Response to "*Tuberculosis in Cattle and Badgers: A report by the Chief Scientific Adviser*"

F.J. Bourne, C.A. Donnelly, D.R. Cox, G. Gettinby, J.P. McInerney,
W.I. Morrison & R. Woodroffe
Former members, Independent Scientific Group on Cattle TB

Summary

ISG1 The Independent Scientific Group on Cattle TB (ISG) was an independent body charged with developing science-based policy options for the control of tuberculosis (TB) in cattle. As the ISG was dissolved in June 2007 following publication of its final report (Bourne *et al.*, 2007), this response to the Chief Scientific Adviser's recent report (King *et al.*, 2007) presents the views of the seven former members of the ISG.

ISG2 A key conclusion of our work was that "*badger culling can make no meaningful contribution to cattle TB control in Britain*" (Bourne *et al.*, 2007). This conclusion is based on the analysis and interpretation of data derived from nearly 10 years' scientific research by ourselves and our colleagues. Our major scientific findings, and their interpretation, have been published in top-quality peer-reviewed journals, and our conclusions are widely accepted within the scientific community. We are surprised, therefore, that King *et al.* (2007) reached a different conclusion, namely that "*the removal of badgers could make a significant contribution to the control of cattle TB in those areas of England where there is a high and persistent incidence of TB in cattle*".

ISG3 We believe that a key reason for these differing conclusions is that King *et al.* (2007) were constrained within their terms of reference, which prevented them from fully evaluating policy options. While we aimed "*to present Ministers with a range of scientifically-based policy options which will be technically, environmentally, socially and economically acceptable*" (Bourne *et al.*, 1998), King *et al.* (2007) were "*...asked to make comment on scientific issues...*"; their "*... brief did not extend to economic or other practical issues*" (Environment, Food and Rural Affairs Committee, 2007). Unfortunately, the complex relationship between badger abundance and cattle TB risks, as revealed by our work, means that "*economic* [and] *practical issues*" – which determine how, where, when, and on what scale badger culling might be conducted – are absolutely critical in determining whether culling would reduce or increase the incidence of cattle TB. By excluding consideration of such issues from Sir David King's remit, Ministers severely hampered his ability to inform policy development.

ISG4 In addition to this broad concern about King *et al.*'s remit, we have identified a large number of scientific problems with their report, which have led them to draw conclusions from our work which are not consistent with the data available. In particular, King *et al.* (2007) dismiss as "*unsound*" our finding that badger culling increases TB risks for cattle on neighbouring unculled land, yet their conclusion is undermined by (i) incorrect interpretation of statistical confidence intervals; (ii) exclusion of data accrued between the first and second proactive culls, even though this cannot be justified either by statistical bias or by the time taken for changes in the badger population to cause detectable effects in TB risks for cattle; and (iii) incomplete consideration of ecological data consistent with detrimental effects observed among cattle. In addition, misinterpretation of our mathematical modelling work is likely to have led King *et al.* (2007) to under-estimate the likely benefits of improved cattle-based controls.

ISG5 Given these concerns, we are not persuaded by the arguments in King *et al.*'s (2007) report and stand by our published recommendations concerning the control of cattle TB in Britain.

Introduction

ISG6 The Independent Scientific Group on Cattle TB (ISG) worked from its outset to build and interpret a science base to inform the control of tuberculosis (TB) in cattle. As members of the ISG, we analysed and interpreted data from the Randomised Badger Culling Trial (RBCT) and related studies. The ISG was dissolved in June 2007 following publication of its final report (Bourne *et al.*, 2007). This response to the Chief Scientific Adviser's recent report (King *et al.*, 2007) thus represents the views of the seven former members of the ISG.

ISG7 Our primary findings, including their interpretation, were peer reviewed, both before publication in scientific journals, and by the Defra-appointed statistical auditor; comments were also sought from colleagues at Defra and its associated agencies, some of whom were co-authors on our papers. We have throughout our work encouraged informed debate and discussion, and continue to welcome further constructive comment and dialogue on any aspect of our work.

ISG8 Like King *et al*. (2007), we recognised from the start of our work that "*the overriding aim is to control TB in cattle*". Indeed, the opening sentences of our final report noted that "*Bovine TB is a serious infectious disease of cattle. It has public health implications, has major economic consequences for Government and the farming industry, and causes distress to farmers and their families*" (Bourne *et al.*, 2007). Hence we firmly agree that "*...strong action needs to be taken now to reverse the upward trend of this important disease*" (King *et al.*, 2007). Our recommendations, summarised in our final report (Bourne *et al.*, 2007) on the basis of data published in a broad array of peer-reviewed papers, therefore represent our views of the best way to achieve control of cattle TB using methods currently available.

ISG9 A key conclusion of our work was that "*...while badgers are clearly a source of cattle TB, careful evaluation of our own and others' data indicates that badger culling can make no meaningful contribution to cattle TB control in Britain. Indeed, some policies under consideration are likely to make matters worse rather than better*" (Bourne *et al.*, 2007). We note that our broad conclusions regarding the role of badger culling are consistent with views expressed previously by experts on the ecology of TB in badgers such as Dr Chris Cheeseman[1], Prof David Macdonald[2] and Prof Tim Roper[3], as well as with recent statements by leading scientists charged with past independent reviews of the issue such as Lord Krebs[4]. However, our conclusion contrasts with King *et al.*'s (2007) recommendation that "*the removal of badgers could make a significant contribution to the control of cattle TB in those areas of England where there is a high and persistent incidence of TB in cattle*" (King *et al.*, 2007).

The importance of terms of reference

ISG10 At the start of our work, our stated aim was "*to present Ministers with a range of scientifically-based policy options which will be technically, environmentally, socially and economically acceptable*" and the RBCT was therefore designed as a trial of potential policy options (Bourne *et al*., 1998). Our approach contrasts with the remit of King *et al*. (2007), who were "*...asked to make comment on scientific issues...*"; their "*... brief did not extend to*

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[1]Dr Chris Cheeseman, Oral evidence to Environment, Food & Rural Affairs Committee 2006 "*I would venture to suggest now that I do not believe that any culling policy is sustainable in the long term*."
http://www.publications.parliament.uk/pa/cm200506/cmselect/cmenvfru/905/6020704.htm
[2]Prof David Macdonald, Letter to *The Guardian* 2006 "*The evidence is that a badger cull on a scale or level of efficiency that seems feasible will not solve cattle farmers' problem*"
http://www.guardian.co.uk/environment/2006/mar/10/guardianletters.conservationandendangeredspecies
[3]Prof Tim Roper, Press release on behalf of the Mammal Society 2006 "*While we understand the farming community's concerns, we believe the available evidence does not justify a policy of badger culling*" http://www.abdn.ac.uk/mammal/badgercull_press.shtml
[4]Lord Krebs, Discussions in House of Lords 2007 "*We now know from reading the report of the Independent Scientific Group that culling is not a viable policy option. There is no wriggle room.*"
http://www.publications.parliament.uk/pa/ld200607/ldhansrd/text/70726-0001.htm

economic or other practical issues" (Environment, Food and Rural Affairs Committee, 2007). We consider this distinction critical, as we believe it partially explains the difference between our conclusions and those of King *et al.* (2007).

