinations per badger and IB = the number of infectious badgers per group. This can then be multiplied up to determine the area of urine contaminated pasture grazed per herd per year.

### *Area of pasture contaminated with badger faeces*

The average area of pasture covered by a badger latrine is 4 m² and the average density of badger latrines on pasture is 0·56 ha$^{-1}$ (J. A. Brown, unpublished). The area of latrine grazed (m²) by a herd in any one year (ALH) can be calculated as:

$$(LD \times P) \times AL \times R,$$

where LD = the density of latrines on pasture (ha$^{-1}$), P = the area of pasture (ha), AL = the area of a latrine (m²) and R = the number of field rotations per year.

### *Probability of infection from a bite of contaminated sward*

Using 0·012 m² as the average area of pasture removed per cow bite [21], the areas of contaminated pasture grazed by cattle, calculated above, were then converted into number of cow bites. The average number of cattle which test positive for TB in a breakdown herd is extremely low and less than three, and this figure includes any lateral spread within the herd (J. Kirkham, personal communication). If it is assumed that only one cow catches TB in a breakdown herd, the infectious probability of one or more bites from an infected sward needed to account for the herd breakdowns in the south-west can then be calculated as:

$$1-(1-PB)^{1/NB}, \quad (1)$$

where PB = the probability of a herd having a breakdown and NB = the number of bites of contaminated sward per herd per year. This could then be used as an indicator of risk posed to cattle by investigative and/or grazing contact with badger faeces and urine.

## Quantifying the risks posed to cattle from investigative contact with contaminated pasture

The initial avoidance of active badger latrines by cattle has the potential to greatly increase the amount of investigatory contact cattle have with them [10]. A high proportion of infected cattle have infections in the thoracic cavity rather than the abdominal cavity, which suggests that a primary route of infection is aerogenous via the respiratory route [6]. Cattle are known to be susceptible to infection by the respiratory route [22]. The increased investigatory contact with latrines may therefore increase the risk of infection posed by latrines even further.

### *Cattle grazing behaviour*

Herds of cattle break up into groups of between 10 and 12 individuals, described here as a feeding group [23]. Individuals in a feeding group graze together with a 10 m personal space [24]. The sweeping side-to-side grazing action of each individual combines with the cohesive grazing action of the feeding group to result in a sward that is all, or nearly all, defoliated to a common height, except for areas around dung deposits which are avoided [23]. In terms of optimum production from each cow, overgrazing occurs when the average length of grass that the cows are prepared to eat is less than 10 cm. This does not necessarily imply an absolute shortage of grass, particularly when stocking density is low, but when the length of the grass is short, cows cannot take in enough nutrients in the time available [23]. Cows graze the upper strata of the sward, normally down to about 2 cm above the soil surface [23]. Cows prefer to graze the edge of a field compared to the middle [10] and there is a general overuse of the grazing by the perimeter fence [23]. Lactating cows have five meals a day each lasting an average of 110 min, which is approximately 9 h of grazing per day [23]. Using an average bite rate of 60 bites per minute [23] and an average bite area of 0·012 $m^2$ [21], each cow grazes approximately 0·72 $m^2$/min. This well documented information on cattle grazing behaviour was used to estimate the number of investigatory contacts between an average herd and badger latrines per year.

### *Probability of infection from an investigation of a latrine*

In order to estimate the level of cattle investigatory contact with badger latrines, it was assumed that an average herd was released into fields with sward heights of greater than 10 cm and that the animals did not graze any one area twice as the sward height would be reduced to 2 cm during the first grazing. Using the information on cattle grazing behaviour given above, the average herd would divide up into approximately seven feeding groups (FG) each of 10·6 animals [23] and would have the potential to contact 22·4 latrines per field rotation when stocked at the average density. Taking the number of cow meals per day (M) as five [23], each lasting 110 min [23] and the number of different animals in a feeding group that contact a latrine per a 110 min meal (I), as three (Hutchings and Harris, unpublished), the number of cattle contacts per herd per day (C) can be calculated as:

$$FG \times M \times I.$$

If it is assumed that cattle avoid grazing badger latrines until the last day of grazing then all contacts up until the last day can be defined as investigatory contacts. This is realistic since cattle avoid grazing badger latrines until competition for uncontaminated pasture increases [10]. As calculated above, it takes 12·49 days for a herd of 74·15 cows to graze a field of 39 ha, and so, an average herd would undergo 11·49 days of grazing where only investigatory contacts between cattle and badger latrines take place. The total number of investigatory contacts per year (IC) between an average herd and badger latrines can then be calculated as:

$$C \times (D-1) \times R,$$

where D = the number of days taken for an average herd to graze a field once over when stocked at the average stocking density and R = the number of field rotations per year.

