Randomised Badger Culling Trial: How big was the perturbation effect?

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In a report issued to the UK government in 2007 on the Randomised Badger Culling Trial (RBCT), it was stated that the incidence of bovine tuberculosis (TB) in cattle increased in areas surrounding where badgers were removed. It is known that badger culling perturbs badgers and this leads to increased TB transmission in and around these treated areas. The increase in TB in the surrounding areas was attributed to this process.

In this study of the RBCT analysis it was found that large TB increases in areas surrounding proactively treated areas depended heavily on adjustments made for pre-cull history. This work looks at the basis for applying these adjustments. Since it is not possible to remove statistical error in the data, which confidence intervals suggest may have been large, it is argued that it was unsafe to apply these adjustments. As such it is argued that TB increases due to perturbation in the report presented to the UK government in 2007 may have been over-estimated.

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INTRODUCTION

Badger perturbation is the change in badger behaviour when badger populations are culled (Gibbens N, 2013). Badgers relocate as a consequence of badger removal and this has a negative impact on TB incidence due to increased contact between badgers. Randomised Badger Culling Trial (RBCT) findings have significantly influenced the perception of badger perturbation (Imperial College London, 2014). Almost all the 'evidence' for perturbation in badgers comes from the RBCT (Gibbens N, 2013). This was the status in February 2016.

This article is based on work first presented at www.bovinetb.info in July 2015. It shows an elementary and stripped down analysis of RBCT data acquired before, during and after badger culling performed between 1998 and 2005. This analysis avoids using a model and instead simply presents the underlying data broken down into simple steps. The data is presented after each step before arriving at calculated cull benefits. These calculated benefits are then compared with those obtained by the more involved model analysis performed by the Independent Scientific Group (ISG) who were charged with presenting results to government (Bourne FJ, 2007). The final discussion is designed to prompt questions as to why the data used in the ISG model was so limited. It also questions whether the model analysis over-estimates increases in TB incidence attributed to perturbation in the outer 2km ring which adjoined where badgers were removed.

DATA

The number of confirmed new herd incidents and the number of baseline herds were extracted from Tables S2 and S3 in Jenkins HE, Woodroffe R, Donnelly CA, 2008a. Culling in each triplet did not start in the same year so these numbers correspond to time periods which were staggered. In addition to this, the time periods were of varying length. Herd incidence, I_u, uncorrected for period length, were calculated as follows.

$$I_u = \frac{N_B \times 100}{N_H}$$

where

N_B = number of confirmed new herd incident breakdowns, and
N_H = number of baseline herds.

N_B was divided by 3 to give annual incidence for the 3-year historic precull period.

These calculated values are shown plotted in Fig. 1 below.

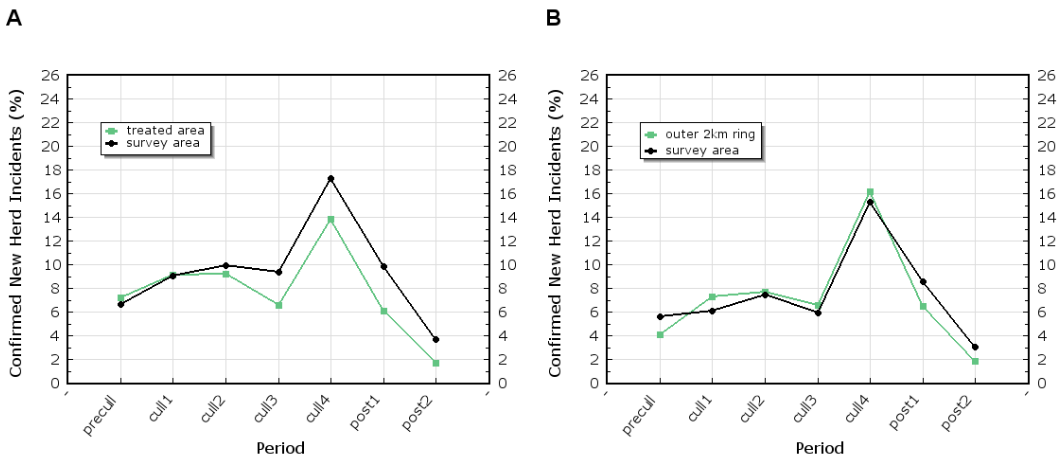

Figure 1. Uncorrected incidences in the treated area and its survey area (A) and in the outer 2km ring and its survey area (B).

