Bovine tuberculosis in cattle from 1986 to 2012 in and around badger-culled areas of the RBCT

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In 2007 the Independent Scientific Group (ISG) reported to the UK government the impact on bovine tuberculosis (TB) in cattle of a trial where badgers were culled between 1998 and 2005. This trial, known as the Randomised Badger Culling Trial (RBCT), was performed across 100 km^2 (nominal) zones in the West of England. The results were based on a model of new herd incidence data. It was concluded that reactive culling generated overall detrimental effects, while proactive culling achieved very modest overall benefits at the cost of elevated incidence in surrounding areas.

This work looks at more extensive RBCT data to examine if these findings hold true. Instead of presenting the results of a model, this work directly illustrates the data. The Animal and Plant Health Agency supplied this data in March 2016. Such data covers a greater number of years (1986 to 2012) and includes the prevalence of herd restrictions as well as herd incidence.

Whilst the proactive culls substantially and sustainably reduced cattle TB in treated areas, such culls did not significantly increase TB in the surrounding areas. In fact New Herd Incidents (NHI's) between 2006 and 2012 dropped by 28%, 1% and 18% in the treated, outer 2km ring, and combined areas respectively. Based on the number of NHI's prevented since 1998, a break-even cost for a badger removal exercise was calculated to be £8,454 per km^2. This figure may be under-estimated because it takes no account of any NHI's prevented after 2012.

The more limited reactive culls were found to have no significant impact. This applied to both the treated area and outer 2km ring.

The data also showed that the culls only reduced confirmed TB with no significant impact on unconfirmed TB. This was also found by the ISG when they reported results in 2007.

Arguments surrounding badger culling in the UK have been poorly based due to incomplete data. In view of this and media hype, it should be emphasised that after the first year of substantial culling across the study area, 9 years of data were needed to clearly see the full extent by which TB dropped in the RBCT. This has implications for the culls which started in South West England in 2013. If the current reporting delay of 20 months persists, it may be the autumn of 2023 at the earliest before the impact of these culls becomes clear. Also, if culls stop after year four in each zone, this risks benefits falling short of those achieved in the RBCT.

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INTRODUCTION

The Randomised Badger Culling Trial (RBCT) was a trial performed in the South West and West of England where badgers were culled between 1998 and 2005 to investigate the impact on bovine TB in cattle. Badgers were either culled proactively or reactively. Ten areas of 100 km^2 each (nominal) were designated to the proactive culls, ten such areas were designated to the reactive culls and ten such areas were designated as survey-only areas. In the proactive areas badgers were culled over the complete area whereas in the reactive areas badgers were only culled local to where infected cattle herds were detected. Reactive culling was undertaken by removing all social groups of badgers having access to the breakdown farm so were conducted on or near farmland where breakdown herds were detected. (Bourne, 2007)

The Animal and Plant Health Agency (APHA) at the Department for Environment, Food & Rural Affairs (DEFRA) made available for the first time raw, monthly, data covering prevalence as well as new herd incidence data for the RBCT on 15th March 2016. This article presents and discusses this data and finally reflects on implications for new culls which started in 2013.

DATA

In August 2015 the following request was submitted by www.bovinetb.info to APHA for raw data covering years leading up to, during and after the trial.

Please email to me for each calendar month from 1986 to 2012 (i.e. 27 years, subject to availability) the following quantities

(a) the number of cattle herds,
(b) the number of confirmed new herd incidents,
(c) the number of unconfirmed new herd incidents,
(d) herds under restriction due to an OTF-W breakdown, and
(e) herds under restriction due to an OTF-S breakdown

in each of the following areas after the ten triplets are combined,

(1) proactive area,
(2) reactive area,
(3) survey area,
(4) 2km ring around the proactive area,
(5) 2km ring around the reactive areas,
(6) 2km ring around the survey area,
(7) high risk area of England.

Please note that I only need data for the total area (not for each triplet) for the area given in (1) to (6).

With help from the Information Commissioner's Office, APHA supplied the data on 15th March

2016 under the Environmental Information Regulations 2004 and Access to Information Reference Number ATIC0693. In that response APHA supplied data in the Excel spreadsheet shown in Data S1.

METHODS

Data smoothing

Data was smoothed by summing the monthly data in each year to give annual quantities, dividing by twelve if a monthly average was needed, and applying a Hann window to smooth the data over 5 years.

Calculation of 95% confidence interval limits

For quantities plotted without smoothing, 95% confidence intervals can be calculated as follows.

$$Confidence\ intervals = p \pm z\sqrt{\frac{p(1-p)}{n}}$$

where

$z\ =\ desired\ level\ of\ confidence\ (1.96\ for\ 95\%\ confidence\ intervals),$
$p\ =\ x/n\ =\ proportion,$
$x\ =\ number\ of\ cases\ for\ which\ the\ condition\ applies, and$
$n\ =\ size\ of\ the\ sample\ in\ which\ those\ cases\ were\ found.$

However results were averaged to reduce sample error and give a Hann-smoothed graph line. This averaging would reduce the confidence interval at each smoothed point. These reduced intervals were calculated by replacing the values of x and n by the sum of x and sum of n respectively after applying a Hann weight to each value. The weighting applied is shown in Fig. 1.

