

BOVINE TUBERCULOSIS IN CATTLE AND BADGERS¹

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REPORT TO SECRETARY OF STATE ABOUT TUBERCULOSIS IN CATTLE AND BADGERS

Introduction

1. The Independent Scientific Group on Cattle TB (ISG) published its final report on 18 June 2007. The report is the culmination of nearly ten years' work by the ISG. It reports on the outcome of the Randomised Badger Culling Trial (RBCT) which was carried out in 30 areas (10 triplets) in England and provides a wealth of valuable information on tuberculosis (TB) in cattle and badgers.

2. As the Government's Chief Scientific Adviser I have considered, with the experts listed below, the ISG report and other scientific evidence relating to badgers and TB in cattle. This report summarises my conclusions and is intended to help Defra in reaching policy decisions.

3. I have considered whether the removal (killing) of badgers in areas of high TB prevalence might (or might not) prevent or reduce the incidence of TB in cattle. In doing so, I have had regard to the fact that the overriding aim is to control TB in cattle. As badgers are a continuing source of infection in certain areas of high cattle TB prevalence, a secondary aim is to control TB in those badger populations. It is not to eliminate badgers; any removal of badgers must be done humanely and within conservation considerations (including the Bern Convention). Thus references to removal in this report are to reducing the number of badgers in an area rather than to completely removing them from that area.

4. It is now more than 10 years since Professor (now Lord) Krebs reviewed the issue and recommended a field trial of the effects of badger removal on the incidence of cattle TB. Since then, the incidence of TB in

cattle has been steadily rising. In the same period a large amount of scientific evidence has been gathered. While that evidence may not be as conclusive as one might like, further trials are unlikely to significantly improve the certainty in the evidence base. Strong action needs to be taken now to reverse the upward trend of this important disease. Decisions therefore need to be taken on badger removal in the light of the existing scientific evidence, in spite of its uncertainties, and this report is framed accordingly.

5. TB control will require interventions that reduce the prevalence of disease in both cattle and wildlife and thus any removal of badgers must take place alongside current or future cattle controls. However, the group of experts did not consider the efficacy of cattle controls. Similarly, much more research is needed before vaccination of cattle and/or badgers, contraception for badgers or other such measures are realistic policy options, and we did not address these. We focussed on the scientific basis rather than on whether any measures would be cost-effective, although we had regard to the practicality of any measures.

6. The group of experts consisted of -

Prof Tim Roper	Ecologist	Department of Biology & Environmental Science, University of Sussex
Prof Douglas Young	Immunologist/microbiologist	Imperial College, London
Prof Mark Woolhouse	Epidemiologist	Centre for Tropical Veterinary Medicine, University of Edinburgh
Prof Dan Collins	Veterinary Medicine	Prof Emeritus of Farm Animal Clinical Studies, University College Dublin

Dr Paul Wood* (present by telephone for part of the discussion)	Veterinary microbiologist/immunologist	Pfizer
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7. I would like to acknowledge the contributions provided by Dr Debby Reynolds, Chief Veterinary Officer, Defra; Professor Sir Howard Dalton, Chief Scientific Adviser, Defra and Fiona Stuart, Scientific Adviser on TB, Defra. They attended as observers to provide the strategic and historical context for the issues under discussion.

Conclusions

- Badgers are a clear source of infection for cattle. Reducing the density of badgers in those areas of England where there is a significant level of TB in cattle reduces the incidence of TB in cattle in the same area;
- Removal of badgers should take place alongside the continued application of controls on cattle. Genuine commitment by all interested parties to the overall TB strategy is needed if TB is to be successfully controlled;
- Removal of badgers is the best option available at the moment to reduce the reservoir of infection in wildlife. But in the longer term, alternative or additional means of controlling TB in badgers, such as vaccination, may become available. Research into these should continue;
- Removal of badgers should only take place in those areas of the country where there is a high and persistent incidence of TB in cattle. It is not an appropriate measure in other areas;
- The minimum overall area within which badger removal should take place is 100 km², although increasing the area would increase the overall benefit;