DATA ANALYSIS

Adjustment for period length

The number of months in each reporting period, N_M, were calculated as follows.

$$N_M = \frac{12 \times N_Y}{N_T}$$

where N_Y = number of triplet-years, and
N_T = number of triplets = 10.

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These numbers are shown plotted in Fig. 2 below.

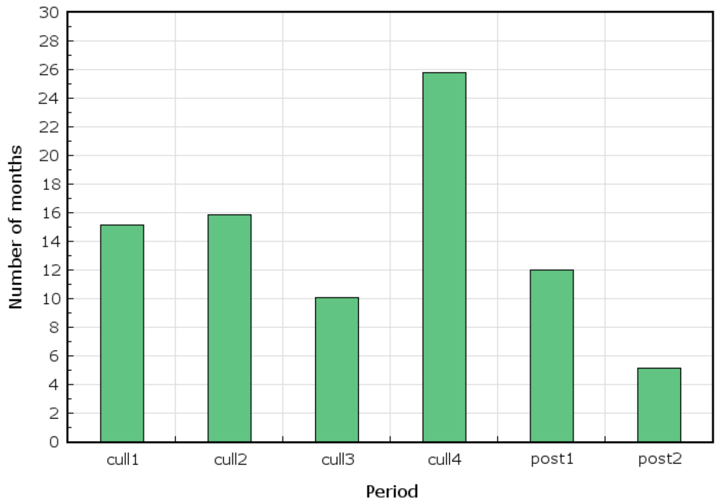

Figure 2. The number of months in each reporting period.

The number of months in the during-cull periods were calculated from the treatment-years taken from Jenkins HE, Woodroffe R, Donnelly CA, 2010. In the two post-cull periods, these numbers were taken from the overall post-cull triplet-years given to be 14.3 in Jenkins HE, Woodroffe R, Donnelly CA, 2008b. The duration of each of these post-cull periods was confirmed in email correspondence with Donnelly CA during August 2016. The periods are described in Tables 1 and 2 of Jenkins HE, Woodroffe R, Donnelly CA, 2008a as follows.

- cull1 - 1st to 2nd cull
- cull2 - 2nd to 3rd cull
- cull3 - 3rd to 4th cull
- cull4 - After 4th cull to end of during-trial period
- post1 - First year of post-trial period
- post2 - Second year of post-trial period

Fig. 3 below shows how each triplet contributed to each period in terms of the number of months herd breakdowns were included in the incidence for each triplet.