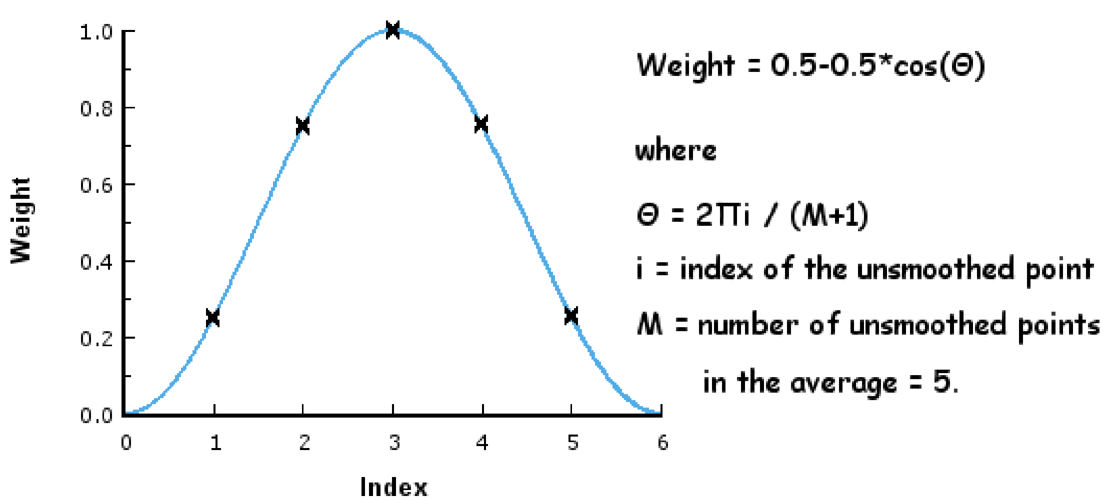

Figure 1. Hann weight when smoothing over 5 points.

The confidence intervals are now calculated as follows.

$$Confidence\ intervals = P \pm z\sqrt{\frac{P(1-P)}{N}}$$

where

$P = X/N,$
$X = \sum_w x = weighted\ sum\ of\ x, and$
$N = \sum_w n = weighted\ sum\ of\ n.$

Calculation of badgers culled per square kilometre

The number of badgers culled per square kilometre were calculated by dividing the number of badgers culled each year by the total treatment area summed across all triplets in which badgers were removed. These areas are given on Pages 205 to 209 of the RBCT Final Report (Bourne, 2007). No badgers were removed in Triplet J in the reactive area so the area of this triplet was not included when calculating the total area. Total treatment and accessible areas, after excluding triplet J when calculating reactive areas, are shown in the table below.

Cull type	Area type	Total area (km^2)
proactive	treatment	1132.4
proactive	accessible	796.6
reactive	treatment	1044.5
reactive	accessible	723.4

Table 1. Total cull areas in the RBCT.

RESULTS

Proactive badger culling substantially reduced confirmed herd breakdowns without significantly increasing herd breakdowns in the 2km rings outside the treatment areas

Proactive culling led to substantially reduced confirmed incidence of cattle herd breakdowns in the treatment areas (see Figs. 2A and 2D) with no overall increase in the 2km rings surrounding these areas (see Figs. 2B and 2E). This is at odds with the conclusions reached in the RBCT Final Report (Bourne, 2007) which stated in Section 5.94 on Page 119 that proactive culling yielded only very moderate benefits at the expense of elevated TB incidence on neighbouring lands. However instead of showing the data (as are shown in the graphs below), the data were modelled and calculated values were given by a model. In addition to this, that model incorporated large pre-cull adjustments in the 2km rings. Concerns regarding the size of these adjustments, and what they were based on, are outlined at www.bovinetb.info .

The graphs below show the data.

