Pilot Badger Culls in Somerset and Gloucestershire

Report by the Independent Expert Panel

Chair: Professor Ranald Munro

Presented to the Secretary of State for Environment, Food and Rural Affairs
The Rt Hon Owen Paterson MP, March 2014

INDEPENDENT EXPERT PANEL ON BADGER CULLING PILOTS

Chairman: Professor Ranald Munro

The Rt Hon Owen Paterson MP
Secretary of State for Environment, Food and Rural Affairs
Nobel House
17 Smith Square
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Date 5th March. 2014

Dear Secretary of State,

REPORT OF THE INDEPENDENT EXPERT PANEL ON BADGER CULLING PILOTS

You appointed us in 2012, originally under the chairmanship of Prof. Christopher Wathes, to serve as the Independent Expert Panel (IEP) on Badger Culling Pilots.

Reduction of badger populations by shooting was considered, by government, as one of a number of measures to control the prevalence of bovine tuberculosis in cattle. However, because of the protected status of badgers, little or no experience of shooting unrestrained badgers was available. A pilot cull was seen as an appropriate way to test assumptions on the effectiveness, humaneness and safety of this type of shooting.

The pilot culls were complex and it was essential that they were conducted with scientific and statistical rigour to ensure that they generated reliable and robust results. Our original terms of reference were refined in 2013 to reflect the primary roles of the IEP in (a) guiding the development of scientifically and statistically sound protocols and (b) assessing the robustness of the data collection and their analyses. The IEP was not involved in either the implementation or the day to day monitoring of the pilots during the six-week period set aside for culling.

Our report, enclosed, sets out our findings. The Panel confirmed that the protocols used to assess the pilot culls were scientifically and statistically sound, as were the data collection and analyses carried out by AHVLA. We concluded, from the data provided, that controlled shooting alone (or in combination with cage trapping) did not deliver the level of culling set by government. Shooting accuracy varied amongst Contractors and resulted in a number of badgers taking longer than 5 min to die, others being hit but not retrieved, and some possibly being missed altogether. In the context of the pilot culls, we consider that the total number of these events should be less than five per cent of the badgers at which shots were taken. We are confident that this was not achieved. The Panel is, however, confident that controlled shooting can be carried out safely, even in the context of protester activity, if Best Practice

Guidance is followed. The implications of the results of the pilot cull on any future roll-out are addressed in Section 6 of our report.

We should like to record our thanks to all who contributed their time, energy and expertise to the development, implementation and analysis of the monitoring of the pilot culls. We are also most grateful to the public for their interest in these pilots and for their unsolicited submissions, which cast light on aspects of the pilots that were not covered by the protocols.

Prof. Ranald Munro

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1. Panel Members

1.1. The members of the Badger Culling Pilots: Independent Expert Panel (IEP) were appointed by Defra for their expertise in animal welfare, veterinary pathology, badger behaviour and ecology, wildlife population biology, statistics, marksmanship and the management of wild animal populations. Their biographies can be found in Appendix 12.1.

2. Terms of Reference

2.1. The panel was appointed specifically to look at the effectiveness, humaneness and safety of controlled shooting as a culling method. It was not the role of the panel to provide advice about, or to comment on, the wider policy approach to tackling bovine TB in England, or the case for badger culling as part of a wider package of measures.

2.2. The Terms of Reference (TOR) for the IEP were originally set out by Defra in March 2012 but were significantly amended in August 2013 to reflect a more restricted remit. In particular, Defra wished to enhance the impartiality of the IEP by enabling it to focus on protocol development and on scientific assessment of the outcome of the pilot culls, whilst remaining separate from day-to-day monitoring of their delivery. It was also agreed that the Panel should not comment on the cost-effectiveness of the pilot culls since operational constraints precluded normal commercial considerations. The IEP agreed to these changes. The original TOR are shown in Appendix 2; the TOR as amended in August 2013 are as follows:

> *'To help Ministers evaluate the effectiveness (in terms of badger removal) and humaneness of controlled shooting the independent expert panel will:*
>
> *a. oversee the development of scientifically robust and policy-relevant monitoring protocols;*
>
> *b. advise on appropriate auditing of data collection and analysis (either by panel members or by the independent auditor);*
>
> *c. On completion of the cull and where appropriate:*
>
> *i. provide advice to Ministers comprising their view of the robustness of the data collection and analysis conducted by the research teams, and a discussion of factors that may have influenced the results obtained;*
>
> *ii. advise on other factors of scientific relevance that are material to the monitoring of effectiveness (in terms of badger removal) and*

humaneness of controlled shooting, and recommend (if appropriate) options for monitoring if the policy is rolled out more widely;

iii. consider the report on the public safety of controlled shooting following the pilots and other information that may arise regarding operator safety; and

iv. recommend any changes or improvements to the licence criteria, training course content, or Best Practice Guidance.

3. Introduction

3.1. The stated purpose of the badger pilot culls was to test the effectiveness, humaneness and safety of controlled shooting. In this context 'controlled shooting', and its synonym ‘free shooting’, refer to the shooting of unrestrained badgers. Although provision for cage trapping of badgers was included in the pilot cull protocol, it was implicit in the project title and description that controlled shooting would be the principal method for removal of badgers and that cage trapping, if used at all, would be implemented only on a small scale. This understanding on the part of the IEP, that the primary focus of the pilot culls was to test assumptions about controlled shooting, was neither challenged nor corrected by Defra.

3.2. The IEP only learned some weeks after the beginning of the pilot culls that cage trapping had been employed on a large scale throughout the duration of the culls in both pilot areas. Cage trapping was not used as a secondary means to cull additional animals towards the end of the pilots but was implemented within two days of the beginning of the cull in Somerset and by day three in Gloucestershire. In the Somerset area more than half of the badgers removed during the pilot culls were cage trapped.

3.3. The decision to use cage trapping on this scale is unfortunate. First, it means that the effectiveness of the pilot culls as a whole (in terms of numbers of badgers removed) does not reflect the effectiveness of controlled shooting as a method of badger control. This distinction is important when the results of the pilots are being communicated. Secondly, from a scientific viewpoint cage trapping constitutes a confounding variable. This makes the effectiveness of controlled shooting more difficult to assess because:

a. Badgers that were cage trapped were not available to be shot as unrestrained animals.

b. Resources and effort were diverted, to an unknown extent, from shooting to trapping.

3.4. A further complication arises because shooting effort and trapping effort were not recorded separately. This means that we cannot calculate the extra effort that

would need to be directed into shooting to increase its effectiveness by any given amount (see below 6.1.3 to 6.1.4 & 10.3.7).

3.5. Because the remit of the IEP is to help ministers evaluate the effectiveness (in terms of badger removal), humaneness and safety of controlled shooting, our report concentrates on the culling of badgers by this means. We do not consider humaneness issues related to cage trapping since this is a well-established method of catching badgers, the humaneness of which has been previously investigated (e.g., Woodroffe et al., 2005). However, we do consider the effectiveness of cage trapping:

a. Insofar as it is relevant to an evaluation of the effectiveness of controlled shooting.

b. In an evaluation of the effectiveness of the combined shooting and cage trapping strategy as it was applied in each pilot area.

3.6. The IEP's remit was limited to advising on controlled shooting over a 6-week period. We were satisfied that the protocols agreed for the 6-week pilot culls were statistically robust and that the AHVLA had collected, during this period, the data needed to enable the Panel to formulate its advice. Because further culling could not influence effectiveness over the first 6 weeks, the IEP did not assess culling activity during the extension periods granted by Natural England (NE) to allow culling of additional badgers for disease control purposes. However, the IEP was made aware that AHVLA statisticians were analysing the effectiveness of the extensions using the same methods as were used to analyse data from the first 6 weeks. The results of this analysis were not available at the time of submission of our report.

3.7. The results and analyses presented in our report are largely taken from reports provided by the AHVLA teams responsible for monitoring effectiveness and humaneness in the pilot culls. Although the reports themselves (Anon, 2013a, b) were written independently by the respective AHVLA teams, the IEP was closely involved in deciding, beforehand, on the relevant monitoring protocols and data analyses. In addition, the work of the monitoring teams was independently audited (Wahl & Coulson, 2013a, b). We are therefore confident that the work of the monitoring teams was appropriate, that it was carried out competently and that the data analyses are valid.

3.8. Throughout this report, and following the precedent set by the AHVLA reports, statistics are reported as upper and lower confidence intervals, usually evaluated to give the 95% range of confidence. The two numbers can be interpreted as representing the best- and worst-case scenarios; they also mean that we can be 95% confident that the true outcome lies between these two values. For example, when it is reported that the pilot cull in Gloucestershire removed between 27.5% and 39.1% of the population, this means that we are 95% certain that more than 27.5%

but fewer than 39.1% of badgers were removed, given the statistical tests that were used.

3.9. We have chosen to report results in this way because it is important for readers to understand that there is always uncertainty around the sorts of average values that are typically reported in the media.

3.10. The IEP did consider reporting the most likely statistical estimates from analyses as well as the 95% range of confidence. This is because the most likely statistical estimate does not necessarily lie halfway between the upper and lower ranges but could be off-centre. However, results in the main AHVLA report reveal that the 95% ranges of confidence did not include the effectiveness or humaneness target thresholds set by Defra. Consequently, there seemed little to be gained from reporting the most likely statistical estimates. Some additional humaneness analyses, requested by Defra in January 2014 and given in an addendum to the AHVLA Humaneness Report (Anon, 2013b), do cite most likely statistical estimates. These analyses are discussed in Appendix 12.5 below.

3.11. In the course of its work the IEP met with various individuals and with representatives of relevant organisations. These meetings are listed in Appendix 12.3. We also received a number of unsolicited submissions from interested individuals, listed in Appendix 12.4. On Defra advice it was agreed that members of the IEP should not, for security reasons, visit either pilot area before the start of the pilot culls. Defra also strongly advised that for reasons of security, and to maintain the independence of the Panel, members should not visit either area while the pilot culls were in progress.

4. Effectiveness Monitoring

4.1. Introduction

4.1.1. The aim of effectiveness monitoring was to test the assumption that controlled shooting is an effective method of badger removal, i.e., is able to remove at least 70% of the starting population of badgers from a given area during the course of a 6-week cull. To do this, it was necessary to establish, as precisely as possible, the proportion of the badger population that was removed, by controlled shooting, from each of the two pilot cull areas. It is important to note that ‘pilot cull area’ in this context means the whole of the designated area, including non-compliant land (i.e., including individual land holdings, situated within the boundary of a pilot cull area, on which culling was not permitted by the owner).

4.1.2. The IEP recommended that two approaches be used to estimate effectiveness, namely, ‘cull sample matching’ and ‘capture mark recapture’.

4.1.3. In what follows we report effectiveness in terms of these two measures. However, we also present estimates of pre-cull population size that were obtained using other methods, since these are relevant to considerations of roll-out.

4.2. Effectiveness monitoring protocols

Choice of methods

4.2.1. The target for the pilot culls was to remove at least 70% of the badger population in each of two areas within 6 weeks, but without removing so many badgers that local extinction was threatened. Evaluation of culling activity against this target required the development of methodology to estimate the percentage of badgers removed during the cull.

4.2.2. The IEP initially considered seven different potential approaches to the estimation of effectiveness, including surveys of badger activity, line transect distance sampling and genetic census techniques. In deciding which approaches to take forward, we considered factors including: the need to ensure statistically robust results; potential for bias; susceptibility to fraud or disruption; and time and resources required to undertake the work.

4.2.3. Based on these considerations, we recommended that two methods, termed ‘cull sample matching’ and ‘capture mark recapture’ respectively, should be developed to evaluate the results of badger removal against the 70% target.

4.2.4. The rationale for choosing these two methods was as follows. *A priori*, we considered cull sample matching to be the most robust method, from those that were available, for estimating effectiveness. This is because it is based on a single estimated parameter (the proportion of hair-trapped badgers that were culled), whereas other approaches would require the estimation of more parameters. However, cull sample matching depends on the (plausible) assumption that hair trapped and non-hair trapped badgers have the same probability of being shot: if this were not the case, the results would be biased. The use of capture mark recapture as an additional way of estimating effectiveness helped guard against this possibility because capture mark recapture relies on estimating pre-cull population size and, hence, depends on a different set of assumptions. Consequently, if both approaches were to provide similar conclusions, this would increase our confidence that the cull-sample-matching results were not biased. On the other hand, if the two approaches resulted in different outcomes, this would suggest that the assumptions underlying one or other method had been violated.

4.2.5. In reality, there was overlap between the 95% confidence intervals of the respective estimates provided by the two methods: that is, the two methods provided broadly similar results (see below, 4.3). However, given that cull sample matching was regarded *a priori* as the more robust of the two methods (see above), we

consider that the cull-sample-matching results provide the better estimate of effectiveness.

Cull sample matching

4.2.6. Cull sample matching involved individually identifying badgers from within each pilot area, using DNA profiling. Prior to the cull, barbed wire 'hair traps' were used to collect badger hair from a proportion of the badger population, for DNA profiling. Then, during the cull, tissue from all culled badgers, in the form of ear tips taken from the carcasses, was also subjected to DNA profiling. The proportion of culled individuals that matched the DNA profiles of those originally hair-trapped was used to estimate the proportion of the population that had been removed.