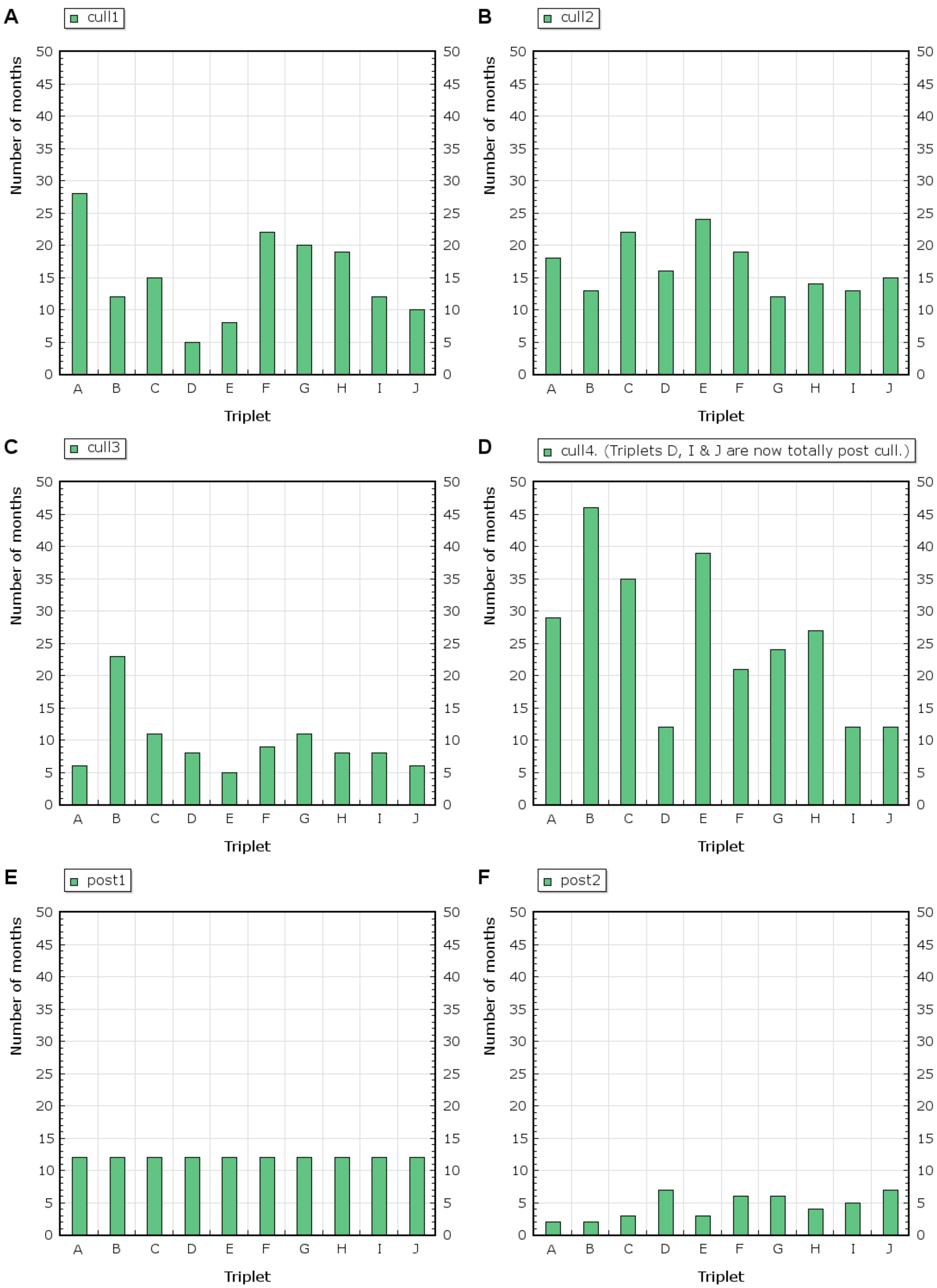

Figure 3. Contribution of each triplet to each period.
Dates were extracted from Table 2.3 in Bourne FJ, 2007.

The percentage of confirmed new herd incidence, I_a, at each period weighted to correspond to 12 months was calculated as follows.

$$I_a = \frac{N_T \times N_B \times 100}{N_Y \times N_H}$$

where N_T = number of triplets = 10
N_B = number of confirmed breakdowns
N_Y = number of triplet-years, and
N_H = number of baseline herds.

These annual incidences are shown plotted in Fig. 4 below.

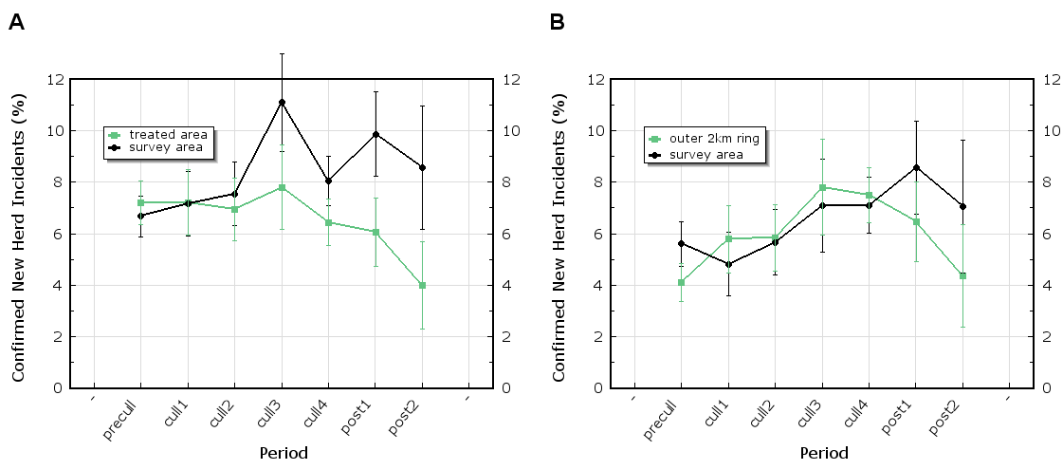

Figure 4. Annual incidences and 95% confidence intervals in the treated area and its survey area (A) and in the outer 2km ring and its survey area (B).

The 95% confidence intervals are large so the plotted values are expected to be subject to large statistical error.

