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Bovine tuberculosis in cattle: reduced risk on wildlife-friendly farms

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The associations between habitat and other factors that lead to the risk of bovine tuberculosis (bTB) in diary cattle were examined in an unmatched case–control study. Data from 60 herds with recent history of bTB and 60 controls were analysed using logistic regression. The predictors included farmland habitat, topography, indices of badger density and herd size. Information-theoretic approaches were used to identify those predictor variables explaining the greatest variation in cattle herd bTB breakdowns. Reduced risk of bTB was associated with the management of farmland in ways favourable to wildlife conservation, as encouraged by recent (2005) European Common Agricultural Policy reforms.

Keywords: badgers; TB; Akaike information criterion; habitat; landscape

1. INTRODUCTION

Bovine tuberculosis (bTB) incidence in British cattle has risen exponentially since 1984 and its annual cost is projected to reach £1 billion by 2011 (DEFRA 2004). In 2004, 5% of cattle farms in South West England, and 1.8% nationally, had confirmed breakdowns (details of cattle testing regimes are provided in the electronic supplementary material). The causes of the epidemic, particularly the local factors explaining why one farm has a breakdown rather than its neighbours, remain poorly understood.

Attention has focused on possible wildlife reservoirs (Griffin *et al.* 2005). A randomized trial of badger culling (RBCT) in Britain recently reduced cattle bTB incidence within areas subjected to widespread badger culling, but increased incidence in adjoining areas (Donnelly *et al.* 2006), probably as a result of altered badger behaviour. Badger culling is nevertheless proposed by government as an integral part of future bTB control strategy. Case–control studies highlight the importance of cattle movements (Gilbert *et al.* 2005; Johnston *et al.* 2005), but most other cattle-management variables have not been associated with increased risk (Johnston *et al.* 2005). The present study investigated the relationship between bTB risk and agri-environmental factors on dairy farms in disease hot-spots. The aim was to identify local conditions associated with the emergence of bTB in cattle, including spill-overs from badgers.

2. MATERIAL AND METHODS

Data on bTB in British cattle were obtained for years 1994–1999 inclusive (data unavailable after the start of the RBCT). Farms eligible for this study had 80 or more cattle, were dairy holdings, and were outside the RBCT. 'Cases' had one or more confirmed breakdown since 1997 and two or more instances of positive reactors to the skin test since 1994. Breakdowns classified by DEFRA as due to cattle imports were excluded (3.9% of total breakdowns). Control farms had no breakdowns (confirmed or unconfirmed) since 1994. Thirty cases and 30 controls were randomly selected from all eligible herds in two geographical areas (i.e. 120 herds were analysed; further details can be obtained from the electronic supplementary material).

Logistic regression was used to investigate the relationship between breakdowns (cases) and non-breakdowns (controls) and potential predictors. The predictors included a wide range of habitat variables, with an emphasis on boundary characteristics. Indices of badger density, herd size and proximity to other recently infected herds were also included, these having been associated with bTB risk (Gilbert *et al.* 2005; Johnston *et al.* 2005), as was farm area (see electronic supplementary material for variable list). Details of boundaries of farm ownership are not publicly available. So, for the purpose of estimating habitat characteristics within farms, each was assumed to be a circular area of 100 ha—the median reported to DEFRA's Rural Payment's Agency by the study farms—and centred on the herd's registered grid coordinates. Dairy enterprises tend to have compact configurations, and to be centred around farm buildings because of the need for milking. Nevertheless, these assumptions will inevitably introduce some errors. Therefore, the observed relationships between bTB and habitat features will be underestimates. Detailed information about badger distribution, density and bTB status is also unavailable (Gilbert *et al.* 2005). Badger road traffic accident (RTA) records, available at a 1 km resolution, were therefore used as indices of population density. No data on the infection status of the RTA badgers was available.