ISG11 We recognise three major reasons why the "*economic* [and] *other practical issues*" excluded from King *et al.*'s (2007) terms of reference should be given detailed consideration in any scientific discussion of future TB control policy. (i) Although our findings suggest that, in principle, modest reductions in the overall incidence of cattle TB would result from simultaneous, coordinated and repeated culls of badgers over extremely large areas of the countryside, using skilled staff and ideally within geographical barriers to badger movement, trying and failing to achieve this is likely to make matters worse, increasing the incidence of disease in cattle and spreading infection to new areas. As discussed in our final report (Bourne *et al.*, 2007), it is highly unlikely that coordinated culls could be conducted simultaneously and repeatedly across hundreds of square kilometres – especially since Defra's Wildlife Unit was dissolved – whereas our work shows that culling which is asynchronous, patchy, small scale or discontinuous is likely to increase rather than reduce the incidence and spatial spread of disease (Donnelly *et al.*, 2007; Donnelly *et al.*, 2003; Woodroffe *et al.*, 2006b; Jenkins *et al.,* 2007). (ii) There are too few natural geographical barriers to badger movement in TB-affected areas of Britain to contribute to national control strategies, while building and maintaining artificial barriers would be extremely costly and highly impractical on the scale at which TB control is needed (Bourne *et al.*, 2007; Poole *et al.*, 2002). (iii) Even if benefits were achieved by culling, our results indicate that these would be modest in comparison with the substantial financial costs of conducting the widespread culls that would be required. These three issues illustrate the critical importance of the "*economic* [and] *other practical issues*" excluded from Sir David King's remit. Our own consideration of these issues was based on systematic evaluation of ecological and epidemiological data derived from the RBCT and other studies, and our conclusions were reinforced by economic data. We feel that it would have been very difficult for Sir David and his team to reach meaningful policy recommendations without similarly detailed consideration of such issues, and it is therefore unfortunate that their terms of reference were so narrow.

Interpretation of scientific data, statistical analyses, and modelling results

ISG12 In addition to this broad concern about the Chief Scientific Adviser's terms of reference, we wish to express six major concerns about the scientific basis of King *et al.*'s (2007) report. These concern (i) incorrect use and interpretation of statistical confidence intervals in subgroup analysis; (ii) inappropriate exclusion of data accrued between the first and second proactive culls; (iii) failure to consider or cite the ecological data and analyses relevant to our conclusions; (iv) misunderstanding of our mathematical modelling work and its implications; (v) incorrect interpretation of our conclusions regarding temporal trends in the effects of culling; and (vi) over-reliance on assumptions concerning the effects of culling on transmission among badgers. These major issues are addressed below; a point-by-point response to King *et al.*'s (2007) report is provided in an Appendix to this document. This report is also accompanied by copies of three scientific papers describing findings from the RBCT, which have been published in the peer-reviewed literature since publication of our final report (Jenkins *et al.*, 2007; Pope *et al.*, 2007b; Woodroffe *et al.*, 2007). Key findings reported in these three papers were cited in our final report (Bourne *et al.*, 2007), referring to the papers as "in press" (in the case of Woodroffe *et al.*), "in review" (in the case of Jenkins *et al.*) or citing a report to Defra (in the case of Pope *et al.*).

(i)   *Interpretation of statistical confidence intervals in subgroup analysis*

ISG13 King *et al.* (2007) place great weight on interpretation of results presented in Figure 5.2B of our final report (Bourne *et al.*, 2007). This figure shows the results of a subgroup analysis, stratifying overall RBCT results into beneficial and detrimental effects recorded at different

distances from the boundaries of proactive trial areas. As is often the case in scientific studies, each effect was presented as a point estimate, associated with 95% confidence limits. The latter give a measure of the uncertainty associated with the point estimate; there will be substantial uncertainty when small sample size prevents a precise estimate from being obtained from a subset of the data.

ISG14 In paragraph 43 of King *et al.* (2007), the detrimental effect of badger culling on cattle TB incidence outside culling area boundaries is dismissed since "*Three out of four* [confidence intervals] *go through zero (i.e. one cannot be confident that the overall effect is detrimental)*". This interpretation is incorrect, as it omits one very crucial proviso in the interpretation of our subgroup analysis. The limits attached to any subgroup of data concern what can be learned from that subgroup of data on its own. While it is useful to know this, it is rarely the primary focus of analysis, and was not so in this case. Indeed if the data are broken into a large number of small subgroups, each on its own will have substantial uncertainty and be indecisive on any issue of concern, even if the overall picture is entirely clear on the point under study, as was the case here. The overall picture must be studied, not fragments of it. This is what we have done in all our analyses, subject to tests of the uniformity of the effect under study.

ISG15 In the interests of consistency, we note that the same analysis showed that all five of the subgroup estimates of beneficial effects of culling inside proactive areas had confidence intervals which included zero. Thus, were the same (erroneous) interpretation to be placed on those findings, evidence of the beneficial effects of culling should likewise have been dismissed.

(ii) *Exclusion of the first year of data post-culling*

ISG16 In our published accounts of the effects of proactive culling on cattle TB incidence (Donnelly *et al.*, 2007; Donnelly *et al.*, 2006), we provided estimates of culling effects following completion of the first proactive cull, and also following the second cull; the latter analyses excluded roughly a year of data accrued in each triplet between the first and second culls. King *et al.* (2007) chose, where possible, to present results from the second cull only, noting in paragraph 29 that our use of the full data set to assess detrimental impacts outside culling areas might "*overestimate the effect*". In fact, there is no such bias toward overestimation, nor do King *et al.* (2007) put forward any case for such a bias. Since cattle in RBCT areas were tested annually but not simultaneously, some breakdowns detected in the first year would have originated from infections which occurred prior to culling, and some infections which occurred in the first year would not be detected as breakdowns until the second year. Contrary to King *et al.*'s (2007) statement, this would make culling and no-culling areas appear more similar in the first year: the estimated effects on the incidence of detected breakdowns – whether beneficial or detrimental – would be smaller than the underlying effects on the incidence of new infections in this time period. This is important because the exclusion of this initial time period, which cannot be justified on the basis of any bias toward overestimation, appears to have contributed to King *et al.*'s (2007) tendency to downplay the importance of detrimental effects.