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Adjustment for history

When an applied effect is referenced to a survey-only area, the overall disease profile in the survey-only areas needs to be comparable to that in the areas where the effect is being investigated. To account for any difference, incidences in the two areas can be adjusted so that they are referenced to the same historical precull reference. Such an adjustment would be valid if the statistical error is so small as to render the results to be independent of sample taken. It is better if this adjustment is zero in cases where statistical error may conceivably be large. Otherwise doubts will exist as to the source of the mismatch. Indeed as can be seen in Fig. 4A the overall difference between historical incidence in the treated areas and their survey areas was small. However in the outer 2km rings and their survey areas depicted in Fig. 4B, this was not the case. In fact the difference in these areas was large. Fig. 5 below shows incidences after the adjustment was applied. Differences between incidences shown in Fig. 5B and Fig. 5B illustrate how big that applied adjustment was.

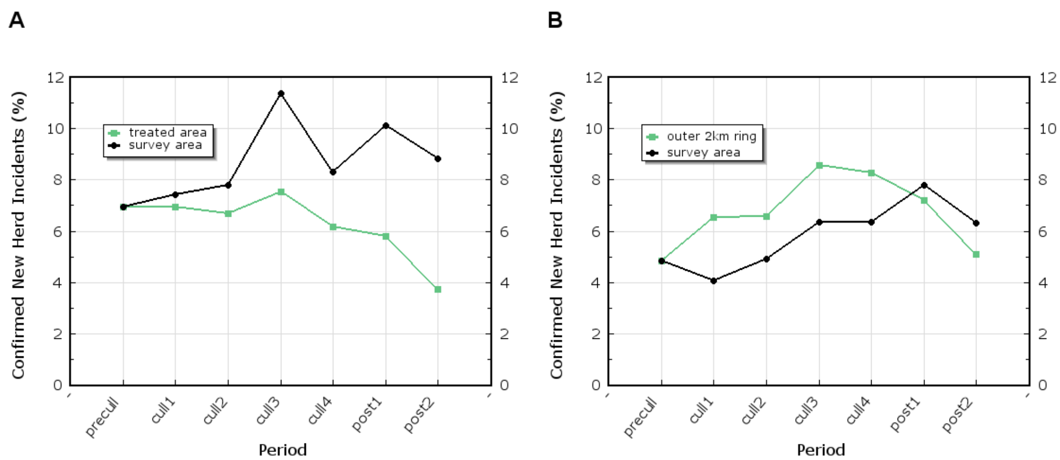

Figure 5. Incidence corrected for pre-cull history and period length in the treated area and its survey area (A) and in the outer 2km ring and its survey area (B).

Calculation of cull benefits

Although there may be doubt as to the origin of the mismatch in the outer 2km ring, the cull benefit, B, as a percentage for each period can now be calculated as follows.

$$B = \frac{(I_{adjusted\ subject} - I_{adjusted\ survey}) \times 100}{I_{adjusted\ survey}}$$

where $I_{adjusted\ subject}$ = $I_{subject} + \Delta$

$I_{subject}$ = incidence as a percentage of the number of baseline herds which were new incidents in the subject area where subject area is either the treated area or the outer 2km ring

Δ = applied adjustment = $(I_{precull\ survey} - I_{precull\ subject}) / 2$

$I_{precull\ survey}$ = incidence in the precull period in the survey area.

$I_{precull\ subject}$ = incidence in the precull period in the subject area

$I_{adjusted\ survey}$ = $I_{survey} - \Delta$

I_{survey} = incidence in the survey area corresponding to the subject area

RESULTS

Fig. 6 shows these calculated benefits and compares them with the benefits calculated by the ISG model using Poisson Regression. The solid lines in Fig. 6A show the basic calculations (i.e. direct illustration of the data) without adjustment and these lines in Fig. 6B (to the right) show the basic calculations with adjustment. The ISG results shown by the dotted lines in Fig. 6 were extracted from Tables 1 and 2 in Jenkins HE, Woodroffe R, Donnelly CA, 2008b after adjustment. These lines are adjusted in both graphs.

