Positive and Negative Effects of Widespread Badger Culling on Tuberculosis in Cattle

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LETTERS

Positive and negative effects of widespread badger culling on tuberculosis in cattle

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Human and livestock diseases can be difficult to control where infection persists in wildlife populations. For three decades, European badgers (*Meles meles*) have been culled by the British government in a series of attempts to limit the spread of *Mycobacterium bovis*, the causative agent of bovine tuberculosis (TB), to cattle[1]. Despite these efforts, the incidence of TB in cattle has risen consistently, re-emerging as a primary concern for Britain's cattle industry. Recently, badger culling has attracted controversy because experimental studies have reached contrasting conclusions (albeit using different protocols), with culled areas showing either markedly reduced[2,3] or increased[4,5] incidence of TB in cattle. This has confused attempts to develop a science-based management policy. Here we use data from a large-scale, randomized field experiment to help resolve these apparent differences. We show that, as carried out in this experiment, culling reduces cattle TB incidence in the areas that are culled, but increases incidence in adjoining areas. These findings are biologically consistent with previous studies[2–5] but will present challenges for policy development.

Bovine tuberculosis is a zoonotic disease with serious consequences for Britain's cattle industry[1]. The causative agent, *Mycobacterium bovis*, has a broad host range, which in Britain includes the European badger, a widespread but protected wildlife species[1]. Regular testing of cattle herds and slaughterhouse surveillance form the main components of national TB surveillance and control; animals that test positive for TB are slaughtered and affected herds are placed under temporary movement restrictions. Similar measures have eradicated TB in cattle across much of the developed world[1]. Patterns of infection in cattle and badgers are closely associated[6] and, in Britain, cattle-based TB controls have been supplemented with various forms of badger culling[1,7,8]. Despite these efforts, over the past two decades substantial increases have been recorded in both the incidence and geographic extent of cattle infection, prompting repeated reviews of control options[1,9,10].

The development of improved TB control strategies has been hindered by contrasting findings regarding the effectiveness of badger culling as a management tool. Two studies in the Republic of Ireland[2,3] and one in Britain[11] have associated substantial reductions in the incidence of TB in cattle with the near-eradication of badgers from large areas of land (a total of six areas ranging from 104 to 528 km^2). In contrast, a field experiment conducted in Britain (the randomized badger culling trial or RBCT) indicated higher cattle TB incidence in nine study areas (each approximately 100 km^2) where badgers were culled locally (average area 5.3 km^2 per cull) in response to specific cattle TB outbreaks ('reactive' culling) than in nearby areas randomly allocated to a no-culling treatment[4,5]. The Independent Scientific Group on Cattle TB (ISG, with members F.J.B., C.A.D., D.R.C., G.G., J.P.M., W.I.M. and R.W.) designed and oversees the RBCT. The ISG has tentatively suggested[4] that this apparently detrimental effect of localized badger culling might be generated by the disruption of badgers' territorial organization at artificially reduced population densities[12–15], potentially influencing contact rates with cattle. However, neither this explanation nor the effect itself has been universally accepted[9,16].

The RBCT included two culling treatments. Localized 'reactive' culling sought to reduce TB risks to cattle while minimizing the number of badgers culled[1,17]. 'Proactive' culling[1,17] involved widespread and repeated culling of badgers across entire trial areas and was included in order to estimate the maximum reduction in cattle TB incidence achievable by culling badgers (subject to animal welfare considerations, non-compliance by land occupiers, and other practical constraints likely to influence the long-term sustainability of a potential culling policy)[17,18]. The rates of cattle TB incidents ('herd breakdowns') in culled areas were then compared with rates in unculled 'survey-only' areas[1,4,5].

Our analyses reveal that, thus far, the incidence of cattle herd breakdowns has been 19% lower in proactive trial areas than in survey-only areas ($P = 0.005$; 95% confidence interval (CI) 6.2–30% reduction; Fig. 1a. The CI is conservatively inflated (like all CIs reported here) to account for any overdispersion). This result was consistent across ten proactive culling areas, each paired with a survey-only area (the test for overdispersion was not significant; $P = 0.58$). The estimated effect was stronger when measured after the first follow-up cull rather than the initial cull (23% reduction, $P = 0.008$; 95% CI: 6.5–36% reduction). Our analyses revealed no significant change in the effect of culling on breakdown incidence over time (see Supplementary Information). The data suggest that the beneficial effects of culling might increase as one moves deeper inside trial area boundaries (see Supplementary Information), but this trend is not consistent. We will continue to examine this possibility as additional data become available.