ISG17 Paragraphs A16 and A41-A44 in the Appendix give more in-depth interpretation of results from different time periods.

(iii) *Failure to consider ecological data*

ISG18 King *et al.* (2007) dismiss detrimental effects of badger culling on cattle TB as "*hard to interpret*" and "*unsound*", noting that they were "*not fully persuaded by*" our explanation for these effects. In this context, it is unfortunate that King *et al.* (2007) appear to have considered only a part of the wealth of ecological data that we have published on the impacts of culling on badger abundance, distribution, ranging behaviour and infection status, citing

none of our primary papers on these issues. This work shows that badger culling prompted immigration into culled areas (Woodroffe *et al.*, 2007) as well as disruption of badger territories and expanded ranging (Pope *et al.*, 2007b; Woodroffe *et al.*, 2006a). These ecological changes were associated with reduced clustering of infection in both badgers and cattle (Jenkins *et al.*, 2007), and also with elevated prevalence of *M. bovis* infection in badgers in both proactive and reactive culling areas (Bourne *et al.*, 2007; Woodroffe *et al.*, 2006b). These ecological findings are consistent with, and hence support, our observation of elevated cattle TB incidence on land neighbouring proactive culling areas, and in reactive areas.

ISG19 King *et al.*'s (2007) failure to give full consideration to the ecological data is important as it may have given them an incomplete or biased picture of badger ecology and *M. bovis* epidemiology, leading to inappropriate conclusions and recommendations. For example, the recommendation to "*reduc*[e] *the migration of badgers into the removal area by ...soft boundaries (such as arable land with no cattle)*" is unsupported by any ecological data and highly unlikely to be effective.

(iv)   Conclusions of our mathematical modelling work

ISG20 King *et al.* (2007) discuss the conclusions of our mathematical modelling work (Cox *et al.*, 2005), on which we based our conclusion that "*the rising incidence of disease can be reversed, and geographical spread contained, by the rigid application of cattle-based control measures alone*" (Bourne *et al.*, 2007). We used this model essentially to estimate how close the epidemic is to criticality and hence to infer the likely consequences of policy action, including controls aimed at cattle. Of course all such modelling is based on highly idealised assumptions but it, combined with careful study of all the relevant data that have been collected, is the only rational basis for assessing the likely consequences of policy actions not yet undertaken.

ISG21 Unfortunately, King *et al.* (2007) have misinterpreted this work. Cox *et al.* (2005) present an explicitly two-species model and the R_0 estimates obtained do not, as stated in paragraph 11 of King *et al.* (2007), refer to cattle-to-cattle transmission alone. Rather, these estimates are for cattle within the badger-cattle disease system, and thus represent contributions from both cattle-to-cattle and badger-to-cattle transmission. Indeed, equations 13 and 14 in Cox *et al.* (2005) present analytical solutions based on two different assumptions regarding disease levels in the badgers, the first that the badger disease levels stay constant and the second that they follow the increasing pattern observed in cattle. These equations give indistinguishable fits to the data, and so the true situation cannot be inferred. The important issue for the conclusions presented in Cox *et al.* (2005) is that the estimates of R_0 are essentially identical. We agree with King *et al.* (2007) that the levels of badger-to-cattle and cattle-to-cattle transmission are likely to vary considerably throughout the UK. However, if the incidence of cattle TB in low incidence areas is driven largely by the epidemic in the South-West of England then the growth rate, and thus the R_0 estimates, for both areas will be similar.

ISG22 We are concerned that the failure by King *et al.* (2007) to fully appreciate the structure of this important modelling work, and the estimates obtained from it, will have led them to under-estimate the potential for reducing the incidence of cattle TB in Britain using cattle-based measures alone.

(v)   Conclusions regarding temporal trends in the effects of culling

ISG23 In paragraph 37 of their report, King *et al.* (2007) raise the possibility that detrimental effects of badger culling on badger ranging and disease transmission might be "*transient*", indicating that we did not consider this possibility. This is incorrect; several of our papers present and discuss evidence for temporal trends in the effects of culling. This issue is discussed in detail in paragraphs A28-A30 below.

ISG24 King *et al.* (2007) restrict their discussion to the transience (or otherwise) of disruption to badger spatial organisation; as detailed in paragraph A30 below, there is evidence to suggest that such ecological effects were sustained in proactive culling areas. However, as discussed in Donnelly *et al.* (2007), the possibility remains that detrimental effects on cattle TB could be transient – or at least of smaller magnitude following later culls when sustained reductions in badger densities have been achieved – despite continued disruption of badger ecology. We believe that the likely outcome of future TB control options involving badger management can be reliably predicted only through separate, but parallel, consideration of effects on cattle and badgers.

(vi)   Capacity to reduce badger-to-badger transmission by culling

ISG25 King *et al.* (2007) note that "*the likelihood of uninfected badgers being exposed to infectious badgers will... be reduced* [by culling]" (paragraph 38). While such an effect would be expected in the randomly-mixing populations assumed in simple epidemiological models, more complex effects can occur in socially structured populations (Keeling & Eames, 2005). In fact, published data suggest that the substantial reductions in badger density which were achieved by proactive culling (Woodroffe *et al.*, 2007) increased badger-to-badger transmission of infection rather than reducing it (Bourne *et al.*, 2007; Woodroffe *et al.*, 2006b). The likely reasons for this pattern are detailed in paragraph A31 below.

ISG26 Although suppression of badger densities to extremely low levels (substantially lower than those achieved in the RBCT) would be expected to reduce badger-to-badger transmission of infection, no data are available on the densities at which this might be achieved in TB-affected areas of Britain. However, evidence for widespread cattle-to-badger transmission (Jenkins *et al.*, 2007; Woodroffe *et al.*, 2006b) suggests that even extremely low-density badger populations would rarely remain TB-free. Hence, data do not support King *et al.*'s (2007) characterisation of culling as an "*intervention...*[to] *reduce the prevalence of disease in... wildlife*" (paragraph 5).

Conclusions

ISG27 In summary, King *et al.* (2007) appear to have given incomplete consideration both to the scientific data and to the wider issues critical for determining the likely outcomes of particular approaches to the management of bovine TB. In addition, we have major concerns about their interpretation of our scientific data. Thus, we are not persuaded by the arguments in their report and stand by our conclusion that "*badger culling can make no meaningful contribution to cattle TB control in Britain*" (Bourne *et al.*, 2007).