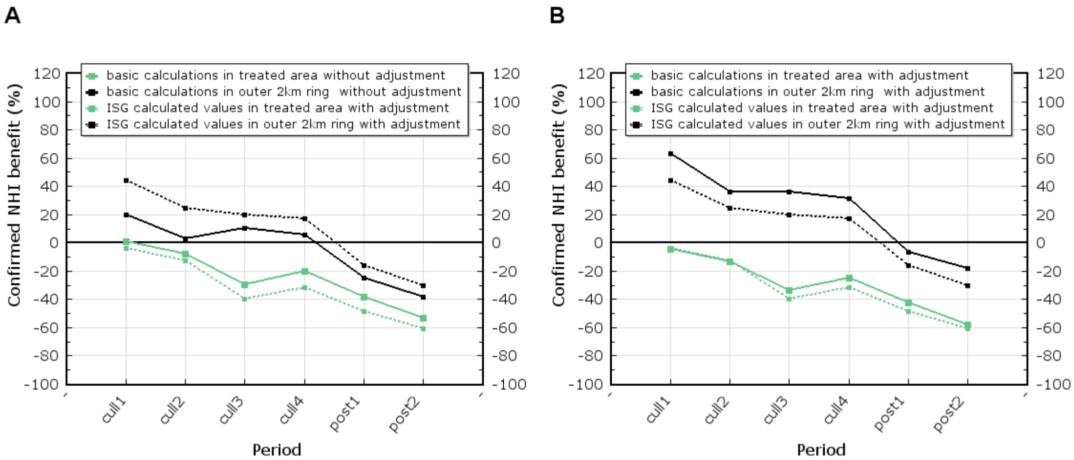

Figure 6. Cull benefit in terms of confirmed new herd incidence (%).
Basic calculations are <u>not</u> adjusted in A and are adjusted in B.

In the graph on the right both sets of results were adjusted to account for the 3-year pre-cull histories. The ISG analysis used a regression model with extra-Poisson overdispersion to account for increased variability (Donnelly CA et al, 2006). Fig. 6B shows that after adjustment substantial differences remain between results from calculations described in the above steps and the results presented by the ISG when using their model.

Fig. 6B implies that adjusting incidences as indicated above applies a bigger adjustment than applied by the ISG in their model analysis. As outlined above, the applied adjustment was calculated by taking the difference between precull incidences in the subject and survey areas. This adjustment accounted for the number of baseline herds and the number of breakdowns in those herds. The reason for the remaining mismatch may be because the ISG adjusted for a third quantity or the ISG applied an adjustment which was less than the full difference. Fig. 7 below shows the match when the applied adjustment is multiplied by a factor of 0.7.

Hopefully further examination of issues and comments received as a result of submitting this article will lead to clarification of why use of this factor was necessary to achieve a better match.

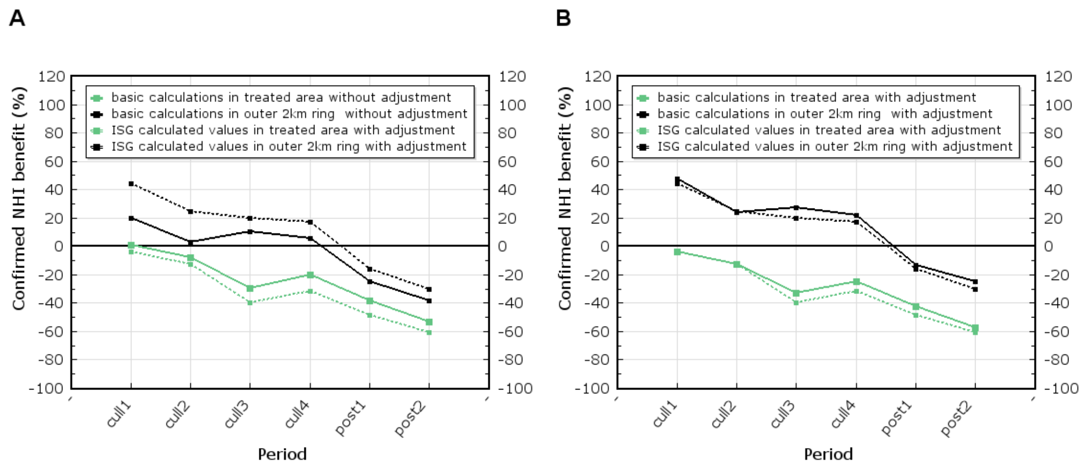

Figure 7. Cull benefit in terms of confirmed new herd incidence (%) when a factor of 0.7 is applied to the applied adjustment.
Basic calculations are not adjusted in A and are adjusted in B.

Fig. 8 below shows analysed results plotted in the RBCT Final Report (Bourne FJ, 2007) and subsequent analysis performed by members of the now-disbanded ISG (Donnelly CA, 2013).