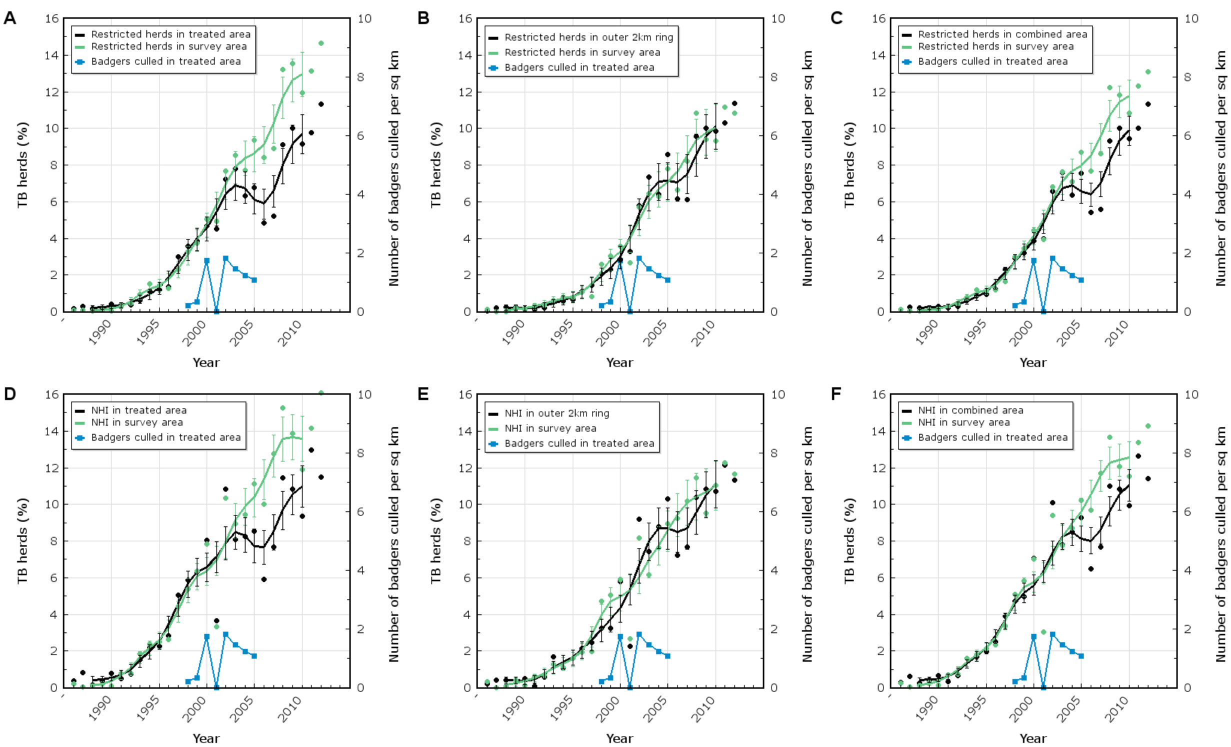

Figure 2. Impact of <u>proactive</u> culling on <u>confirmed</u> TB herds in terms of annual average percentage of restricted herds (A,B,C) and annual percentage of New Herd Incidents (D,E,F).

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Badger culling did not significantly reduce unconfirmed cattle breakdowns

Although proactive badger culling may have slightly reduced the incidence of unconfirmed cattle breakdowns (Fig. 3F), such culling does not appear to have had any significant impact on the prevalence of unconfirmed restricted herds (Fig. 3C) . Culling clearly reduced the prevalence of confirmed restricted herds (Fig. 2C) so why did the culling not reduce the prevalence of unconfirmed restricted herds? The ISG reported an absence of clear impact on unconfirmed new herd incidence in Section 5.22 on Page 95 of Bourne FJ, 2007. The lack of impact on unconfirmed TB is intriguing and perhaps worth investigating but is not pursued further in this study.