The number of investigatory contacts per herd per year were then entered into equation (1) as variable NB to produce a probability of disease transmission per investigatory contact to account for the prevalence of TB in cattle in south-west England.

## RESULTS

### The risks from cattle grazing contact

The area of pasture ($m^2$) within a badger territory covered by badger urine on any one night (AUN) was: spring, 0·089; summer, 0·074; autumn, 0·020. If only infected urine is considered, these figures become: spring, $8·9 \times 10^{-4}$; summer, $7·4 \times 10^{-4}$; autumn, $2·0 \times 10^{-4}$. The average figure for the spring, summer and autumn seasons is $6·1 \times 10^{-4}$ $m^2$. If it is assumed that cattle herds are rotated around two fields to enable sward growth in the 'resting field', badger urinations will accumulate in the resting field. The total area of infected urine contacted by a herd in any one year can be calculated as:

$$AUN \times D \times R = 0·167 \text{ m}^2.$$

This equation does not account for any urinations deposited in the field being grazed by the herd which would increase the area of contaminated pasture contacted by the herd.

Using an estimated bite area of 0·012 $m^2$ [21], this equates to 13·9 bites of contaminated sward per herd per year. For urine alone this equates to an infection probability of $1·3 \times 10^{-3}$ per bite from swards contaminated with infected urine to account for the prevalence of TB in south-west England. *M. bovis* on pasture could survive for several months (E. King, unpublished). If a conservative survival of 1 month

Table 1. *Probabilities of infection per contact with badger excreta to account for the prevalence of bovine tuberculosis in cattle in south-west England*

| Type of pasture contamination | Mode of contact | Probability of infection |
|---|---|---|
| TB infected badger urine | Investigation | — |
| TB infected badger urine | Grazing | $3{\cdot}7 \times 10^{-4}$ |
| TB infected badger urine | Investigation + grazing | $3{\cdot}7 \times 10^{-4}$ |
| Badger latrine | Investigation | $6{\cdot}9 \times 10^{-7}$ |
| Badger latrine | Grazing | $1{\cdot}1 \times 10^{-7}$ |
| Badger latrine | Investigation + grazing | $9{\cdot}3 \times 10^{-8}$ |

(30 days) is assumed and is included in the above calculations, the probability of infection needed to account for the level of disease in the south-west falls to $3{\cdot}7 \times 10^{-4}$ per bite from swards contaminated with infected urine (Table 1).

The area of pasture contaminated with badger faeces contacted per herd per year (ALH) = 22·4 latrines per field rotation × 4 m² per latrine × 21·94 field rotations = 1966 m². This equates to 163833 bites of contaminated sward per herd per year. As *M. bovis* can persist in soil for up to 2 years at a depth of 5 cm and 1 year at a depth of 1 cm [25] and any *M. bovis* leaching out of badger excreta into the soil could accumulate over this period, it can be assumed that most latrines would constitute some risk to cattle. These calculations do not include inactive latrines which may contain active TB bacilli in the soil, nor do they include single faeces deposited away from latrines.

The level of grazing contact with latrines equated to an infection probability of $1{\cdot}1 \times 10^{-7}$ per bite from a latrine to account for the prevalence of TB in south-west Britain (Table 1). The combination of faeces and urine, with up to 60% of urinations occurring at latrines [18], creates relatively small areas of concentrated contamination. The leaching of *M. bovis* into the soil from this excreta could create reservoirs of contamination in the soil. Soil is ingested by cattle when grazing [26–29], with up to 450 kg of soil ingested by each cow per year [30] and so bacilli in the soil also constitute a risk.