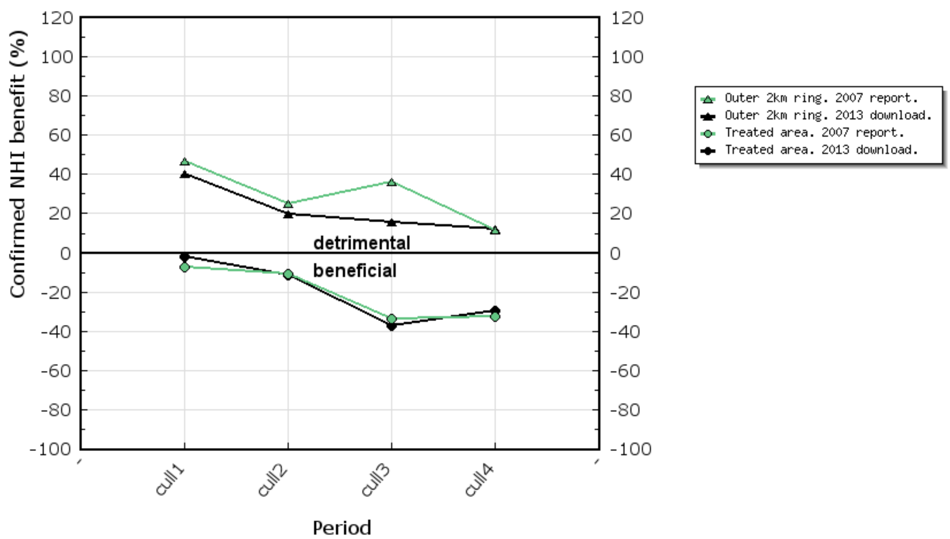

Figure 8. Cull benefits (%) reported in 2007 and 2013.

RBCT conclusions are no doubt influenced to a certain extent by the large detrimental incidence increase in the cull3 period in Fig. 8 which in subsequent analyses has been found to be considerably smaller as can be seen by the point on the black line in Fig. 8. This change is likely to be due to a change in the data which DEFRA supplied to the former ISG members for analysis in subsequent analysies (Personal correspondence with Donnelly CA). The 2007 Final Report values were extracted from figures supplied by Donnelly in personal correspondence and the 2013 Download values were extracted from Tables 1 and 2 in Donnelly CA, 2013.

DISCUSSION

Duration of badger culling impact

The accruing impact of badger culling in the RBCT both inside the treated areas and the outer 2km rings is presented in Jenkins HE, Woodroffe R, Donnelly CA, 2010. It can be seen that confidence intervals associated with data in the outer 2km rings, where perturbation is considered to have greatest noticeable effect, are much larger than confidence intervals associated with incidences in the treatment areas. This means that on repeating these measurements, values of data associated with areas where perturbation is most noticeable would be expected to change a lot more than values of data in the treatment areas. Regarding confidence intervals, in the year 2010, members of the ISG concluded that culling benefits were not sustained (Jenkins HE, Woodroffe R, Donnelly CA, 2010) when in fact they were found to be continuing 3 years later in 2013 (Donnelly CA, 2013). Note how the point at months 31-36 in the treatment area in Fig 1 of Jenkins HE, Woodroffe R, Donnelly CA, 2010 stands out from the points preceding it in terms of the large confidence interval associated with it. Yet two members of the then-disbanded ISG team in 2010 still took it to mean that culling benefits were not sustained.

Criteria for meaningful results

However it should be noted that although individual points would be subject to considerable statistical error, the accrued data over a number of years would be expected to be more stable. This does reduce the risk that the overall large size of effects attributed to perturbation in ISG-analysed results was due to statistical error. The likelihood of whether or not significant statistical error still existed is examined in more detail below.

In general, statistical confidence will improve both from

- increasing the time period over which data is accrued to give each point in the analysis for a given area, and by
- increasing the area (and hence number of herds and associated breakdowns) over which data is accrued for a given time period.