The fit of different logistic regression models was assessed using an information-theoretic approach. In this, a series of relationships (models) between the herd breakdowns variable and the habitat predictors is formulated. Competing models with different combinations of predictor variables are compared and ranked according to their ability to explain the observed phenomenon. The Akaike information statistic—which provides an inverse measure of model fit—was used to compare models (see electronic supplementary material). A second, derived, measure (Akaike weight) was also used. This can be interpreted in a heuristic way, as the probability, given the data, of each model being the best out of all those considered. The relative importance of *individual* variables is indicated by their predictor weights (see electronic supplementary material). The overall objective of the analysis was to include those variables accounting for some variation in the herd breakdowns, and so develop an approximating model that lost as little information as possible about the real-world system (Anderson *et al.* 2000). Where several variables are believed to explain a given process, the approach is less likely than traditional hypothesis-testing methods to generate spurious findings (Burnham & Anderson 2002).

Since many predictors could plausibly contribute to herd breakdowns, we fitted multiple models with permutations of the predictor variables. To keep the number of possible combinations within reasonable limits, the models were built in stages. First, the habitat data alone were used. In addition to the summary variables for land cover, deciduous woodland area and grazed grassland area (variable 'grazed/mown turf') were included separately because of their associations with badger density (Reason *et al.* 1993). Further sets of models were then produced using the variables featured in the top-ranking models and also factors considered *a priori* likely to be associated with bTB risk: badgers, county and topography; and agricultural data including herd size, stocking density and proximity to other bTB cases.

3. RESULTS

All the top-ranking models included distance to the next nearest infected herd (range 0.3–8.7 km) and herd size (table 1). Of the badger variables tested,

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Table 1. Akaike information statistics for logistic regression models relating bTB incidence in cattle herds to agricultural, badger and habitat predictors. (The overall percentage correct classification ranges from 68.3 to 75.8 (mean 70.1% correct presence and 74.4% correct absence).)

model	AIC$_c$[a]	ΔAIC$_c$[a]	w[b]	w_i/w_j[c]	R^2[d]
herdsize,[e] nearcase,[f] hedgepc2[g]	138.90	0.00	0.085	1.00	0.34
herdsize, nearcase, hedgepc2, head,[h] badgers[i]	139.00	0.09	0.081	1.05	0.38
herdsize, nearcase, hedgepc2, head	139.00	0.09	0.081	1.05	0.36
herdsize, nearcase, hedgepc2, turfedge[j]	139.60	0.70	0.060	1.42	0.36
herdsize, nearcase, hedgepc2, turfedge, head	139.90	1.00	0.051	1.68	0.37
herdsize, nearcase, hedgepc2, gaps,[k] head, badgers	139.93	1.03	0.051	1.68	0.39
herdsize, nearcase, hedgepc2, turfedge, head, badgers	138.96	1.06	0.050	1.70	0.39
herdsize, nearcase, hedgpec2, gaps, head	139.99	1.09	0.049	1.72	0.37
herdsize, nearcase, hedgepc2, badgers	140.05	1.15	0.048	1.78	0.35
herdsize, nearcase, hedgepc2, gaps	140.27	1.37	0.043	1.98	0.35
herdsize, nearcase, head	140.29	1.39	0.042	2.00	0.33
herdsize, nearcase, hedgepc2, width[l]	140.33	1.43	0.042	2.04	0.35
herdsize, nearcase	140.41	1.51	0.040	2.12	0.31
herdsize, nearcase, turfedge	140.45	1.55	0.039	2.17	0.33
herdsize, nearcase, hedgepc2, density[m]	140.57	1.67	0.037	2.30	0.35
herdsize, nearcase, head, badgers	140.59	1.69	0.036	2.33	0.35
herdsize, nearcase, hedgepc2, turfedge, badgers	140.75	1.85	0.034	2.52	0.37
herdsize, nearcase, hedgepc2, head, width, badgers	140.78	1.88	0.033	2.56	0.38
herdsize, nearcase, hedgepc2, SDI[n]	140.79	1.89	0.033	2.57	0.35
herdsize, nearcase, hedgepc2, coverpc1[o]	140.80	1.90	0.033	2.58	0.35
herdsize, nearcase, hedgepc2, head, width	140.84	1.94	0.032	2.63	0.36