- Where there is inaccessible land within the overall removal area, badgers should be removed on the accessible land bordering it;
- Badger removal programmes should be sustained (unless replaced or supplemented by alternative means of control);
- The removal process must be effectively and humanely carried out by competent operators. Removal which is improperly carried out, or which is fragmented in space or time, could cause detrimental effects on the incidence of cattle TB. Further consideration should be given to the way in which the removal process should be carried out;
- There is some evidence of an adverse effect on the incidence of cattle TB in the area 0.5 - 1.0 km outside the removal area. This may or may not be totally related to the removal programme, and there should be monitoring outside the removal area to detect any such effect. Measures should be taken to limit the risk of such an effect by –
 - where possible, reducing the migration of badgers into the removal area by hard geographical boundaries such as rivers or motorways or, where these do not exist, soft boundaries (such as arable land with no cattle) which are at least 1km wide; or
 - if immigration of badgers into the removal area cannot be prevented or sufficiently inhibited, then, subject to epidemiological findings, sustaining removal (or replacing it by or combining it with measures such as vaccination once they become available).
- The incidence of TB in cattle in the removal areas should be monitored on an annual basis. After four years, the badger removal programme should be reviewed. This may entail some assessment of the prevalence of TB in badgers.

- The badger population should be monitored.

Reasoning

8. There is clearly a link between TB in cattle and in badgers and in some areas of the country both species provide a reservoir of infection. However, the relative contribution of each to maintaining the disease is unknown and likely to vary according to region. The RBCT trials suggest that badgers could account for 40% of cattle breakdowns in some areas. Donnelly and colleagues (2006) reported that a 40% reduction in incidence of cattle herd breakdowns (95% CI 7% to 61%) was observed in inner proactive removal areas, when measured from the second removal to the end of the trial. [The purpose and our view of the ISG use of confidence intervals (CI) are explained at Annex 1.]

9. R_0 is used in modelling the progress of diseases and the potential effect of control measures. It cannot be manipulated directly but indicates whether or not a disease could persist in a population independently. It is explained in more detail at Annexes 2 and 3. But, in short, if only one transmission route is involved -

- if R_0 is more than 1, the incidence of the disease in a population will increase; and
- if R_0 is less than 1, the incidence of the disease in a population will decline.

10. The size of the R_0 figure indicates how rapidly the incidence will increase or decline. However, the R_0 for transmission within one species cannot be viewed in isolation from the R_0 for transmission from and within other species. Thus the beneficial effect of introducing measures to get R_0 below 1 for one species could be largely offset if new infections are introduced from another species and the incidence of infection in that other species

continues to increase. This is demonstrated by the table at Annex 2, which illustrates that the ultimate aim must be to get the basic reproduction number (R_0) of TB below one for all routes of transmission among cattle and badgers.

11. We do not know what the value of R_0 is for transmission routes among cattle and badgers, although the ISG referred to an estimate of 1.1 for the R_0 of cattle to cattle transmission (Cox et al, 2005) and a value close to 1 is consistent with the observed behaviour of the disease. It is likely that its value for each transmission route varies from one region of GB to another, in which case the contribution of badger removal to TB control will also vary. However, it is clear that any badger measures must be applied alongside continued cattle controls if the best results are to be achieved. If R_0 is below one for all of the transmission routes for cattle and badgers, levels of infection will decline substantially. Intervening to reduce the R_0 for these routes will also serve to limit the spread between cattle and badgers.

Link between badgers and cattle

12. We can be confident that badgers are a source of TB infection for cattle, and that cattle can be a source of infection for badgers.

Badgers to cattle

13. By showing a clear reduction in the incidence of cattle TB in areas in which badgers were repeatedly removed, the ISG report demonstrates that badgers are a source of TB infection for cattle, although it also indicates that the relationship is complex and non-linear. The Four Areas Trial in the Republic of Ireland similarly demonstrated that badgers are a source of infection for cattle. Reducing the numbers of badgers significantly reduced the incidence of TB in cattle.

14. Since 1997, the incidence of TB in cattle has increased numerically and spread geographically. These trends cannot be wholly attributed to cattle movements. There have been two different kinds of geographical spread -

- the areas with a high incidence of cattle TB have gradually spread outwards; and
- there have been sporadic outbreaks in previously TB-free areas.

