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Setting the minimum and maximum numbers for Year 2 of the badger culls

Advice to Natural England

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Overview

The Government's policy is to allow controlled culling and vaccination of badgers in areas of high incidence of bovine TB in cattle in a carefully regulated way for the purpose of controlling the spread of the disease. The aim is to achieve and maintain a reduction in the badger population of at least 70 percent of the estimated original starting population. Culling also needs to "not be detrimental to the survival of the population concerned" within the meaning of Article 9 of the Bern Convention on the Conservation of European Wildlife and Natural Habitats. For that purpose Natural England must set a maximum number of badgers to be removed from the licence area.

Hence, there is a requirement to gain an estimate of the population size that is sufficiently accurate for setting targets that meets these requirements. The estimate of population size must be based on information that is available to Natural England during the application process, and must relate to the whole culling area, including any land within that area on which no culling is planned to take place. With the possible exception of a full census, any population estimate will have some degree of uncertainty; there will be an interval around the population estimate within which the true population is likely to lie.

To provide Natural England with advice on setting the minimum and maximum number of badgers to be culled in Year 2, Defra considered the use of several methods to estimate the current population. This paper sets out that advice and those methods.

Purpose of the minimum number

1. Natural England is the licensing authority for the badger culls. It is a requirement of the Guidance and the licences to set a minimum number in advance of each year's cull in an authorisation letter that is issued to each cull company once the licensing authority is satisfied that the cull company's operations planning and funding are sufficient to deliver a successful cull. The purpose of setting a minimum number under the current licence is to ensure that the cull company delivers the required level population reduction in order to achieve the expected disease control benefits.

Why 70% of the population?

2. The minimum number is intended to correspond to a 70% reduction of the population relative to the initial starting population before the culls started in

2013. The culling objective is for no more than 30% of the starting population to remain on conclusion of the cull. The 70% target is derived from the Randomised Badger Control Trial (RBCT) where it was estimated that the culls achieved a mean of 70% control of the starting populations across the 10 areas, which resulted in disease reduction benefits for the cattle herds in those areas.

Limitations of population estimates

3. After the first year's cull reproduction and immigration will result in some population recovery before the second year's culling resumes. In order to set the minimum number for year 2, we needed to:

    a) Estimate the new badger population at the start of the second year of the cull;

    b) Use the estimate of the new population to set the minimum number in order to achieve 70% control of the original starting population.

4. The process of estimating wildlife populations in order to set targets is subject to uncertainty. This point was recognised by the Independent Expert Panel (IEP) in its report. The sett surveys and hair trapping methodologies used to date have provided inconsistent results, and each has limitations in the accuracy they are able to deliver.

5. Similarly, it is difficult to predict how a population may recover as a result of breeding and immigration from surrounding areas after a period of culling. However, operating with uncertainty does not prevent an effective cull from being carried out, as shown during the RBCT culls, where no minimum numbers or targets were set.

6. Outline of approaches used

    Four methods have been used to estimate the current population and, hence, the number of badgers to be culled. Three of these methods (labelled Methods i, ii and iii) use estimates of net growth of the population from the end of the first cull to the expected start of the culls in 2014, and one method uses estimates based on recent sett surveys.

    The methods estimating net population growth used the following calculations:

    The minimum number of badgers to be culled to reduce the population by 70% is

    $$S - C + G - (S \times 30\%)$$

    The maximum number of badgers to be culled to reduce the population by 95% is

S – C + G - (S x 5%)

Where

S is the starting population before the first cull

C is the number of badgers culled in year 1

G is the net growth in the population between culls

30% and 5% represent targets of reducing the population by 70% or 95%

The method using sett surveys (labelled Method iv) applied a slightly different calculation:

The minimum number of badgers to be culled to reduce the population by 70% is:

(N x B) - (S x 30%)

The maximum number of badgers to be culled to reduce the population by 95% is:

(N x B) - (S x 5%)

Where

N is the estimated number of currently active setts and

B is the average number of badgers per sett based on the starting population estimates and number of active setts before the first cull.

7. All of the parameters used in these methods have uncertainty associated with them. The consequences of this uncertainty are explored in subsequent sections.

Starting points

8. The level of population recovery and the target for the second year is largely dependent on how many badgers we think were left over at the end of the cull in the first year. Last year there was significant variability and uncertainty about the starting population and there were different results depending on which methodology was used.

9. Before the culls in 2013, the population was estimated in each area by carrying out sett surveys and “hair trapping”. Hair traps consist of short lengths of barbed wire which catch the fur of passing badgers, either close to sett entrances or on established badger runs. The DNA profile of each badger can then be

determined. Two techniques were used for estimating the population and the effectiveness of the cull:

a) **Capture Mark Recapture**; the pre-cull badger population was estimated based on the number of setts in the area and the average number of badgers per sett based on the frequencies with which badgers were repeatedly hair-trapped. Then, the number of badgers culled was compared against this estimate of pre-cull population size, in order to provide an estimate of the proportion of badgers removed;

b) **Cull-sample matching;** the proportion of individuals that were hair-trapped pre-cull which were subsequently culled was used to estimate the proportion of the population that had been removed.