4.2.7. One of the IEP's key recommendations in relation to cull sample matching was that at least 50 (1km x 1km) squares in each pilot area should be covered by hair traps, and that these squares should be distributed randomly across compliant land throughout the cull areas. In the event, hair traps were deployed in 71 (1km x 1km) squares in Gloucestershire and 78 (1km x 1km) squares in Somerset, equivalent to approximately 24% of the total squares in Gloucestershire and 26% of the total squares in Somerset.

Capture mark recapture

4.2.8. Capture mark recapture required that the pre-cull badger population size be estimated in each pilot area, based on the frequencies with which the hair of different individual badgers appeared and reappeared in hair traps. This was done using the same hair-trap data as were collected for purposes of cull sample matching (see above). Then, the total number of badgers removed during the course of the 6-week cull was compared against this estimate of pre-cull population size, in order to provide an estimate of the proportion of badgers removed during the cull.

'Sett sticking'

4.2.9. In addition to the two methods of estimating effectiveness described above, it was originally intended that a 'sett sticking' operation would be carried out at the end of the 6-week pilot culls. This would have involved sticks being placed over the entrances of a sample of setts that were known, prior to the culls, to have been occupied. Then, after a period of time, the displacement or non-displacement of these sticks would have been recorded. This would have provided an additional post-cull check on effectiveness by determining the proportion of setts that still showed signs of badger activity. However, because culling was extended beyond the 6-week period of the pilot in both areas, sett sticking could not be employed as intended.

4.3. Results and interpretation

Effectiveness of controlled shooting

4.3.1. During the 6-week pilot culls, 398 badgers were removed by controlled shooting in Somerset and 543 in Gloucestershire. Estimates of the effectiveness of controlled shooting with 95% confidence, based on the two methods recommended by the IEP, are summarised in Table 4.1.

	Cull sample matching	Capture mark recapture
Somerset	14.6-24.8	20.9-46.8
Gloucestershire	25.3-37.1	16.7-39.0

Table 4.1 *Estimates of the effectiveness of controlled shooting (% of badgers removed; 95% CI) for the two pilot areas, based on cull sample matching and capture mark recapture respectively.*

4.3.2. Based on the more robust estimate of effectiveness (namely, cull sample matching: see above, 4.2.1 - 4.2.5), we can be 95% certain that controlled shooting removed less than 24.8% of the pre-cull badger population in Somerset, and less than 37.1% of the pre-cull population in Gloucestershire.

Effectiveness of controlled shooting plus cage trapping

4.3.3. During the 6-week pilot culls, 865 badgers were removed from the Somerset pilot area and 708 from the Gloucestershire area, by a combination of controlled shooting and cage trapping. Estimates of the effectiveness of shooting plus trapping, with 95% confidence, based on the two methods recommended by the IEP, are summarised in Table 4.2.

	Cull sample matching	Capture mark recapture
Somerset	34.5-48.1	45.5-101.9
Gloucestershire	27.5-39.1	21.8-50.8

Table 4.2 *Estimates of the effectiveness of controlled shooting plus cage trapping and shooting (% of badgers removed; 95% CI) for the two pilot areas, based on cull sample matching and capture mark recapture respectively.*

4.3.4. Based on the more robust estimate of effectiveness (namely, cull sample matching: see above, 4.2.1 – 4.2.5), we can be 95% certain that a combination of controlled shooting and cage trapping removed less than 48.1% of the pre-cull population of badgers in Somerset and less than 39.1% of the pre-cull population in Gloucestershire.

Pre-cull population sizes

4.3.5. The capture-mark-recapture approach involved estimating pre-cull population sizes on the basis of hair-sampling data collected immediately prior to the pilot culls. The estimates of pre-cull population size (95% CI) obtained in this way were 850-1905 for Somerset and 1394-3242 for Gloucestershire.

4.3.6. It was also possible to produce estimates of pre-cull population sizes from the cull-sample-matching data, by dividing the number of badgers culled by the estimated effectiveness. Estimates of pre-cull population sizes (95% CI) obtained in this way were 1802-2512 for Somerset and 1811-2575 for Gloucestershire.

4.3.7. In addition to these estimates based on capture mark recapture and cull sample matching respectively, four other estimates of the size of the pre-cull badger population were made for each pilot area. These four additional estimates were based on data or information collected for reasons other than effectiveness monitoring in the pilot culls: for example, for logistical planning purposes or to set maximum and minimum numbers of badgers to be removed. Although these estimates were not specifically requested by the IEP, we include them here for purposes of comparison and because they are relevant to the issue of roll-out (see below, 6.1.5 – 6.1.9)

4.3.8. The six separate pairs of estimates of pre-cull population size that were available by the end of the pilot culls are listed in Table 4.3 and shown graphically in Fig. 4.1. These estimates of population size varied considerably in their accuracy and precision. The first pair of estimates, based on historical data from the Randomised Badger Culling Trial (RBCT), is low by comparison with most other estimates, perhaps because some of the assumptions on which it was based were not valid, or perhaps because badger population sizes have risen since the RBCT was completed. However, this estimate was only ever regarded as a rough attempt, for planning purposes, to gauge the magnitude of the task facing Contractors, so it would be wrong to invest it with too much significance.

4.3.9. Estimate 5 for Somerset, based on capture-mark-recapture analysis of hair-trapping data, also seems low by comparison with most other estimates. The reason for this is unclear. Since the confidence intervals associated with this estimate overlap with those of other recent estimates this may be a chance effect resulting from the precise pattern of capture-recapture data (see also section 6 below).

4.3.10. The last pair of estimates (Estimate 6, based on the results of cull sample matching), is the best of the more recent estimates in terms of precision and provides remarkably similar results for the two pilot areas. We consider this pair of estimates to provide the best indication of pre-cull population sizes.

Est. #	Date	Source	Method	Population size	
				Somerset	Gloucs
1	2011	Defra	Based on numbers of badgers removed in initial culls during the RBCT*	1098	1339
2	2012	Farming industry	Survey work to determine number of main setts, which was then multiplied by 5.4**	2553	2492
3	2012	Farming industry	Same as above but based on additional field work	1787	1557
4	2012-2013	Defra	Survey work to determine number of active setts (2012), plus CMR*** analysis of hair-trapping data to determine average number of badgers per active sett (2013)	1501-3905	1999-5423
5	2013	Defra	CMR analysis of pre-cull hair-trapping data to determine average number of badgers per active sett. Number of active setts was taken from the 2012 survey.	850-1905	1394-3242
6	2013	Defra	Cull sample matching	1802-2512	1811-2575

Table 4.3 *Six different estimates of population size (number of badgers) in each of the two pilot areas, in chronological order. Where a range is given for population size, this represents the 95% CI.*

** RBCT: Randomised Badger Culling Trial. ** 5.4 was taken as the average number of badgers per social group, based on trapping data obtained in the RBCT (Independent Scientific Group on Cattle TB, 2007). *** CMR: capture mark recapture.*

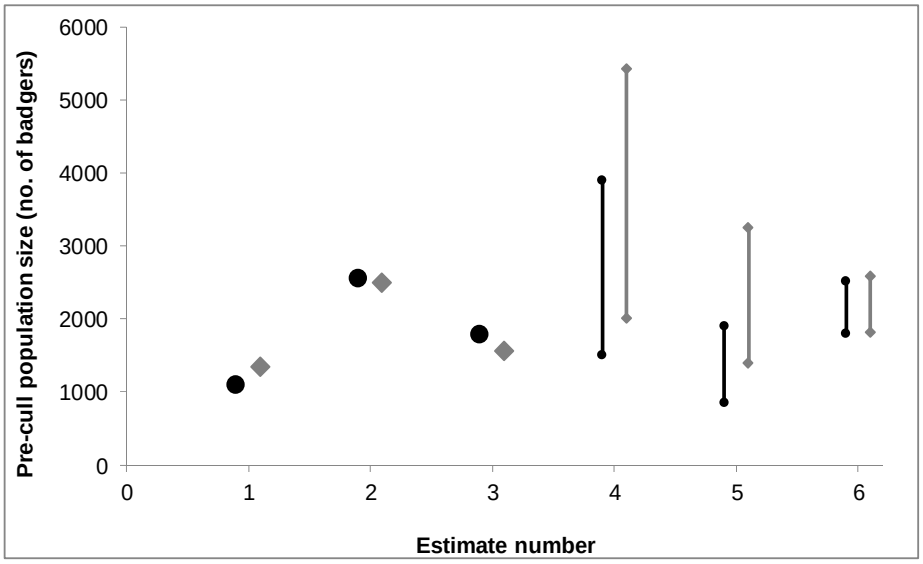


Fig. 4.1 *Estimates of pre-cull population size (number of badgers) for each study area, arranged chronologically from left to right and numbered as in Table 8.2. Black points and lines: Somerset pilot area. Grey points and lines: Gloucestershire pilot area.*

4.4. Robustness of data collection and analysis

4.4.1. As with all data analyses it is necessary to consider factors that might generate biases in the results; whether any assumptions associated with the methods used were violated; and whether data quality and quantity were sufficient to conduct the analyses.

4.4.2. Several steps were involved in estimating the effectiveness of the pilot culls using the capture-mark-recapture method. These were:

1) Deployment of hair traps around active badger setts.

2) Regular retrieval of hair from hair traps.

3) Genetic profiling of the collected hair.

4) Construction of a frequency distribution of captures from the number of times each genetically profiled badger was captured.

5) Calculation of the likely population size from this frequency distribution.

6) Division of this number by the number of setts at which hair traps were employed, to give an estimate of the average number of badgers per sett.

7) Multiplication of the average number of badgers per sett by the number of setts within the pilot area.

4.4.3. In order to estimate the total number of setts within the pilot area the following steps were followed:

8) Surveying to determine the number of setts within a proportion of the pilot area.

9) Division of the number of setts surveyed by the proportion of the pilot area surveyed.

4.4.4. These steps provided an estimate of the number of badgers living in the pilot area. To obtain a measure of effectiveness it was necessary to:

10) Cull badgers.

11) Divide the number of culled badgers by the estimate of the total population size.

4.4.5. Fewer steps were required to estimate the effectiveness of the cull using the cull-sample-matching approach. When the step is the same as that used in the capture-mark-recapture approach (see above) we give it the same number; new numbers are used for new steps:

1) Deployment of hair traps around active badger setts.

2) Regular retrieval of hair from hair traps.

3) Genetic profiling of the collected hair.

10) Culling of badgers.

12) Genetic profiling of all culled badgers.

13) Identifying culled badgers that had been genetically profiled through hair trapping (in step 3).

14) Calculating the proportion of genetically profiled badgers that were culled, so as to give an estimate of cull effectiveness.

4.4.6. To turn this cull-sample-matching estimate of effectiveness into an estimate of population size it was necessary to:

15) Divide the total number of badgers culled by the proportional effectiveness estimate.

4.4.7. There are several, rather technical, statistical steps required to gain an estimate of uncertainty around these estimates of population size, recapture rate and cull effectiveness. These steps are described in detail in the AHVLA Effectiveness Report (Anon, 2013a), to which interested readers are directed.

4.4.8. In practice, various things may not work quite as expected at each of the above steps. Some of these will bias estimates; others will not bias the estimates but will affect the degree of uncertainty surrounding them. There are also various assumptions underpinning the two approaches. In Table 4.4 we identify issues that could arise at each step, describe what the consequences would be if these issues did arise, and present evidence as to whether the issue in question is likely to have arisen. Table 4.4 also directs readers to paragraphs describing assumptions and whether they were likely to have been violated.

4.4.9. Further details of assumptions, and of how they were addressed if thought likely to have been violated, are dealt with in Appendices 1 to 3 of the AHVLA Effectiveness Report (Anon, 2013a, pp. 12-31).

Step	Issue	Consequence		Evidence that issue occurred	Statistical assumption
		Capture mark recapture	**Cull sample matching**		
1)	Traps deployed incorrectly, e.g., deployed in areas that are not active setts	Bias down population estimate; likely to increase uncertainty	No effect on bias; likely to increase uncertainty	None	None
2)	Trapped hair removed from traps by protestors	Could bias down population estimate; likely to increase uncertainty	No effect on bias; likely to increase uncertainty	Protestors report removing hair from traps, particularly in Somerset	None (see this report, paras 4.4.10-4.4.14)
3) and 11)	Errors in genetic profiling	Could bias population estimates	Could bias effectiveness estimates	Low rates of genetic mismatches in samples	Mismatches corrected for in analyses (see appendices 1 and 3 in Anon, 2013a; this report, paras 4.4.15-4.4.17)
4)	Errors in data handling	Could bias population estimates; could influence uncertainty	N/A	Audits found no evidence of this	Distribution modified to account for errors in genetic profiling (see appendix 3 in Anon, 2013a)
5)	Incorrect likelihood formulation	Could bias population estimates; could influence uncertainty	N/A	None	Likelihood formulation (see this report, paras 4.4.18-4.4.26) Population closure (see this report, paras 4.4.27-4.4.31)
6), 7) and 9)	Errors in calculations	Could bias population estimates; could influence uncertainty	N/A	Audits found no evidence of this. These are all straightforward calculations	None
8)	Failure to identify badger setts	Could bias down population estimates	N/A	In Gloucestershire and Somerset respectively, observers misidentified as badger setts 10.3% and 27.3% of holes in the ground that were not due to badgers	This error rate could not entirely be corrected for (see this report, paras 4.4.32-4.4.37)
12) and 13)	Errors in calculations		Could bias effectiveness estimates; could influence uncertainty	Audits found no evidence of this	Calculations included correction for assumption of population closure, & genetic mismatches (see this report, paras 4.4.10-4.4.31)

Table 4.4 *Ways in which various factors could intervene to bias estimates or influence the degree of uncertainty attached to them.*

Protestor activity during hair trapping

4.4.10. If protestors were able to remove sufficient hair samples from one or more setts, this would generate spatial heterogeneity in the hair-trapping data. This could alter the frequency distribution of the number of times each genetically profiled badger was hair-trapped, which would in turn impact on estimates of population size and on estimates of effectiveness obtained by capture mark recapture. In statistical parlance, the effect would make some badgers trap-shy.