The latter are almost all attributable to movements of infected cattle (Gilbert et al, 2005). Cattle movements alone cannot explain the persistence of the geographically compartmentalised areas of high incidence of cattle TB, nor their gradual expansion over the last decade. The occurrence of these areas in areas of the country where there are the largest number of badgers, and their persistence despite measures to control TB in cattle, provides a good indication of a wildlife reservoir of infection.

Cattle to badgers

15. During the outbreak of Foot and Mouth Disease in 2001, the majority of cattle TB testing was halted. This provided an opportunity for infected cattle to spread TB to other cattle and, potentially, to badgers. The prevalence of infection in adult badgers increased substantially and a weaker trend was observed in badger cubs across all seven proactive trial areas. A similar pattern in road-killed badgers from the seven counties in which the trial areas were situated confirms that this was not driven by badger removal. As the ISG noted, this suggests that cattle to badger transmission may be an important factor in TB dynamics and that cattle controls may influence the chances of reinfection of badgers.

Clustering of infection

16. Molecular genetic techniques allow us to distinguish different strains of *M.bovis* and to see how these change over time (Smith et al, 2003). There is strong evidence for clustering of particular strains in particular geographical areas and, where data are available, badgers and cattle in the same area

frequently share the same strain (Woodroffe et al, 2005). Molecular typing clearly identifies instances of dispersal of *M. bovis* caused by cattle movement from areas of high incidence of cattle TB, but cannot distinguish cattle-to-cattle from badger-to-cattle transmission within those areas. Use of molecular tools in association with appropriate modelling of the RBCT data could provide useful insights into the epidemiology of disease in badgers and cattle.

Wildlife reservoir

17. In other countries where a wildlife reservoir has been implicated, TB in cattle has not been controlled without addressing the wildlife reservoir. In New Zealand, TB in cattle was largely under control until possums became infected. Reducing that reservoir of infection by removal of possums dramatically reduced the incidence of cattle TB (Tweddle & Livingstone, 1994).

Means of transmission

18. Aerosol transmission seems the most likely route of infection between cattle. However, badger-to-badger transmission also takes place by general close contact including pseudo-vertical transmission (intimate contact between mother and cub) and through bite wounding. In both species respiratory tract lesions predominate, but it is not possible to be certain about the route of transmission between badgers and cattle.

19. After the first tuberculous badger was found in 1971, the Veterinary Laboratories Agency demonstrated experimentally that badger to cattle transmission of TB infection can occur. Badgers do not excrete many *M. bovis* organisms in faeces, but excrete more in urine and sputum. There is a significant opportunity for direct transmission from badgers to cattle in cattle sheds (as well as indirectly at pasture or through unsecured feed stores) (Roper et al 2003; and Defra Project SE3029). Badgers have been videoed making close physical contact with cattle within cattle housing (Defra Project SE3029). The majority of infected badgers do not die of TB but some can

behave oddly and badly debilitated (often tuberculous) badgers have been observed occupying and feeding in cattle sheds (Cheeseman 1981).

20. Not all badgers respond in the same way to TB infection. Some have been detected excreting high levels of *M. bovis* on several occasions (super excretors) while others have not (although the tests are insensitive) (Delahay et al, 2000). Intermittent excretion is also common. An important gap in knowledge is the extent to which infected animals are infectious. The prevalence of TB detected in populations of badgers varies but in the proactive RBCT trial during 2002-2005 it averaged 16.6% (range 6.3% to 37.2%) by routine post-mortem examination and culture of tissues. When more detailed examination was carried out, the prevalence was almost double that (Crawshaw et al, submitted).

Impact of removing badgers

Inside the removal area

21. It is clear from the ISG report that removal of badgers can have a beneficial effect on the incidence of TB in cattle in those parts of the country where there is a high incidence of TB in cattle. We recognise that there are some data where the results are not statistically significant and are difficult to interpret but even so removal resulted in some real benefits, particularly in the inner part of the trial areas and after repeated removal. The results of the Four Areas Trial in the Republic of Ireland support this conclusion.

22. As reported by the ISG, the average overall incidence of new confirmed TB herd breakdowns in cattle for all proactive removal trial areas, over the time period from the second removal to the end of the removal period, was 26.6% (95% CI 14.8% to 36.8%) lower inside the removal area than in the survey-only area. (This was measured from the second removal; for the reasons explained below, we consider that data collected immediately after the first removal should be discounted). After the fourth removal the

beneficial effects were 33% fewer new herd breakdowns (95% CI 8% to 50%). These are approximate estimates based on figure 5.1 in the ISG report.