We also compared the incidence of cattle herd breakdowns in areas up to 2 km outside proactive and survey-only trial areas (Fig. 2). Parallel ecological studies have revealed reduced population densities

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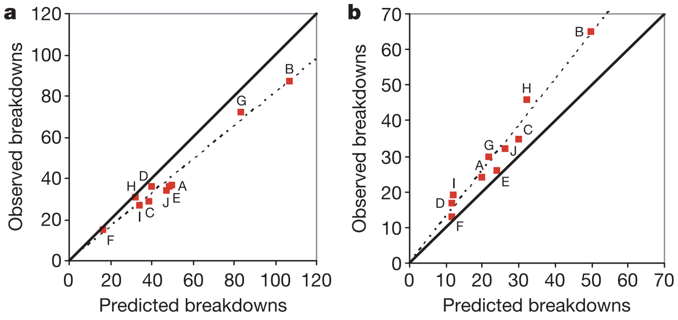

Figure 1 | Effects of badger culling on cattle TB incidence. **a**, **b**, Observed numbers of confirmed breakdowns (after initial culls), plotted against the numbers of breakdowns predicted with no culling, either inside (**a**) or ≤2 km outside (**b**) proactive culling areas A–J. Predictions for each proactive trial area were calculated on the basis of their specific features, replacing the parameter associated with proactive culling with that for survey-only (see Supplementary Information). If incidence rates for proactive areas match those for survey-only areas (after appropriate adjustments), points should fall on the solid lines. Dashed lines indicate the differences in incidence actually observed inside (**a**, total observed, 404; total predicted, 496.7) and outside (**b**, total observed, 307; total predicted, 238.4) trial areas.

and expanded ranging behaviour in badger populations studied up to 2 km outside proactive areas, as well as in reactive areas[19]. Therefore, if as hypothesized[4], expanded badger movement patterns caused the increase in cattle TB incidence recorded in reactive areas, we predicted that a similar pattern would be observed on farms neighbouring proactive trial areas. Analyses revealed a 29% increase in cattle TB incidence ($P = 0.015$; 95% CI: 5.0–58% increase; Fig. 1b) on land neighbouring proactive areas, relative to land neighbouring survey-only areas. Again, the effect was consistent across proactive/survey-only pairs (the test for overdispersion was not significant, $P = 0.38$), but the estimated increase was smaller when measured from the first follow-up cull rather than the initial cull (22% increase, $P = 0.15$; 95% CI: 6.9% reduction to 59% increase). Again, analyses revealed no significant change in the effect of culling on breakdown incidence over time (see Supplementary Information).

Our results help to resolve apparently contrasting findings from previous studies of badger culling. The 19% reduction in cattle TB incidence observed inside proactive culling areas can be compared with reductions detected, on similar timescales, by two previous studies of widespread culling in Ireland (26% reduction[3] and 58% reduction (95% CI: 41–70%)[2]; see Supplementary Information for details; the different design of a third study[11] (in Britain) precluded direct comparison). One explanation for the greater beneficial effect of culling in the Irish studies is that greater reductions in badger density may have been achieved, both because land occupier compliance was higher[2] and because the culling method (snaring[2,3]) was probably more efficient than that used in the RBCT (although arguably less publicly acceptable, being perceived as less humane). None of the three previous studies has investigated effects of culling on neighbouring areas. However, in two of these studies[2,11] we would expect such effects to be weak because culled areas were isolated from neighbouring cattle and badger populations by coastline, rivers or motorways.

Our results are also consistent with findings from the reactive culling treatment of the RBCT. The 29% increase in TB risk that we recorded among cattle herds living close to (but outside) proactive trial areas is similar to the 25% (95% CI: 2.6–52%) increase recorded in reactive areas[5]. This similarity would be expected if proximity to badger culling increases TB risks for cattle (whatever the mechanism) because, in reactive culling areas, small-scale culls were scattered across the landscape, placing a high proportion of herds close to one or more culled areas. The mechanism by which proximity to badger culling may influence cattle TB risks is uncertain. However, the ecological patterns observed are consistent with the hypothesis that culling affects the probability of contact between infected badgers and cattle herds, because badgers range more widely when their densities are artificially reduced[12–15,19]. Such disruption would be expected to occur throughout the period of a culling strategy, for in the absence of substantial geographic barriers, badgers continue to immigrate into culling areas[3]. However, contacts with cattle might be particularly frequent at the onset of culling, when territorial