Appendix: Detailed responses to King *et al.* (2007) *(by paragraph number)*

Paragraph 5

A1   King *et al.* (2007) refer to the need for an intervention that would *"reduce the prevalence of disease in both cattle and wildlife"*. Detailed analysis of the prevalence of *M. bovis* infection among badgers culled in the RBCT demonstrated that prevalence was <u>increased</u> following both proactive and reactive culls, where prevalence is the proportion affected (Bourne *et al.*, 2007; Woodroffe *et al.*, 2006b). We note that Sir David King's oral evidence to the Environment, Food and Rural Affairs Committee suggests that his team were envisaging a policy entailing reductions in badger density (i.e. the numbers of badgers per unit area) similar to those achieved in the RBCT (Q407, Environment, Food and Rural Affairs Committee, 2007). In this context, and in the absence of any data on the level to which population densities would need to be suppressed in order to reduce disease transmission among badgers in TB-affected areas of Britain, we do not consider badger culling able to fulfil King *et al.*'s (2007) criteria for appropriate intervention.

A2   Proactive culling, as conducted in the RBCT, substantially reduced the density of badgers (Woodroffe *et al.*, 2007), and thus it probably reduced the density of *M. bovis* infected badgers despite increased prevalence. However localised reactive culling produced smaller reductions in overall badger density (Woodroffe *et al.*, 2007) yet was still associated with elevated prevalence (Bourne *et al.*, 2007); hence the density of infected badgers may not have been reduced and could have been increased.

Conclusions – Third Bullet Point

A3   We believe that clarity is critical to this scientific debate, and therefore note that the statement that *"removal of badgers is the best option... to reduce the reservoir of infection in wildlife"* is imprecise and potentially misleading. *"Reduc*[ing] *the reservoir of infection in wildlife"* could refer to reducing wildlife density, to reducing the prevalence of infection within the wildlife population, or to both. If this wording is intended to refer to a reduction in the prevalence of infection in wildlife, then it is erroneous: as described in paragraphs ISG25 and A1 above, there is strong evidence showing that RBCT culling increased, rather than reduced, the prevalence of infection in badgers (Bourne *et al.*, 2007; Woodroffe *et al.*, 2006b). If the wording is intended to refer to a reduction in the density of badgers, it is important to recognise the very strong evidence that such a reduction could decrease <u>or increase</u> TB risks to cattle (or both, Donnelly *et al.*, 2006; Donnelly *et al.*, 2003), depending on the form of culling. There is consistent evidence that if badger culling were to be conducted in a patchy, inefficient, or uncoordinated manner, then subsequent risks of transmission to cattle would probably be no lower – and could possibly be higher – than they were before culling even though badger densities were being suppressed (Bourne *et al.*, 2007).

Conclusions – Fifth Bullet Point

A4   We are unsure of the evidence used by King *et al.* (2007) to select 100 km^2 as the minimal area for badger removal. While this was the scale of RBCT areas, it was clear from our analyses that, when surrounding areas were also considered, the benefits within the 100 km^2 culled area were largely offset by the detrimental effects on surrounding land (Donnelly *et al.*, 2007). Two extrapolations that we considered could be supported by the RBCT data indicated that the minimal area required to obtain a statistically significant overall benefit was either 265 km^2 (Paragraph 5.41 and Figure 5.4A in Bourne *et al.*, 2007) or 455 km^2 (Paragraph 5.42 and Figure 5.4B in Bourne *et al.*, 2007), depending on the assumptions used. Any such extrapolation requires untestable assumptions (by the very definition of extrapolation), yet it is clear from the RBCT data that 100 km^2 is too small an area to be confident of an overall beneficial effect on cattle TB incidence.

Conclusions – Ninth Bullet Point

A5   As noted in paragraphs ISG13-ISG15 above, we strongly disagree with King *et al.*'s (2007) statement that the evidence for a detrimental effect is limited to the area between 0.5 and 1 km outside the removal area.

A6   Further, on the basis of RBCT and other data we consider it highly unlikely that the "*soft boundaries*" mentioned would either "*reduc[e] the migration of badgers into the removal area*" as stated, or markedly reduce detrimental effects on neighbouring land. These arguments are outlined in paragraphs ISG19 and A34-A35 of this document.

Conclusions – Tenth Bullet Point

A7   While King *et al.* (2007) recommend monitoring of cattle TB incidence in the proposed culling areas, we are concerned that no detailed consideration has been given to the precision of the analysis of such monitoring data. Without knowing the spatial extent over which any such culling would occur, it is impossible to provide statistical guidance. More importantly, it would be extremely difficult to obtain reliable estimates of the effects of culling on TB incidence (particularly any detrimental effects in neighbouring areas) if no unculled comparison areas were available. Indeed, this is one of the reasons why Krebs *et al.* (1997) recommended that a randomised controlled experiment be conducted, on an appropriate temporal and geographical scale, to evaluate the impacts of badger culling on cattle TB.

Paragraph 11

A8   As noted in paragraphs ISG20-ISG22 above, the results of Cox *et al.* (2005) have been misinterpreted.

Paragraph 14

A9   King *et al.* (2007) comment that "*...cattle movements alone cannot explain the persistence of the geographically compartmentalised areas of high incidence of cattle TB, nor their gradual expansion over the last decade...*" but provide no evidence in support of this statement. In considering the potential contribution of cattle movements to the geographical spread of TB, it is worth noting that, in western England and Wales, 43% of cattle movements occur over a distance of less than 20km (Mitchell *et al.*, 2005). Hence, cattle movement is likely to contribute to local as well as long-distance spread of infection.

Paragraph 24

A10   This paragraph notes that "*most of the areas had only four removal operations*". This is incorrect. The number of proactive culls conducted in each triplet were: A 5 culls, B 7 culls, C 6 culls, D 4 culls, E 6 culls, F 5 culls, G 5 culls, H 5 culls, I 4 culls, J 4 culls, giving a mean of 5.1 and a mode of 5 culls per triplet.

A11   Consideration is given in this paragraph to the non-significant trend for the benefits of culling within trial areas to increase on later culls. While mathematical modelling could be used to extrapolate the likely benefits of conducting further annual culling operations, this would again require untestable or uncertain assumptions (including, but not limited to, how badger recolonisation and birth rates might change with repeated culling, what proportion of breakdowns were due to badger-to-cattle transmission, and how badger ranging behaviour might change with badger density). While detailed mathematical models of the cattle-badger disease system have been constructed (e.g. Smith *et al.*, 2001), considerable detailed sensitivity analyses of parameter values and model structure would be required before their predictions of future benefits could be considered reliable.

Paragraph 25

A12   The RBCT did demonstrate that repeated culling carried out by skilled members of the Defra Wildlife Unit delivered significantly decreased TB incidence in cattle within the 100km^2

RBCT trial areas (Donnelly *et al.*, 2006). However, these beneficial effects were accompanied by detrimental effects in neighbouring areas (Donnelly *et al.*, 2006).