23. Figure 5.2 of the ISG report indicates a trend (that does not reach statistical significance) for the beneficial effect of removal to increase towards the centre of the removal area. This indicates that benefits may be most pronounced in the inner part of the removal area.

24. Although the original intention was for one removal programme to take place each year in each proactive removal area, in practice most of the areas had only four removal operations over 5 or 6 years. The trial was interrupted or delayed by the outbreak of Foot and Mouth Disease in 2001 and disruptions to subsequent TB testing once it was resumed in the following year. Four removal operations appear to be the minimum needed to give meaningful results and ideally the trial would have been continued for longer. Nevertheless, the beneficial effect on cattle TB appeared to increase with repeated badger removals and the ISG's data suggest there was an 11.2% increase in beneficial effect with each removal. This figure is on the borderline of statistical significance ($p=0.064$); no confidence limits were provided in the report. This indicates that continuing removal beyond four removal operations/years may increase the benefits further, but mathematical modelling would be needed to extrapolate from the available data.

25. The trial areas were sited in those zones where there is a high incidence of TB in cattle and demonstrated that real benefits could be derived from removing badgers from areas of 100 km². As noted in paragraph 22 above, the beneficial effect appeared to be greater towards the centre of the area. It is therefore probable that the beneficial effect will increase as the size of the area is increased. Again, mathematical modelling would be useful to extrapolate from the ISG's data.

26. In the trial, only around 70% on average of the land in the removal area was accessible, as not all landowners gave their consent to trapping on their land. The ISG report indicates that removal of badgers along the edges of the

relatively small areas of inaccessible land was effective in minimising any adverse effect that this might have had.

Outside the removal area

27. The ISG reported an increase in confirmed herd breakdowns in the area up to 2km outside the removal area and attributed this to dispersal of badgers caused by their removal and subsequent increased TB transmission rates. The results are hard to interpret but it would appear that there is some evidence for an increase in cattle TB outside the removal area and that measures directed to the control of TB in both cattle and badgers should be put in place to minimise that increase.

28. Over the whole of the area of the 2 km zones outside the removal areas from the second removal to the end of the removal period, there was an increase of 19.6 % (95% CI minus 10.3% to plus 59.5%) in herd breakdowns when compared to the survey only areas. This increase was not statistically significant. This effect was most pronounced in the early stages of the trial and the linear trend suggests a decrease in the detrimental effect with each removal to a level of 11% after the fourth removal (estimated from figure 5.2 (95% CI minus 36% to plus 80%)). This indicates that the detrimental effect outside the trial areas may have continued to reduce if the trial had continued, although it must be noted that this decrease was not a statistically significant trend.

29. The detrimental effect was not spread over all of the area 2 km outside the removal area. Using estimates based on figure 5.2 in the ISG report -

- there was an apparent small beneficial effect in the area up to 0.5 km from the removal area, where there was a reduction in the number of herd breakdowns. These data are hard to interpret since removal had taken place in those areas when badgers' territories extended outside of the designated removal areas;

- in the area 0.5 – 1.0 km from the removal zones, approximately 55% (estimated from figure 5.2 (95% CI 18% to 115%)) more cattle breakdowns occurred than in the same area outside the survey-only zones. This was the only consistent figure for detrimental effects outside the removal area (i.e. the 95% CI levels do not cross zero). It includes figures from the first, rather than the second, removal so is likely to be an overestimate of the effect;
- In the area 1.0 – 2.0 km from the removal area, there was also an apparent detrimental effect (i.e. the confidence intervals cross zero).

30. The ISG figures are presented as percentages rather than as absolute numbers of herd breakdowns. This makes it hard to compare data as the areas inside the trial area were not equal in size to those studied outside the boundaries. The use of percentages also makes it difficult to assess how much changing the size of the removal area would alter the overall beneficial/detrimental effect (see Annex 4). Similarly, because herd density is not included in the relevant tables in the report, the ISG data do not permit consideration of the role of cattle herd density, which is likely to vary inside and outside a trial area.