4.4.11. The statistical approach used by AHVLA attempts to correct for this effect by fitting mixture distribution (the Two Intrinsic Rates Model (TIRM)) as described in the AHVLA Effectiveness Report (Anon, 2013a, Appendix 3). The IEP has not been able to assess how effective this approach is at correcting for protestor activity because it is unclear whether the method would be able to distinguish between badgers living at setts where interference occurred and those where it did not.

4.4.12. Removal of hair from hair traps by protestors is less likely to bias estimates of effectiveness using cull sample matching, as these do not rely on estimates of pre-cull population sizes. The cull-sample-matching approach simply requires individual badgers to be genetically profiled.

4.4.13. If protestors were to add hair from badgers living outside the pilot areas to hair traps, this would bias down estimates of effectiveness obtained using cull sample matching, as these badgers could never be returned in the cull. In practice, field workers did find some interference of this kind but false hair samples were easily detected, for example because they had skin tissue attached to them.

4.4.14. The IEP concludes that protestor activity may have biased down population estimates in the capture-mark-recapture analysis but is unlikely to have introduced bias into the cull-sample-matching method.

Genetic profiling errors

4.4.15. If one badger is genetically profiled twice and methodological errors mean that the two genetic profiles do not match, this badger will be included in the analyses twice. This is known as a false negative. If two different badgers generate the same genetic profile, this is known as a false positive. Such genotyping errors are rare but can occur.

4.4.16. Tables 6.1 and 6.4 in the AHVLA Effectiveness Report (Anon, 2013a, pp. 21 and 25) report genotyping issues that arose for Somerset and Gloucestershire respectively. Error rates were low, and statistical methods were used to correct for any bias these errors could have introduced into the results (Anon, 2013a, Appendix 1).

4.4.17. The IEP concludes that genetic profiling errors did not introduce bias into population size estimates or effectiveness estimates.

Likelihood formulation

4.4.18. Likelihood methods are powerful statistical tools. They work through the construction of an equation that is designed to capture the processes that would generate the data that are collected, as well as providing an estimate of the desired statistic.

4.4.19. In the capture-mark-recapture case, the data are the number of badgers captured once, twice, three times, …, n times. The desired statistic is population size.

4.4.20. The likelihood equation contains parameters that are typically estimated through an iterative process. The parameter values that best explain the data are the maximum likelihood parameter estimates. The equation is then used, with these parameters, to calculate the desired statistic.

4.4.21. If the likelihood equation is inappropriate, then results could be biased either up or down.

4.4.22. The likelihood equation used in the capture-mark-recapture approach is based on the assumption that there are two classes of badgers. It also assumes that there is a difference in the chance of badgers being hair-trapped between these two classes, but that badgers within each class have the same chance of being hair-trapped.

4.4.23. The choice of two classes is arbitrary. The likelihood equation may provide biased estimates of population size if, in reality, there are more or less than two classes of badgers in the population with different chances of being hair-trapped.

4.4.24. The IEP concludes that the choice of likelihood function is appropriate in the absence of further information to guide choice of function. However, we do not know whether the likelihood function accurately captures the processes that generated the data. It is possible that the choice of likelihood function biased estimates of population size but we cannot know whether any such bias would be upward or downward.

4.4.25. It is also theoretically possible that the function was more appropriate for one pilot area than for the other but we have no evidence to suggest that this was the case.

4.4.26 We conclude that there is no evidence suggesting that assumptions underlying the likelihood function in the capture-mark-recapture analysis were violated. However, we cannot rule out the possibility that assumptions were violated, with consequent biasing of estimates of population size.

Population closure

4.4.27. A closed population is one in which animals do not leave through natural death or emigration or enter through birth or immigration over the course of a study. When the duration of the study is short, it is likely that the population is closed. As the duration of the study increases, it becomes more likely that closure will be violated because the recapture rate is estimated over a longer period of time.

4.4.28. There is a greater chance that the population closure assumption is violated for the cull-sample-matching estimate of effectiveness than for the capture-mark-recapture estimate. This is because the recapture rate used to estimate population size as part of the likelihood for the capture-mark-recapture method is estimated over the duration of the hair-trapping exercise, while the recapture rate used to estimate effectiveness with the cull-sample-matching method is estimated over the duration of both the hair-trapping exercise and the cull. Violation of the population closure assumption can bias down estimates of effectiveness if large numbers of badgers leave the pilot area.

4.4.29. Statistical analyses carried out by AHVLA attempted to correct for this effect by correcting for what their report refers to as ‘churn’ (Anon, 2013a, Appendix 2).

4.4.30. Estimates of churn for Somerset were between 0% and 3.5% of the population and for Gloucestershire between 0% and 6.5%. These estimates of churn are included in the effectiveness estimates reported in the AHVLA Effectiveness Report (Anon, 2013a) and in this report.

4.4.31. We conclude that because hair trapping occurred over a short period of time it is highly unlikely that the assumption of population closure was violated. The closure assumption could have been violated during the course of the cull and this could bias estimates of effectiveness based on the cull-sample-matching approach. However, AHVLA analyses on the effectiveness of the cull using this approach attempted to correct for violation of the closure assumption.

Failure to identify badger setts

4.4.32. AHVLA field workers sent out to record badger setts photographed those they found. These photographs were independently checked by a badger ecologist. Field workers did not photograph holes that they thought did not belong to badger setts.

4.4.33. The field workers employed in Somerset misidentified more than one in four holes in the ground as a badger sett entrance.

4.4.34. In Gloucestershire, only one in 10 holes in the ground was misidentified as a badger sett entrance.

4.4.35. What is not known is the percentage of badger setts that observers dismissed as being created by something else (e.g., rabbits). If observers failed to identify true badger setts, this would bias down estimates of population size.

4.4.36. The limited abilities of the Somerset observers to identify badger setts could have biased down population estimates. However, because the same sett survey was used to produce population estimates 4 and 5 in Table 4.3, both of these estimates would be downwardly biased whereas, in fact, only estimate 5 looks low.

4.4.37. The IEP is concerned by the high error rate in identifying setts in Somerset. Appropriate steps were taken by the AHVLA to correct for those cases where holes in the ground were classified as badger setts when in fact they were made by other animals, but no correction was made for badger setts that were classified by fieldworkers as being made by another animal. Such errors would bias down population-size estimates and, consequently, would bias up effectiveness estimates based on the capture-mark-recapture method.

Spatial bias

4.4.38. In addition to issues arising at each step in data collection, there are also potential statistical issues resulting from the spatial distributions of hair-trapped badgers and shot badgers. These issues could arise as a function of badger or Contractor behaviour.

4.4.39. Bias could occur if the population of hair-trapped badgers differed from the population of shot badgers. Put another way, if badgers that were hair-trapped were more or less likely to be shot than those that had not been hair-trapped, then estimates of the effectiveness of the cull could be biased. The most likely cause of this type of bias would be a mismatch between the places where hair trapping was implemented and the places where shooting activity was concentrated.

4.4.40. Spatial data on the distribution of hair-trap locations and areas of land where Contractors shot badgers were provided by the Cull Companies but we were unable to access them owing to security concerns. In addition, other data received from the Cull Companies proved questionable: for example, some Contractor shifts were recorded as lasting for less than 1 min while another ran uninterrupted for 32 days. We have also been shown at least two different sets of cull data. We therefore felt that it would be unwise to base any conclusions on data, including spatial data, provided by the Cull Companies.

4.4.41. Nevertheless, the IEP was given sight of maps showing the distribution of hair traps and the land holdings where badgers were reported to have been shot. These maps revealed many land holdings where no badgers were reported shot. However, interpretation of these maps is difficult, given our concerns about data on Contractor effort. Consequently, we do not know whether badgers were not shot in

certain areas because of limited Contractor effort, low badger numbers or protestor activity.

4.4.42. Natural England was unable to confirm to us the percentage of land in the two pilot areas over which shooting had occurred. One condition in the licences issued to Cull Companies was that there should be access to at least 70% of the total land area in each pilot area. However, the terms of the licences did not require that the removal of badgers occur over the full extent of this area.

4.4.43. One strand of evidence arguing against spatial bias is provided in Appendix 2 of the AHVLA Effectiveness Report (Anon, 2013a), namely, analysis of the proportion of carcasses returned for each square where badgers were reported as having been shot. This analysis suggests that variation in return rates across squares was not a major source of uncertainty. In addition, the fact that some of these squares were reported as experiencing interference suggests that protestor activity was not a major source of bias in those squares where badgers were shot.

4.4.44. We conclude that although this latter analysis provides some evidence that spatial variation in return rates did not contribute bias, we cannot, in the absence of reliable data on Contractor effort per land holding, rule out bias. However, only substantial bias would affect our general conclusions about the failure of controlled shooting to reduce the pre-cull badger population by at least 70% over the 6-week pilot cull in each area.

Cage trapping

4.4.45. The fact that a significant number of badgers were culled by cage trapping rather than by controlled shooting could provide a substantial source of bias in our ability to estimate the effectiveness of controlled shooting, particularly if there were overlap between the population of badgers available to be shot and the population of those available to be cage trapped. The reason for this is that if an individual badger is cage trapped, it is not available to be shot, so the potential effectiveness of controlled shooting as a means of reducing badger populations will be biased downwards. In other words, the proportion of the population culled by shooting will be lower than would have been achieved in the absence of cage trapping, if the population of badgers available for cage trapping is not independent of that available for controlled shooting.

4.4.46. Because each badger is either killed by cage trapping or by controlled shooting only once, and because both cage trapping and controlled shooting occurred in some of the same land holdings, it is not possible to determine robustly whether the population of badgers available for cage trapping, and that available for controlled shooting, were independent. However, we can use the data available to provide best- and worst-case scenarios.

4.4.47. In the worst-case scenario, the population of badgers available for cage trapping and the population available for controlled shooting are assumed to be independent, i.e., we assume that removing a badger by cage trapping did not change the size of the population available to be shot. In this case, our estimates of the effectiveness of controlled shooting remain unchanged from those reported in Table 4.1 above.

4.4.48. In the best-case scenario, if every badger that was cage trapped would have been shot in the absence of cage trapping, we can use the combined totals to provide an upper limit on the possible effectiveness of controlled shooting. Note that this logic assumes, almost certainly fallaciously, that cage trapping did not reduce Contractor effort focused on controlled shooting, and that cage trapping and controlled shooting are equally effective at removing badgers. In this case, our estimates of the effectiveness of controlled shooting are the same as those for controlled shooting plus cage trapping (see Table 4.2 above).

4.4.49. Given that the best-case scenario yields an efficacy estimate that lies well below the 70% threshold, we can still conclude with confidence that controlled shooting is not an effective tool with which to reduce a population of badgers by at least 70% within a 6-week time frame.

Protestor activity during the pilot culls

4.4.50. An analysis carried out by the AHVLA and made available to the IEP in mid-January 2014 provides evidence that being hair-trapped prior to the cull did not influence the probability that a badger would be shot during the cull. This means that effectiveness estimates do not appear to have been biased by occupation, during the cull, of land on which hair trapping had occurred. However, such activity may have increased the degree of uncertainty in the estimates.

4.4.51. Given uncertainty about the quality of the information supplied by Contractors, together with concerns raised about the data by AHVLA, the results of this analysis at best constitute anecdotal evidence that effectiveness estimates were not biased by protestor activity.

Quality and quantity of data

4.4.52. The Auditors concluded that the data collected were sufficient in quality and quantity to assess effectiveness in both pilot areas (Wahl and Coulson, 2013a). The IEP concurs with this view.

Competence of field staff

4.4.53. With the exception of field workers' ability to identify badger setts in Somerset, the IEP is satisfied that the experience and training of field staff was

sufficient to provide robust data on which to base conclusions regarding the effectiveness of the culling operations conducted in the pilot areas.

5. Humaneness Monitoring

5.1. Introduction

5.1.1. In this context we take humaneness to mean ‘absence of suffering’. The IEP was required only to assess the extent to which suffering could have occurred in the pilot culls, not to consider whether any suffering was ‘necessary’ or ‘unnecessary’.

5.1.2. The severity of incidents of animal suffering is made up of three components:

a. Number of animals that experience suffering.

b. Duration of that suffering.

c. Intensity of the suffering.

5.1.3. All three of these components need to be considered when forming a judgement about where a particular outcome or situation falls within an overall suffering-severity spectrum. However, the monitoring protocol was not designed to assess the third component directly because this depends to a large extent on the form of the suffering and would be difficult to evaluate on the basis of observational data obtained under field conditions. Consequently, the analysis that follows concentrates on the first two components.

5.1.4. The potential forms of suffering that exist when shooting wildlife in the field include:

a. Pain caused by the firearm injury itself.

b. Inflammatory pain in individuals which do not immediately die.

c. Inability of a wounded animal to take care of itself as a result of debility caused by the injury (e.g., hunger if unable to forage and feed adequately, cold associated with haemorrhage or inability to reach shelter).

d. Fear linked to the activities of people in the region, and resulting from the situation or condition of the animal.