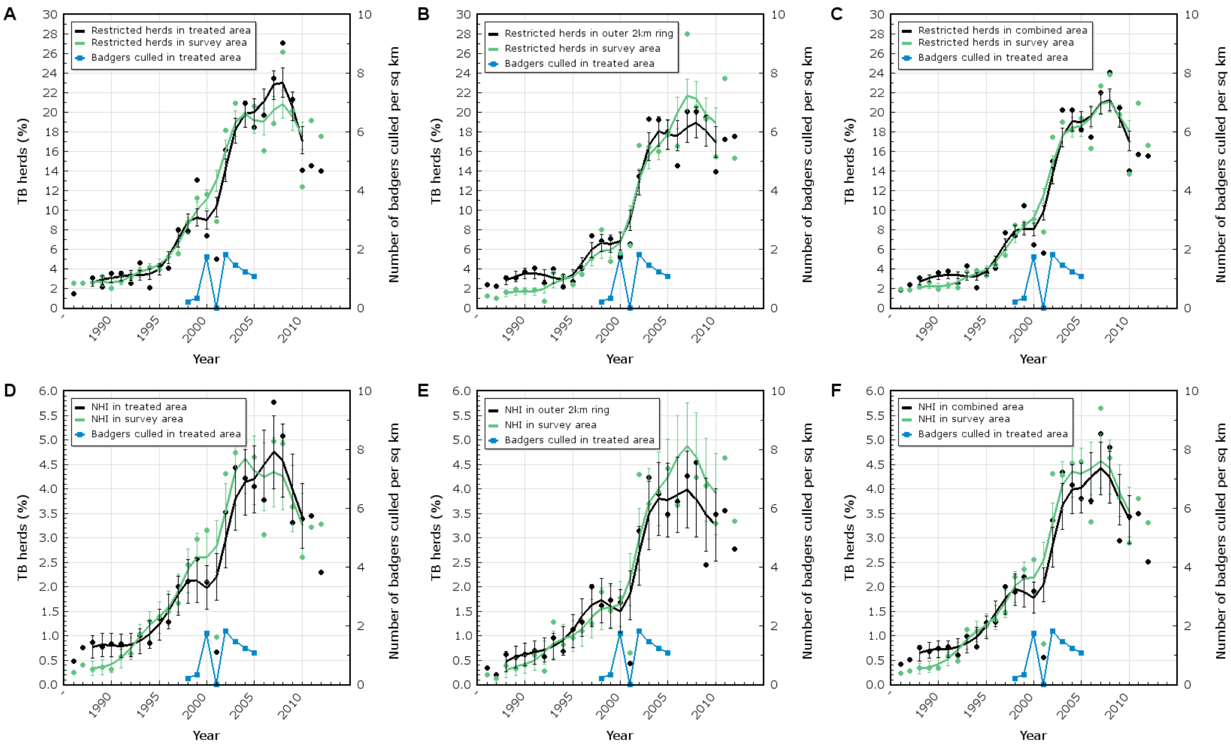

Figure 3. Impact of <u>proactive</u> culling on <u>unconfirmed</u> TB herds in terms of annual average percentage of restricted herds (A,B,C) and annual percentage of New Herd Incidents (D,E,F).

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The limited reactive culls had no impact on cattle TB

Reactive culling was limited for the following reasons.

- It was only concentrated over 2 years.
- It only involved culling 2,067 badgers as opposed to the 8,892 badgers culled in the proactive culls.
- No reactive culling was performed in triplet J.

Figs. 4 and 5 show that reactive culling had no obvious impact on either confirmed or unconfirmed herd breakdowns respectively. This is at odds with conclusions in the RBCT Final Report (Bourne, 2007) which state in Item 10.45 on Page 172 that reactive culling generated overall detrimental effects.

The graph below shows the impact on <u>confirmed</u> breakdowns.

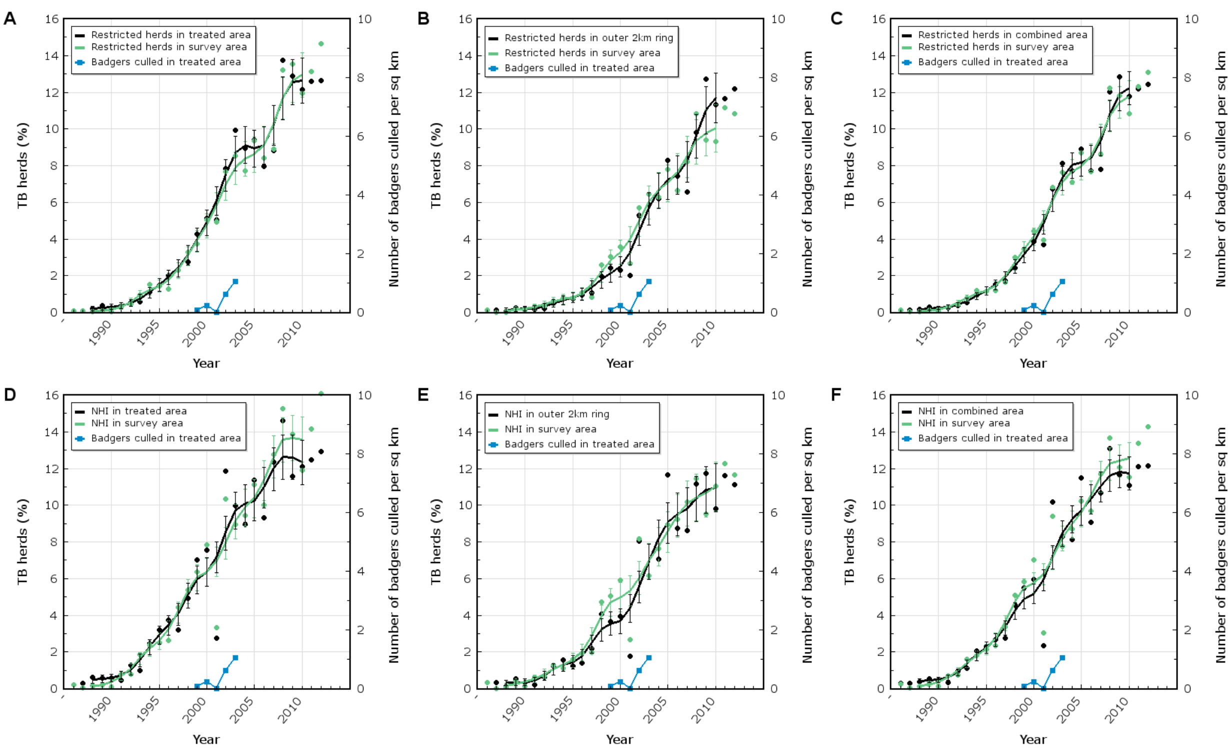

Figure 4. Impact of <u>reactive</u> culling on <u>confirmed</u> TB herds in terms of annual average percentage of restricted herds (A,B,C) and annual percentage of New Herd Incidents (D,E,F).