31. There was a non-significant decrease in detrimental effects after each removal operation. This, together with our understanding of the ecology of badgers (discussed below), indicates that the detrimental effects seen outside removal areas may well be transient. Nevertheless, the overall beneficial effect on incidence of cattle TB will be maximised if steps are taken to minimise that detrimental effect. We recommend that there should also be monitoring of these effects up to 2 km outside the removal area.

Effect of removal on badgers' behaviour

32. Natural ranging behaviour is influenced by the population density of badgers. In areas of high density badgers are very territorial and most live

permanently within their social group. This is the situation in the South West of England. In countries with lower densities (such as Poland and Spain), the territorial groups are smaller and badgers are wider ranging.

33. Over the whole duration of the RBCT, badger density was reduced by about 70% in each of the proactive removal trial areas (though the data are indirect field signs and this is, therefore, an informed guess). As the ISG note, removal of badgers disrupts their social structure. When a social group is disrupted, and population density is reduced, other badgers move in rapidly (possibly within days). There will also be mixing within groups neighbouring the removal areas. Overall there will be net immigration into the removal areas. If removal is not sustained, the badger population is likely to recover over time, although this may happen slowly.

34. Breeding opportunities and the availability of a vacant sett primarily drive dispersal. However, recent genetic studies suggest that there is a higher level of dispersal over longer distances than behavioural studies might suggest (Pope et al, submitted). A small number of badgers are thought to be making longer journeys (> 5 km). In undisturbed populations, most journeys are temporary excursions with badgers often remaining in the same social group for their entire lives. However, badgers can disperse to new areas at any age and do so opportunistically.

35. Dispersed, infectious badgers are more likely to come into contact with uninfected, susceptible badgers through fighting over mates and territory and via general close contact. Therefore they are more likely to spread TB to new areas. There may also be a stress effect of perturbation which may trigger infectiousness of infected badgers.

36. As noted earlier, at the start of the RBCT there were clusters of infection within areas of 1-2 km, reflecting the territory of individual social groups. Because of the dispersal effect brought about by removal, this clustering was disrupted over the course of the trial and there is evidence that the prevalence of infection in badgers in those areas increased. If removal is

not sustained, there is a risk that the population of badgers could return to pre-removal levels, but with an increased prevalence of infection. It is therefore extremely important that removal is carried out effectively and be sustained.

37. The ISG considered that the disruption of badgers and the increased ranging behaviour was a permanent effect, as discussed above. However, there is a reasonable possibility that the disruption is transient. The data do not discount this theory. If the disruption is transient, the single regression model for the effect of perturbation, used by the ISG, is not adequate. Were this to be the case, the consequential effects on the incidence on cattle TB outside the removal zone may not be as severe as the ISG suggest.

38. With efficient and sustained removal, the density of badgers will be significantly reduced. If, as discussed above, disruption is transient, this population will also be stable, thus reducing the badger-to-badger transmission rate. But even if the disruption is not transient, a significant reduction in the numbers of badgers will reduce the numbers available to come into contact with cattle, thereby reducing the likelihood of cattle being exposed to infectious badgers. Similarly, the likelihood of uninfected badgers being exposed to infectious badgers will also be reduced, ideally to a level at which TB cannot sustain itself within the badger population.

Means of minimising risk of edge effect

39. There are a number of measures which can help to minimise any detrimental effect on the incidence of TB in cattle outside the removal area. These are -

- continuing the removal programme beyond four years. The detrimental effect appeared to reduce with each successive removal operation;

- hard boundaries such as rivers and motorways, which will prevent contact between badger groups;
- soft boundaries such as arable land with no cattle. These should be at least 1 km wide;
- badger fencing (electric fencing is most effective); and
- increasing the size of the removal area.

40. Annex 4 indicates how an increase in the removal area decreases the relative size of the outer zone. Thus a removal area of 100 km² has a 2 km outer zone of 83 km² (ie 17% smaller than the removal area) while a removal area of 300 km² has an outer zone of 135 km² (55% smaller).

Differences from conclusions in ISG report

41. At paragraph 10.92 of their final report the ISG states that “badger culling cannot meaningfully contribute to the control of cattle TB in Britain”. However, the data do not support such an unqualified conclusion.