10. Of the two techniques, the IEP considered that cull-sample matching (or the "ear tip" method) was the most reliable[1]. The 95% confidence intervals[2] for the population estimates were smaller – that is the level of statistical uncertainty about the true value was less than the Capture Mark Recapture method. In the light of the IEP conclusion, we used the outcome of the cull-sample matching methodology as a starting point for estimating how much the population subsequently recovered after the cull finished in both areas. Please note that this paper uses the number of badgers culled and population estimates from the entire cull period, not just the 6-week period considered by the IEP, although the statistical methods used to estimate efficacy for both periods are essentially identical.[3]

Estimating the current population and minimum number

11. Because the IEP considered the cull-sample matching method more reliable, we used the results derived from this method as the starting point for assessing how the population may have recovered between the time the cull finished and resuming the following year. Using the range of population estimates (lower and

[1] Munro et al Pilot Badger Culls in Somerset and Gloucestershire Report by the IEP

[2] A 95% confidence interval for a particular figure is the range of values within which one can be 95% confident that the 'true' figure lies. 95% is an arbitrary figure but is accepted by convention as the normal level of confidence to use.

[3] Anon, The efficacy of badger population reduction by controlled shooting and cage trapping, and the change in badger activity following culling from 27/08/2013 to 28/11/2013 AHVLA Report to Defra 6-2-2014

upper 95% confidence intervals and the mid-point) derived from cull-sample matching that were published in the AHVLA report on the extensions, we used the number of badgers that were estimated to remain in each cull area as the starting point.

12. There are a limited number of techniques or methods available to estimate how much a population may have recovered after a cull, and we considered all four methods that were available to estimate the populations in each area this year in order to set a minimum number:

    i. Using the actual experience of the RBCT. During the RBCT a mean of 103% of the starting population was estimated to have been culled over the first two years. It was assumed that population recovery in the cull areas was the same as in the 10 smaller RBCT areas, and by extrapolating from the proportion of the starting population culled in the first two years of the RBCT, a minimum number was estimated for each cull area;

    ii. Using a published epidemiological model of TB in a badger population;

    iii. Using a step-by-step series of assumptions about badger reproduction, mortality and badger incursions from outside the cull area, which resulted in an approximate 21% net increase in the remaining population between the end of the first cull and the start of the second based on figures in the literature;

    iv. A method based on recent (June –July 2014) data on the number of active setts in the two areas and estimates of the numbers of badger per active sett from 2013.

The number of badgers that need to be removed to reduce the population to 30% of the estimated starting population before the first cull started, using each method are set out for each cull area in Tables 1 and 2 below. The details of the methods of how the minimum numbers were estimated are set out in Annex 1 to this paper.

Rationale for setting the maximum number

13. The licence also requires Natural England to set a maximum number, for the purposes of avoiding too many badgers from being removed. This process follows a similar logic and the methodology is the same as that for setting the minimum number.

14. In the first year of the cull, NE set the maximum reduction level at 95% of the initial starting population (as opposed to the 70% minimum number) to avoid local

extinction in the area. Therefore all of the calculations for the minimum can be repeated for this purpose, simply altering the goal to leave 5% of the initial population rather than 30%.

15. In practice, this can be achieved by simply adding 25% of the starting population number to the minimum target. If the minimum target leaves 30% of the starting population, then removing a further 25% of the starting population would leave 5% of the starting population. This then gives a range of maximum targets depending on which set of assumptions we use about the starting population pre-cull and the number of badgers on the ground now.

Results and conclusions

Our objective

16. Under the current licence each cull company is required to achieve the minimum number that Natural England set out in the authorisation letter. The objective in setting a minimum number is to achieve and maintain a reduction in population of at least 70% of the estimated original starting population in order to achieve disease control benefits from the cull. In setting the minimum number we need to be mindful of the uncertainty in estimating badger populations. In addition, failure to achieve this minimum number constitutes a breach of the Badger Control Deed of Agreement. Its provisions enabling remedial action to be taken would be triggered by failure to achieve the minimum number set. If the minimum number was set too high, this would be inappropriate and may risk a scenario where too many badgers may be removed. In order to have the best chance of delivering disease control benefits, we need to manage the uncertainty in estimating badger populations appropriately, using the best evidence available.

Cull sample matching as a starting point

17. We have used estimates based on the methodology that the IEP considered to be the most reliable. However, in Somerset this methodology provided estimates that were inconsistent with the capture mark recapture method, and the estimated low effectiveness of the cull in Somerset is not supported by the experience on the ground, where the level of sett activity is less than expected based upon the apparent effectiveness of the cull.

18. So while we have taken a consistent and comparable approach for starting points in both cull areas, we need to be careful how we rely on them as estimates of how many badgers remained when the 2013 cull finished.

Outcome of estimates from different methodologies of population recovery

19. There are a limited number of techniques available to estimate how much a population may have increased after a cull. We have chosen to conduct an assessment based on each of these four further methods to assist in the process of setting a minimum number. The four different methodologies we used to estimate minimum numbers produced different results:

    a) **Method i**: using the outcome of the RBCT resulted in relatively high population estimates. The RBCT- based approach is based on the estimate that the cull achieved a mean of 103% reduction of the initial starting populations over the first two years. However, the initial starting populations were only calculated after the culls and were themselves not independent of the data emerging from the culls. This raises a question as to whether this method is valid, because there was no independent estimate of the number of badgers. In addition, the assumption that the badger populations in the Gloucestershire and Somerset cull areas will have responded to culling in the same way as in the smaller RBCT areas is weak. Consequently, we have placed very low confidence on the estimates from this method.

    b) **Method ii:** The epidemiology model has been validated to estimate longer-term changes in more stable badger populations; but there are doubts about its validity in assessing recovery in a significantly disrupted population after a cull.