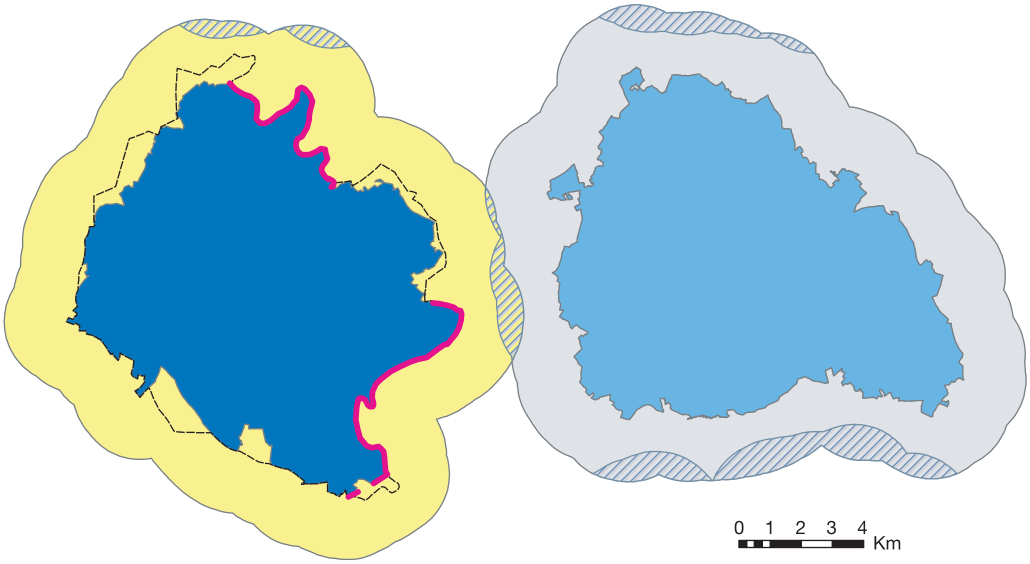

Figure 2 | Simplified map of proactive and survey-only areas of triplet A. Shown are (1) trial areas: proactive trial area (95.7 km^2, dark blue), survey-only trial area (99.4 km^2, light blue) and (2) neighbouring areas: proactive neighbouring area (98.9 km^2, yellow), survey-only neighbouring area (88.0 km^2, grey). The boundary of the badger-culling area (black dashed line) and possible geographical barriers to badger movement (red lines) are also shown. Portions of the neighbouring areas overlapping with the neighbouring areas of other nearby trial areas (not shown) account for 4.6 km^2 of the proactive neighbouring area and 14.9 km^2 of the survey-only neighbouring area, and are denoted by diagonal hatching.

organization is disrupted but badger population densities may still be comparatively high.

Our finding that widespread culling of badgers has simultaneous positive and negative effects on the incidence of TB in cattle has important implications for the development of sustainable control policies. We would expect the overall reduction in cattle TB to be greatest for very large culling areas (with consequently lower perimeter:area ratios), although in absolute terms the costs, as well as the benefits, will be greatest for large areas. Detailed consideration is needed to determine whether culling on any particular scale would be economically and environmentally sustainable.

METHODS

Trial design. Thirty trial areas were recruited sequentially as ten matched 'triplets' denoted A–J[4]. Trial areas were selected on the basis of high cattle TB incidence. Attempts were made to place trial area boundaries along geographic features that might impede badger movement (for example, coastline, rivers or major roads; Fig. 2), but in most cases this was impossible and trial area boundaries mainly followed property boundaries. Neighbouring trial areas were separated by buffer zones at least 3-km wide. All trial areas were surveyed for badger activity and then randomly allocated to treatments (except in triplet I, for which security concerns directed a specific allocation) such that each treatment—proactive culling, reactive culling, or no culling ('survey only')—was repeated ten times, once within each triplet.

Immediately after treatment allocation, initial proactive culls were conducted on all land for which consent was given[10] (see Supplementary Information). In the absence of geographical barriers, the boundaries of the area to be culled were delineated (beyond trial area boundaries as necessary; Fig. 2) using field survey data to ensure that culling targeted all badgers likely to use farms inside the trial areas. The method used[20] provides a good estimate of the disposition of badger home ranges when based on good survey data[21].

