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## ENVIRONMENTAL RISK FACTORS ASSOCIATED WITH BOVINE TUBERCULOSIS IN CATTLE IN HIGH RISK AREAS

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1 **ENVIRONMENTAL RISK FACTORS ASSOCIATED WITH BOVINE**  
2 **TUBERCULOSIS IN CATTLE IN HIGH RISK AREAS**

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7 **ABSTRACT**

8 Our research shows that environmental features are important predictors of bovine  
9 tuberculosis (bTB) in British cattle herds in high-prevalence regions. Data from 503 case and  
10 808 control farms included in the Randomised Badger Culling Trial (RBCT) were analysed.  
11 Bovine TB risk increased in larger herds and on farms with greater areas of marsh, deciduous  
12 woodland and maize, whereas a higher percentage of boundaries composed of hedgerows  
13 decreased the risk. The model was tested on another case-control study outside RBCT areas  
14 and had a much smaller predictive power when compared to the first study, possibly  
15 indicating a different infection dynamics outside high risk areas although other confounding  
16 factors could have also influenced this outcome.

17 **KEYWORDS:** habitat, badgers, cattle, ecology, epidemiology, landscape-scale

18 **INTRODUCTION**

19 Bovine tuberculosis is a significant economic burden to agriculture, particularly in the UK  
20 where the number of new breakdowns remains high. Within high risk areas, there is spatial  
21 heterogeneity in the risk of both new and recurrent breakdowns that remains largely  
22 unexplained (1). The movement of infected cattle plays an important role in the range

1 expansion of the disease (2). However, recent work modelling transmission pathways  
2 suggests that the environment plays an important role in the within farm maintenance and  
3 short distance spread of the disease (2). The European badger (*Meles meles*) is an important  
4 wildlife reservoir of bTB in the UK (1). The farm environment can become contaminated  
5 due to the presence of infected badgers (3) and/ or cattle (4). It has been suggested that the  
6 importance of environmental factors to bTB epidemiology has increased since the foot and  
7 mouth outbreak, possibly due to greater contamination of badgers by infected cattle (5).

8 Reducing exposure to environmental contamination could therefore play a fundamental role  
9 in managing bTB. This may extend beyond simply excluding badgers from cattle feeding  
10 areas, to wider landscape management which influences habitat use by both badgers and  
11 cattle. For example, increased density of hedges and the presence of buffer strips on field  
12 margins have been linked with reduced risk of bTB in cattle herds(6).

13 The aim of our study is to identify environmental variables that influence the risk of cattle  
14 acquiring bTB, in order to explore the potential for landscape-management to contribute to  
15 bTB control.

## 16 MATERIAL AND METHODS

17 We analysed data collected between 1998 and 2004 as part of the TB99 case-control study  
18 associated with the RBCT. Within the 10 trial areas of the RBCT all breakdowns (whether  
19 confirmed or not) triggered a survey of potential farm-level risk factors (7). In addition, for  
20 each breakdown, the same survey was conducted at 1- 3 control herds within the same trial  
21 area (including, where possible, one contiguous herd). Control herds had no bTB test reactors  
22 in the previous 12 months, and were selected to represent the range of herd sizes within the  
23 trial area. In total, we analysed data from 503 case and 806 control farms.

1 The ability of habitat and herd management data to predict bTB breakdown status was  
2 analysed using generalised linear modelling with a binomial error structure in R 3.1.0 (8). All  
3 models included the case-control design variable as a fixed factor. In addition, they accounted  
4 for the RBCT treatment (proactive and reactive badger culling or control) because breakdown  
5 risk among farms recruited some years after the onset of the study could have varied  
6 according the treatment regime.

7 We used an information-theoretic approach to model selection, as this is designed to capture  
8 real-world complexity whilst minimising the risk of making spurious associations (9). We  
9 screened all environmental variables and a subset of herd management predictors, selected  
10 based on results obtained by other authors when analysing similar datasets (7) (10), with  
11 univariate logistic regression and a relaxed inclusion criterion ( $p < 0.10$ ). See Electronic  
12 Supplementary Material (ESM) for complete list and descriptive statistics. We repeated the  
13 analysis only including control herds that did not have a previous breakdown trying to  
14 account for any possible residual effect of a breakdown before the 12 month selection period.  
15 The results did not differ to the previous analysis (see ESM).

16 The relative measure of predictive ability of the models was compared using Akaike's  
17 Information Criterion (with  $\Delta AIC \leq 4$ ) (9) (R 3.1.0, MuMIn package). Inferences were  
18 made based on model-averaged predictions and were computed as a weighted mean for the  
19 set of best models. We then tested the consistency of the variables in predicting a bTB  
20 outbreak on a separate case-control dataset, the CCS05. This study was conducted in 2005-6  
21 and focused on four areas where the number of bTB breakdowns in cattle herds ranged from  
22 medium to high (Carlisle, Carmarthen, Stafford and Taunton). It included 400 case farms  
23 that were randomly selected from farms that suffered bTB outbreaks (confirmed or not). Two  
24 control farms were randomly selected in the same region for each case farm, one matching

1 the case farm in herd size and type. The same criteria as in the TB99 study were used to  
2 define control herds.