    c) **Method iii:** The step-by-step approach used simplified assumptions based on long-term studies about mortality and reproduction of badgers, and immigration to estimate how the population may have recovered. These are similarly subject to weak assumptions about how well the estimates of mortality reproduction and immigration apply to populations that have been subjected to culling.

    d) **Method iv:** The sett surveys[4] showed that ~57% of the setts in Gloucestershire had evidence of occupancy by badgers. Equivalent

[4] The ISG final Report on the RBCT (2007) highlighted that because badgers are active at night, and rest by day in underground dens (setts), they are difficult to count, especially over large areas. However, there are broad correlations between the densities of badgers and the densities of field signs such as setts and latrines (Tuyttens et al., 2001; Wilson et al., 2003; Sadlier et al., 2004), suggesting that these measures give a reasonable indication of true badger densities. It further set out that a minimum estimate of badger density in RBCT areas prior to culling can also be obtained from the numbers of animals taken on initial proactive culls. These numbers need to be interpreted with caution since the proportions of badgers resident within a trial area that were captured on a

surveys in Somerset showed that 28-38% of setts were occupied. The total badger population was estimated from the product of the number of occupied setts and the average number of badgers per sett based on surveys carried out before the cull. However, these numbers are probably over-estimates, because even in occupied setts the number of badgers per sett will have been reduced by culling. The method mainly relies on the assumptions that the number of badgers per sett is similar to the number estimated before the culls began in 2013.

20. None of these methods can be viewed as entirely independent of one-another because they all use the same starting population. In addition, Methods ii and iii are very similar in concept and are more likely, therefore, to produce similar results.

21. Overall, there is high uncertainty around all of these methods, but the temporal proximity of the sett surveys used in method iv with the timing of the 2014 culls and the need to invoke fewer assumptions using this method mean that it probably has highest reliability. Consequently, if a single method is to be chosen as a guide to the population of badgers at the start of the 2014 culls then method iv should be used. However, this approach (if used to the exclusion of the other approaches) ignores some of the information that is used to derive the estimates used in the other methods. The results from methods ii and iii may still be used as a guide to the number of badgers in the populations even if there is lower confidence in them.

22. Tables 1 and 2 present the output estimates from methods i-iv of the number of badgers to be culled in Gloucestershire and Somerset respectively. These show the mid-point estimates with the lower and higher end of the likely range. However, note that these ranges are defined entirely by the confidence in the initial population estimate and they do not include uncertainty in the parameter estimates used in the various methods of calculating the badger populations. Consequently, the ranges are certain to be wider than shown in these tables.

23. When setting the number of badgers to be culled it is important to consider this high level of uncertainty. It is more prudent to manage this uncertainty by setting a realistic minimum number that can be revised in the light of new data as the culls proceed than to set it too optimistically with a risk of removing too many badgers.

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particular initial cull varied according to local conditions such as season, weather, and disruption by protestors (Smith and Cheeseman, 2007).

24. The problem of setting the number of badgers to be culled can then be approached in two ways: either (a) by choosing the most reliable of the four methods (probably method iv for the reasons given above) and the lowest point on the range of figures for the estimated starting population, to take account of the uncertainty in a precautionary manner; or (b) in order to take account of the likelihood that methods ii and iii contain information that can usefully contribute to the estimate, making a precautionary estimate based upon this additional information.

25. How to incorporate this additional information depends on the level of precaution being applied. As a general principle, it would be best to attempt to use all the information available in proportion to its reliability. In general, all the estimates from Somerset should be seen as being less reliable than those from Gloucestershire (Contrast table 1 with table 2). Method iv is likely to be the best available method in Somerset. In contrast, applying the highest level of precaution for Gloucestershire would result in using the lower end of the range but, since there is general alignment of the estimates from Gloucestershire as well as other empirical evidence to build confidence that the estimates for that region are valid, there is more reason to be less precautionary in Gloucestershire than Somerset. These factors point to using the mid-points of the population ranges in Gloucestershire rather than the lower end, because these are the most likely values using the different approaches.

Gloucestershire

26. The estimated number to be culled in Gloucestershire based on Method iv is provided in Table 1, and this can be compared with the estimated number using the other methods. Given the overall uncertainty there is in the methods and the range (Lower to Higher limits), there is little to choose from between Methods ii, iii and iv. Under these circumstances there are two options available for setting the number to be culled, if there is a wish to set this at a precautionary level and using all the evidence that is available:

    a) Use only Method iv and set the precautionary level at the lower end of the range. This assumes that Method iv is more reliable than the other Methods. There may be reasons for believing this to be the case as explained above. This would set the number of badger to be culled in Gloucestershire at 570.

    b) Use the lowest figure for the mid-point in the range of all the estimates. This assumes that there is no rational way of distinguishing between these methods. This would set the number of badger to be culled in Gloucestershire at 615.

27. In practice, in relation to Gloucestershire, it makes little difference which of these numbers is chosen, because, given the levels of uncertainty in the estimates (this is of order of magnitude 10^2), rounding to the nearest 100 badgers would be reasonable and, rounding in this way produces the same number, i.e. 600 badgers. It is an operational decision whether to round the estimates or to use the numbers as presented in Table 1. It is also possible to see the precise choice of the number of badgers to be shot as an operational decision especially because the target number may be updated with new data when the cull is under way. However, given the relative consistency of the results from all the methods it may be more justified to use method b. above, i.e. **615**.