42. We agree that the data in the ISG report demonstrate that removal gives a real reduction in the incidence of cattle TB within the removal area. However, we consider that the ISG’s view that this benefit was largely offset by the increase in incidence outside the removal area is unsound and should be subject to further spatial and temporal analysis.

43. The confidence intervals for the detrimental effect outside the removal area are very large. Three out of four go through zero (i.e. one cannot be confident that the overall effect is detrimental). There was only one result (at 0.5 – 1.0 km outside the removal area) that was statistically consistent in showing detrimental effects (i.e. the 95% CI levels do not cross zero). The fact that there had been some badger removal in the area 0 – 0.5 km outside the removal zone also complicated interpretation of the results. It was unclear whether it had been considered as an internal or external effect.

44. We are concerned about the timeframe in which changes in the incidence of cattle TB are attributed to the impact of badger removal as presented in the report. It would be reasonable to expect there to be a time lag between removal of badgers and detection of changes in infection in cattle.

45. The sequence of events that has to occur before an association between badger removal and cattle TB incidence can be detected is: infectious badgers need to disperse, come into contact with cattle or contaminate animal feed or pasture, thereby exposing cattle to *M. bovis*, the cattle need to become infected and then develop an immune response that can be detected by the tuberculin test. Thereafter, the cattle need to be skin tested (routine tests are performed only once a year) or examined following slaughter. Samples need to be taken and cultured in the laboratory to confirm the test results. TB infection is usually slow to develop and it can take months or even years before it is detected by the tuberculin skin test in a high proportion of infected animals. (Experimental challenge studies show that skin tests can become positive within a few weeks of infection with a high dose of bacteria, but natural transmission studies demonstrate that the period between infection and skin test conversion can in fact often extend over a period of many months.)

46. This time lag does not seem to have been taken into account when the ISG collected data on cattle TB incidence immediately after the first proactive removal.

47. For this reason, we consider that the results for the first year of the proactive trials should be viewed with extreme caution. This was the year in which the greatest detrimental effect (and smallest beneficial effect) was seen.

48. Nevertheless, there was evidence of some detrimental effect outside the removal area and that removal disrupts badgers' social groups. The ISG put forward the perturbation theory to explain these effects. Although we

were not fully persuaded by it, in the absence of any other theory, the perturbation theory was seen as a plausible explanation.

49. The data do not discount the theory that the detrimental effects are transient although the ISG does not seem to have considered the possibility. The overall detrimental effect outside the area appeared to be reducing year on year although this was not statistically significant.

Reactive badger removal

50. Because the reactive badger culling trials were stopped before robust results could be obtained, we are not able to comment with any confidence on whether or not reactive removal can make a contribution to controlling TB in cattle. However, we have concerns about the biological plausibility of the ISG's interpretation of the results and do not consider that the evidence in the ISG report should be used to either support or rule out a reactive removal strategy.

Conclusions

51. In our view a programme for the removal of badgers could make a significant contribution to the control of cattle TB in those areas of England where there is a high and persistent incidence of TB in cattle, provided removal takes place alongside an effective programme of cattle controls.

CONFIDENCE INTERVALS

The ISG states that a confidence interval is “a numerical interval in which a population attribute or treatment effect is estimated to lie within a specified probability”.

The ISG addressed the question “What effect, in practice is badger culling likely to have in reducing the number of herd breakdowns in an area?”

In using statistical analysis to answer such a question it is common practice to use 95% confidence intervals.

A 95% confidence interval is the numerical range of values in which one can be 95% confident that the true value lies.

It therefore follows that a smaller confidence interval means that one has narrowed down the range of values in which one is 95% confident that the true value lies. Larger confidence intervals mean that one is more uncertain about where the true value lies.

When looking at beneficial and detrimental effects it is important to understand the importance of a confidence interval including zero. If the mean value is above zero but the confidence interval nevertheless extends below zero, one cannot be 95% confident that the true value lies above zero, i.e. one is less than 95% sure that the effect being measured is beneficial. The same would be true when looking at detrimental effects.

Many of the figures in the ISG report include decimal points. Given the often very wide confidence intervals, I consider that this level of precision may give the impression of more certainty than is the case. Nevertheless I refer to the figures and confidence intervals exactly as reported in the ISG report. Where the ISG did not report figures, I indicate in the text where I have estimated them from graphs.