A13 With regard to extrapolation of effects of culling over larger areas, paragraphs 5.41-5.42 and Figure 5.4 of Bourne *et al.* (2007) provide what we consider to be reliable extrapolations from our results.

Paragraph 27

A14 We are unsure why the increased incidence of cattle TB observed on land neighbouring RBCT trial areas was judged "*hard to interpret*". We have published a body of research on this issue and the evidence is considered "*substantial*" and "*strong*" by scientific authorities (e.g. Royal Society, 2006; Shepherd, 2005; Shepherd *et al.*, 2005). We have published a number of peer-reviewed papers showing that culling leads to disrupted territorial organisation and expanded ranging by badgers (Pope *et al.*, 2007b; Woodroffe *et al.*, 2006a), as well as immigration of badgers into culled areas (Woodroffe *et al.*, 2007). These ecological changes are associated with reduced clustering of infection in both badgers and cattle (Jenkins *et al.*, 2007), and with increased prevalence of infection in badgers (Bourne *et al.*, 2007; Woodroffe *et al.*, 2006b). The causality of the relationship between culling-induced changes in badger ecology and increased TB incidence in cattle is suggested not only by these broad patterns, but also by details including modification of the effects by factors such as geographic barriers to badger movement, and the practice of non-simultaneous culling (Woodroffe *et al.*, 2006b). Indeed, it was the observation of expanded ranging by badgers living immediately outside proactive culling areas (Woodroffe *et al.*, 2006a) that prompted us to investigate cattle TB incidence on these lands (Donnelly *et al.*, 2006). It is unfortunate that none of this ecological work is cited by King *et al.* (2007).

A15 King *et al.* (2007) go on to recommend that "*measures... should be put in place to minimise that increase* [in cattle TB]". This appears to ignore the detailed consideration in paragraphs 10.8-10.48 of Bourne *et al.* (2007) which concludes that no practical measures are likely to be able to achieve this. Further details are given in paragraphs A33-A35 below.

Paragraph 28

A16 As mentioned in paragraph ISG16 above, we consider it inappropriate to exclude data from the period between the first and second culls. The reason for this is detailed in the peer-reviewed Supplementary Information of Donnelly *et al.* (2006), which we reproduce here:

"Interpretation of analyses from different time periods
The main text presents analyses from two time periods, one dating from the completion of the initial cull (which shows statistically significant effects both inside and outside trial areas), and one dating from completion of the first follow-up cull (which shows a significant effect inside, but a non-significant trend outside). The reasons for considering these two time periods, and their implications for the interpretation of our findings, merit further comment. We used incidence from the date of the initial cull as our primary analysis, mainly because this measure is the most relevant to policy: the effects detected reflect what one could expect to achieve from a proactive culling policy implemented on the timescale measured. As described briefly in the main text, there were two reasons for performing secondary analyses which excluded data from before the first follow-up cull. First, this excluded breakdowns that might have originated prior to the onset of culling, even though (given annual testing) they were not detected until after culling had begun. Such breakdowns would lead to under-estimation of culling-induced effects on incidence in the first year – essentially this would bias estimates of increases or reductions toward no effect. Our findings of statistically significant effects dating from completion of the initial cull, both inside and outside trial areas, therefore indicate the strength of both positive and negative effects of culling.

An additional reason for performing the secondary analyses was that a more complete badger removal would have been achieved from the date of the first follow-up cull (see Section 1 above). This more complete cull would be expected to generate a greater reduction in cattle TB inside trial areas, and the results of the secondary analysis are indeed consistent with this prediction, albeit with a wider confidence interval due to the smaller dataset.

In contrast with the situation inside trial areas, however, the circumstances of incomplete badger removal that would have occurred between the initial cull and the first follow-up could be expected to increase any detrimental effects of culling, if such effects were caused by disruption of badger territorial organisation at artificially reduced population densities. The frequency of potentially infectious contacts between cattle and badgers will be related to both the density of badgers, and the ranging behaviour of those badgers. We have hypothesised that, where densities are substantially reduced, contact rates will be reduced despite expanded ranging behaviour, but that smaller reductions in density will generate increased contact rates if (as observed) they are also accompanied by expanded ranging. In this scenario, we would expect detrimental effects to be particularly marked following the initial cull since densities were probably reduced to a lesser extent during this period. Our secondary analysis excluded this potentially important time period and this, along with the reduced sample size, helps to explain why the culling effect in 'neighbouring areas' was found to be weaker."

Paragraph 29

A17 As noted by King *et al.* (2007), "*the detrimental effect was not spread over all of the area* [up to] *2km outside the removal area*" although we wish to clarify that the analyses to which this comment refers considered distance from the boundary of the trial area, rather than the treatment area (Donnelly *et al.*, 2007). Trial area boundaries were delineated mainly along property boundaries, so that herds could in principle be classified unambiguously as located inside or outside the trial area. Treatment areas, within which culling was conducted, were slightly larger than trial areas, and delineated according to the estimated boundaries of social group territories so that all badgers using farms inside the trial areas could be targeted (Bourne *et al.*, 2007). As a consequence, some culling was conducted on land immediately adjoining trial areas, but outside their boundaries, and this almost certainly explains the (non-significant) beneficial effect of proactive culling among herds on land 0-0.5km outside RBCT trial areas.

A18 Our decision to analyse data from all land up to 2km outside trial areas (except when it was within 2km of more than one trial area), rather than treatment areas, was a deliberate one, taken to be conservative and to avoid any accusations that data were selected or excluded in order to obtain a particular result. However, the occurrence of apparently beneficial effects within 500m of the trial area boundary would be expected to offset, to some extent, the detrimental effects observed at greater distances and could therefore lead to under-estimation of detrimental effects on unculled land.

A19 To provide further clarity on this point, we have repeated our analyses of the incidence of cattle TB on land up to 2km outside trial area boundaries, excluding herds occupying land outside the trial area but inside the treatment area. These analyses, which are presented in Table 1 below, reveal estimated detrimental effects slightly stronger than those reported in our published papers. These results confirm that our inclusion, in primary analyses, of herds outside the trial areas but inside the treatment areas was conservative and probably led to slightly under-estimation of detrimental effects on unculled land.

A20 As discussed in paragraphs ISG13-ISG15 above, it is inappropriate to judge the overall detrimental effect of culling by considering confidence intervals for individual subgroups of data. Also, as noted in paragraphs ISG16 and A16 above, and in paragraphs A40-A44 below, we consider it appropriate to include all data, from the completion of the initial proactive cull, in primary analyses of the effects of culling.