Somerset

28. The estimated number to be culled in Somerset based on method iv is provided in Table 2, and this can be compared with the estimated number using the other methods. Although the overall uncertainty in the methods and in the range (Lower to Higher limits) is similar to Gloucestershire, there are widely differing results obtained from Methods ii, iii and iv (in particular, the possible range for Method iv does not overlap with the ranges for Methods ii and iii). Despite this the same two options exist for Somerset as existed for Gloucestershire:

    a) Use only Method iv and set the precautionary level at the lower end of the range. This assumes that Method iv is more reliable than the other Methods, and there may be reasons for believing this to be the case as explained above. This would set the number of badger to be culled in Somerset at 316.

    b) Use the lowest figure for the mid-point in the range of all the estimates. This assumes that there is no rational way of distinguishing between these methods. This would set the number of badger to be culled in Somerset at 375.

29. In this case, rounding using the same rules as for Gloucestershire would produce a different estimate (400 badgers for a. and 300 badgers for b.) but, as with Gloucestershire it is an operational decision as to whether to round the estimates or to use the numbers as presented in Table 2. It is also possible to see the precise choice of the number of badgers to be shot as an operational decision, especially because the target number may be updated with new data when the cull is under way. However, there is less consistency in the results from the different methods for Somerset than for Gloucestershire (Table 2 compared with Table 1). Consequently, in these circumstances it may be most justifiable to set the minimum number using the method in a. above, i.e. **316**.

Maximum numbers

30. The maximum numbers are set using the method set out in paragraphs 13 to 15 above and using the same sets of assumptions as for the minimum numbers. Therefore we have used the mid-point estimate from Method iii for Gloucestershire (**1091**). For Somerset the lower estimate from Method iv (**785**), (see tables 3 and 4) was used.

The need for a cautious and flexible approach

31. Setting a minimum number does not necessarily mean that there is a high level of certainty or confidence in the number. Last year we learned that we were dealing with more uncertainty than we anticipated and therefore in setting minimum numbers this year we needed to avoid false levels of confidence. We need to consider two realistic scenarios:

    a) That during the cull, there is accumulating evidence that the number of badgers in the cull area is low, and that the number of badgers removed, against a high level of contractor effort sustained across the whole cull area, is towards the lower end of our estimates. In this scenario, if the minimum and maximum numbers were set too high, Natural England would need to consider adjusting the numbers down to bring them in line with the actual circumstances being observed in the cull to manage the risk of too many badgers being removed.; OR

    b) That during the cull, there is accumulating evidence that the number of badgers is higher than the minimum and maximum numbers suggest, either because the cull company quickly exceeds the minimum number, or because feedback from observations suggests there is a higher level of activity observed than expected. In these circumstances, Natural England would need to consider the need to compel the cull company to continue the cull by revising the minimum and maximum numbers upwards to ensure that the optimum disease benefits can be secured.

32. We consider it is more prudent to manage the uncertainty by setting a realistic minimum number that can be revised in the light of new data, than to set it too optimistically with a risk of removing too many badgers. This year we have implemented enhanced daily data requirements about the level of effort being applied across the cull area, together with more detailed information about the locations of badger removal. Based on the information submitted, Natural England will be able to build a more accurate assessment of progress, and in addition to using emerging intelligence about levels of badger activity, Natural

England will be able to assess more accurately what the true population might be as the cull progresses.

33. The Badger Control Deed of Agreement will allow Natural England to adjust the minimum number during the cull, if required. If the evidence suggests that there are more badgers than the estimates indicated, Natural England will have the ability to revise the number upwards to ensure that the cull company is required to carry on the cull in order to achieve effective disease control, within the 6-week period.

34. Conversely, if the estimates are too high and the numbers of badgers are low, Natural England can, on the basis of careful consideration of the evidence and provided that the level of effort applied by the cull company has been sufficient, adjust the maximum number downwards before 6 weeks have elapsed if they consider that there is a risk of removing too many badgers.

35. A brief overview of how cull rates will be monitored is as follows

36. The cull companies will be obliged to provide sufficient data from the field regarding levels of culling effort applied (e.g. contractors deployed, hours spent shooting, number of traps set) and the number of badgers removed as well as the location where such effort was deployed.

37. It is anticipated that a reliable estimate will not be available until towards the end of the 6-week cull. A similar method was used after the RBCT by Smith and Cheeseman in order to determine what proportion of the population was removed in the first cull.

Summary of results

Table 1: Summary of estimates of minimum numbers to achieve 70% reduction of the initial starting population in 2013 for West Gloucestershire

West Gloucestershire	**Cull Sample Matching Results**		
Starting population estimates for 95% confidence intervals	**Lower**	**Mid**	**High**
Estimates of starting population in 2013	1,658	1,904	2,151
30% of starting population (the culling objective is for no more than 30% of the starting population to remain on conclusion of the cull)	497	571	645
Year 2 minimum number to remove in order to achieve 70% reduction of initial starting population			
Method I: Estimation of Minimum Number using RBCT outcome where it was estimated 103% of starting population was culled in Year 2. This assumes the same population recovery happens in current cull areas.	784	1,037	1,292
Method II: Estimation of minimum number using a badger TB epidemiology model	561	750	931
Method III: Estimation of minimum number using assumptions based on the scientific literature and long-term studies	391	615	840
Method IV: Estimation of minimum number using the 2014 sett survey data, assuming no change in active sett density in non-participating land.	570	654	739
Chosen Minimum Number	**615**		

Table 2: Summary of estimates of minimum numbers to achieve 70% reduction of the initial starting population in 2013 for West Somerset.