Badgers were captured in cage traps placed primarily at setts; details of culling protocols have been published previously[14]. No trapping occurred between 1 February and 30 April each year, to avoid killing mothers with dependent cubs below ground[22]. Few badgers sustained trap-related injuries[23], and badger killing (by gunshot) was deemed 'humane' by independent audit[24]. Initial culls for each proactive trial area were completed between December 1998 and December 2002. 'Follow-up' culls were repeated approximately annually (dates in Supplementary Information). Field surveys showed that badger activity in trial areas changed according to the treatment applied[19,25], providing no evidence that treatment comparisons were substantially compromised by illegal culling in survey-only areas.

Once the initial proactive cull was complete, data were collected on cattle TB incidence in and around trial areas, using established veterinary surveillance (see Supplementary Information). Data were available until 4 September 2005, and consisted of accrued totals from 46.6 'triplet years' since initial proactive culls and 34.1 'triplet years' since first follow-up culls (where a 'triplet year' is one triplet observed for 12 consecutive months).

Statistical analysis. We used log–linear Poisson regression to compare the numbers of confirmed breakdowns recorded in trial areas subjected to the proactive and survey-only treatments. As in previous analyses[4,5], the regression models adjusted for triplet, the log of the number of baseline herds at risk, and the log of the number of confirmed breakdowns recorded in a three year period before RBCT culling (other time periods investigated are presented in the Supplementary Information). Primary analyses included all breakdowns since completion of the initial proactive cull, but we also performed secondary analyses investigating incidence recorded after completion of the first follow-up cull. We performed these secondary analyses for two reasons. First, some breakdowns early in the trial could represent infections acquired (but not detected) before culling began. This could make treatments appear more similar, leading to underestimation of effects; excluding data before the first follow-up cull avoided this potential problem. Second, badger capture rates (see Supplementary Information) suggested that a higher level of badger removal was achieved after the first follow-up cull. Excluding earlier data therefore indicated the maximum potential benefits of culling inside trial areas, but also risked underestimating any detrimental effects in neighbouring areas, which were expected to be greatest immediately after initial culls.

Cattle herd locations from the animal health information system VETNET were used to identify herds inside trial areas. Parallel analyses were performed using the RBCT database to identify herd locations; the results obtained were similar but less consistent (see Supplementary Information). Herds up to 2 km outside trial area boundaries could be identified comprehensively only using VETNET, because the RBCT database did not include all farms on neighbouring land. Any herds within 2 km of more than one trial area boundary (whether proactive, reactive or survey-only) were omitted from these analyses (Fig. 2). Analyses based on VETNET herd locations include 2,810 herds inside trial areas and 2,163 herds in neighbouring areas.

We sought evidence that the effects of proactive culling were systematically influenced by particular circumstances of local cattle and badger populations, land occupier consent, time since enrolment in the RBCT, and the geographic isolation of trial areas, by investigating interactions of these measures with treatment effects. No such differences were detected in the analyses of confirmed breakdowns (see Supplementary Information).

Models were also fitted replacing the log of the number of baseline herds at risk with either the log of the estimated number of cattle at baseline, the log of the number of tests conducted, or the log of the estimated number of cattle tested, and varying the time period over which past incidence was calculated. The results obtained were similar in each case (see Supplementary Information).