5.1.5. The monitoring protocol was not intended to provide information about fear because, under the circumstances of the pilot culls, it would have been difficult to distinguish fear and to attribute it, with accuracy, to any specific activity or cause. Nor were we able to make any assessment of suffering due to inability of a wounded animal to care for itself. Our analysis is therefore restricted to consideration of the likelihood that an animal experienced pain as a consequence of shooting.

5.2. Development of monitoring protocols

Rationale for the methods used

5.2.1. The monitoring protocol, in common with other studies on similar topics, was designed to identify the risk of suffering according to the ways in which animals died. For example, if an animal is wounded but does not die promptly, the risk of suffering is higher than for one which immediately collapses and dies.

5.2.2. On the advice of the IEP, two approaches were used to assess potential suffering in terms of the number of animals experiencing suffering and the duration of that suffering. These approaches were:

a. Examination of the behaviour of a sample of animals when they were shot at and, in particular, estimation of their time to death. This was achieved by direct observation, in the field, of shooting events, and by subsequent inspection of thermal-imaging recordings taken at the time of the shooting.

b. Post-mortem examination (including radiography) of a selection of fatally wounded badger carcasses for injuries, with a view to establishing the extent and nature of the injuries and the cause of death.

5.2.3. Injuries caused by high-velocity rifle bullets and by shotgun pellets differ considerably. Accordingly, the IEP recommended that badgers killed by rifles and those killed by shotguns should be monitored separately (i.e., observational and post-mortem data were to be collected on samples of badgers killed in each of these two ways).

5.2.4. In the event, however, only 11 badgers were culled using shotguns during the 6-week pilot culls. Consequently, we were unable to assess the humaneness of shooting by means of shotguns and are unable to comment further on the humaneness of this form of culling.

5.2.5. We are unaware of published information on the time of onset of pain in badgers, following significant trauma. Equally, we are unaware of any evidence indicating that badgers would not suffer from pain after a gunshot that inflicts trauma but does not lead to immediate unconsciousness. In humans who experience a serious injury there can be a delay before the onset of severe pain, and this applies to a wide range of forms of trauma (Melzack, Wall and Ty, 1982). The delay is due to the time it takes for pain agonists to leak from injured tissues and accumulate at the site of the wound, where they provoke pain.

5.2.6. Combat injuries caused by blast and gunshot in US soldiers indicate that intense pain frequently begins at the time of injury, as a consequence of the initial

traumatic insult (Clark et al, 2007). However, observations of firearms injuries in humans by the International Red Cross (R. Coupland, personal communication), suggest that there can be an interval between being shot and the onset of severe pain. This interval is thought to be around 5 min.

5.2.7. In the absence of physiological data showing fundamental differences in the mechanisms of pain perception amongst higher mammals, we have assumed that the onset of firearms injury pain in badgers mimics that of people. That is, an unknown proportion of badgers may experience marked pain from the time of injury whilst, in others, there may be a short time lag (up to 5 min) before pain onset. Therefore, for the purposes of interpreting the pilot cull data we have taken the view that suffering from marked pain is very likely in badgers that survive more than 5 min after being shot.

5.2.8. Before the pilot culls began, an interim reporting protocol was established to inform Defra ministers, daily, of 'events of concern' noted during observed shooting events. On the advice of the IEP it was decided to record two types of such events: situations in which a badger was recorded to take more than 5 min to die were termed 'time events'; situations in which badgers were believed to have been hit but in which no carcass was retrieved (because the animal in question was lost in cover or had retreated into a sett) were termed 'non-retrievals'. The daily reports to Defra provided the cumulative number of events of concern and the total number of observed shootings. In addition, the IEP recommended that the updates should include the expected outcome in terms of the likelihood that the total number of events of concern at the end of the 6-week period would not exceed 5% of all observed shootings. These calculations were intended to inform decisions, by Defra ministers, on whether alterations to pilot protocols were required or whether to conclude the pilot culls prematurely for humaneness reasons.

5.2.9. Under its revised terms of reference the IEP had no sight of the daily reports of events of concern, so was not involved in evaluating the data while the pilot culls were in progress. However, it remains the IEP's view that concern about the humaneness of controlled shooting would be justified should more than 5% of badgers be found to take more than 5 min to die.

5.2.10. Setting a level for events of concern is, to some extent, subjective. However, comparisons with other methods of killing animals for disease control purposes or population management provide a context within which to make judgements.

5.2.11. Cattle infected with tuberculosis are killed in abattoirs where in excess of 98% will experience a humane death following stunning (Grandin, 2005). Cage-trapped badgers, although subject to some distress at being caught, die in less than 30 s after being shot in the head. Concern for the welfare of free-ranging badgers could, quite reasonably, be set at this level.

5.2.12. In practice, however, culling wildlife by shooting in the field does not always result in a clean kill. Estimates vary as to the proportion of deer and foxes that are wounded and escape. Experienced professional shooters strive for the desired result of zero per cent wounding but consider that a minimum of 95% clean kills is a practical, achievable outcome. Bradshaw and Bateson (2000) studied the welfare implications of culling deer and noted from a self-selected sample of stalkers that 4.4% +/-2.3% (i.e.. 2.1% to 6.7%) of deer survived more than 2 min after being shot; 9.8 +/-3.0% (i.e., 6.8% to 12.8%) required two or more shots; and 3.5% +/- 1.5% (i.e., 2% to 5%) escaped wounded. Unfortunately, there was no discussion in the paper of deer that were 'missed'. The IEP considers that, in the context of controlled shooting of badgers by trained and licensed Contractors, the percentage of animals surviving for more than 5 min after being shot, and the percentage being wounded but not retrieved, should not together exceed 5%.

Observational data

5.2.13. Field observations focused on events surrounding the shooting of a representative sample of badgers. This involved collection by Observers of a comprehensive range of data including time from shot to last movement of the animal, number of bullets fired, and distance at which the shot was taken. As well as collecting data in the field at the time of the shooting event, Observers took thermal imaging recordings for subsequent analysis. If a badger was shot at but escaped, the time elapsing between the shot being taken and the animal disappearing from view was calculated using the thermal imaging recordings.

5.2.14. To minimise bias and provide an adequate sample size, the IEP recommended that observations be made of at least 60 shootings involving 60 different Contractors.

5.2.15. The presence of an Observer could have an effect on shooter behaviour. For example, it might make shooters more risk averse in shot selection (i.e., make them avoid taking shots that were less likely to hit or mortally injure the animal), in which case the observed sample of badgers might under-represent the potential for suffering. Accordingly, the IEP recommended that post-mortem examinations be carried out on a minimum of 60 badgers whose shooting was observed and 60 whose shooting was not observed. It was stipulated that each pair of badgers (Observed and Unobserved) should be killed by the same shooter. Data from this matched-pair sample of post mortems were intended to allow assessment of the effect, if any, of the presence of an Observer.

5.2.16. We are confident that Observers were adequately trained and supervised, and that their independence was maintained.

Post-mortem examinations

5.2.17. As already noted, the IEP recommended that the carcasses of at least 60 rifle-shot badgers whose shooting had been observed, and 60 whose shooting had not been observed, should be subjected to post-mortem examination. Bearing in mind that it was also originally intended to examine the carcasses of an additional 120 shotgun-shot badgers, these numbers were the maximum achievable owing to:

a. Time constraints related to the need to complete the examinations whilst the badger cadavers were still fresh.

b. Health and safety regulations (related to the potential for zoonotic infections) requiring that pathologists use full personal protection equipment.

However, the IEP is confident that this sample size was sufficient to allow pathologists to form a reliable understanding of the nature, extent and anatomical distribution of injuries in both the Observed and Unobserved groups of badgers.

5.2.18. The post-mortem examinations were undertaken to determine the location, nature and extent of skin wounds and internal injuries. Radiography (x-ray) was used to locate bullets and to identify related injuries to bones.

5.2.19. To avoid bias, the veterinary pathologists were unaware whether the badgers being examined, post mortem, belonged to the Observed or Unobserved categories.

Analysis of data

5.2.20. There were three potential outcomes for animals in the Observed group:

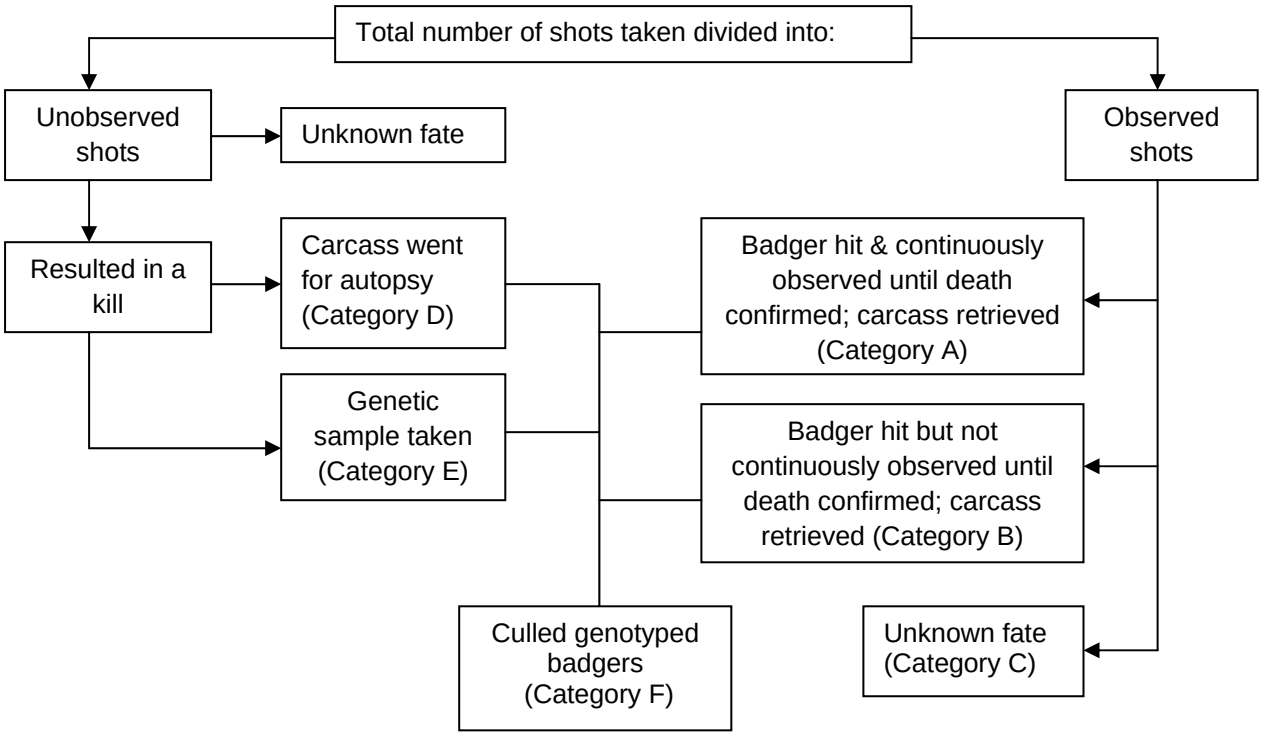
a. Category A: shot at and observed continuously with thermal imaging equipment until the last movement (which was taken as the time at which the animal died).

b. Category B: shot at and escaped but their carcasses were subsequently retrieved. These animals were not observed continuously between the shot and last movement but death was determined from responses tested when the carcass was found.

c. Category C: shot at and escaped, and their carcasses were not subsequently retrieved. Consequently, these animals were observed only for a limited period after the shot.

5.2.21. The time-to-death distribution results that follow are population-level estimates derived from all observed shootings, i.e., they include all Category A, Category B and Category C individuals. However, because the fate of Category C individuals is not known, no carcasses exist for these badgers. A consequence of this is that results from autopsies come from a sample distribution that is not representative of the population of all badgers that were shot at. Note, however, that

autopsied badgers come from both Observed and Unobserved successful shootings. Figure 5.1 explains the data types that were used for different analyses.



Analysis	A	B	C	D	E	F	Estimate Type
Time to death distribution	✓	✓	✓	✓	✓		Population level estimate
Accuracy of shot	✓	✓		✓			From culled sample
Shot at but not retrieved			✓				From missed sample
Marked pain	✓	✓		✓	✓		From culled sample

Fig. 5.1 *Flow diagram showing the distinctions between data collected from Unobserved and Observed badgers. The lower chart shows which types of analysis and which forms of estimate were available for each category of animals.*

5.3. Results and interpretation

Observed shooting events

5.3.1. Observers accompanied 106 Contractors, from the total of 130 available, into the field on 218 occasions. The behaviour of 88 badgers, during controlled shooting by 57 different Contractors using rifles, was observed and recorded using thermal imaging equipment.

5.3.2. Category A (see 5.2.20 above) contained 69 animals, Category B contained 9 animals and Category C contained 10 animals.

5.3.3. In Category A, accurate times to death were recorded for the 69 badgers. Sixty-eight of these died in 66 s or less, while a single animal had an extended time to death of 13 min 43 s.