Table 1 – Comparison of estimated detrimental effects of proactive badger culling on the incidence of cattle TB on farms up to 2km outside RBCT areas, when herds falling outside the trial areas but inside the treatment areas are included (as in our published analyses, Bourne *et al.*, 2007; Donnelly *et al.*, 2007) or excluded. Confidence intervals and p values are adjusted for overdispersion as described in our published work.

Time period	INCLUDING herds inside treatment area		EXCLUDING herds inside treatment area	
	estimated effect (95% CI)	*p*	*estimated effect (95% CI)*	*p*
Using VetNet location data				
First cull to one year after last cull	24.5% (-0.6 – 56.0%)	0.057	29.3% (1.1 – 65.3%)	0.040
Second cull to one year after last cull	19.6% (-10.3% – 59.5%)	0.22	23.1% (-7.9 – 64.6%)	0.16
First cull to second cull	46.8% (-0.4 – 116.4%)	0.052	57.0% (-4.3 – 157.5%)	0.074
Using RBCT location data				
First cull to one year after last cull	35.3% (5.8 – 73.0%)	0.016	43.8% (9.1 – 89.6%)	0.010
Second cull to one year after last cull	24.9% (-7.2 – 67.9%)	0.14	35.5% (-1.1 – 85.5%)	0.058
First cull to second cull	95.4% (10.5 – 245.5%)	0.021	95.0% (3.3 – 264.3%)	0.039

Paragraph 30

A21 King *et al.* (2007) found it "*hard to compare data*" from our report as "*figures are presented as percentages rather than as absolute numbers of herd breakdowns*". We are surprised at this concern. It is standard to report percentage differences in risks, and then for these to be translated into absolute numbers for specific considerations, such as cost benefit analyses. Indeed, we give specific calculations for 100km^2 areas in Bourne *et al.* (2007) paragraph 5.39. These indicate that, over a five-year period of culling, 116 fewer confirmed breakdowns would have occurred within 10 circular 100km^2 areas, and 102 additional breakdowns would have occurred in the 10 associated 83.5km^2 neighbouring areas. This gives a net overall benefit of 14 fewer confirmed breakdowns (Donnelly *et al.*, 2007). Detailed consideration of the costs and benefits of this scale of operation was presented in Chapter 9 of Bourne *et al.* (2007).

A22 King *et al.* (2007) suggest that the potential role of cattle herd densities was not considered in our analyses. In fact, the inclusion of the (ln transformed) number of herds as an independent variable in our log-linear regression analyses allowed us to characterise the relationship between herd density and the incidence of cattle TB, since all trial areas were of similar size.

A23 The full raw data on the numbers of herds, breakdowns and historic breakdowns were provided in supplementary data files published with both papers on the effects of proactive culling (Donnelly *et al.*, 2007; Donnelly *et al.*, 2006). While we did not specifically report herd densities (per km^2, for example) in Bourne *et al.* (2007), we did provide the number of cattle herds at baseline in Tables 5.1 and 5.7, and the sizes of trial areas are given in the peer-reviewed Supplementary Information of Donnelly *et al.* (2006). Hence, relevant data have been publicly available since December 2005 (when Donnelly *et al.* (2006) was published online), allowing interested parties to examine herd density effects in further detail had they so wished.

Paragraph 31

A24 As noted in paragraphs A33-A35 below, King *et al.*'s (2007) comment that "*the overall beneficial effect on incidence of cattle TB will be maximised if steps are taken to minimise that detrimental effect*" fails to take account of the absence of practical measures likely to minimise detrimental effects.

A25 As noted in paragraph A7 above, we are concerned that it would be extremely difficult to obtain reliable estimates of the effects of badger culling on the incidence of cattle TB by "*monitoring of these effects up to 2 km outside the removal area*" if no comparable unculled comparison areas were available. Indeed, this is one of the reasons why Krebs *et al.* (1997) recommended that a randomised controlled experiment be conducted to measure the impact of badger culling on cattle TB.

Paragraph 33

A26 We consider the evidence for the reduction in badger density achieved through proactive culling to be considerably stronger than "*an informed guess*". Multiple indices of badger abundance gave similar estimates of the impact of proactive culling (Woodroffe *et al.*, 2007). Several of these indices were based on densities of badger field signs; these were shown to correlate with the numbers of badgers captured per unit area on initial culls, indicating that they are likely to be reasonable measures of badger abundance (Woodroffe *et al.*, 2007). Another index used, the density of road-killed badgers retrieved, is a more direct measure of badger abundance and gave similar results (Woodroffe *et al.*, 2007). Improved methods for measuring badger density were developed while the RBCT was in progress (Frantz *et al.*, 2004; Hounsome *et al.*, 2005; Wilson *et al.*, 2003) but were not available at the start of the study and so could not be used to monitor culling effects throughout the course of the study. Nevertheless we consider the close agreement between estimates based on different measures to indicate that the effects of culling on badger density were estimated reasonably reliably (Woodroffe *et al.*, 2007).

Paragraph 36

A27 King *et al.* (2007) rightly note that clustering of *M. bovis* infection in badgers "*was disrupted over the course of the trial and... the prevalence of infection in badgers... increased*". Their report fails to note, however, that similar changes in the clustering of infection were also observed in cattle: in reactively culled areas, and on land neighbouring proactively culled areas, cattle infections became less clustered as successive badger culls were conducted (Jenkins *et al.*, 2007). This change in the geographical distribution of cattle infections reflects expanded ranging behaviour by badgers in the same areas (Woodroffe *et al.*, 2006a), contributing to the large body of evidence linking detrimental effects of culling to disruption of badger social organisation.

Paragraph 37

A28 The conclusions reached in this paragraph are difficult to interpret since it is not clear whether they refer to badger populations inside the culling areas, to those immediately outside, or to both. In either case, the statement that "*The ISG considered that the disruption of badgers and the increased ranging behaviour was a permanent effect... However, there is a reasonable possibility that the disruption is transient*" is misleading in that it implies that the ISG gave no consideration to temporal trends. In fact, Woodroffe *et al.* (2006b), Woodroffe *et al.* (2007) and Pope *et al.* (2007a) sought evidence for temporal trends in the effects on badgers, Donnelly *et al.* (2007) and Bourne *et al.* (2007) sought evidence for temporal trends in the beneficial and detrimental effects on cattle, and Jenkins *et al.* (2007) evaluated temporal trends in the relationship between infections in the two host species. In particular, the Discussion section of Donnelly *et al.* (2007) includes several paragraphs proposing an ecological mechanism that might explain the temporal trends observed in cattle.