3

#### 4 **RESULTS**

5 The risk of bTB breakdown increased on farms with greater areas of deciduous woodland,  
6 marsh, rough pasture, maize, in larger and dairy herds and herds that fed silage. The risk  
7 decreased on farms with greater percentage of hedges in boundaries, herds that graze silage  
8 hay fields and herds that had greater number of cattle moving on. The models explaining the  
9 risk of bTB breakdown in the TB99 dataset are presented in Table 1 and the predictor  
10 weights, model averaged odds ratio and confidence interval for variables in the top models  
11 are shown in Table 2. No difference to the results was observed according to whether or not  
12 RBCT treatment was included in the model. The pseudo- $R^2$ , that indicates the goodness of fit  
13 of the top TB99 model, was 0.21 and the AUC 0.71 (a measure of the predictive ability of the  
14 model) (11).

15 When testing the same variables as the TB99 dataset using the CCS05 dataset many variables  
16 had the same weight in the top ranking models (Table 3), though seasonally wet soils  
17 (corresponding to 'marsh' in TB99) and percentage of hedgerows appeared in less than half  
18 the top models. Area of woodland decreased the odds ratio of bTB breakdown having an  
19 opposite effect when compared to the TB99 study. Full outcomes for the CCS05 dataset and  
20 differences between the 2 datasets are shown in the ESM. The positive predicted value of the  
21 top model when applied to the new dataset was 61.5 % and the negative predicted value was  
22 31.0 %, indicating that 61.4 % of the case herds and 31.04 % of the control herds were  
23 correctly classified (AUC 0.63, suggesting poorer predictive ability).

#### 24 **DISCUSSION**

1 Our research shows that environmental features (hedgerows, woodland, etc.) are important  
2 predictors of bTB in high-prevalence areas, but may be less useful elsewhere, where  
3 between-herd contact may be more important and less affected by these factors (1). Contrary  
4 to the TB99 study the CCS05 study comprised areas with mixed risk of infection. It is also  
5 notable that whilst the TB99 dataset on which our models were based, is derived from farms  
6 in South-west England, all of which fell within land class groups 1 and 4 (12), the CCS05  
7 dataset was much more geographically dispersed, and only one region (Taunton) fell into this  
8 grouping. Some of the variables included in the top models may therefore be of less  
9 relevance in these regions. For example, some have few hedgerows with stone walls being  
10 used instead as field boundaries. It is also possible that the relative importance of badger-  
11 cattle and cattle-badger transmission (and the interactive effects of land management which  
12 could modify this transmission risk) differed in these other land classes that have lower  
13 density and abundance of badger social groups (13).

14 The use of the landscape by both badgers and cattle affects the likelihood of successful bTB  
15 transmission between the two. The environmental composition affects the distribution of  
16 badger setts in the landscape, with higher sett densities found in areas with greater length of  
17 hedgerows, area of broadleaved woodland and area of improved grassland and lower  
18 densities found in heather moorland (14). Therefore, we expected a reduced risk of  
19 breakdown associated with areas of rough and moorland grazing in the TB99 study however,  
20 the risk of breakdown increased in all datasets. This may reflect a wider classification of  
21 rough grassland adopted by the TB99 study. The placement of badger latrines and urination  
22 sites is highest in woodland areas and adjacent to hedges and stone walls (15). An earlier  
23 study demonstrated a lower risk of bTB on farms with greater hedgerow abundance (6). The  
24 placement of latrines and urination sites near hedges limits the contamination of pasture  
25 areas. How close cattle graze near the pasture boundaries will depend on management

1 practices and grazing pressure on the pasture. Much of the variability in landscape  
2 management is tightly tied with herd size and enterprise type (for example, large herd sizes  
3 are associated with large fields and lower hedgerow densities).

4 The higher risk of breakdown observed on herds with greater areas of maize and use of silage  
5 was also linked to larger herds. Our study demonstrates that the model for cattle production  
6 based on larger herd sizes, and the use of silage and field maize for the maintenance of high-  
7 productivity animals, is associated with increased bTB risk. The dairy industry has undergone  
8 many changes driven by the market and regulatory changes. The average dairy herd size has  
9 increased in England by 36 % from 1990 to 2003 and is greater in the south. In that same  
10 period the area planted with maize in the South West has increased fourfold (16). Badgers  
11 favour maize as a food source: in the South West of England 72.1 % of land owners reported  
12 cereal crop (oats, maize, barley and wheat) damage by badgers(17). Contamination of maize  
13 by badger faeces and urine may therefore present a possible route of infection. Maize may  
14 also play a role on altering the badger population size and their nutrition. The 70% increase in  
15 risk of breakdown observed for every 10 ha of marsh area in the TB99 study may be linked  
16 with exposure to liver fluke (*Fasciola hepatica*), which is transmitted by an amphibious snail  
17 *Galba truncatula*, and affects the sensitivity of bTB tests (18).