The graph below shows the impact on <u>unconfirmed</u> breakdowns.

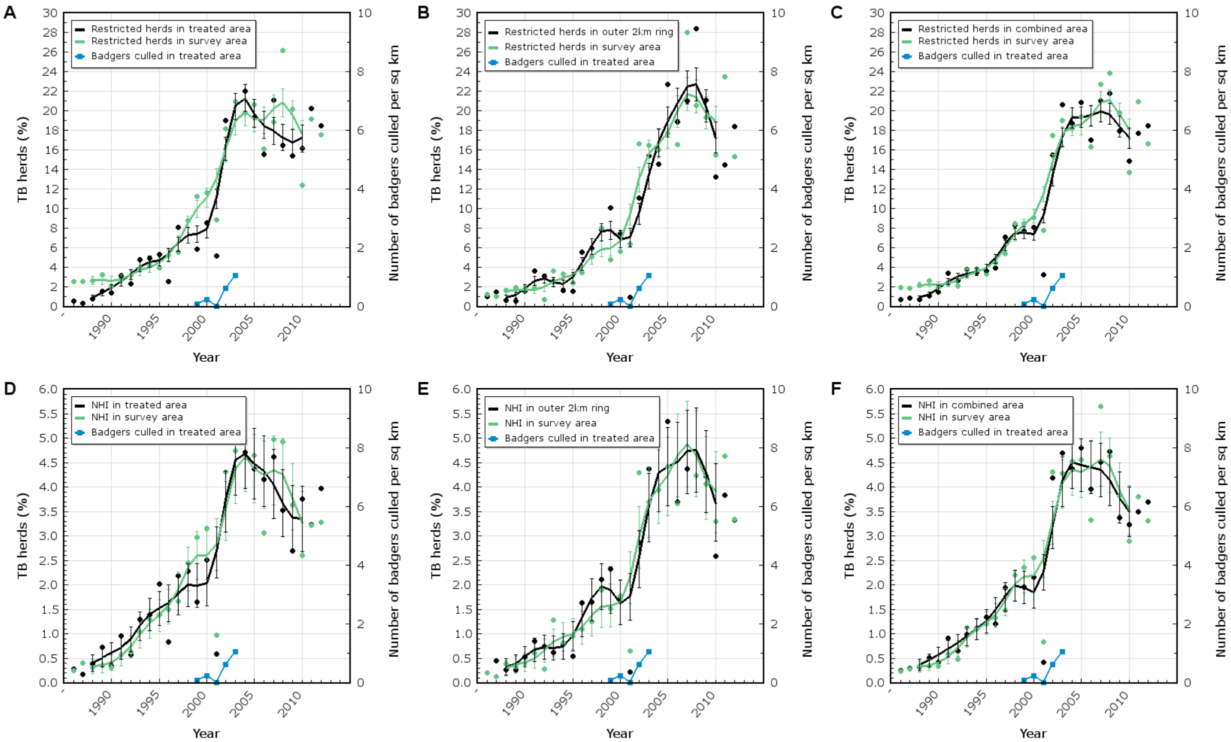

Figure 5. Impact of <u>reactive</u> culling on <u>unconfirmed</u> TB herds in terms of annual average percentage of restricted herds (A,B,C) and annual percentage of New Herd Incidents (D,E,F).

Incident herd breakdowns in proactive areas did not clearly reduce until 5 years after the first substantive cull

Although there was no culling of badgers in 2001 due to Foot and Mouth, the first year incident herd breakdowns due to proactive culling reduced in the treated and outer rings combined was 2005. See Fig. 2F above. The year 2000 was the first year in which a large number of badgers were removed. If the year 2001 is excluded, years 2000, 2002, 2003, 2004 and 2005 elapsed before incident breakdowns clearly reduced; another words, 5 years. However it should be noted that years were shifted in the analysis reported in the final RBCT report (Bourne, 2007). Indeed some areas were further advanced and others less advanced depending on when culling in those areas started. However 1998 will always remain the earliest year culling could have possibly started in any area and 2006 will be the last complete year data could have been included in that report's analysis.

According to the final RBCT report (Bourne, 2007), the ISG performed the concluding analyses of proactive culling data on 1 May 2007. As such conclusions were drawn based on data only in whole years 2005 and 2006 of significant TB incidence reduction in the combined areas (Fig. 2F). That is 2 years. In addition to this, those last 2 years would have been needed to give a 5-year smoothed value for the last year so would not have been depicted in any 5-year, smoothed graph line because that smoothed graph line would only have extended up to the year 2004.