A29 The first investigation of any transience of the effects on cattle was not a "*simple regression*" as stated, but rather a detailed consideration of the stratified data presented in Figure 5.2A of Bourne *et al.* (2007). Any modelling beyond the linear regression suggested by the pattern observed over the first four culls would require untestable assumptions and would thus be unlikely to give consistent results over the possible range of parameter values and model structures consistent with the known data. The evidence of the RBCT is clear over the first four annual culls.

A30 While King *et al.* (2007) are correct that "*the data do not discount this theory*" [that disruption of badger spatial organisation is transient] <u>outside</u> culling areas where data are limited, data from <u>inside</u> culling areas suggest that disruption was sustained. As successive proactive culls were conducted, an increasing proportion of badgers were captured close to culling area boundaries, indicating sustained badger immigration into culled areas with no

evidence of this effect levelling off on later culls (Woodroffe *et al.*, 2007). Genetic studies likewise show an increasing proportion of the badger population engaging in long-distance movements following successive culls, confirming sustained disruption of badger populations (Pope *et al.*, 2007a). Finally, the prevalence of *M. bovis* infection among badgers rose, and the spatial distribution of infection became less clustered, on successive culls, once again with no evidence of lesser effects on later culls (Jenkins *et al.*, 2007; Woodroffe *et al.*, 2006b) despite declining badger density over the same time period (Woodroffe *et al.*, 2007). All of this evidence indicates that "*disruption of badgers*" was sustained throughout the course of the RBCT, contrary to King *et al.*'s suggestion. In contrast, evidence cannot discount the hypothesis that detrimental effects for cattle may have declined on later proactive culls (Donnelly *et al.*, 2007) as the suppression of badger densities was sustained. The reduction in spatial clustering of cattle infections likewise appears to have been greatest between the first and second culls (Jenkins *et al.*, 2007).

Paragraph 38

A31 As in paragraph 37 of King *et al.* (2007), it is not clear whether the conclusions reached in this paragraph refer to badger populations inside, or immediately outside, the culling areas. If they refer to badgers inside the culling area then, as detailed above, the statement that "*the likelihood of uninfected badgers being exposed to infectious badgers will... be reduced, ideally to a level at which TB cannot sustain itself within the badger population*" is at odds with the available evidence, which has been published in peer-reviewed scientific journals. Woodroffe *et al.* (2006b) showed that the prevalence of infection among badgers <u>increased</u> as successive proactive culls depressed badger density (Woodroffe *et al.*, 2007). Moreover, the finding that these infections were also less spatially clustered on later culls (Jenkins *et al.*, 2007) is consistent with the hypothesis that disruption of badger spatial organisation led to increased badger-to-badger transmission (Woodroffe *et al.*, 2006a). While in principle it is to be expected that extremely low population densities would limit contact between badgers and, hence, badger-to-badger transmission of infection, there are no data to indicate the level of population reduction needed to achieve this in TB-affected areas of Britain. Moreover, there is evidence for widespread cattle-to-badger transmission in Britain (Jenkins *et al.*, 2007; Woodroffe *et al.*, 2006b), and this could well contribute to continued infection in very low-density badger populations despite low badger-to-badger transmission rates.

A32 As noted in paragraphs A2 and A3 above, substantially lowering badger density by sustained, simultaneous, coordinated culling across very large areas could reduce the incidence of cattle TB inside culled areas, even though the remaining badgers might experience increased prevalence of infection. However, since the relationship between badger density and TB risk to cattle is strongly non-linear, culling in smaller areas, for shorter time periods, or in an uncoordinated manner will all seriously undermine any beneficial effects of culling and have the potential to generate detrimental effects.

Paragraph 39

A33 All of the measures proposed in this paragraph were considered systematically in Chapter 10 of Bourne *et al.* (2007), and found to be unworkable. For example, we noted that too few existing barriers to badger movement occur in southern and western Britain for these to be used to delineate culling zones over a meaningful proportion of TB-affected areas, and that the mitigating effect of such barriers on the incidence of cattle TB (as opposed to infection prevalence in badgers) was unproven. We also drew attention to the cost of constructing badger-proof electric fences (Poole *et al.*, 2002), and the impracticality of fencing any but the smallest culling areas given the number of roads traversing the British countryside.

A34 We wish to comment in particular on the suggestion of using "*...soft boundaries such as arable land with no cattle...*" to minimise detrimental effects on cattle TB. This sort of approach – which we considered in paragraph 10.22 of Bourne *et al.* (2007) – would not

prevent disruption of badger populations immediately outside culling areas (since badgers regularly occupy arable land). However, this measure could reduce the impact of such disruption on cattle by ensuring that few or no cattle inhabited the areas where disease transmission from badgers was most likely.

A35 In our view, any such "*soft boundaries*" would have to be substantially wider than the 1km proposed. We observed changes in badger ranging behaviour, and detrimental effects on cattle TB, up to 2km outside RBCT trial area boundaries (Donnelly *et al.*, 2006; Woodroffe *et al.*, 2006a). Bait-marking studies can be used to derive conservative estimates of badger home range sizes inside proactively culled areas: the mean value was 0.77 km^2, equivalent to a circle with a diameter of approximately 1km. Adding one standard deviation to this mean home range size gives an area of 1.34km^2, equivalent to a diameter of about 1.3km. A 1km-wide band would therefore be fairly small in relation to the scale of badger ranging, and would be regularly traversed by local badgers. We therefore considered somewhat wider bands in Bourne *et al.* (2007). To illustrate the scale of effects, if culling were to be conducted within circular 100km^2 areas, each surrounded by a cattle-free buffer 2km wide, each buffer would cover 83.5km^2. Buffers would be proportionally smaller (though absolutely larger) for larger culling areas, and would also be larger where culling areas were not circular. We concluded that the costs (in the broadest sense) of excluding cattle from such large areas of the British countryside would be likely to out-weigh the benefits (Bourne *et al.*, 2007).

Paragraph 42

A36 This paragraph contains a statement fundamental to King *et al.*'s (2007) conclusions, namely that our own "*...view that this benefit* [of proactive culling] *was largely offset by the increase in incidence outside the removal area is unsound*". We consider this statement to be inconsistent with the data available. As discussed elsewhere in this document, King *et al.*'s downplaying of the detrimental effects of culling appears to be based upon a number of misunderstandings including inappropriate interpretation of confidence limits (paragraphs ISG13-ISG15), exclusion of data from the initial time period which cannot be justified on the basis of any statistical bias toward overestimation (paragraphs ISG16 and A16) or time delay between performing badger culling and detecting its effects (paragraphs A40-A44), and failure to take full account of ecological data which offer a plausible and consistent explanation for both the detrimental and beneficial effects observed (paragraph ISG18). In particular, the increased incidence of cattle TB observed in herds up to 2km outside proactively culled trial areas was a consistently observed phenomenon and, given its magnitude, largely offset the benefits of reduced TB incidence among cattle within proactively culled trial areas (Donnelly *et al.*, 2007). This offsetting is clearly demonstrated for culling areas up to 300km^2 in Figure 5.4 of Bourne *et al.* (2007).