West Somerset	**Cull Sample Matching Results**		
Starting population estimates for 95% confidence intervals	**Lower**	**Mid**	**High**
Estimates of starting population in 2013	1,876	2,225	2,584
30% of starting population (the culling objective is for no more than 30% of the starting population to remain on conclusion of the cull)	563	667	775
Year 2 minimum number to remove in order to achieve 70% reduction of initial starting population			
Method I: Estimation of Minimum Number using RBCT outcome where it was estimated 103% of starting population was culled in Year 2. This assume the same population recovery happens in current cull areas.	977	1,337	1776
Method II: Estimation of minimum number using a badger TB epidemiology model	720	972	1,298
Method III: Estimation of minimum number using assumptions based on the scientific literature and long-term studies	552	870	1,196
Method IV: Estimation of minimum number using the 2014 sett survey data, assuming no change in active sett density in non-participating land.	316	375	435
Chosen Minimum Number	**316**		

Table 3: Summary of estimates of maximum numbers to remove for West Gloucestershire.

West Gloucestershire **Starting population estimates for 95% confidence intervals**	**Cull Sample Matching Results**		
	Lower	**Mid**	**High**
Estimates of starting population in 2013	1,658	1,904	2,151
5% of starting population (the culling objective is for no less than 5% of the starting population to remain on conclusion of the cull)	83	95	108
Year 2 maximum number to remove that would give no more than a 95% reduction of the initial starting population			
Method I: Estimation of maximum Number using RBCT outcome where it was estimated 103% of starting population was culled by the end of Year 2. This assumes the same population recovery happens in current cull areas.	1199	1513	1830
Method II: Estimation of maximum number using a badger TB epidemiology model	976	1226	1469
Method III: Estimation of maximum number using assumptions based on the scientific literature and long-term studies	806	1091	1378
Method IV: Estimation of maximum number using the 2014 sett survey data, assuming no change in active sett density in non-participating land.	984	1130	1277
Chosen maximum Number	1091		

Table 4: Summary of estimates of maximum numbers to remove for West Somerset.

West Somerset	**Cull Sample Matching Results**		
Starting population estimates for 95% confidence intervals	**Lower**	**Mid**	**High**
Estimates of starting population in 2013	1,876	2,225	2,584
5% of starting population (the culling objective is for no less than 5% of the starting population to remain on conclusion of the cull)	94	111	129
Year 2 maximum number to remove that would give no more than a 95% reduction of the initial starting population			
Method I: Estimation of maximum Number using RBCT outcome where it was estimated 103% of starting population was culled by the end of Year 2. This assumes the same population recovery happens in current cull areas.	1446	1893	2422
Method II: Estimation of maximum number using a badger TB epidemiology model	1189	1528	1944
Method III: Estimation of maximum number using assumptions based on the scientific literature and long-term studies	1021	1426	1842
Method IV: Estimation of maximum number using the 2014 sett survey data, assuming no change in active sett density in non-participating land.	785	931	1081
Chosen maximum Number	785		

Annex 1

Method I: approach using RBCT experience

38. AHVLA was commissioned to prepare estimates of the pre-cull badger population size of the two cull areas, based on the average proportions of the starting population in the proactive cull areas of the RBCT:

    a) Raw data from the RBCT were used to estimate the proportion of the starting population that was removed in the first 4 years of culling (Table 1). The average proportion was then used to estimate the number of individuals that would need to be removed in the two areas to produce an overall reduction consistent with average removal rates during each year of the RBCT.

    b) These average proportions of the pre-cull starting population in the RBCT were then used to estimate the population immediately prior to the second cull in the RBCT by extrapolating back from the estimated average proportion removed in the second cull, with the assumption that the average proportion of the population remaining in the RBCT at the end of the second cull was 30%. The resulting average proportion of the RBCT starting population was applied to the cull sample matching estimate for the cull areas to produce an estimated Year 2 pre-cull population size for the two areas.

39. AHVLA noted that this approach provides a very crude estimate to account for net recruitment, which underpins all the estimates made. All the estimates below contain uncertainties around the cull area starting population estimates, and uncertainties associated with the data from the RBCT which we are not able to quantify. AHVLA's confidence in these estimates was therefore "no more than moderate". The main assumptions are that:

    a) Net recruitment in the cull areas is in proportion with the net average recruitment observed in the RBCT. However, the level of net recruitment is likely to be subject to multiple influences which may differ between the RBCT proactive areas and the current cull areas. In their estimates, AHVLA assumed the differing levels of removal between the cull areas and the RBCT areas will not have affected net recruitment, however;

        I. Removing a lower proportion of the population may have resulted in a greater number of breeding animals left in the population which could result in a higher number of cubs produced.

        II. Furthermore, breeding levels in badger populations are complex. At stable densities it is thought that breeding is limited to only one or two females per social group. Therefore, there is a potentially large, latent reproductive capacity which will interact with the number of females remaining in the areas which could lead to more females producing cubs.

    III. Removing a lower proportion of the population may also have reduced the level of migration of adult animals into the area.

b) the differences in geography and landscape will not have had an effect on net recruitment irrespective of a difference in the proportion of the population removed, however:

    I. There may be more, or less, suitable habitat in the current cull and surrounding areas than was available in the RBCT areas and their surrounds. This could affect the population density of the surrounding areas and, therefore, the number of animals available to immigrate from the non-culled areas.