Conditions for arriving at a pre-cull reference from which to calculate culling benefit should be such that no adjustment should be necessary to account for mismatch in incidence in the area under investigation and the survey area if potential statistical error is large. Otherwise it will not be known if the mismatch is due to statistical error or a difference in disease profile in the two areas. In the RBCT analysis, the area over which perturbation was most strongly observed (i.e. the outer 2km rings) is to a certain extent fixed. This is due to the need to avoid area overlap and the proximity of each area in each triplet. The area is also limited because the impact of perturbation diminishes with increasing distance from the treatment boundary. Indeed the ISG reported that when results from the first follow-up cull were analysed, no evidence was found of an effect when the rings were extended to 3 kilometres. Also when the first year is included, incidence increase was found to be statistically insignificant in that 3 kilometre ring. This may be largely due to reduced statistical error from that seen in the 2 kilometre ring. However if statistical errors are not a problem, a 2 kilometre ring may be better to observe what the ISG attributed to perturbation.

This only leaves the ability to change time period in order to improve statistical confidence in the result. In order to establish a representative pre-cull reference, disease incidences in the total area under investigation and the total survey area should match as explained above. This requires two criteria to be met. The two areas disease profile must match. Another words the susceptibility and exposure to disease in both areas must be the same. The time period over which data is accrued must also be long enough for disease incidences to become immune to variation due to sampling and small sample size i.e. statistical error. In order to achieve the first criteria, the RBCT total area was taken from ten widely separated 100 km2 areas located in different counties in Western England. Regarding achieving the second criteria, the time period used to arrive at this reference was taken to be 3 years. In view of the nature of the data shown in Fig. 4 was this 3-year period long enough?

The following table shows calculated 95% confidence intervals assuming a normal distribution for the 3-year incidences and baseline herds.

Location	Herd incidence accrued over 3 years	Number of baseline herds multiplied by 3	3-year herd incidence/(3 * Baseline herds) * 100	Confidence intervals associated with the 3-year quantities
Outer 2km rings	117	2859	4.09	3.37 - 4.82
Survey-only	151	2694	5.61	4.73 - 6.47

Table 1. Details showing how confidence intervals for the 3-year, pre-cull, new herd incidences were calculated.

Fig. 9 below shows these calculated confidence intervals.

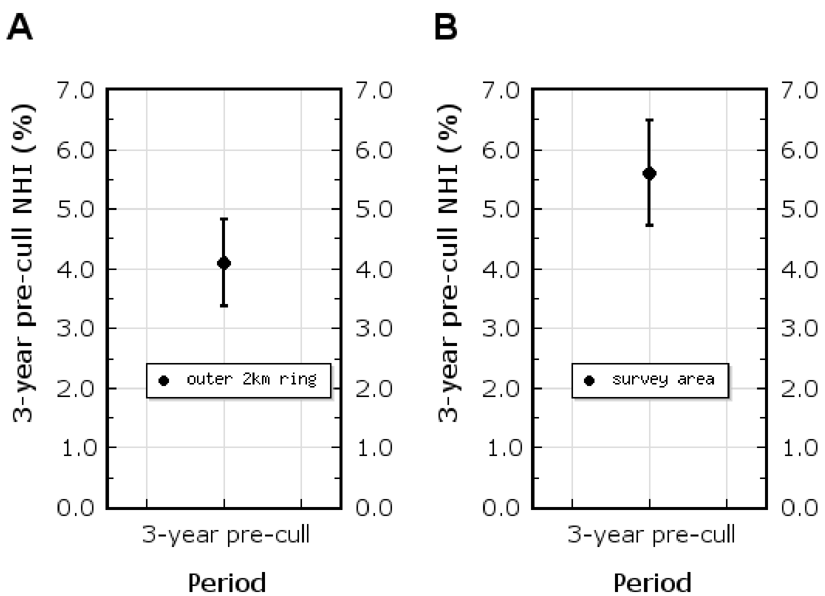

Figure 9. 3-year, pre-cull, confirmed, new herd incidence (%) and associated 95% confidence intervals in the outer 2km ring (A) and its survey area (B).

The 95% confidence intervals shown in the above graph merge. As such there is significant risk that the large difference between incidence in the outer 2km rings (4.09%) and the incidence in the survey-only areas (5.61%) may be largely due to statistical error. In view of this an analysis based on no adjustment should also have been carried out when calculating cull benefit because the difference may have been largely dependent on the sample taken. In view of this, perhaps the ISG in their analysis should have used a longer time period (the ISG only reported results for 1, 3 and 10 years and nothing in between (Donnelly CA et al, 2006)) or they should have both (a) made clear in the discussion of results that a substantial adjustment had to be made to achieve a common reference between the outer 2km rings and their survey-only areas and (b) also presented results without adjustment.

