Localized reactive badger culling increases risk of bovine tuberculosis in nearby cattle herds

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Human and livestock diseases can be difficult to control when infection persists in wildlife populations. Control of bovine tuberculosis (bTB) in British cattle is complicated by the maintenance of Mycobacterium bovis (the causative agent of bTB) in badgers, acting as reservoirs of infection. Although over 20,000 badgers were culled to control bTB between 1975 and 1997, the incidence of bTB in cattle has substantially increased in parts of Great Britain in recent decades. Our case-control study, involving 1208 cattle herds, provides further evidence of the detrimental effect of localized reactive badger culling in response to the disclosure of a confirmed bTB herd breakdown in cattle. The presence of any reactive badger culling activity and increased numbers of badgers culled in the vicinity of a herd were associated with significantly increased bTB risk, even after adjusting for other important local risk factors. Such findings may partly explain why some earlier localized approaches to bTB control were ineffective.

Keywords: bovine tuberculosis; case-control study; localized reactive badger culling; Randomized Badger Culling Trial

1. INTRODUCTION

Bovine tuberculosis (bTB) remains a major animal health problem in Great Britain. Regular testing of cattle herds and slaughterhouse surveillance form key components of national bTB control, with cattle testing positive being slaughtered and affected herds placed under temporary movement restrictions (an event known as a ‘herd breakdown’). In 2009, one in every 10 cattle herds tested showed evidence of bTB leading to 35,000 cattle being slaughtered [1]. Disease control efforts have been hampered by Mycobacterium bovis (the causative agent of bTB) in wildlife, in particular badgers, which sustain endemic infection and can transmit M. bovis to cattle. Infections in cattle and badgers are closely associated [2] and, in Britain, cattle-based bTB controls have been supplemented with various forms of localized badger culling.

The Randomized Badger Culling Trial (RBCT) evaluated the impact of badger culling on bTB risk in British cattle. The RBCT compared the incidence of bTB in cattle under three strategies—repeated widespread (‘proactive’) culling, localized (‘reactive’) culling and no culling (‘survey-only’)—each replicated 10 times in 100 km² trial areas recruited as matched sets of three, known as ‘triplets’ [3]. Reactive culling occurred in response to the disclosure of a confirmed bTB herd breakdown (incident in which post-mortem examination of cattle led to the detection of bTB lesions or culture of M. bovis) and sought to only remove badgers whose home ranges overlapped the land used by the breakdown herd (‘reactor land’) [4]. Reactive culling was suspended in November 2003, after it was revealed that it was associated with a 27 per cent increase in the incidence of confirmed bTB breakdowns [5].

Ecological studies undertaken during the RBCT showed that badgers in reactive areas had lower population densities (32% reduction in active badger hole density) and larger home ranges than in survey-only areas [6,7] and that repeated reactive culling was associated with elevated M. bovis prevalence in badgers [8]. This combined evidence suggests that herds located on land near, but outside, reactive culling operations may have experienced elevated bTB risks, as observed among herds just outside proactive areas [3]. Our study complements previous RBCT analyses [4,5] by testing this hypothesis using a case-control study involving 604 pairs of herds within reactive areas, comparing herds with confirmed bTB breakdowns (cases) with herds that were tested but revealed no evidence of infection (controls).

2. MATERIAL AND METHODS

The Defra VETNET system provided data on cattle bTB tests and herd breakdowns. Each case was matched to a control selected randomly from herds within the same triplet that had a clear herd test within a year of the breakdown disclosure date and that had no associated land within 5 km of the reactor land. Data were analysed for four time periods:

- the completion of the initial proactive cull until the first reactive cull (‘leading’);
- the first reactive cull until the suspension of reactive culling in November 2003 (‘during’);
- November 2003 to 1 year after the completion of the last proactive cull (‘post1’); and
- November 2003 until the compilation of the RBCT database on 21 January 2007 (‘post2’).

Previous studies revealed the evidence of association between M. bovis infections in badgers and cattle over a distance of up to 1 km [2] and of badger movement up to 5 km [9]. For each herd, RBCT data were extracted on whether any culling had occurred nearby (within 1, 3 or 5 km of the farm land boundary), the number of badgers culled nearby and the number of nearby confirmed breakdowns. The number of nearby cattle herds tested but not under bTB-related movement restrictions was recorded as a measure of the herd population at risk. Variables were calculated for 1 year (and 2 years) prior to the date, the breakdown was detected in the case and the herd test date of the control (table 1).