18 On areas with high number of bTB breakdowns environmental features appeared constantly  
19 in the main models of breakdown risk. It is therefore vital for food security that holistic  
20 approaches to disease control are implemented, which consider landscape as well as herd  
21 management and the badgers use of the environment. The measures have to be tailored to  
22 different regions. Disease surveillance should be tailored taking into account factors that  
23 increase the risk for breakdown, such as herd type, presence of marsh areas and the planting  
24 of maize. Further studies should try to pinpoint disease hotspots within farms, synthesising  
25 data on cattle grazing management, habitat and distribution of badger setts and pathways.

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23

1 **Table 1. Akaike information statistic ranking logistic regression models containing**  
 2 **variables that affect the odds of bovine tuberculosis on cattle farms**

<b>Model</b>	<b>AIC</b>	<b>ΔAIC</b>	<b>Akaike weight</b>
Deciduous wood (ha), Marsh (ha), Rough pasture (ha), Maize (ha), Internal boundary hedges (%), Grazing silage hay aftermath (y/n), Feeding silage (y/n), Herd size category, Enterprise type, N. Cattle moving on, Incident number <sup>a</sup>	1600.66	0.00	0.56
Deciduous wood (ha), Marsh (ha), Maize (ha), Internal boundary hedges (%), Grazing silage hay aftermath (y/n), Feeding silage (y/n), Herd size category, Enterprise type, N. Cattle moving on, Incident number	1603.40	2.38	0.17
Deciduous wood (ha), Marsh (ha), Rough pasture (ha), Internal boundary hedges (%), Grazing silage hay aftermath (y/n), Feeding silage (y/n), Herd size category, Enterprise type, N. Cattle moving on, Incident number	1603.50	2.40	0.17
Deciduous wood (ha), Marsh (ha), Rough pasture (ha), Maize (ha), Internal boundary hedges (%), Grazing silage hay aftermath (y/n), Feeding silage (y/n), Herd size category, Enterprise type, N. Cattle moving on, Incident number, Cull areas	1604.10	3.45	0.10

AIC – Akaike information criterion, Δ AIC - amount of support for the model relative to the top ranking model, Akaike weight - probability of the candidate model being the ‘best’ out of all those considered,

<sup>a</sup>Incident number - case control design variable

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4

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1 **Table 2. Predictor weights and odds ratios of variables appearing in the top models**  
 2 **from logistic regression of bovine tuberculosis breakdown risk**

Variable	Number of models in which variable appears (out of 4)	Predictor weight	Univariate odds ratio	Odds ratio from multivariate model	95% CI for multivariate odds ratio
Deciduous wood (10 ha)	4	1.00	1.40	1.32	1.08 – 1.62
Marsh (10 ha)	4	1.00	1.79	1.70	1.11 – 2.60
Rough pasture (10 ha)	3	0.83	1.10	1.07	1.00 – 1.15
Internal boundary hedge (%)	4	1.00	0.66	0.63	0.47 – 0.83
Maize (10 ha)	3	0.83	1.40	1.20	1.01 – 1.44
Grazing silage hay aftermath (yes/no)	4	1.00	0.71	0.56	0.43 – 0.73
Feeding silage (yes/no)	4	1.00	2.98	2.20	1.45 – 3.32
Herd size category:	4	1.00			
Small (<50 cattle)			0.33	0.50	0.33 – 0.75
Medium (50-150 cattle)			0.73	0.88	0.66 – 1.19
Large (>150 cattle) <sup>1</sup>			-	-	-
Cattle enterprise type:	4	1.00			
Beef <sup>1</sup>			-	-	-
Dairy			1.83	1.24	0.91 – 1.69
Sheep			0.88	1.01	0.62– 1.64
Other			0.48	0.46	0.30 – 0.71
Cattle moving on (10 cattle)	4	1.00	0.96	0.95	0.93 – 0.97
Cull areas:	1	0.10			
control <sup>1</sup>			-	-	-
reactive			0.96	0.95	0.90 – 1.20
pro-active			1.07	1.07	0.70- 1.43

<sup>1</sup>Levels with no odds ratio were used as the reference level

3

4

1 **Table 3. Predictor weights of the variables in the logistic regression models of the TB99**  
 2 **and CCS05 datasets**

<b>Variable</b>	<b>Number of models in which variable appears in the TB99 dataset (out of 6)</b>	<b>Predictor weight TB99 dataset</b>	<b>Number of models in which variable appears in the CCS05 dataset (out of 35)</b>	<b>Predictor weight CCS05 dataset</b>
Deciduous wood	6	1.00	32	0.96
Marsh (TB99) - seasonally wet soil (CCS05)	6	1.00	17	0.50
Rough pasture	4	0.81	27	0.88
Internal boundary hedge (%)	6	1.00	8	0.20
Maize (y/n) <sup>1</sup>	4	0.80	27	0.88
Feeding silage (y/n)	6	1.00	18	0.53
Herd size category	6	1.00	35	1.00
Cattle enterprise type	6	1.00	35	1.00
Cattle moving on	6	1.00	19	0.61

<sup>1</sup>Maize was included as a binomial variable (grown/not grown) when both models were compared, but remained a numeric variable (ha) in the main TB99 analysis

3