    II. The boundaries of the areas may have had different levels of permeability i.e. the cull areas may have had ‘harder’ boundaries such as large rivers, or unsuitable habitat all of which would affect the ease with which animals could immigrate from the non-culled areas.

    III. The larger size of the cull areas will not have an effect on net recruitment; however, differences in the size of the areas affects the edge to area ratio and we do not know what effect this would have on migration.

c) The unquantifiable uncertainties around the RBCT starting population figures and average proportions used in this estimate will not have a significant effect on the estimates produced for the cull areas.

40. The estimation of the Year 2 pre-cull population size and guideline maximum numbers include all uncertainties and assumptions mentioned above, plus:

    a) It is assumed that the RBCT population was reduced to an average of 30% of the starting population by the end of the second cull.

    b) It is assumed that the calculated average proportion of the starting population in the RBCT prior to the second cull is accurate.

    c) It is assumed that the cull areas’ populations now (i.e. between the first and second culling event) are the same proportion of their starting populations as the average proportion of the starting population in the RBCT areas before the second cull.

Table 1: Minimum number estimates based on application of RBCT experience, using the RBCT mean level of 103% control of the estimated starting population.

Gloucestershire

	Pre-cull starting population estimates		
	1658 (Lower 95% CI)	**1904** (mid-point)	**2151** (upper 95% CI)
Number removed in year 1	924	924	924
Year 2 Guideline minimum[1]	784	1037	1292
Year 3 Guideline minimum	365	419	476
Year 4 Guideline minimum	431	495	559

Somerset

	Pre-cull starting population estimates		
	1876 (Lower 95% CI)	**2225** (mid-point)	**2651** (upper 95% CI)
Number removed in year 1	955	955	955
Year 2 Guideline minimum[1]	977	1337	1776
Year 3 Guideline minimum	413	490	583
Year 4 Guideline minimum	488	579	689

[1] The Year 2 figure is calculated so that proportion of the starting population removed by the end of year 2 is consistent with the RBCT i.e. 103% of starting population minus the number removed in year 1.

Method II: computer generated simulation model

41. An alternative option is to utilise the latest badger/TB model simulation model. The badger model (Smith et al. 2012) has recently been updated with revised badger mortality parameters (Graham et al. 2013). The model was constructed to look at medium term (5-10 year) dynamics of the badger population, the spread of bTB in badgers and the transmission to cattle (incidence of herd breakdowns).

42. This model was used to simulate specific geographical areas (start density, number of groups, farm density and compliance), and an exact number of badgers removed as in year 1 of the cull. The model was run for each area until the start of the year 2 cull and the number of animals needed to be removed in year 2 to achieve a 70% reduction from the initial start population is recorded. This is a stochastic model, so with 100 simulations, we will have 100 start populations and 100 different estimates of the required level of removal. This can provide an estimate of precision, but not a true 95% confidence interval. This approach included a number of assumptions, particularly:

    a) That the model realistically represents badger population dynamics. This is the aspect of the model for which we have the greatest amount of data. However there are limited data to validate population recovery rates after culling, although the model does match the available evidence. Also, the population dynamics in both cull areas are assumed to be represented by the average dynamics at Woodchester Park.

    b) That the model can realistically represent the different population size in each area. To do this manual adjustments needed to be made to the carrying capacity and make very small changes to the mortality or fertility rate to ensure this is a stable population. To achieve this, the following assumptions were made:

        I. The starting population in the cull areas could be accurately matched in terms of badger sett density and population parameters.

        II. The starting population in the cull areas prior to the year 1 cull are relatively stable: i.e. have not been subjected to recent changes.

        III. The model realistically represents the behavioural changes that individuals adopt following culling, for example that the distance that non-breeding animals move to find territories and breed.

    c) AHVLA advised that although the model was a reliable tool for assessing longer term population changes in stable populations, and in estimating trends in disease transmission to cattle, it has not been validated for short term changes in populations in scenarios such as culling, and how populations may recover after being disrupted.

Table 2: Minimum numbers for Year 2 using population model, using cull sample matching estimates as starting points (number of model runs for each scenario in brackets):

Location	Lower 95% CI estimate	Mid-point population estimate	Upper 95% CI estimate
Gloucestershire	561 (100)	750 (50)	931 (100)
Somerset	720 (35)	972 (100)	1298 (150)

Method III: estimating population recovery since 2013

43. The key factors that influence the size of the badger population after a cull are:

    a. How many badgers were left when the cull finished in the previous year;

    b. The number of female badgers that have bred and produced young;

    c. The numbers of surviving cubs per litter;

    d. The number of badgers coming in from outside the cull area ("incursions")

    e. Natural mortality in the surviving population

44. Working with Natural England, we agreed that the following parameters be used in an approach to estimating how the population may have increased since the culls finished in 2013. These are based on scientific studies drawing from long term studies of badger populations. Reproductive success and survival always depend on the availability of food, and weather conditions, among other factors. Since it is not possible to estimate how the exact overwintering conditions affect survival, we have been pragmatic in assuming that since field observations indicated that wild food sources appeared to be sufficient and that because the winter was relatively mild, conditions for cub survival were optimal. Other weather events, such as severe flooding in nearby regions are considered to have had a minimal impact in the cull areas.