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DISCUSSION

Quantitative and financial impact of proactively culling badgers

The full extent of the drop in the number of New Herd Incidents (NHI) in and around the proactively treated areas of the RBCT was reached in 2006 (Fig. 2). The total number of NHI between 2006 and 2012 given by summing the raw unsmoothed data supplied by APHA in Data SI are shown in the table below.

Area	NHI in survey area	NHI in subject area
treated	950	687
outer 2km ring	540	534
combined	1490	1221

Table 2. The total number of New Herd Incidents between 2006 and 2012.
This table shows the number of New Herd Incidents in and around the proactively treated areas. These numbers were calculated by summing the raw unsmoothed data in Data S1.

Examination of the way in which the data behaves in Fig. 2 shows that NHI in the subject and survey areas leading up to the start of culling in 1998 closely overlaid. If it is assumed that any differences were largely due to sample error, which cannot be adjusted for, it is appropriate to calculate the number of NHI prevented by simply subtracting the number of NHI in the survey areas from the number of NHI in the subject areas. These subtractions give the following percentage drops in NHI in the 7 years between 2006 and 2012.

Percentage by which NHI dropped in treated area = (950-687)/950x100 = 28%
Percentage by which NHI dropped in 2km ring = (540-534)/540x100 = 1%
Percentage by which NHI dropped in combined area = (1490-1221)/1490x100 = 18%

Each NHI costs approximately £30,000 (DEFRA, 2011a). Between 1998 and 2012, the sum of incidents recorded in the raw unsmoothed data in Data S1 supplied by APHA reveals that, subject to the assumption stated above, 1716-1397=319 incidents were prevented. The total cost of the RBCT was estimated to be about £49,030,000 (DEFRA, 2011b). However this is the cost of a trial and a culling exercise would be expected to be cheaper because it would not carry with it the cost of a trial's overheads. In total 1,132 km^2 were treated in the proactive area as shown in Table 1. This suggests the break-even cost per km^2 in any future proactive badger culling exercise with the same effectiveness will be approximately

(30,000 x 319) / 1,132 = £8,454 per km^2.

If the cost per km^2 is less than this, the cost of badger removal will be recouped and there will be a cost benefit. However this break-even point may be an under-estimate because this figure only accounts for NHI prevented up to 2012. Between 2006 and 2012 the drop in NHI was sustained and indeed was continuing in 2012 as shown in Figs. 2A and 2D. Hence the break-even point and financial gain would be expected to be higher.

Data available to the ISG whilst writing the RBCT Final Report

Fig. 6 shows what proactive cull data was available to the ISG when they wrote the Final RBCT Report (Bourne FJ, 2007). The ISG performed the concluding analyses of proactive culling data on 1 May 2007 before presenting the Final Report to the Minister of State on 23 May 2007. Hence 2006 is the last whole year of data which was included in the analysis.

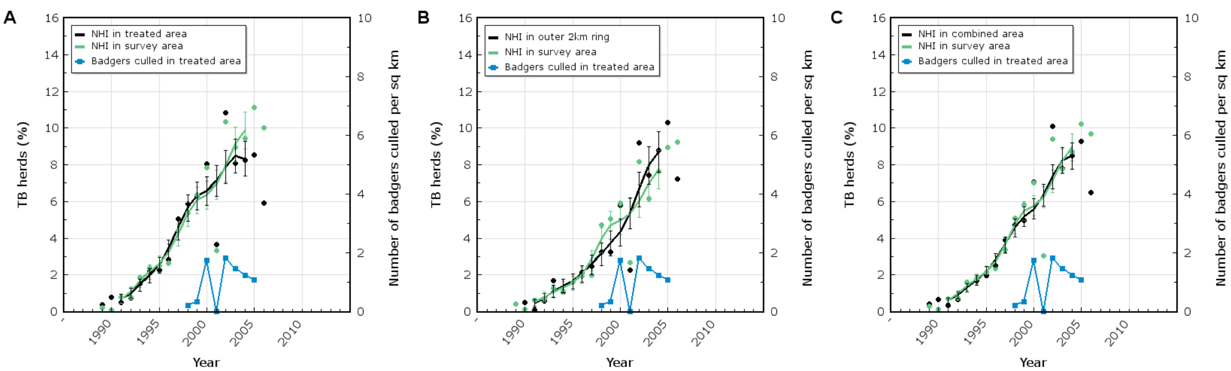

Figure 6. Data available to the ISG whilst writing the RBCT Final Report.

The ISG time shifted the data to account for the different years in which culling was introduced into the different cull zones. This may have resulted in an earlier onset of impact by bringing the impact of the phased culling into focus. However this would have been at the expense of defining impact after onset for which data for the late starting zones would have been missing. Differences between culling effects shown in Fig. 7 suggests that this poor definition in the ISG analysis at the end of the reporting periods may have affected results over the course of 6 to 12 months. However the data in the last reporting period did not extend across the complete 6 months (Donnelly CA, 2010).