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1. Krebs, J. R. *et al. Bovine Tuberculosis in Cattle and Badgers* Report PB3423 (HMSO, London, 1997).
2. Griffin, J. M. *et al.* The impact of badger removal on the control of tuberculosis in cattle herds in Ireland. *Prev. Vet. Med.* **67,** 237–266 (2005).
3. Eves, J. A. Impact of badger removal on bovine tuberculosis in east County Offaly. *Ir. Vet. J.* **52,** 199–203 (1999).
4. Donnelly, C. A. *et al.* Impact of localized badger culling on tuberculosis incidence in British cattle. *Nature* **426,** 834–837 (2003).
5. Le Fevre, A. M. *et al. The Impact of Localised Reactive Badger Culling Versus No Culling on TB Incidence in British Cattle: a Randomised Trial.* ⟨http://www.defra.gov.uk/animalh/tb/isg/pdf/lefevre1005.pdf⟩ (2005).
6. Woodroffe, R. *et al.* Spatial association of *Mycobacterium bovis* infection in cattle and badgers. *J. Appl. Ecol.* **42,** 852–862 (2005).
7. Dunnet, G. M., Jones, D. M. & McInerney, J. P. *Badgers and Bovine Tuberculosis: Review of Policy* (HMSO, London, 1986).
8. Zuckerman, S. *Badgers, Cattle and Tuberculosis* (HMSO, London, 1980).
9. Godfray, H. C. J. *et al. Independent Scientific Review of the Randomised Badger Culling Trial and Associated Epidemiological Research* ⟨http://www.defra.gov.uk/science/documents/publications/2004/GodfreyReport_BovineTBEpidemiology.pdf⟩ (HMSO, London, 2004).
10. Bourne, J. *et al. An Epidemiological Investigation into Bovine Tuberculosis—Towards a Science-Based Control Strategy*. Fourth Report of the Independent Scientific Group on Cattle TB ⟨http://www.defra.gov.uk/animalh/tb/isg/4th-isgreport.pdf⟩ (Department for Environment, Food & Rural Affairs, London, 2005).
11. Clifton-Hadley, R. S., Wilesmith, J. W., Richards, M. S., Upton, P. & Johnston, S. The occurrence of *Mycobacterium bovis* infection in and around an area subject to extensive badger (*Meles meles*) control. *Epidemiol. Infect.* **114,** 179–193 (1995).
12. Roper, T. J. & Lüps, P. Disruption of territorial behaviour in badgers *Meles meles*. *Z. Saugetierkd.* **58,** 252–255 (1993).
13. Cheeseman, C. L., Mallinson, P. J., Ryan, J. & Wilesmith, J. W. in *The Badger* (ed. Hayden, T. J.) 78–93 (Royal Irish Academy, Dublin, 1993).
14. O'Corry-Crowe, G., Hammond, R., Eves, J. & Hayden, T. J. The effect of reduction in badger density on the spatial organisation and activity of badgers *Meles meles* L. in relation to farms in central Ireland. *Biol. Env. Proc. R. Ir. Acad.* **96B,** 147–158 (1996).
15. Tuyttens, F. A. M. *et al.* Spatial perturbation caused by a badger (*Meles meles*) culling operation: implications for the function of territoriality and the control of bovine tuberculosis (*Mycobacterium bovis*). *J. Anim. Ecol.* **69,** 815–828 (2000).
16. Woolhouse, M. E. J. Dangers of moving cows. *Nature* **435,** 431–432 (2005).
17. Bourne, J. *et al. Towards a Sustainable Policy to Control TB in Cattle—A Scientific Initiative*. First Report of the Independent Scientific Group on Cattle TB (Ministry of Agriculture, Fisheries & Food, London, 1998).
18. White, P. C. L. & Whiting, S. J. Public attitudes towards badger culling to control bovine tuberculosis in cattle. *Vet. Rec.* **147,** 179–184 (2000).
19. Woodroffe, R. *et al.* Effects of culling on badger (Meles meles) spatial organization: implications for the control of bovine tuberculosis. *J. Appl. Ecol.* doi:10.1111/j.1365-2664.2005.01144.x (in the press).
20. Woodroffe, R., Frost, S. D. W. & Clifton-Hadley, R. S. Attempts to control tuberculosis in cattle by culling infected badgers: constraints imposed by live test sensitivity. *J. Appl. Ecol.* **36,** 494–501 (1999).
21. Cresswell Associates. *TB in Cattle: Report of the Independent Audit of Surveying and Badger Social Group Territory Delineation Procedures Used in The Randomised Badger Culling Trial and MAFF's Response*. ⟨http://www.defra.gov.uk/animalh/tb/publications/pdf/cresswell.pdf⟩ (2001).
22. Woodroffe, R. *et al.* Welfare of badgers (*Meles meles*) subjected to culling: development and evaluation of a closed season. *Anim. Welf.* **14,** 19–25 (2005).

23. Woodroffe, R. *et al.* Welfare of badgers (*Meles meles*) subjected to culling: patterns of trap-related injury. *Anim. Welf.* **14,** 11–17 (2005).
24. Kirkwood, J. K. *Humaneness of MAFF's Badger Despatch Procedures*. ⟨http://www.defra.gov.uk/animalh/tb/publications/auditor/report.htm⟩ (2000).
25. Le Fevre, A. M. *et al. Changes in Badger Setts Over the First Three Years of the Randomised Badger Culling Trial*. ⟨http://www.svepm.org.uk/posters/2003/LeFevre.pdf⟩ (2003).

Supplementary Information is linked to the online version of the paper at www.nature.com/nature.

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