5.3.4. In Category B, estimation of time to death was confounded by loss of observation before the animal's last movement. Seven of these badgers were found dead in less than 9 min 30 s; two others were not found dead until more than 60 min after the shots were fired. However, we know that none had moved more than 15 m from where they were shot and post-mortem examination revealed that seven had chest or brain injuries indicative of rapid death. We are therefore confident that these seven animals did not suffer marked pain. Uncertainty remains regarding the injuries and time to death of the two badgers in Category B that were not subjected to post-mortem examination because of logistical issues with the collection and selection procedures.

5.3.5. In Category C, observations suggested that at least three of the10 badgers were wounded but uncertainty exists as to whether the remaining seven animals escaped unhurt (missed shot), were non-fatally wounded or died later from firearms wounds. AHVLA (Anon, 2013b) estimated, from the binomial confidence interval for the observed proportion of non-recovered badgers, that the proportion of non-recovered badgers after a rifle shot lay between 6% and 19% (95% CI). In other words, when estimating the proportion of non-retrievals amongst all of the badgers that were shot at during the 6-week pilot culls, we have very high confidence that the minimum proportion that would not have been retrieved was 6% and the maximum proportion 19%.

5.3.6. The AHVLA Humaneness Report (Anon, 2013b, Appendix 11) describes three approaches to estimating a time-to-death distribution for the population as a whole, using the data summarised above. The two most reliable approaches, 'censoring' and 'modelling', produce similar time to death distributions. These suggest that 7.4% - 22.8% (95% CI) of badgers were still alive after 5 min. This estimate assumed that

time to death in Category B badgers corresponded to the time at which their carcasses were found; and that animals in Category C were still alive when lost to observation and survived to the maximum observed time to death. (For a justification of these assumptions see 5.4.15 – 5.4.17 below.)

5.3.7. According to this analysis, we can be 95% confident that the number of badgers estimated as taking more than 5 min to die exceeded 5%.

Post-mortem examinations

5.3.8. Sixty four carcasses from the Observed group and 94 from the Unobserved group of badgers were submitted for post-mortem examination. In all 158 carcasses, death was attributed directly to rifle bullet injuries; no cases of death from disablement or subsequent infection were found. In three of the Observed group and five of the Unobserved group, uncertainty existed over where the fatal shot entered the body but this did not affect interpretation of the internal injuries.

5.3.9. Fifty (92.5%) of 54 badgers whose times to death were known from observational data had major injuries to lungs, heart and blood vessels within the chest. Observational data show that these badgers died in 66 s or less. Post-mortem examination showed that accurate (i.e., ideal) chest shots inevitably caused this type of damage. However, post-mortem examination revealed that bullet fragmentation in non-ideal shots could also result in destruction of vital organs and blood vessels in the chest, causing rapid death.

5.3.10. Altogether, 57 (89%) of the 64 retrieved badger carcasses, from Observed groups A and B, that were examined post mortem showed the type of severe chest injury that would have resulted in rapid unconsciousness/death before the onset of marked pain. Seventy eight (83%) of the 94 badger carcasses from Unobserved shootings showed similar chest injury.

5.3.11. In addition, three (4.7%) Observed and seven (7.5%) Unobserved badgers showed head and neck wounds that were likely to have been fatal before pain onset.

5.3.12. To summarise, post mortem data show that rapid death was caused by severe chest injury in a total of 86.0% (136/158) of badgers and by head and neck wounds in 6.3% (10/158) of badgers. Abdominal or hindquarter injuries in two Observed badgers were also shown by observational data to have resulted in rapid death. However, injuries to the abdomen or hindquarters do not necessarily kill rapidly and these two cases highlight the need for caution when interpreting post-mortem findings in the absence of observational data.

5.3.13. In the remaining 6.3% (10/158) of badgers, death may not have supervened before the onset of marked pain.

5.3.14. Eight badgers (three Observed and five Unobserved, totalling 5.1% of the 158 subjected to post-mortem examination) had been hit by more than one shot. Times to death were recorded for three of these badgers. Two died within 27 s but it is highly likely that the third one, which survived for 13 min 43 s, suffered marked pain before being killed. Because the times between first shot and fatal shot are unknown in the five Unobserved badgers, there is considerable uncertainty over the occurrence and extent of suffering in these badgers.

Accuracy of shooting

5.3.15. Post-mortem examinations highlighted concerns over the accuracy of shooting. Only 56 (35.4%) of 158 badgers submitted for post-mortem examination were hit in the target area described in the Best Practice Guidance.

5.3.16. However, after the pilot culls had finished, we became aware that the NFU and Contractors decided, early in the culls, that it was more effective and humane to alter slightly the recommended point of aim (POA). Thermal imaging observations of badgers being shot provided support for this change of practice. Specifically, the POA was changed from the centre of the target area specified in the Best Practice Guidance to a point that would ensure that at least one shoulder and the underlying chest were hit. This, it was felt, was more likely to produce immediate immobilisation and to increase thoracic damage. This decision was not discussed with Natural England or Defra, nor were NE or Defra informed of the change. Nevertheless, post mortem evidence indicates that this POA did result in a high incidence of rapidly fatal chest shots.

5.3.17. Further concern about the accuracy of shooting stems from the following observations:

a. Seven badgers required at least two shots, with one Observed shooting recording six shots fired at a single badger.

b. A further seven badgers (in Category C) may have been missed completely. In one of these cases two shots were fired at two badgers, with both shots being considered misses on the basis of thermal imaging observations and subsequent analysis of thermal imaging recordings.

Effects of Observer presence

5.3.18. There were no important differences in the pattern of wounding between carcasses in the Observed and Unobserved groups. Thus there was no evidence that the presence of an Observer influenced the behaviour of the shooter.

5.4. Robustness of data collection and analysis

5.4.1. The plans for collecting, collating and analysing the data were assessed by the Independent Auditor, who commented on potential weaknesses before the study started. Those comments were acted on. Overall, the Auditor concluded that 'there was no evidence of systematic fraud or errors that could introduce bias into the data'.

Reliability of behavioural data

5.4.2. We intended that time to death would be assessed in two ways from the behaviour recordings:

a. As the period of time between firing the rifle to last movement of the shot badger.

b. As the period of time from firing the rifle to confirmation of the absence of responses in the badger when examined at close quarters.

5.4.3. Observers reported that as the cull progressed, Contractors and Observers sometimes needed to leave the site promptly following a shot, in order to avoid contact with protestors drawn to the area by the sound of the shot. This meant that in some instances the second variable (time to confirmed death) was not always recorded as accurately as intended. The proportion of instances where this occurred is not known, so we have placed more reliance on reports regarding the first variable (time to last movement).

5.4.4. Three thermal imaging recordings that had already been assessed by AHVLA staff were re-assessed by the Auditor in order to check for inter-observer reliability in the scoring of behavioural data. The Auditor's assessments of these recordings agreed in all respects with those of the relevant AHVLA staff. Although the number of recordings re-assessed in this way was too small to provide a convincing check on reliability, the results suggest that behavioural interpretations of thermal imaging recordings were consistent.

5.4.5. At an early stage during the cull it became apparent that some non-retrieval cases were not being recorded by Observers. This error was retrospectively corrected and the final data set was considered by Observers to be complete in this respect.

5.4.6. Fifty seven Contractors (54% of registered Contractors) were observed while taking a shot. The original aim was that these would be selected randomly but it was reported by Observers that, initially, some Contractors were unwilling to allow Observers to join them in order to observe a successful shot. Thus, some Observers were prevented from observing some shots. However, it is unlikely that this produced any systematic bias in the data.

5.4.7. Observers were equipped with thermal imaging equipment to observe the animals' behaviour in the dark. Making effective use of this equipment, whilst performing simultaneous recordings and commentaries, required experience and it may have taken a few nights of culling before Observers acquired the skills needed to make accurate assessments. Although data from the first few nights of culling were included in the analysis, it is unlikely that this constituted a significant source of bias.

Reliability of post-mortem data

5.4.8. At an early stage during the cull there was some mismatch between Observed animals that should have been submitted for post-mortem examination and the carcasses that were actually received at the post-mortem centre. Data from mismatched carcasses were excluded from the analysis and corrective actions were put in place that prevented further mismatches. All of the animals that were included in the final post-mortem data set were killed by shooting. It is possible that carcasses of Unobserved animals could have been incorrectly identified but there is no objective information that could be used to test this possibility.

5.4.9. Post-mortem changes can affect post-mortem appearance. However, the veterinary pathologists who carried out the post mortems reported that this was not a concern. This was unsurprising as most carcasses were presumably collected on the night they were shot.

5.4.10. A gender bias was noted in the study, whereby the Unobserved group contained a higher proportion of female badger carcasses than the Observed group. Since this did not result in a significant difference in body size between the two groups, it is unlikely that it had a significant bearing on the humaneness outcomes.

Shot placement

5.4.11. Post-mortem examination proved to be invaluable in the assessment of shot placement. Entry wounds, internal injuries and multiple shots were accurately recorded. Comparison of lesion profiles in Observed and Unobserved badgers allowed indirect assessment of the effect of Observer presence on the accuracy of shots in those badgers that were retrieved and subjected to post-mortem examination. However, it is not known whether Observer presence influenced the frequency of missed shots

Statistical considerations in estimating time to death

5.4.12. Two sub-sets of the data that were collected could be used to assess humaneness: data from the post-mortem examinations and data from observations.

5.4.13. Data from post-mortem examinations revealed the locations of entry wounds and the damage that the shot caused. These data could be used to infer the likelihood that the animal died rapidly. However, by definition, all animals available for post-mortem examination must be in Categories A and B (see paragraph 5.2.20).

5.4.14. Consequently, drawing conclusions about humaneness from these data alone would provide a biased view of humaneness, because Category A and B animals died directly as a result of being shot.

5.4.15. The second way to assess humaneness is to estimate the distribution of times to death using data collected by Observers. Times to death were known accurately for individuals in Category A. An estimate of time to death for those individuals in Category B was based on the time taken to find the carcass. As far as the Category C badgers are concerned, it is uncertain whether the shot resulted in a miss, non-fatal wounding or death.

5.4.16. If we were to estimate a distribution of times to death using only those individuals in Categories A, or A and B, this would constitute a downwardly biased sample of times to death because all individuals in Categories A and B were definitely hit and killed. Consequently, we also want to use information from those animals that were shot at, but which had an unknown fate (Category C animals). This was achieved by the use of statistical methods that factored-in Category C individuals as surviving for a period of time after being shot at and, through censoring, as having an unknown fate.

5.4.17. Estimating the distribution of times to a particular event is a question of interest in economics, medicine, ecology and engineering. Our conclusions are based on the Kaplin-Meier approach used by AVHLA (Anon, 2013b), which is widely accepted to be the most appropriate approach available for providing an unbiased estimate of the distribution of times to death. AHVLA used various methods based on this approach. The ‘censored’ method provides a description of the distribution of times to death from the data, based on observations of both known fate (death) and unknown fate (a shot taken but the outcome unknown). The ‘modelled’ case fits a mathematical function to this distribution. Both approaches gave very similar overall conclusions.

5.4.18. The AVHLA Humaneness Report (Anon, 2013b) presents two types of result. The first is the proportion of badgers estimated to have died within a certain time of a shot being taken. For example, between 77.2% and 92.6% (95% CI) of badgers died within 274 s of being shot.

5.4.19. The second type of result is the time taken for a specific proportion of badgers to die. For example, we can say we are 95% confident that 50% of badgers took between 9 and 20 s to die.

5.4.20. Given that the IEP chose to assess humaneness from the time-to-death distribution as the proportion of badgers that died within 5 min, we report results as the range of percentages of badgers that died within that time. The lower percentage value represents the worst-case scenario, while the upper percentage value is the best-case scenario.

5.4.21. It is important to note that the population estimate for time to death is not an absolute measure: it is an estimate falling within a range of values. As pointed out in the Auditors' report (Wahl and Coulson, 2013b), uncertainty around times to death for the 5% of badgers that took longest to die was large and could not be satisfactorily estimated. There is less uncertainty around the time to death for those badgers that died quickly. This pattern is unsurprising and reflects the small numbers of animals in Categories A and B that had long confirmed times to death, and of those animals that were shot at but whose fates were unknown (Category C animals).

5.4.22. The IEP is content that the estimated distribution of times to death is unlikely to be substantially biased, but notes considerable uncertainty around the 5% of badgers that took longest to die.

Considerations in interpreting the behavioural data

5.4.23. In the time-to-death analysis, Category C animals were treated as having an unknown fate. However, behavioural observations were taken from these animals by Observers with thermal imaging equipment, as well as being taken from those animals that were shot and killed.

5.4.24. Some animals that were shot at, and subsequently died, showed no immediate behavioural signs of being hit: they ran off as if simply startled by the noise. Some Contractors reported these cases as being missed shots but the subsequent retrieval of a carcass revealed that they were mistaken. Thus, the lack of any immediate behavioural signs of being mortally injured makes it impossible to draw any firm conclusions about Category C animals from the behavioural data.

5.4.25. When considering estimates of the proportion of badgers hit but not retrieved, we take the view that humaneness concerns are correctly addressed by taking a pessimistic view of the likelihood of suffering. In this case, this means assuming that all Category C animals were hit. This approach is accepted practice in medical and veterinary medical research where there is the potential for severe animal suffering. It is also supported by the following considerations:

a. Observers reported that Contractors sometimes thought they had missed animals, whereas subsequent investigation found either a carcass or other evidence of a hit badger. Thus, the absence of behavioural evidence that an animal has been hit does not necessarily mean that the shot was a miss.

b. The short duration of observation in most cases before Category C animals were lost from view meant that a reliable retrospective assessment of the number that had been hit was not possible, even using thermal image recordings and site assessment.