[a] Akaike's information criterion adjusted for small sample sizes. ΔAIC$_c$ indicates the amount of support for the model relative to the top-ranking one (higher values show less support). [b] Akaike weight, another index of the strength of evidence for each model. It is the ratio of the ΔAIC$_c$ of the target model relative to all the other models and can be interpreted, heuristically, as the probability of the model being correct, given the data. [c] Evidence ratio. The ratio of the Akaike weight of candidate model to that of top-ranking model. It shows the extent to which the 'top' model is better than the model in question. [d] Nagelkerke's R-square. [e] Number of cattle in herd. [f] Distance to next nearest case of bTB (km). [g] Second principal component describing hedgerow abundance. [h] Mean number of wildlife strips per hedgerow. [i] Number of badger road-kill records within 1 km of farm grid-reference. [j] Length of edge of mown or grazed turf (km). [k] Mean number of gaps in hedgerow per 100 m. [l] Mean hedgerow width (m). [m] Stocking density of cattle (number per hectare). [n] Shannon's diversity index. [o] Coverpc1, principal component 1 describing landcover.

Table 2. Predictor weights for variables appearing in the most parsimonious models (ΔAIC$_c$ < 2), together with odds ratios from logistic regression of bTB risk.

variable	predictor weight	number of models in which variable appears	univariate odds ratio	95% confidence interval for odds ratio[a]	change in 2 log likelihood (R^2)[a,b]	odds ratio from multi-variate model[c]
herdsize	1.00	21	1.01	1.01, 1.02	—	—
nearcase	1.00	21	0.72	0.53, 0.98	—	—
hedgepc2	0.84	17	1.61	1.07, 2.44	3.65 (0.03)	1.56
head	0.51	10	0.01	0.00, 2.0	2.26 (0.02)	0.01
badgers	0.33	7	1.14	0.94, 1.39	0.80 (0.02)	1.11
turfedge	0.23	5	0.92	0.83, 1.03	2.10 (0.02)	0.91
gaps	0.14	3	4.08	0.78, 21.35	1.21 (0.01)	2.56
width	0.11	3	0.91	0.77, 1.08	0.69 (0.01)	0.92
density	0.04	1	0.95	0.80, 1.12	0.63 (0.01)	0.93
SDI	0.03	1	2.34	0.51, 10.81	0.54 (0.01)	1.93
coverpc1	0.03	1	1.00	1.00, 1.00	0.12 (0.00)	1.00

[a] From univariate logistic regression. [b] Compared with a model which includes herd size and nearcase only. [c] From logistic regression models also containing herd size and nearcase.

only the number of badger road-kill reports within 1 km was an important predictor. The estimated odds ratios for all the variables appearing in the most parsimonious models were robust: with the exception of the variable 'gaps', the estimates from univariate analyses were virtually unaltered by the addition of herd size and nearest bTB case (table 2), or other explanatory variables to the models.

Hedgerow characteristics appeared in 19 of the 21 top-ranking models (table 1). (Models using habitat predictors only are shown in electronic supplementary material). Key parameters were the number of wildlife strips (ungrazed buffer strips adjacent to field boundaries from which cattle are excluded, usually by fencing), the number of hedgerow gaps and the score for hedgerow abundance (summarized in variable 'hedgepc2', see electronic supplementary material). High hedgepc2 scores typified 'hedge-poor' farmland with few hedgerows and large field sizes, as result from industrial post-war management. Taking for illustration the hedgerow parameters of two contrasting farms in this study, a 'hedge-poor' farm with a hedge density of 5.3 km per 100 ha, mean hedge length of 186 m and a mean connectivity score of 2.9 would be expected on average to have a 1.6 times greater risk of bTB (95% confidence interval: 1.0, 2.4) than a 'hedge-rich' farm with a hedge density of 13.4 km per 100 ha, mean hedge length of 177 m and a connectivity score of 3.7, after controlling for the other factors (herd size and distance to next bTB case) in the top-ranking model. Comparisons of the predictor weights (table 2) show that the hedgerow parameter was about 2.5 times more important than the badger abundance index, and 28 times more important than Shannon's diversity index in explaining bTB incidence.

4. DISCUSSION

Habitat management appears important to a farm's bTB risk. 'Nature friendly' management practices—the presence of ungrazed wildlife strips, and the greater availability, width and continuity of hedgerow—are all associated with reduced bTB incidence. The results are unlikely to be artefactual: in contrast to other habitat variables, such as deciduous woodland configuration, the boundary characteristics were retained in high-ranking models after adjustment for herd size and the proximity of the nearest infected herd. Further, the top-ranking model, which included hedgerow availability, had more than twice the support of the model containing just these non-habitat variables. Within-farm habitat characteristics were estimated with some random error in our study (because farm perimeter locations were not known), and the true relationships will therefore tend to be even stronger than those we have observed.