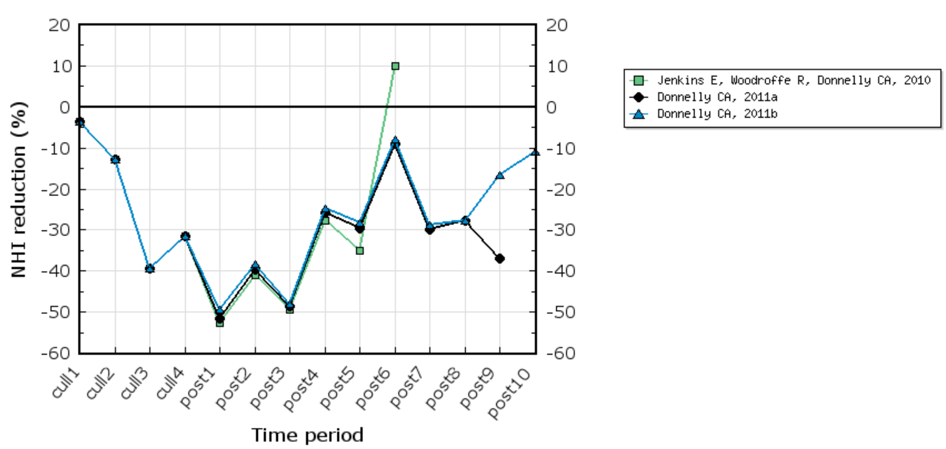

Figure 7. Differences in proactive culling effects calculated by the ISG time-shifted analysis. The interval between points on this graph of post-cull time periods was nominally 6 months. The interval between points of during-cull time periods varied.

Data needed to see the full extent by which TB dropped in the RBCT

Fig. 8 below which shows how many years of data is needed to reveal the full extent to which TB dropped in smoothed RBCT data. Data will need to extend up to 2009 which, after excluding the year 2001, is 9 years worth of data starting at the first year of substantial culling.

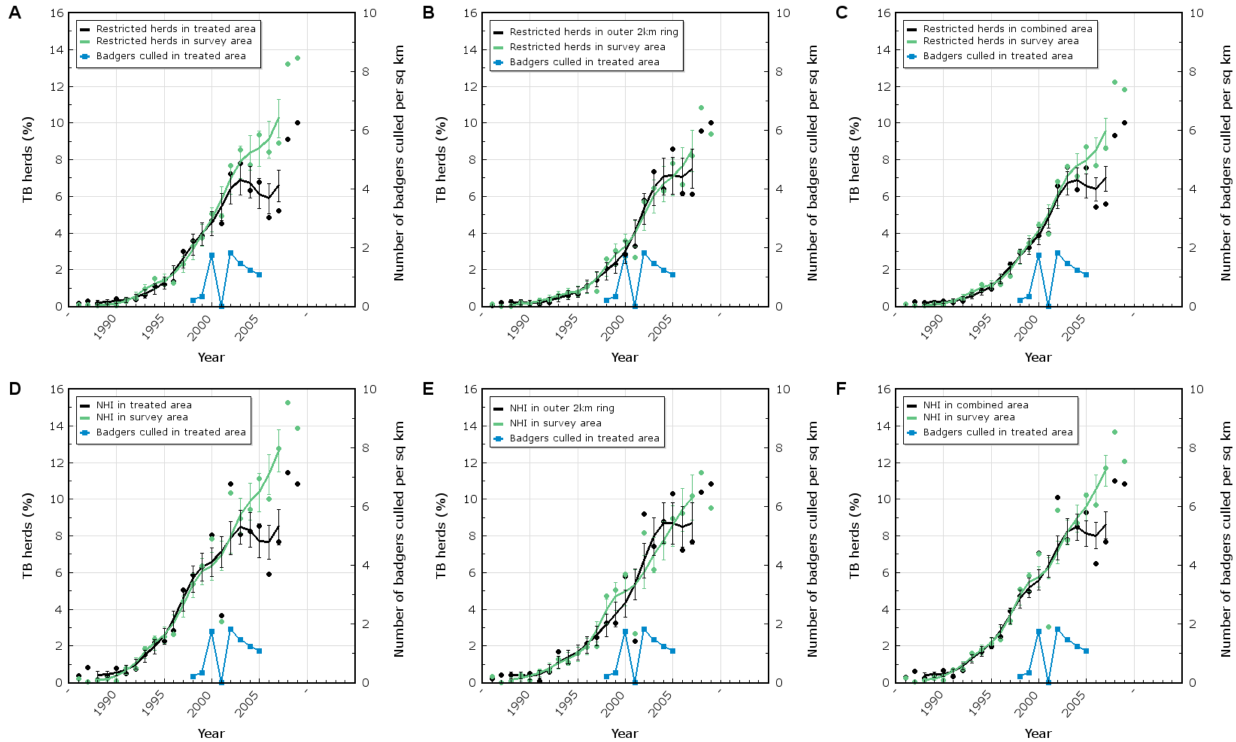

Figure 8. Data required before the culling impact becomes clear.