5.4.26. The Kaplin-Meier time-to-death analyses require each badger in Category C to be allocated a time duration for a minimum length of time that the animal survived after being shot at.

5.4.27. Most animals in Category C were lost from view quickly. If each badger in this category was assumed to have survived for the duration of time between the shot being taken and the animal being lost from view, it is assumed that there is no difference between the fates of Category A and Category C badgers.

5.4.28. The IEP took the view that Category C animals survived for longer than Category A animals because their carcasses were not retrieved, even though the areas where the Category C animals were shot at were carefully searched.

5.4.29. In the time-to-death analyses in the AHVLA report, animals in Category C were allocated as surviving for longer than 5 min. The IEP felt that this assumption was justified because, since no carcasses were recovered, it is known that none of these badgers died close to the area where they were shot at.

5.4.30. When the IEP report was at an advanced stage, Defra requested AHVLA to conduct further analyses of time to death and to recalculate the proportion of badgers that may have survived for longer than 5 min. We consider these analyses in Appendix 12.5 below.

5.4.31. The first of these analyses made the assumption that seven Category C animals were not hit and were, therefore, not at risk of suffering marked pain. These animals were removed from the analysis. However, because their fate is unknown, and because they could have been hit, we consider the assumption that they were not hit to be unjustified.

5.4.32. Additional analyses by the AHVLA made the assumption that these animals survived for 4 min 59 s, at which point their fate became unknown. This analysis concludes that it is unlikely that more than 5% of badgers survived for more than 5 min. However, the result is not surprising as the assumption reduces the number of animals that could contribute to estimates of the part of the time-to-death distribution that is greater than 5 min.

6. Implications for Roll-out

6.1. Effectiveness

Reasons for failure to meet the 70% target

6.1.1. There are various possible reasons why the pilot cull failed to meet its target of reducing the pre-cull badger population by at least 70%. These reasons, together with relevant evidence, are summarised in Table 6.1 overleaf.

6.1.2. Data needed to properly assess the relative importance of the various factors listed in Table 6.1 are lacking. However, it seems likely that non-compliance, heterogeneous spatial coverage by Contractors of compliant land, variability in Contractor effort or ability, and protestor activity were all contributory factors.

Additional effort required to meet the 70% target

6.1.3. In considering whether the policy of controlled shooting should be rolled out more widely, it would be useful to know how much additional shooting effort would be needed to achieve 70% removal. Unfortunately, we are unable to answer this question because the only measure of effort available, namely, number of Contractor shifts, fails to distinguish between shifts devoted to controlled shooting and shifts devoted to cage trapping and shooting.

Possible reason	Relevant evidence
Non-compliant land holdings	Culling was not permitted on up to 30% of land in each pilot area. However, culling on the borders of non-compliant land holdings may have removed some badgers from them.
Heterogeneous Contractor coverage of compliant land	On some land holdings, few or no badgers were shot. Because data on Contractor effort are lacking, we cannot assess whether this resulted from lack of Contractor effort in these areas or from low badger densities. However, in some land holdings where no badgers were shot, hair traps successfully collected samples. This suggests that heterogeneous Contractor effort was a contributing factor.
Insufficient Contractor effort/ability	Individual Contractors differed markedly in the number of badgers they shot (Anon, 2013b, p.25). Also, a significant number of Contractors dropped out during the 6-week period, presumably because they failed to shoot as many badgers as they had expected. We cannot assess whether these effects resulted from differences in effort or in ability.
Downwardly biased statistical estimates	These are unlikely, because upper 95% confidence intervals of the effectiveness of controlled shooting were mainly below the 70% threshold required for the cull to be successful, regardless of the statistical method used. (See section 4.4 for discussion of sources of bias.)
Badgers became more reluctant to visit baited sites, or to emerge from setts, as culling progressed	There is no evidence for or against this suggestion.
Badgers migrated away from areas where the cull was most active	This is unlikely because badgers are reluctant to leave established territories, especially in areas of high badger population density.
Protestor activity	Badgers were successfully shot in some areas that were reported as being subject to protestor activity. However, the extent to which protestor activity disrupted culling cannot be quantified.

Table 6.1 *Possible reasons why controlled shooting failed to remove 70% of badgers, and evidence relevant to these.*

6.1.4. AHVLA statisticians have attempted to estimate the additional Contractor effort that would be needed to achieve removal of 70% of badgers using a combination of controlled shooting and cage trapping (Anon, 2013a). However, the IEP regards the data provided by the Cull Companies as insufficiently reliable for this purpose (see also 4.4.40 above).

Setting targets for badger removal

6.1.5. Censusing mammals is notoriously difficult, especially when, like badgers, the animals in question are relatively small, shy, cryptic and nocturnal. This is illustrated by the results presented in Table 4.3 and Fig. 4.1, which show considerable variation in the various pre-cull estimates of badger population sizes that were undertaken. Even when substantial resources are put into obtaining estimates (as was the case with estimates 4, 5 and 6 in Table 4.3), the results may still be subject to considerable uncertainty.

6.1.6. Under current arrangements, the pilot culls will continue in Somerset and Gloucestershire in 2014 and beyond, in which case estimates of population size and effectiveness will be required in order to set quotas in each year that culling occurs. Similar estimates will also be required for other areas, should culling be rolled out more widely.

6.1.7. We consider the cull-sample-matching approach to be the most appropriate way in which to provide a robust assessment of effectiveness in any future culling operations, and mark-recapture methods using hair-trapping data to be the most appropriate way of estimating pre-cull population size. However, it is important to note that the degree of uncertainty in estimates of both pre-cull population size and effectiveness decreases as the proportion of the population that is genotyped increases. Conversely, the lower the proportion genotyped, the greater the uncertainty attached to estimates of population size and effectiveness, and the harder it will be to set valid quotas or to conclude, with confidence, that culling has achieved its aim.

6.1.8. For this reason, we suggest that in the case of future culling operations, either in the pilot areas or elsewhere, hair trapping and genotyping effort should be at least as great as it was in the pilot culls.

6.1.9. The shorter the duration of any cull, the less likely it is that any violation of the population closure assumption (see paragraphs 4.4.27-4.4.31 above) will bias results.

Spatial distribution of shooting effort

6.1.10. As noted in para 4.4.41, maps showing the distribution of land holdings where badgers were reported to have been shot show many land holdings from which few or no badgers were culled. If culling is continued in the pilot areas in

subsequent years, or in the event of wider roll-out, it is important that culling effort be applied as evenly as possible over all compliant land holdings.

Quality of data provided by Contractors

6.1.11. We have remarked above (e.g., paragraphs 4.4.40, 6.1.3) on the unreliability of data (for example, on Contractor effort and on the locations at which badgers were shot) provided by Contractors. This meant that important analyses (for example, to determine whether estimates of effectiveness were spatially biased, and the extent to which culling effort was evenly applied across compliant land holdings) were not possible. Although we appreciate the difficulties that Contractors might sometimes experience in recording data under field conditions, such analyses would be highly desirable in the case of future culling. There needs to be discussion, therefore, as to which data would be most useful for Contractors to record, and how best to record them. Then, steps need to be taken to ensure that these data are complete and reliable (see also 6.3, below).

6.2. Humaneness

6.2.1. The IEP is unable to comment on the humaneness of using shotguns in any subsequent roll-out, as there was insufficient relevant evidence from the pilot culls. It follows, therefore, that shotguns should not be included in any roll-out unless monitoring, of similar rigour to that carried out in the pilot culls, provides evidence that controlled shooting with shotguns is humane and safe.

6.2.2. We understand that the Cull Companies would like to see revision of the requirements to permit shooting away from bait points and at greater distances. As regards use of baits, we see no reason why shooting away from bait points should not be permitted, provided that appropriate measures are taken to ensure that public safety is not compromised.

6.2.3. However, we are less convinced about shooting at longer ranges. It is clear (e.g., from reports of Observers) that some Contractors were shooting at ranges in excess of Best Practice Guidance, but the sample size is too small for us to know whether this affected humaneness. Examination of the shooting assessments suggests that 17% of Contractors using a lamp and 16% of those using night vision equipment would fail to achieve the required accuracy at 140 m, which is the maximum range proposed by the NFU. On this basis we are opposed to any extension of the maximum range because of the increased chance of non-fatal wounding and missed shots.

6.2.4. Observers reported that some Contractors were shooting at badgers which were close to cover or to setts. These observations are supported by retrospective analysis of the thermal imaging recordings for badgers in Category C. It is important that this does not happen if the cull is rolled out, since it reduces the opportunity for a

second shot at a wounded badger before the badger takes refuge and becomes inaccessible.

6.2.5. AHVLA (Anon, 2013b) estimated that 6-19% of badgers may not be recovered following a rifle shot. Badgers in this group may be at risk of marked suffering through failure to find and despatch individuals that were hit but not killed by the first shot. This issue could be addressed, at least partially, by licensing only those shooters who have demonstrated a high standard of marksmanship in the field and have a good working knowledge of badger behaviour. Additional measures might include strict enforcement of the use of 'shooting buddies'.

6.2.6. We recommend that if controlled shooting is to be considered for use in any future culls, the overall standard of competence of Contractors in the field must be raised (see paragraph 7.3 below).

6.2.7. Thermal imaging equipment proved to be very useful when trying to locate shot badgers. We would encourage its use in any future roll-out as it can help reduce the interval between the first and second shots, should a second shot be needed.

6.3. Monitoring in the event of roll-out

6.3.1. In order for any badger cull to be effective, the population needs to be reduced to, and held at, a size at least 70% lower than the pre-cull size. The IEP considers that for controlled shooting the threshold of concern for humaneness should remain at 5%, i.e., at least 95% of the badgers that are shot at should die within 5 min.

6.3.2. In the event of roll-out, monitoring should be continued for the following reasons:

a. Monitoring data will allow effectiveness and humaneness to be assessed during culling operations. If monitoring data are not available, events of concern will not be recorded and it will not be possible to make decisions as to whether culling should proceed or stop.

b. Monitoring data will allow improved targeting of badgers. For example, monitoring data on the location of each culled animal could be used to identify which land holdings might benefit from additional contractor effort.

c. In this report we suggest various modifications to training, Best Practice Guidance and Licence criteria, aimed at improving the effectiveness and humaneness of culling in the event of roll-out. Should these recommendations be implemented, monitoring will be necessary to determine whether they have the desired effect.

d. As noted above, data provided by Contractors were deemed insufficiently reliable for valid conclusions to be drawn. Training of Contractors to enable them

to collect and collate reliable data is necessary and monitoring by independent observers is required to check the reliability of Contractors' data in any future culling operations.

6.3.3. The sample sizes and analytical methods used in the two pilot culls were carefully chosen to ensure that effectiveness and humaneness could be assessed accurately. Should fewer data be collected in any roll-out cull, uncertainty around estimates of effectiveness and humaneness will be greater. Therefore, a similar level of effort to that employed in the pilot culls will be necessary if additional culls are to be satisfactorily assessed.

6.3.4. Humaneness cannot be assessed appropriately unless observers (with suitable night vision equipment) record the following: shots being taken; subsequent behaviour of the badgers; the flight of 'hit but not retrieved' badgers; and the times to death of those badgers whose carcasses are retrieved. Without these data, animals cannot be classified as being in Categories A, B or C; and calculation of unbiased time-to-death distributions depends on identifying Category C animals. Observer data are also necessary for noting missed and multiple shots.

6.3.5. The IEP did not see the daily briefings provided to the Secretary of State during the course of the pilot culls. However, in subsequent discussion with Defra, it became clear that the briefing needs to include daily estimates of the time-to-death distribution. Without this, Ministers have insufficient information on which to base assessments of humaneness.

7. Changes to Licence Criteria, Training Course Content and Best Practice Guidance

7.1. As noted above (para 5.4.6) a minority of Contractors were initially unwilling to be accompanied by Observers. If Observers are deployed in future culls it must be explained to Contractors before the cull starts that part of the requirement for being a Contractor is that he/she would be joined by an Observer and that evasive action on the part of the Contractor would violate that requirement.

7.2. The findings reported in paragraphs 5.3.15 – 5.3.17 suggest that shooting accuracy (as judged by reference to the anatomical target area given in Best Practice Guidance) was low. However, NFU and the contractors recognised that chest and shoulder shots were more effective and humane, and this has been confirmed by post-mortem examinations. Consequently, we recommend that shots should be aimed at the middle of the chest when high velocity rifle bullets are used. The Best Practice Guidance should be amended accordingly, with advice from AHVLA as to the size and shape of the target area.

7.3. It seems likely that the Best Practice assessment used before the cull started did not detect all of the Contractors who were poor shots in the field. Since the shooting

assessment alone is not a sufficient measure of competence in the field, Cull Companies and Natural England as the Licensing Authority must have robust systems in place to monitor Contractor performance, identify inefficient individuals quickly and remove them from the cull. We suggest that Contractors should be selected and initially licensed using the current criteria, but that early in any future culls individuals should be observed in the field by an independent assessor on at least one occasion (possibly as part of compliance monitoring by Natural England), possibly using the Deer Stalking Certificate Level 2 [1] portfolio model. Once assessment had been carried out and performance of the Contractor was deemed to be satisfactory, the licence would be confirmed.