Any of the habitat factors associated with bTB risk locally could operate in conjunction with parameters important at a larger spatial scale, such as climate (Wint *et al.* 2002) and cattle movements (Gilbert *et al.* 2005). We, as in some (Johnston *et al.* 2005), though not all (Griffin *et al.* 1993) previous studies, found little evidence for badger density being associated with bTB risk. The extent and configuration of deciduous woodland and the amount of pasture—likely determinants of badger densities—were also of little predictive value, as reported previously (White & Benhin 2004). Nevertheless, better indices, particularly farm-level data on bTB prevalence in badgers, may show stronger associations.

Further work is warranted to establish the mechanism linking habitat to bTB risk. Broadly, habitat could influence cattle contact rates or be associated with agricultural management practices in ways relevant to bTB transmission. For example, there may be different rotational patterns on hedgerow-rich farms that could lower the ingestion of potentially contaminated soil (Healy 1968). Favourable habitat could also reduce badger–cattle *Mycobacterium bovis* transmission. This may initially appear counter-intuitive, since both cattle and badgers preferentially use hedgerows, the former for grazing (cattle have a strong preference for long swards; Hutchings & Harris 1997), and the latter for commuting routes and latrine sites (Stewart *et al.* 2001). However, when long forage is readily available, as when hedgerow density is high, cattle markedly avoid grass contaminated by active badger latrines (Hutchings & Harris 1997; for further details on mechanism see electronic supplementary material). Also, only the extremities of hedgerows are grazed, with the interior providing areas where cattle cannot access infected badger faeces and urine. Thus, a greater density of hedgerows provides a greater density of land where badger–cattle contact is prevented. The fact that wildlife strips and a lack of hedgerow gaps—which would both reduce badger–cattle contact rates—were also negative correlates of bTB incidence provides some support for this idea.

The reform of the Common Agricultural Policy has decoupled farm subsidies from production, with increased funding being provided through agri-environment schemes (DEFRA 2005). The baseline 'Entry Level' Environmental Stewardship Scheme rewards favourable boundary feature management, including hedgerow retention and creation, and the formation of wildlife strips. These habitats are important for wildlife conservation (Macdonald & Johnson 2000). Our work suggests that boundary management may also reduce the risk of bTB in cattle, including financially debilitating repeated breakdowns (see electronic supplementary material). Taking, for simplicity, just one parameter contributing to the hedgerow score—total hedgerow length—an increase of 1 km per 100 ha was associated with a decrease in the odds ratio of bTB of about 12.5% (95% confidence interval: 0.3% increase to 26.3% decrease) in univariate analysis. In absolute terms, this equates to the annual risk of bTB changing from the current rate of 9.2% (2152 confirmed incidents in 23 471 herds in 2004) to 8.1% (1901 incidents) for herds in the West of England: an annual reduction of 251 infected herds. Conversely, there is little evidence that increasing farm woodland area or altering its configuration would adversely affect bTB risk.

Managing zoonotic risks to human and animal health is fundamentally important: virtually all emerging infectious diseases originate in wildlife. Superficially, the simplest method of control is to reduce prevalence in the reservoir host by culling. However, effective reductions in population densities can be difficult to achieve, and may be undesirable for species of conservation concern (as for bat-reservoirs of emerging viruses (Dobson 2005), and British badgers are legally protected). Culling may even be counter-productive: the recent evidence from the RBCT in the UK (Donnelly *et al.* 2006) supports the contention that social perturbation among surviving badgers can increase local bTB risks (Tuyttens *et al.* 2000). An alternative, and possibly complementary strategy is to establish the ecological conditions associated with the spill-over of disease and to manage these (Dobson 2005). We studied the multifactorial reality of British farmland ecosystems and found, using recent advances in statistical modelling, a link between farmland habitat management and bTB risk. The collective effects of ecological factors were marked. We conclude that managing the landscape in ways that are also beneficial to conservation generally may provide an additional means of controlling bTB.

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