Paragraph 43

A37 As mentioned in paragraphs ISG13-ISG15 above, counting how many confidence intervals of stratified analyses include zero is statistically inappropriate.

A38 The occurrence of some badger removal immediately outside RBCT trial areas, and the way in which data from these areas were included in analyses, should not have been "*unclear*" given the detailed descriptions of methodology provided in Bourne *et al.* (2007). The 'trial' and 'treatment' areas are defined in paragraphs 2.11 and 2.12, and illustrated in Figure 2.1. Paragraphs 5.5 and 5.25 indicate that primary analyses concerned herds inside or outside trial (rather than treatment) areas and paragraphs 5.15 and 5.33 make explicit reference to distances from the 'trial area boundary'. Moreover, paragraph 5.33 states that "*...herds... less than 0.5km outside the trial area boundary appeared to experience a benefit... this... was unsurprising, because badger culling extended just beyond the boundaries of the trial areas to target social groups judged... to occupy home ranges falling partially inside the trial areas...*".

A39 To provide further clarity on this point, we have repeated our analyses of the incidence of cattle TB on land up to 2km outside trial area boundaries, excluding herds occupying land outside the trial area but inside the treatment area. These results are presented in paragraph A19 above.

Paragraph 44-47

A40 King *et al.* (2007) note that "*it would be reasonable to expect... a time lag between removal of badgers and detection of changes in infection in cattle*" but that "*this time lag does not seem to have been taken into account when the ISG collected data on cattle TB incidence immediately after the first proactive removal*".

A41 Our reasons for including data between the first and second proactive culls in our primary analyses are detailed in paragraphs ISG16 and A16 above. Since we considered it likely that the effects of culling might change over time, our publications also presented estimates of effects from the date of completion of the second cull (Bourne *et al.*, 2007; Donnelly *et al.*, 2007; Donnelly *et al.*, 2006) and explicitly investigated changes across different time periods (Bourne *et al.*, 2007; Donnelly *et al.*, 2007). The suggestion that a possible time lag "*does not seem to have been taken into account*" is therefore incorrect.

A42 We discussed this possible time lag in detail in the peer-reviewed Supplementary Information of Donnelly *et al.* (2006). Available data indicate that such time lags could be short. This is because (i) behavioural data show that local reductions in badger density affect ranging behaviour within a few days or weeks (Cheeseman *et al.*, 1993; Roper & Lüps, 1993; Woodroffe, Macdonald & da Silva, 1995), allowing contact with additional cattle herds; and (ii) once infected, cattle become responsive to the tuberculin test after approximately three weeks (Thom *et al.*, 2006). Hence, if badgers can infect susceptible cattle rapidly on contact, increased cattle incidence would be detectable 2-3 months after badger culling.

A43 King *et al.* (2007) state that naturally-acquired infections entail longer delays to skin test responsiveness than do experimental infections, but provide no data to support this assertion. We are not persuaded that time to responsiveness could be estimated for natural cases since infection dates would be unknown. Thom *et al.* (2006) used infective doses of *M. bovis* that resulted in disease similar to that observed in naturally infected cattle, and we therefore consider their experimental findings the most reliable data currently available.

A44 We also wish to note that this concern about time delays refers to our hypothesis about the mechanism whereby badger culling prompts detrimental effects in cattle, not to the existence of detrimental effects themselves. Since there is strong and highly consistent evidence that detrimental effects occur, and since these are costly for farmers, for the farming industry, and ultimately for the taxpayer, it is vital that they be taken into account in developing TB control policy.

Paragraph 48

A45 As discussed in paragraphs ISG18-ISG19 and A14 above, we consider it unfortunate that King *et al.* (2007) state that they were "*not fully persuaded by*" our explanation for detrimental effects of culling yet fail to cite any of our peer-reviewed papers which provide strong support for this hypothesis. As noted in paragraph A14, there is consensus within the scientific community that evidence in support of our hypothesis is "*substantial*" and "*strong*" (e.g. Royal Society, 2006; Shepherd, 2005).

Paragraph 49

A46 As detailed in paragraphs A28-A30 above, the ISG gave explicit consideration to the possibility that the effects of culling might change over time.

Paragraph 50

A47 King et al.'s (2007) statement that RBCT data should not be used "*...to either support or rule out a reactive removal strategy...*" contrasts with their earlier conclusion that "*...the minimum overall area within which badger removal should take place is 100 km²*" (the average area targeted by reactive culling was 8.8km²).

A48 King *et al.* (2007) dismiss our findings regarding reactive culling, partly because this part of the RBCT was "*stopped before robust results could be obtained*". We note that the decision to halt reactive culling was taken by Defra ministers; the ISG had recommended that culling be continued while recognising that this might be difficult for Defra to justify (Bourne *et al.*, 2005).

A49 Despite this, the consistency of our original results (Donnelly *et al.*, 2003) with the findings of subsequent analyses indicate that our conclusions concerning reactive culling are indeed "*robust*". Subsequent analyses provide (i) evidence that detrimental effects occur on land neighbouring proactive culling areas (Donnelly *et al.*, 2006), making an overall detrimental effect predictable where culling areas are small and hence exceeded in extent by the areas of neighbouring land (Bourne *et al.*, 2007); (ii) evidence that the detrimental effect of reactive culling disappeared following cessation of culling, indicating that the effect was not due to a systematic bias between trial areas unrelated to reactive culling (Bourne *et al.*, 2007); (iii) evidence that herds located in close proximity to reactively culled land experienced elevated TB risk, even after controlling for the effect of contiguous breakdowns (Bourne *et al.*, 2007); (iv) evidence that repeated reactive culling was associated with spatial spread of infection in cattle (Jenkins *et al.*, 2007); and (v) evidence that repeated reactive culling, like proactive culling, was associated with elevated infection prevalence in badgers (Bourne *et al.*, 2007). This information indicates that it is extremely unlikely that a future reactive culling strategy could contribute to the control of cattle TB, and would probably exacerbate disease spread. Given this evidence we consider it remarkable that King *et al.* (2007) failed to "*rule out a reactive removal strategy*".

Annex 1

A50 In a comment about the use and interpretation of confidence intervals, King *et al.* (2007) comment that our inclusion of "*decimal points... may give the impression of more certainty than is the case.*" While we agree that the individual values make sense only to fewer digits, our reason for giving more in this case had a scientific basis: it was to allow any reader wishing to make some additional calculations with the limits to do so without appreciable loss of information from rounding errors.

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