7.4. Following the pilot cull, AHVLA Observers reported that the standard of sett assessment, baiting and pre-baiting varied considerably amongst Contractors. In future, greater emphasis should be given to selecting Contractors with adequate field craft. It should also be emphasised that cull effectiveness would be improved if Best Practice Guidance on sett assessment, baiting and pre-baiting was followed and training improved.

7.5. A condition of the TB Area Control Licences as issued for the pilot culls was that no badger should be taken or killed in the relevant Control Area until Natural England had specified in writing that there was access to at least 70% of the total land area. It now seems that a likely contributory reason for the low effectiveness of the pilot culls was that less than 70% of land in each area was covered by cage trapping or shooting. This needs to be rectified in any subsequent culling operation, either in these pilot areas or in the event of roll-out.

7.6. Future licences should specify both that (a) the Licensing Authority must be satisfied that at least 70% of the land comprising the relevant Control Area is accessible for control prior to badger removal commencing, and (b) 70% of the Control Area is covered by cage trapping and/or shooting during the period of control. The Licensing Authority should put in place procedures to monitor compliance with these conditions during the period of the cull.

8. Safety

8.1. ‘Lessons learned’ exercises, each with its own timescale and terms of reference, are being conducted by the various Departments and agencies involved in ensuring that the pilot culls were delivered safely. However, the results of these exercises will not be known in time for them to be considered in this report. We understand that the Home Office and Police have not yet received requests from Defra for formal reports on the safely of the pilot culls. Nevertheless, both Avon and Somerset and Gloucestershire constabularies have been most cooperative with the IEP and have

[1] www.dmq.org.uk/...

openly shared their experiences of policing the pilot culls. The IEP has also received submissions, some of which are relevant to safety issues, from a range of organisations and individuals (see Appendices 12.3 and 12.4 below).

8.2. Much of the safety-related evidence available to the Panel is anecdotal or contradictory. However, we have been able to draw a number of conclusions from this material and can provide recommendations relating to continuation of the pilot culls in future years or to potential roll-out.

Geography and demography

8.3. It is clear, from the police briefings, that the geography and demography of the two pilot areas had a significant impact on the perception of risk to both Contractors and protestors. It is also clear that there were more dissimilarities between the two pilot cull areas than similarities.

8.4. In Somerset much of the culling took place in sparsely populated areas with relatively few roads and paths. In this area the police report that it was simple to arrange for a limited number of extra patrols at night. An arrangement was made between the police and the Cull Company that if Contractors and protesters came in contact then the Contractors would withdraw for the night and restart the following day. Consequently, there were few incidents and no reported 'near misses'. The Avon and Somerset police have reported ‘no substantial evidence of dangerous practice’.

8.5. The police characterised the Gloucestershire situation as involving a wider geographical area and a largely resident protestor population. At times, the Cull Company and the police had strongly contrasting views on the safety of the shooting operation. Two of the main issues relating to controlled shooting and public safety were:

a. Public footpaths were identified early as a clear risk to public safety during night shooting, since occupying these footpaths would be an obvious protester tactic.

b. It became clear that some Contractors were sometimes not adhering to basic safety considerations. For example, there were occasions when Contractors were surprised by protestors, almost immediately after shooting, because ‘clearing’ of the shooting area by Contractors was not carried out sufficiently well. A pre-condition of granting the variation to firearms certificates permitting Contractors to shoot badgers was that they would not shoot if it became apparent that protestors or members of the public were in the vicinity. This pre-condition was proposed on the basis of the Cull Company’s own risk assessments.

8.6. Whilst none of the above resulted in a serious incident, the police recorded a number of events termed ‘near misses’. For example, Contractors continued to shoot whilst protestors were in the vicinity. No specific complaints of illegal activity were made to the police and no specific complaints were reported to the Health and Safety Executive (HSE).

8.7. Although there is no statutory requirement to report ‘near misses’ to the HSE, the lack of adherence to Best Practice Guidance and to the Cull Companies’ own Risk Assessments is a matter of concern.

8.8. Gloucestershire Constabulary was concerned that, in addition to these near-misses, a number of incidents involving confrontation between cull operators and protestors occurred. The police believe that this had safety implications for both sides and in some cases necessitated a police response. In addition, the police reported that Contractors were not experienced in dealing with protestors who were well prepared, particularly with regard to legal matters. Occasions arose where accounts by Contractors conflicted directly with video evidence of incidents.

8.9. The police in Gloucestershire also believe that this was complicated by a general lack of co-operation from Contractors. In some cases Contractors refused to identify themselves or sought to conceal their identities from police officers because of concerns that they and their families might suffer intimidation by protestors. This reluctance, on the part of Contractors, to pursue criminal complaints led to a situation where no further action was taken although 13 people had been arrested.

8.10. Natural England (NE) was responsible for ensuring Licence compliance. During the 6-week period of the pilot culls, NE (as the Licensing Authority) undertook a programme of monitoring to assess Contractors’ compliance with licence conditions and Best Practice Guidance. The aim of this programme was to monitor 10% of Contractors or 10 Contractors (whichever was the greater) for both controlled shooting and cage-trapping operations. The majority of monitoring involved NE Monitors (five in total) accompanying Contractors during operations but some telephone assessments were also conducted.

8.11. NE recorded that a total of 20 Contractors were monitored in each of the pilot areas, comprising 22 controlled shooting (and 18 cage-trapping) events overall. In addition, eight Contractors were also monitored while performing the ‘shooting buddy’ role. NE reported to the IEP that Contractors displayed a professional attitude in terms of safety and operations, and that no major breaches were detected. Any minor breaches were resolved through on-site advice to Contractors or guidance notes to the Cull Companies, to clarify Best Practice Guidance and licence requirements.

8.12. However, NE also reported that Contractors did not always adhere to Best Practice Guidance: for example, they tended not to don face masks when dispatching and bagging cage-trapped badgers. In addition, disinfectant was sometimes not used when Contractors were moving from one land holding to another. Consequently, all Contractors were reminded of the risk of zoonotic disease transmission when dealing with carcasses and of the importance of disinfection procedures. HSE noted, in video footage, that there appeared to be a lack of adherence by some Contractors to Best Practice Guidance relating to the handling of carcasses. Whilst this did not constitute a reportable offence, it suggested that the Contractors were not always acting in a professional and competent manner. This is of concern to the IEP.

8.13. NE will feed its experiences into the Defra 'lessons learned' process and, in the event of roll-out, will consider revisions to Best Practice Guidance, monitoring processes and procedures (including the process of making contact with Contractors).

9. Data Auditing

9.1. The Role of the Independent Auditors

9.1.1. Dr Martine Wahl was appointed as the Principal Independent Auditor by Defra. Her role was to audit data collection, data entry and database construction by government staff. Professor Tim Coulson was appointed as the Statistical Auditor. His role was to audit the compilation and content of data sets, and the statistical analyses, conducted by AHVLA statisticians. The Auditors were paid by Defra but acted independently and experienced no influence from Defra. Both Auditors worked closely with relevant government staff who, they concluded, were committed and helpful.

9.1.2. Humaneness and Effectiveness Audit Reports (Wahl and Coulson, 2013 a, b) were produced by the Auditors and made available to the IEP. These contain a full account of the Auditors' findings and the steps that were taken to rectify any shortcomings. These reports are due to be published at the same time as the IEP report.

9.1.3. Activities of, and data collection by, Contractors were beyond the scope of the audit.

9.2. Effectiveness auditing

9.2.1. The Independent Auditors audited the selection of squares to be hair trapped, the training of hair trappers, the setting of hair traps in Gloucestershire, the collection of hair samples in both pilot areas, data management, statistical analysis, and

production of the final AHVLA Effectiveness Report (Anon, 2013a). Laboratory analysis of hair samples and ear tips was audited in part to ensure that laboratory practice conformed to laboratory protocols. The setting of hair traps in Somerset and collection of ear tips by Contractors were not audited.

9.2.2. The audit concluded that government teams followed procedures with respect to data collection and analysis. Some shortcomings in practice were identified early in the pilot culls and these were promptly rectified. Other shortcomings were identified at a later stage but none of these was considered serious.

9.3. Humaneness auditing

9.3.1. The Auditors audited the training of Observers, data collected by Observers accompanying Contractors, data on the transfer of carcasses from pilot areas to government laboratories, laboratory work, the collection and management of data from the laboratory work, statistical analysis, and the compilation of the AHVLA Humaneness Report (Anon, 2013b). Contractor data recorded in the absence of Observers were not audited.

9.3.2. The audit concluded that the post-mortem and observation teams were efficient and worked well; training was of a high standard; and data were of high quality and were well managed. However, it suggested that a single lead scientist should have been appointed to oversee all aspects of the work. Other shortcomings were identified but these were either immediately rectified or were minor in nature.

9.3.3. As regards statistical analysis, the original aim of comparing 60 paired Observed and Unobserved carcasses from the same Contractors could not be completed. This was because matched pairs from sufficient Contractors could not be collected, owing to the number of Contractors being smaller than expected. Consequently, the matched-pair statistical analysis had less power than anticipated. In other respects, statistical analyses were conducted as planned.

9.4. Data auditing: conclusions

9.4.1. Overall the IEP is confident that the auditing of data was carried out thoroughly and effectively. No serious shortcomings were identified in collection, handling or analysis of data.

10. Conclusions

10.1. Note on interpretation of conclusions

10.1.1. For clarity of interpretation, we have expressed our conclusions according to the terminologies of likelihood and confidence developed by the Intergovernmental Panel on Climate Change (Committee to Review the Intergovernmental Panel on Climate Change, 2010). The likelihood scale is used in relation to results which have a quantitative basis in statistical analysis or modelling, while the confidence scale is used in relation to results for which the evidence base may either be quantitative but not statistically determined, or a mixture of quantitative and qualitative information. The confidence scale therefore represents our best estimate based on the information available to us. The relevant scales are as follows:

Likelihood scale

Terminology	*Statistical likelihood of outcome*
Extremely likely	>95% probability
Very likely	>90% probability
Likely	>66% probability
More likely than not	>50% probability
About as likely as not	33 to 66% probability
Unlikely	<33% probability
Very unlikely	<10% probability
Extremely unlikely	<5% probability

Confidence scale

Terminology	*Degree of confidence in being correct*
Very high confidence	At least 9 out of 10 chance
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance

10.2. Monitoring protocols, data collection and analysis

10.2.1. We have very high confidence that robust monitoring protocols were put in place to monitor the effectiveness and humaneness of the 6-week pilot culls.

10.2.2. We have very high confidence in the data collection and analysis performed by AHVLA in relation to assessing the effectiveness and humaneness of the 6-week pilot culls, and in the auditing processes applied to these activities.

10.3. Effectiveness of the culling pilots

10.3.1. Controlled shooting alone, over the 6-week period of the pilot culls, failed to remove at least 70% of the pre-cull badger population from either of the two pilot areas. It is extremely likely that controlled shooting removed less than 24.8% of the badgers in Somerset and less than 37.1% of the badgers in Gloucestershire.

10.3.2. Controlled shooting in conjunction with cage trapping, over the 6-week period of the pilot culls, failed to remove at least 70% of the pre-cull badger population from either pilot area. It is extremely likely that combined shooting and cage trapping removed less than 48.1% of the badgers in Somerset and less than 39.1% of the badgers in Gloucestershire.

10.3.3. The decision to include cage trapping as a primary method of badger removal, taken without consulting the IEP, complicates our analysis of the effectiveness of controlled shooting. Nevertheless, we have very high confidence that controlled shooting would still have failed to remove 70% of the badger population, had it been the only method of culling.

10.3.4. We were not permitted to have access to, or to undertake any formal analysis of, data relating to spatial locations of Contractor effort, owing to security concerns. However, on the basis of evidence from Defra and Natural England, we observed that there were many land holdings on which few or no badgers were shot. We were unable to assess whether the spatial distribution of Contractor effort within the pilot cull sites complied with licence conditions.

10.3.5. We have high confidence that spatial variation in Contractor effort was a contributory factor to the failure to meet the 70% removal targets, but we do not know whether this spatial variation was due to limited Contractor effort, low badger numbers or protestor activity.

10.3.6. We have high confidence that spatial variation in Contractor effort did not contribute bias to the calculations of effectiveness.

10.3.7. Owing to the lack of reliable data on Contractor effort, we were unable to determine how much additional effort would have been necessary to achieve a 70% cull, either by controlled shooting alone or by controlled shooting in combination with cage trapping.

10.4. Humaneness of the culling pilots

10.4.1. In the face of sparse evidence, but based on observations of firearms injuries in humans, our considered opinion is that any badger surviving for more than 5 min after being shot is at risk of experiencing marked pain.

10.4.2. After reviewing relevant evidence and as a result of discussions with Defra prior to the cull, we suggest that a threshold of concern for humaneness should be set at 5%, i.e., it is reasonable to expect that 95% of shot badgers should be dead within 5 min.

10.4.3. Over the population of badgers culled, it is extremely likely that up to 52% of badgers would have died rapidly, within 10 s of being shot.

10.4.4. It is extremely likely that more than 79% of shot badgers had acute damage in the thoracic cavity, which would have resulted in rapid death in well under 5 min and a likely absence of any marked pain.

10.4.5. It is extremely likely that between 7.4% and 22.8% of badgers that were shot at were still alive after 5 min, and therefore at risk of experiencing marked pain. We are concerned at the potential for suffering that these figures imply.