Variables were log transformed and screened using conditional logistic regressions after adjusting for herd type (dairy/non-dairy), herd size and farm area, as well as bTB historic incidence [10]. We investigated any impact of unmodelled spatial correlation on our results using permutation tests. The estimated odds ratios (OR) reported for covariates correspond to a change in bTB risk following the doubling of the covariate. See the electronic supplementary material for details.

3. RESULTS

(a) Nearby reactive culling and bovine tuberculosis risk

The presence of any reactive culling activity in the previous year, within 1 km of a herd more than doubled its
bTB risk, even after adjusting for the number of confirmed bTB breakdowns nearby (OR: 2.49, 95% CI: 1.73–3.59, p < 0.001). The detrimental effect of reactive culling remained when the distance to the herd increased (3 km: OR: 2.47, 95% CI: 1.67–3.65, p < 0.001; 5 km: OR: 2.86, 95% CI: 1.79–4.59, p < 0.001). The detrimental effect of reactive culling was associated with elevated bTB incidence [5] was debated, with some arguing that the survey-only areas were inappropriate controls and that the inclusion of breakdowns disclosed before reactive culling began was inappropriate [11]. Here, we addressed those concerns by only analysing data from herds within trial areas randomized to reactive culling and by stratifying the data into distinct time periods: prior, during and after the implementation of localized reactive badger culling.

The risk of a confirmed bTB breakdown significantly increased with the presence of any reactive badger culling activity, and increased numbers of badgers reactively culled, in the vicinity of a herd, even after adjusting for the number of nearby confirmed bTB breakdowns and other local bTB risk factors. These findings provide additional evidence of the detrimental effect of localized reactive badger culling on bTB risk for British cattle [4,5,12] beyond that of local bTB herd breakdowns. As badgers in RBCT reactive areas showed expanded ranging behaviour [7], the number of contacts of each infected badger with neighbouring cattle herds and other badgers could have increased while reactive culling was in place despite badger density being somewhat reduced (the ‘perturbation effect’). Additionally, as repeated reactive culling was associated with elevated M. bovis prevalence in badgers [8], the reduction in overall badger density would not have entailed the same reduction in the density of infected badgers.

It is difficult to formulate a biological explanation for the apparent protective effect of increased numbers of badgers proactively culled near a herd before the onset of reactive culling; however, this makes the estimated detrimental effect of reactive badger culling all the more striking.

Past localized badger culling operations in the Republic of Ireland did not result in a detectable increase in bTB risk for nearby herds [13]. However, bTB incidence, badger density, farmer practices and culling methods in Ireland differ from those in Britain [14] making these studies and the RBCT not directly comparable. The RBCT reactive culling was similar

(b) Associations with the numbers of nearby culled badgers and confirmed bovine tuberculosis breakdowns

While reactive culling was taking place, the univariable models showed strong associations between cases and increased numbers of badgers culled in the previous year. The number of (proactively) culled badgers within 3 and 5 km of a herd significantly decreased its bTB risk prior to the onset of reactive culling. Cases were consistently associated with increased numbers of nearby confirmed bTB breakdowns in all four time periods and all three distances; with a doubling in the number of nearby confirmed bTB breakdowns resulting in estimated increases in bTB risk from 34 to 231 per cent (see the electronic supplementary material).

When both variables were included in a multivariable model, the number of nearby (proactively) culled badgers in the previous year significantly decreased a herd’s bTB risk both prior to, and following, reactive culling operations (table 2). This pattern remains in alternative models adjusted for the herd’s distances to the trial area boundary (a potential correlate of a herd’s distance to the nearest proactively culled trial area). The number of confirmed bTB breakdowns nearby remained a significant risk factor before and after reactive culling operations. During reactive culling, the number of badgers culled nearby was the only significant bTB risk factor. Comparable results were obtained in the analyses including variables based on the previous 2 years. Permutation-based p-values reveal that unmodelled spatial correlation in our dataset did not affect our conclusions. See the electronic supplementary material for these alternative analyses.