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Timescales associated with the 2013 culls

Badger culls in the South West of England started in the counties of Gloucester and Somerset in 2013. If results for these culls are published every year at the same time as last year (i.e. 5th September), this will incur a 20-month delay beyond the last year of data shown in the results. If trends in the current culls follow those of the RBCT and 9 years of data are needed to see the full extent to which TB drops, 9 years of data will extend from 2013 to 2021. If this 20-month delay in publishing data persists, this data will be published in September 2023. However whether or not this data will be sufficient depends on if the results in Gloucestershire and Somerset over 9 years carry the same significance as the results over this same length of time in the RBCT. In fact the significance will be less because the zones in South West England cover less total area. Time will need to be extended to reduce sample error. The treatment area is 256 km^2 in Somerset and 311 km^2 in Gloucestershire (DEFRA, 2015a). This is exactly half the total proactive treatment area in the RBCT shown in Table 1. In addition to this, for culls starting in 2013, there are only two zones as opposed to ten in the RBCT. This increases the risk that overall TB dropped in the zones for reasons other than culling. However, an extra zone (in Dorset) was added in 2015 and additional zones are expected to be added in 2016. A discussion of the statistics and outcomes surrounding timescales and number of culling zones is given by Donnelly CA et al, 2015.

Effectiveness of the 2013 culls

DEFRA are stipulating that the culls are only carried out for 4 years minimum. (DEFRA, 2015b). If culling stops after 4 years, no culling will take place in 2017 in Gloucestershire and Somerset where culling started in 2013. Culling in the RBCT was carried out in seven out of the ten proactive areas for at least 5 years, i.e. for an extra year, as shown in Table 4.8 of Bourne, 2007. It was not until during that fifth year in the RBCT, in which culling was taking place in those seven areas, that a clear reduction was seen. In terms of the number of badgers removed per square kilometre, cull rate each year in the current culls when averaged across the first 3 years (www.bovinetb.info) has been comparable to that in the RBCT. If culls stop after Year 4 in each cull zone in the current culls, this is likely to reduce the extent to which TB drops and lasts in the current culls. This will increase the risk that results fall short of what was achieved in the RBCT.

CONCLUSIONS

Badger culling in the UK is a very emotive subject which hampers rational debate. As a result of incomplete data, arguments surrounding badger culling have been poorly based. Strong public opposition to the culls has resulted in the majority of reports in the media being biased against culling. As a result it has been very difficult for government ministers to garner support for badger culling and to date progress towards implementation has been very slow. In view of this, perhaps the most important findings in this study of more extensive RBCT data are as follows.

a. Proactive badger culling substantially and sustainably reduced TB in cattle from 2005 to 2012.
b. Proactive badger culling in the treated areas did **NOT** significantly increase cattle TB in the surrounding areas.
c. Nine years of data were required after the first year of substantial culling to clearly identify the full extent by which TB dropped.

FUTURE WORK

This study looked at the impact of culling when results for all ten zones were combined. The number of badgers removed per square kilometre over the complete cull period from 1998 to 2005 ranged from 3.5 to 12.3 depending on zone. These figures were calculated from data presented in the RBCT Final Report (Bourne, 2007). This is a large range. A current unknown in TB endemic areas, which makes it difficult to assess the effectiveness of badger culling in terms of TB control, is how sensitive TB control is to badger density. Specifically, what badger density needs to be reached before cattle measures in endemic areas start working as they currently do in cattle-dense regions of England, such as in Lancashire, where TB is not endemic? DEFRA has set itself an undertaking to reach TB free by 2035 (DEFRA, 2014a). Indeed TB is a zoonotic disease so DEFRA has a responsibility to control TB. Knowing the efficacy associated with reducing badger density in areas which are currently endemic will help to gauge what effort will be needed to achieve TB eradication.

Cull sample matching (CSM) performed in the 2013 culls raised hope that efforts were at last being made to gather data to make the results of a cause and effect study more meaningful. CSM is considered to be the most reliable way for determining the proportional reduction in a culled badger population (Independent Expert Panel, 2014). Given that the number of culled animals is known, the size of that population can be determined. However DEFRA saw reason to abandon CSM after 2013 (Page 7 of DEFRA, 2014b). As of July 2016, CSM has not been used since.

Can some insight be still gained regarding efficacy? Perhaps some evidence can be provided by studying data which has accrued to the present time in RBCT areas, broken down by cull zone ,or certain zones combined. The strength of this evidence will not only depend on the size of larger sample error but also on the reliability of population estimates. CSM was not used in the RBCT because CSM was still in its infancy when the RBCT started.

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