10.4.6. It is extremely likely that less than 45% of badgers were shot in the target area identified in the Best Practice Guidance, and that up to 15% were shot in the head and neck region. Contributory reasons for this may include changes in the protocols adopted by the Cull Companies shortly after the pilot culls began, and an unwillingness or inability of Contractors to adhere to Best Practice Guidance. However, in the absence of a better understanding of how the majority of Contractors interpreted the revised target area recommendations, we are unable to comment further on the accuracy of shooting by Contractors.

10.5. Safety

10.5.1. In the light of the police reports we are confident that controlled shooting, when carried out in accordance with Best Practice Guidance, poses no threat to public safety even in the presence of local protest. There were a small number of occasions when Best Practice Guidance relating to shooting was not followed but they did not result in reportable incidents under Health and Safety legislation and were not the subject of police action.

10.5.2. Incidents involving confrontation between cull operators and protestors did have potential safety implications for both sides and in some cases necessitated a police response. Contractors were not experienced in dealing with protestors who were better prepared to deal with the confrontation. Assessing the seriousness of these incidents is made more complex by the withdrawal of statements of evidence by Contractors, with the result that there was only one prosecution.

10.5.3. It is clear that a number of Contractors failed to follow Best Practice Guidance in relation to carcass handling and bio-security. We are aware that in part this was due to the need for Contractors to leave the area quickly to avoid potential confrontation with protestors drawn by the noise of the shot

10.6. Implications for roll-out

10.6.1. Current evidence suggests that culling badgers over a 6-week period by shooting, or by shooting and cage trapping, fails to meet the criteria of effectiveness set out by Defra.

10.6.2. Evidence suggests that between 7.4% and 22.8% of badgers that were shot at were still alive after 5 min and therefore were at risk of experiencing marked pain. We are concerned at the potential for suffering that these figures imply.

10.6.3. If culling is continued in the pilot areas, or in the event of roll-out to additional areas, standards of effectiveness and humaneness must be improved. Continuation of monitoring, of both effectiveness and humaneness, is necessary to demonstrate that improvements have been achieved. In addition, such monitoring should be independently audited.

10.6.4. To minimise the likelihood of biased effectiveness estimates arising from violation of the population closure assumption, culls should be conducted over as short a period as possible.

10.6.5. As regards humaneness, steps should be taken to reduce the number of badgers that may take more than 5 min to die after being shot at. This means improving the accuracy of shooting so as to avoid non-lethal wounding and misses, and minimising the number of badgers that are able to take refuge in cover or in a sett after being wounded. Section 10.7 (below) contains specific recommendations aimed at achieving these goals.

10.6.6. Point estimates of populations, which have been used to set targets for the pilot culls, are inherently uncertain and variable. If shooting alone is used to control badgers across a 150 km^2 area over a 6-week period, pre-cull targets may not be necessary, since we have high confidence that shooting alone over a 6-week period would be insufficient to remove >95% of the badger population.

10.6.7. If shooting is combined with other forms of badger culling over a 6-week period, then initial population estimates and targets should be used to safeguard against >95% removal. However, the imprecision and potential inaccuracy of these estimates and targets should be recognised.

10.6.8. Steps need to be taken to ensure that data provided by Contractors are fit for use in any assessments relating to population size, effectiveness or humaneness.

10.6.9. The cull-sample-matching approach represents the most reliable way in which to assess the effectiveness of any future culling operations. However, the uncertainty of population and effectiveness estimates increases as the proportion of the population that is genotyped decreases. Therefore, in any future culling operations, either in the pilot areas or elsewhere, hair trapping and genotyping effort should be at least as great as in the pilot culls.

10.6.10. If the pilot culls proceed in the current areas, or if culling is rolled out more widely, there needs to be closer monitoring of adherence of the Contractors to all of the conditions under which culling licences were granted. This should include the area of land covered by culling activities, so as to ensure that all compliant land is covered appropriately by culling effort.

10.6.11. In the event of changes being made to training and Best Practice Guidance on shooting, field observations by competent individuals and post-mortem examinations should continue throughout the culling period in order to assess the

effects of these changes. If no changes to Best Practice Guidance are made, field observations should continue nevertheless to ensure adherence to good practice and licence conditions.

10.7. Training, Licensing and Best Practice Guidance

10.7.1. The AHVLA reports provide no analysis of the influence of rifle calibre and ammunition type on humaneness outcomes. Therefore we are not in a position to recommend changes to the current guidelines regarding the types of rifle or ammunition used.

10.7.2. Lack of data prevented us from evaluating the effectiveness and humaneness of shotguns. If shotguns are to be used in future culling, monitoring should be put in place to assess their effectiveness and humaneness.

10.7.3. We do not recommend any increase in the specified distance from which badgers may be shot.

10.7.4. We do not recommend any reduction in the minimum distance from a sett at which badgers should be shot. However, Natural England may wish to review the minimum distance criterion with a view to reducing the number of wounded badgers that find refuge in a sett.

10.7.5. In view of the post-mortem data collected during the pilot culls, Best Practice Guidance on the optimal target area for shooting badgers should be reviewed.

10.7.6. Thermal imaging equipment should be used more widely, to assist in locating shot badgers. This measure would reduce the likelihood of badgers being hit but not retrieved, and hence of being at risk of marked suffering.

10.7.7. During training of Contractors, greater emphasis should be placed on field craft, including sett assessment, pre-baiting and baiting, and it should be strongly emphasised that these must be done in accordance with Best Practice Guidance.

10.7.8. To improve standards of effectiveness and humaneness, only shooters who have demonstrated a high standard of marksmanship in the field, and who have a good knowledge of badger behaviour, should be licensed.

10.7.9. To ensure that culling takes place over a minimum of 70% of the land within each Control Area, Natural England (as the licensing authority) should adopt procedures to allow it to be confident that this 70% level is covered by cage trapping and/or shooting during the period of control.

11. References

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12. Appendices

12.1. Membership of the IEP

Professor Tim Coulson

Tim Coulson is a Professor of Zoology at the University of Oxford. He is a quantitative biologist with research interests in wildlife management, statistical ecology and the development and testing of ecological theory. Much of his recent work has focused on the demography of wild animal populations.

Professor Neville Gregory

Neville Gregory is the former Professor of Animal Welfare Physiology at the Royal Veterinary College. His research interests include the suffering associated with clinical diseases and disorders, and with routine methods used in managing livestock and wildlife. In addition, he has practical experience and knowledge of humane killing of animals in the field.

Professor Ranald Munro (Chair)

Ranald Munro is the former Head of Pathology at the Veterinary Laboratories Agency, and former president of the World Society for Protection of Animals (WSPA). He is currently Honorary Professor of Forensic Veterinary Pathology at the Royal Veterinary College, and an Honorary Fellow at the Royal School of Veterinary Studies, Edinburgh. He specialises in forensic pathology in free living species, companion animals and farmed livestock.

Professor Timothy Roper

Timothy Roper is Emeritus Professor of Biology at the University of Sussex. He is an expert on animal behaviour and has published extensively on the behaviour, ecology and management of badgers.

Peter Watson

Peter Watson is Executive Director of the Deer Initiative and a non-executive Director of Deer Management Qualifications. He was formerly a military engineer and is now a trained ecologist with extensive practical experience in wildlife management and related training.

Professor Piran White

Piran White holds a Personal Chair in the Environment Department at The University of York. He is an ecologist whose research interests focus on wildlife management and disease, biodiversity, and ecosystem services.

12.2. Original Terms of Reference

Department for Environment, Food and Rural Affairs

Badger culling pilots: Independent Expert Panel ('The Panel')

To help Ministers evaluate the effectiveness, humaneness and safety of controlled shooting the independent expert panel will:

a. oversee the development of scientifically robust and policy-relevant monitoring protocols, that offer good value for money, including considering an assessment of the field and post-mortem data;

b. advise on appropriate auditing of data collection and analysis (either themselves or by appointing a suitable auditor separately;

c. provide timely advice to Defra Ministers comprising their view of the robustness of the data collection and analysis conducted by the research teams and a discussion of factors that may have influenced the results obtained;

d. advise on any other factors of scientific relevance that are material to the monitoring of effectiveness (in terms of badger removal) and humaneness of controlled shooting both in the pilot areas and if the policy is rolled out more widely;

e. recommend any changes or improvements to the licence criteria, training course content or Best Practice Guidance and;

f. consider the report on the public safety of controlled shooting following the pilots and other information that may arise regarding operator safety.

It is not the role of the panel to provide advice or to comment on the wider policy approach to tackling bovine TB in England, or on the case for badger culling as part of a comprehensive package of measures. This has already been the subject of extensive public consultation which has informed the Government's policy decision. The panel has been appointed specifically to look at the effectiveness, humaneness and safety of controlled shooting as a culling method.

12.3. List of contacts between IEP and individuals/organisations

- Avon and Somerset Constabulary
- British Deer Society
- Cull Companies
- Gloucestershire Constabulary
- Natural England
- National Farmers Union
- Observers
- Police and Crime Commissioner, Avon and Somerset.
- RSPCA

12.4. Unsolicited submissions

The IEP received unsolicited submissions from:

- Gloucestershire Against Badger Shooting (GABS)
- Ian Doucet and others
- RSPCA
- Secret World Wildlife Rescue

We are grateful to these organisations for the time and effort they have expended on preparation of their reports.

The documents range from background information (e.g., responses to FOI requests to Defra, Natural England and other similar sources) to accounts of harassment of 'wounded badger patrollers', alleged shooting incidents in the vicinity of protesters, interference with badger setts and breaches of biosecurity measures by shooters. Most of these events fall outside the remit of the IEP but highlight the stresses occurring between those involved in culling and the groups opposed to it.

Details were presented of two well-documented cases concerning shot badgers that were discovered by the public. One involved firearms injuries caused by high velocity ammunition. The other (which was reported to the police) may involve breaches of licence conditions, firearms certificate violations and unnecessary suffering.

The ramifications of the pilots extended into the wider community. Of particular relevance is the impact that secrecy over the boundaries of the cull zones had on legitimate animal welfare duties of the RSPCA inspectorate. Uncertainty over locations where shooting might be occurring presented difficulties when responding to calls from the public regarding animal welfare incidents (not necessarily confined to injured/dead badger sightings). Both the Avon & Somerset and the Gloucestershire Constabulary were as helpful as possible to the RSPCA, but better liaison by Defra and the Cull Companies with the RSPCA inspectorate appears to be needed.

12.5. Consideration of additional time to death analyses (January 2014)

When the IEP report was at an advanced stage, Defra became aware of our conclusion that more than 5% of badgers may have experienced marked pain. At that point, Defra requested AHVLA to perform new analyses of times to death and the proportion of badgers that may have survived longer than 5 min after being shot, using different assumptions to those originally used in the AHVLA Humaneness Report (Anon, 2013b).

The potential outcomes for badgers in the Observed group are set out in paragraph 5.2.20 of our report. The badgers in Category C were shot at and escaped but their carcasses were not retrieved. The IEP considered, most carefully, the field observations, the uncertainties surrounding the times to death and the potential for marked pain in the 10 badgers included in Category C.

Three of these non-retrieved badgers were observed to be wounded; the other seven were shot at and escaped but uncertainty exists as to whether they were wounded. Paragraph 5.4.25 (reproduced below) explains the rationale underlying the Panel's view on how uncertainties regarding the onset of marked pain in this category should be addressed.

5.4.25 When considering estimates of the proportion of badgers hit but not retrieved, we take the view that humaneness concerns are correctly addressed by taking a pessimistic view of the likelihood of suffering. In this case, this means assuming that all Category C animals were hit. This approach is accepted practice in medical and veterinary medical research where there is the potential for severe animal suffering. It is also supported by the following considerations:

a. *Observers reported that Contractors sometimes thought they had missed animals, whereas subsequent investigation found either a carcass or other evidence of a hit badger. Thus, the absence of behavioural evidence that an animal has been hit does not necessarily mean that the shot was a miss.*

b. *The short duration of observation in most cases before Category C animals were lost from view meant that a reliable retrospective assessment of the number that had been hit was not possible, even using thermal image recordings and site assessment.*

Some of the new analyses (analyses 2 to 5 in Table 12.1), requested by Defra, assume that seven Category C badgers were missed. These seven animals were removed from the data set before analysis in order to present a first 'best case' scenario with a lower population estimate of time to death. An additional analysis (Analysis 6) keeps all 10 Category C badgers in the analysis but assumes that all ten badgers were still alive 4 min and 59 s before their fate became unknown. Analysis 1 treats all 10 Category C animals in the same way as in the main AHVLA report. In addition, these analyses also assign Category B animals to have shorter times to death than used in the analysis in the AHVLA main report. These additional analyses reveal that in order to reduce the proportion of animals with times to death

of less than 5 min, it is necessary either to exclude animals from analyses, or to assume that animals are censored before the 5 min threshold.

We consider the new treatments of animals in Category C to be inappropriate and not in accordance with best scientific practice. We cannot endorse a method that excludes data, or makes assumptions that will bias a result in a particular direction, without good scientific justification. Consequently, the IEP rejects the basis for the revised (lower) estimates of the proportion of badgers that survived more than 5 min after being shot.

New analysis	Lower 95% CI	Upper 95% CI
1	0.101	0.278
2	0.043	0.175
3	0.032	0.186
4	0.019	0.128
5	0.022	0.144
6	0.002	0.087

Table 12.1 *Summary of the time-to-death analyses requested by Defra in January 2014. Further details of these analyses are described in an Addendum to the AHVLA Humaneness Report (Anon, 2013b).*