45. We used the following average statistics based on long term studies to build an estimate of population net growth since last year:

    a) The mean adult mortality rate from natural causes (and road kill) is:

        - 33% per year males
        - 25% per year females

    b) We assumed that in the surviving population there was a 50:50 male to female ratio.

    c) Normally 30% of females in a stable population breed as in the badger social groups there is a hierarchy whereby only dominant sows breed and produce litters of cubs. It is possible that if many dominant sows were culled, the time for other sows to opportunistically breed in the late autumn or early winter was very limited. To avoid serious under-estimates of population recovery, and given the lack of data, we assumed that dominant sows either survived, or were replaced by other females in the social groups and that "compensatory breeding" made up for any losses.

    d) For each breeding female, an average of 2 to 3 cubs survive. Litters can be larger, but cub mortality is well known, and for the purposes of these estimations, and given food availability and the mild winter, we used the figure of 3 cubs per litter.

e) Incursions, or the numbers of badgers coming in from outside the cull area, depend on the “hardness” of the boundaries around the cull areas. Expert advice suggests that the proportion of the population increase after a cull (based on RBCT experience) may be between 10 and 40%, depending on the hardness of the boundary. Bearing in mind that the size of the cull areas is larger than the RBCT areas, the population increase attributable to badgers coming in is likely to be proportionately lower. Also, we know that the boundaries of the cull areas are” hard” with features that reduce the likelihood of regular movement of badgers into the cull areas. Therefore, we concluded that the proportion of the population increase attributable to this immigration should be assumed to be the lower end – i.e. 10%.

Approach to estimating population change after 2013 Cull

46. We carried out calculations using all the outputs from both methodologies. A spreadsheet was set up to carry out the calculations using the estimates of the surviving population based on lower, upper and mid-points of the cull sample matching estimates published by AHVLA and the IEP. This took the following steps:

1) Use number of surviving badgers as a starting point

2) Adjust figure for mortality

3) Calculate number of females who bred

4) Calculate number of surviving cubs produced;

5) Add 10% of the resulting population increase to allow for additions through incursions:

6) Calculate the number of badgers that need to be controlled to achieve 70% control of the 2013 starting population

Table 3: Minimum number estimates to achieve 70% control of the starting population for each cull area, using the Cull Sample Matching (Ear Trip comparison methodology) results as a starting point:

	Gloucestershire			Somerset		
Confidence Intervals	**Lower**	**Mid**	**Upper**	**Lower**	**Mid**	**Upper**
Cull Sample Matching (Ear Tip" method) estimates of starting population in 2013	1,658	1,904	2,151	1,876	2,225	2,584
30% of population estimate*	497	571	645	563	667	775
Number of badgers culled in 2013	924			955		
Number of badgers estimated to have survived	734	980	1,227	921	1,270	1,629
Estimation of the current 2014 population after breeding, incursions and taking into account natural mortality.	888	1,186	1,485	1,114	1,537	1,971
Estimation of minimum number of badgers to be removed to achieve 70% control of 2013 population:	**391**	**615**	**840**	**552**	**870**	**1,196**

*This is the number to which the population needs to be reduced in order to achieve the desired 70% level of control needed to realise optimum disease control.

Method IV: assessment of current badger activity in each cull area

47. This year cull companies have continued to carry out surveys of badger activity to finalise their operational planning in terms of where they need to deploy contractors. They need to understand where setts are still active, and where areas may be less active, as more effort may need to be deployed to achieve an effective cull. We have asked the cull companies to submit information that allows us to understand whether the level of activity they are observing is consistent with our thinking about the indicative minimum number.

48. Activity estimates are important for operational planning but they cannot, in themselves, deliver accurate estimates of the badger population. If done properly, the cull company can build up an accurate assessment of the numbers and positions of active setts. We can then confidently used these up to date survey data to estimate the numbers of active setts in the cull area, and then then use previous survey work results to identify an appropriate mean number of badgers per sett and use this as a multiplier to generate an approximate population estimate to compare with the numbers generated. This population estimate can then be used to set the minimum number.

Somerset

49. The cull company has consistently reported since early spring that their surveys were indicating a very low level of badger activity. Using sett sticking and cameras, they gathered evidence that suggested that a significant number of setts were inactive, and those that were active were only visited at intervals, suggesting a low density population that was moving from sett to sett. The cull company was concerned that their observations did not appear to correlate with a population estimate based on the cull sample matching outcome. Whilst recognising that the IEP view was that this method was the most reliable, the monitoring carried out by the cull company consistently suggested a level of activity that was lower than expected if the cull sample matching estimates were a true reflection of the effectiveness of the cull.

50. The cull company requested an independent survey of areas to ensure that their own approach was appropriate. AHVLA carried out detailed sett surveys of a proportion of the land in two representative areas of the overall cull area:

- Area A: Selected as an area where sett density is low and badger activity reported as very low. This area

- Area B: Selected as an area where sett density is comparatively high.

Table 4: Summary of sett survey results in Somerset in 2014

	Total Number of Setts	Number of Inactive Setts	Number of Active Setts	Total Area Surveyed (km^2)	Total Size of Area (km^2)	Proportion of Total Area Surveyed %	Number of Active Setts per km^2
Area A	66	47	19	26	145	18%	0.73
Area B	62	38	24	18.5	111	17%	1.3
Total Area Surveyed km^2				44.5			
Proportion of total cull area surveyed				17%			
Total size of cull area km^2				256			
Mean number of active setts per km^2 across whole cull area				0.97			
Total number of active setts in cull area (mean no. / km^2 x total area)				248			

51. These surveys have been carried out in a systematic way by experienced surveyors. They confirm the cull company's conclusions based on its own surveys that the number of active setts is low. Our conclusion from these surveys is that we cannot use the outcome of the cull sample matching with any confidence in order to set a minimum number for the second year of the cull. It is important that we take into account what the surveys in the cull area are indicating, otherwise:

a) We risk setting an unrealistic and unachievable minimum number ;

b) Requiring the cull company to achieve a high number risks the cull achieving a higher level of control than necessary, with potential longer term impacts for the longer term recovery of a sustainable badger population within the cull area.