4. DISCUSSION

The original analysis of the effect of reactive culling on bTB incidence [5] was debated, with some arguing that the survey-only areas were inappropriate controls and that the inclusion of breakdowns disclosed before reactive culling began was inappropriate [11]. Here, we addressed those concerns by only analysing data from herds within trial areas randomized to reactive culling and by stratifying the data into distinct time periods: prior, during and after the implementation of localized reactive badger culling.

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Table 2. Odds ratios (OR) with 95% CI for the multivariable models of the associations of cases with increased numbers of RBCT culled badgers and increased numbers of confirmed bTB breakdowns in the previous year. (Models are adjusted for herd type, herd size, farm area, historic incidence and the number of nearby herds (in grey). Significant associations are denoted in bold. Dashed line (--) denotes that odds ratios were not estimable.)

<table>
<thead>
<tr>
<th>distance (km)</th>
<th>leading</th>
<th>during</th>
<th>post1</th>
<th>post2</th>
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<tbody>
<tr>
<td>nearby RBCT culled badgers</td>
<td></td>
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<tr>
<td>p = 0.001, OR: 1.00 (1.20–1.14)</td>
<td>p = 0.001, OR: 1.00 (1.24–1.16)</td>
<td>p = 0.01, OR: 0.88 (0.72–1.07)</td>
<td>p = 0.03, OR: 0.72 (0.52–0.95)</td>
<td>p = 0.049, OR: 0.70 (0.43–1.10)</td>
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<tr>
<td>nearby confirmed bTB breakdowns</td>
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<tr>
<td>p = 0.001, OR: 1.60 (1.20–2.14)</td>
<td>p = 0.001, OR: 0.88 (0.50–1.56)</td>
<td>p = 0.02, OR: 1.12 (0.96–1.31)</td>
<td>p = 0.01, OR: 0.84 (0.67–1.03)</td>
<td>p = 0.045, OR: 0.67 (0.45–0.99)</td>
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<td>herd type (dairy)</td>
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<tr>
<td>p = 0.001, OR: 1.74 (2.80–26.30)</td>
<td>p = 0.001, OR: 1.00 (1.46–3.93)</td>
<td>p = 0.001, OR: 1.00 (1.15–4.66)</td>
<td>p = 0.001, OR: 1.00 (1.24–2.31)</td>
<td>p = 0.001, OR: 1.00 (1.46–3.93)</td>
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<tr>
<td>p = 0.03, OR: 0.74 (0.70–0.79)</td>
<td>p = 0.04, OR: 0.83 (0.70–0.99)</td>
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<td>p = 0.001, OR: 0.72 (0.52–0.91)</td>
<td>p = 0.02, OR: 1.00 (1.24–2.22)</td>
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<td>farm area</td>
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<td>p = 0.001, OR: 15.97 (3.23–79.07)</td>
<td>p = 0.001, OR: 15.97 (3.22–75.88)</td>
<td>p = 0.001, OR: 15.97 (3.22–75.88)</td>
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<td>p = 0.001, OR: 15.97 (3.22–75.88)</td>
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<tr>
<td>bTB historic incidence</td>
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<tr>
<td>p = 0.07, OR: 0.30 (0.12–0.72)</td>
<td>p = 0.06, OR: 0.32 (0.12–0.82)</td>
<td>p = 0.02, OR: 0.32 (0.12–0.82)</td>
<td>p = 0.001, OR: 0.72 (0.50–1.05)</td>
<td>p = 0.001, OR: 0.72 (0.50–1.05)</td>
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<td>number of nearby herds tested not under bTB restriction</td>
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<tr>
<td>p = 0.45, OR: 1.12 (0.72–2.22)</td>
<td>p = 0.45, OR: 1.14 (0.73–3.19)</td>
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in scope to pre-RBCT badger culling policies in Britain in which localized culling (by gassing, trapping, shooting or snaring) was undertaken on the reactor land following a bTB breakdown [15], with an expectation of a reduction in the risk of future breakdowns. Our findings could partly explain why some of these localized past approaches were ineffective in reducing bTB incidence in cattle.

The localized culling of disease reservoirs may result, in some ecological systems, in social and spatial disturbances that have the potential to contribute to an increased disease risk in and around areas where such operations take place. Such “perturbations” have clear implications when considering the spatial scale and methods of delivery of disease control strategies in wildlife reservoirs.

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