### The risks posed by cattle investigative contact

The average herd has 25516 investigatory contacts with badger latrines per year. Using equation (1) this level of investigative contact equated to an infection probability of $6{\cdot}9 \times 10^{-7}$ per investigation of a latrine to account for the prevalence of TB in cattle in south-west England (Table 1). This figure does not include any olfactory investigation of latrines by cattle immediately preceding and during the grazing of the latrine, which would act to increase the estimated risk associated with investigation of latrines.

Combining the level of grazing contact with the level of investigatory contact constitutes a total of 189349 contacts per herd per year which corresponds to an infectious probability of $9{\cdot}3 \times 10^{-8}$ per contact to account for the prevalence of TB in cattle in south-west England (Table 1) or 1 contact in over 10 million contacts with latrines.

## DISCUSSION

The high numbers of bacilli that can be excreted in the urine of infected badgers, combined with the grazing behaviour of cattle and the amount of contact they have with badger urine, ensures that infected badger urine placed at crossing points constitutes a high.risk to cattle. The lack of any avoidance shown by cattle to badger urine deposited away from latrines, combined with the distribution of urine at the field edges and the preference of cattle to graze field perimeters first, ensures that urine scent marks are contacted and the contaminated pasture grazed soon after cattle are released into the field. Badger urine enhances the survival of *M. bovis in vitro* (E. King, personal communication); using a conservative estimate of survival of *M. bovis* on pasture in urine, an infection probability of $3{\cdot}7 \times 10^{-4}$ between cattle and infected urine would account for the TB prevalence in cattle in south-west England.

For latrines, the greater area of contamination compared to crossing point urinations means that even though cattle initially avoid grazing at latrines, the level of grazing contact cattle have with contaminated swards is increased to such an extent as to reduce the probability of infection from a single bite from a latrine to $1{\cdot}1 \times 10^{-7}$ in order to account for the level of disease prevalence in the south-west. Furthermore, the initial avoidance of grazing at latrines by cattle actually increases the number of investigative contacts. If the investigative contacts are incorporated into the risk calculations, the probability of infection of a contact with a latrine required to account for the disease prevalence in the south-west falls to $9{\cdot}3 \times 10^{-8}$. However, these calculations include all latrines,

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regardless of levels of contamination with *M. bovis*. Badger faeces have been shown to contain fewer TB bacilli compared to badger urine [13] and faeces are not as volatile a medium compared to urine, thus reducing the chances of aerosols infecting cattle. This, combined with the fact that most faeces in latrines are in pits, which greatly reduces the probability of direct physical muzzle contact with cattle, suggests that the risks to cattle per contact with a badger latrine are low.

The low probabilities resulting from the models clearly shows that badger excreta could account for the number of herd breakdowns in the south-west. These calculations have also shown that the far greater potential risk of infection comes from badger latrines since the area of infection is great compared to urine and the accumulation of badger excreta over long periods of time may create localized high-risk reservoirs of TB infection. The question therefore arises as to why there are not more herd breakdowns with TB per year. If it is assumed that badgers do give cattle TB, the strong spatial association between TB in badgers and TB in cattle suggests that the risks to cattle are not consistent throughout the south-west. If this is the case only the high-risk areas of the south-west should be taken into consideration when quantifying the risks posed to cattle by badgers. This can be estimated if it is assumed that the parishes in south-west England with a recent history of TB in cattle (constituting 12·34% of the south-west) are 'high-risk' areas and that these areas contain a proportionate number of the total herds in the south-west. Using these figures, the probability of infection per bite of pasture contaminated with infectious badger urine increases from $3{\cdot}7 \times 10^{-4}$ to $3{\cdot}0 \times 10^{-3}$ in high-risk areas to account for the prevalence of TB in the south-west. This would increase the probability of infection from a bite from a badger latrine from $1{\cdot}1 \times 10^{-7}$ to $8{\cdot}7 \times 10^{-6}$. This still constitutes a high level of risk due to the far higher levels of cattle contact with badger excreta than was previously thought. This suggests that it is the rate of transmission which has the greater influence on the probability of transmission and not the level of contact, and that the infectious probability per cattle contact with infected badger excreta is extremely low.

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