Considering non-participating land

52. Not all land in each cull area is accessible for culling. Non accessible land, where landowners have not signed up to participate in the cull, is also not surveyed. It is likely that the number of surviving badgers in these areas is higher, although some are still likely to have been culled outside these areas, and a proportion may have opportunistically moved out of these areas to less populated areas after the cull. During the surveys there was some anecdotal feedback that there was greater badger activity in the boundary areas close to non-participating land and that these setts may be more active. We have accounted for this possible difference in badger populations by assuming that the number of active setts per km2 in the inaccessible land (which occurs in less than 30% of the total cull area) is the same as the number before the cull (3.2 setts per km2). This is a highly conservative assumption, but it is based on the data from last year's sampling, and it was not considered appropriate to adjust this figure without a basis.

Table 5: Adjusted population estimates for Somerset allowing for a possible difference in number of active setts per km^2 in participating and non-participating land using Cull Sample Matching population data from 2013 to estimate mean number of badgers per sett.

Somerset	Number of active setts before cull: 3.17 / km^2		Number of active setts after cull: 0.97 / km^2	
In non-participating land	60.44		-	
In participating land	-		195.55	
Total number of active setts	192		190	
Overall total of active setts	381.9			
Number of badgers per sett (CSM estimate from 2013)	**Lower** 2.30	**Mid** 2.73		**Upper** 3.17
Estimated population for 2014 (number of badgers per sett x number of setts)	878	1043		1211
Original population estimate in 2013	1,876	2,225		2,584
30% of original 2013 population estimate	563	668		775
Minimum number required to achieve 30% of original starting population	316	375		435

53. Somerset, unlike Gloucestershire, presents some challenges and it is difficult to interpret or explain the results we obtained in 2013:

- Somerset is a topographically diverse area and there is significant heterogeneity in sett density across the area.
- The results secured during the 2013 cull using two different estimation methodologies gave significantly different results. The cull sample matching

methodology, considered by the IEP as the most reliable produced high population estimates, that indicated that the effectiveness of the cull was lower than expected, resulting in an estimate of a higher residual or surviving population.

- Using the cull sample matching estimates as a basis for estimating the population in 2014 gives a range between 1,114 to 1,971 badgers (mid-point = 1,537). Thus the minimum number required to bring the population down to 30% of the estimated starting population would be correspondingly between 552 and 1,196 (mid-point = 870).

- Observations from current sett surveys do not support the conclusions from the estimates offered by the cull sample matching methodology. The additional sett surveys carried out in the cull areas by AHVLA accounted for nearly 20% of the cull area. Whilst these surveys were snapshots of the wider area covered by the cull company, they were over large enough areas to be considered as valid confirmations of the cull company's own findings.

- We have used these data to re-estimate what the population might be. This produced a population range from 896 – 1,233 Badgers, and the minimum numbers required to achieve 70% control of the original starting population are between 316 – 435.

Gloucestershire

54. The cull company has carried out its own independent systematic survey of setts and established an estimate of active and inactive sett entrances. From their independent estimate, a relatively high proportion of setts are still active, and this suggests that the level of activity matches our indicative population estimates.

Table 6: Summary of sett survey results in Gloucestershire in 2014

Total Number of Setts found	Number of Inactive Setts	Number of Active Setts	Total Area Surveyed (km^2)	Total Size of Area (km^2)	Proportion of Total Area Surveyed
301	128	173	167.35	311	54%

Table 7: Adjusted population estimates for Gloucestershire allowing for a difference in number of active setts per km^2 in accessible land and inaccessible land, using Cull Sample Matching data from 2013 to estimate mean number of badgers per sett.

<table>
<tr><td>Gloucestershire</td><td colspan="2">Number of active setts before cull: 2.11 / km^2</td><td colspan="2">Number of active setts after cull: 1.03 / km^2</td></tr>
<tr><td>In non-participating land</td><td colspan="2">93.3</td><td colspan="2">-</td></tr>
<tr><td>In participating land</td><td colspan="2">-</td><td colspan="2">217.7</td></tr>
<tr><td>Total number of active setts</td><td colspan="2">196.5</td><td colspan="2">225</td></tr>
<tr><td>Overall total of active setts</td><td colspan="4">421.5</td></tr>
<tr><td rowspan="2">Number of badgers per sett (Cull Sample Matching (CSM) estimate from 2013)</td><td>Lower</td><td colspan="2">Mid</td><td>Upper</td></tr>
<tr><td>2.53</td><td colspan="2">2.91</td><td>3.28</td></tr>
<tr><td>Estimated population for 2014 (number of badgers per sett x number of setts)</td><td>1067</td><td colspan="2">1226</td><td>1385</td></tr>
<tr><td>Original CSM population estimate in 2013</td><td>1,658</td><td colspan="2">1,904</td><td>2,151</td></tr>
<tr><td>30% of original 2013 population estimate.</td><td>497</td><td colspan="2">571</td><td>645</td></tr>
<tr><td>Minimum number required to achieve 30% of original starting population, based on mid-point estimate.</td><td>570</td><td colspan="2">654</td><td>739</td></tr>
</table>