Better fit after applying adjustments

Prof CA Donnelly was vice chairperson in the ISG and was partly responsible for designing the RBCT trial. On approaching Prof Donnelly regarding these doubts concerning whether or not the data should have been adjusted for precull differences, she presented in a personal communication the following headline numbers for the effect inside the trial areas and outside the trial areas. She stated that the numbers showed that the fit of the model substantially worsened when the adjustments were removed.

The headline numbers for the effect inside the trial areas were:
19% reduction (95% CI: 6.2% reduction to 29% reduction).
The adjustment for historic incidence was very important (chi-square = 34.1, p<0.0001).
If you ignored this evidence and removed the historic incidence from the model, then the overdispersion increased substantially indicating the model no longer fits well.
The estimated impact of proactive culling is now very imprecisely estimated:
11% reduction (95% CI: 21% increase to 35% reduction)
demonstrating how little the model without adjustment for historic incidence tells us.

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Similarly, the headline numbers for the effect outside trial areas were:
29% increase (95% CI: 5.1% increase to 58% increase).
The adjustment for historic incidence was very important (chi-square = 8.4, p=0.0037).
If you ignored this evidence and removed the historic incidence from the model, then the overdispersion increased substantially indicating the model no longer fits well.
The estimated impact of proactive culling is now very imprecisely estimated:
11% increase (95% CI: 13% reduction to 42% increase)
demonstrating how little the model without adjustment for historic incidence tells us.

However the significance of how well the model fits depends on how well the model and data used represented actual processes in the outer 2km ring as TB progressed through the herds during the reporting period. If actual processes in this ring were poorly represented, the meaning and reassurance derived from any deterioration in fit after adjustments were removed would be questionable.

Limited data used in the RBCT analysis

It should be noted that no prevalence data had been published for the RBCT areas in May 2015 (Personal communication with Prof Donnelly dated May 2015). If this was the case, little or no usable data had been released which revealed the extents of TB which the incidences gave rise to. In addition to this, the data has been time-shifted to account for the different years in which culling started in each area. Plotting unshifted results may reveal aspects which a time-shifted analysis has obscured. Of particular note, Foot and Mouth made considerable impact in 2001 and in years which followed.

Benefits of analysing more extensive data

Now that more data has become available since culling ended, it is now possible to present results using longer time periods to help reduce statistical error. The results obtained from the following analysis will give a considerably clearer picture of cull benefit than presented to-date in Donnelly CA, 2013 which uses very short 6-month periods.

- Present results without adjusting for precull levels. It is possible references did not match due to statistical error rather than differences in disease profile. If profiles did in fact match the adjustment made by the ISG (and perhaps the ongoing analysis in Donnelly CA, 2013) would have skewed the results. If these historical adjustments were to be removed, the large perturbation effects presented by the ISG would reduce substantially as can be seen by comparing Fig. 5B with Fig. 4B. As such the adjustment had pivotal impact.
- Plot results against calendar date without time-shifts.
- Carry out an analysis using prevalence data as well as incidence data. Karolemeas K et al, 2012 concluded that RBCT badger culling strategies are unlikely to reduce either the prolongation or recurrence of future breakdowns in the long term. However including prevalence data would not only add to data used and hence give welcome reassurance on account of concerns regarding statistical error but would also offer a more revealing measure of the impact of badger culling on herd breakdowns which persist. Such impact is not shown in an analysis of incidence.

CONCLUSIONS

The RBCT analysis performed by the ISG used limited cattle data and confidence intervals were barely acceptable. Of principle concern is the mismatch between the pre-cull references in the outer 2km rings and survey-only areas. It is in these lands where perturbation effects have most noticeable impact. Accounting for this mismatch introduced a pivotal offset into TB incidences in the outer 2km rings. If the mismatch was largely due to statistical error, accounting for the mismatch throughout the trial period and after would have skewed all the results reported in the outer 2km rings. Perceived perturbation effects in these outer 2km rings are having a profound influence on views as to whether or not badger culling should be viewed as an effective strategy. This is bound to be having an impact on current government TB control strategy and hence the UK's ability to control TB.

In essence a re-analysis using more of the available data both in terms of incidence and prevalence (which were not used at all) has the potential to offer better insight and hence improved TB control prospects.

ADDENDUM

Since writing this article, more extensive RBCT data has become available. This data has been illustrated and discussed by the author (Hendy D, 2016).

ACKNOWLEDGEMENTS

I would like to thank Prof CA Donnelly for providing very prompt help by pointing out relevant reports and supplying additional data.

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