ANNEX 2

THE EFFECT OF CONTROL MEASURES ON THE BASIC REPRODUCTION NUMBER (R_0) OF TB IN BADGERS AND CATTLE

		Badgers	
		$R_0 > 1$	$R_0 < 1$
Cattle	$R_0 > 1$	TB can persist in either badgers alone or cattle alone. Badger removal necessary but has small effect on cattle TB unless measures are continued to reduce cattle-to-cattle transmission.	Cattle are main reservoir. Badger removal likely to reduce cattle TB minimally.
	$R_0 < 1$	Badgers are main reservoir. Badger removal likely to reduce cattle TB significantly.	Infection cannot persist in either population alone (theoretical possibility). Badger removal effective

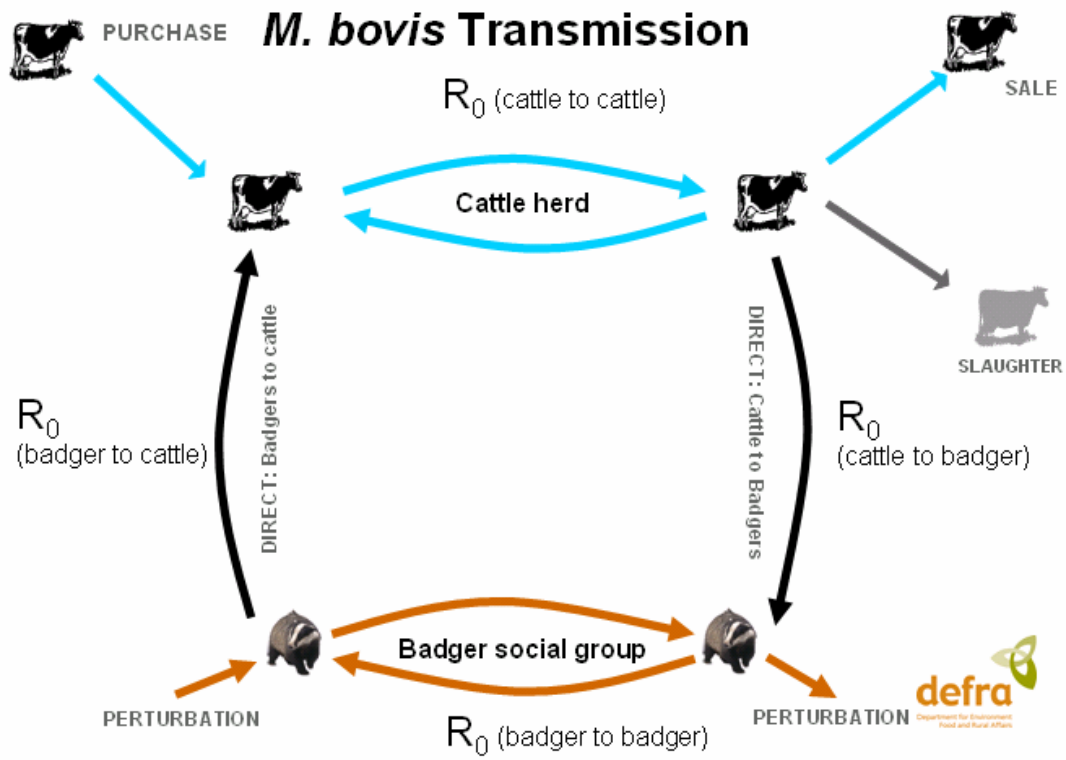
R_0 is the number of secondary infections produced by spread from the first infected animal (the primary case) after infection has been introduced into a large population of previously unexposed hosts. R_0 is not directly measurable. It is distinct from R (the Effective Reproductive Rate), which is the number of secondary cases resulting from each infected animal at any stage of an outbreak ie it is the number of new infections detected in a specific time period.

The theoretical assumptions underlying R_0 do not usually hold in real life. R can be considered to be the “real-life” version of R_0 , and is the number of secondary cases resulting from each infected animal at any stage. It differs from R_0 in that it does not assume such characteristics as a totally susceptible population, equal likelihood of contact with an infectious case and the same

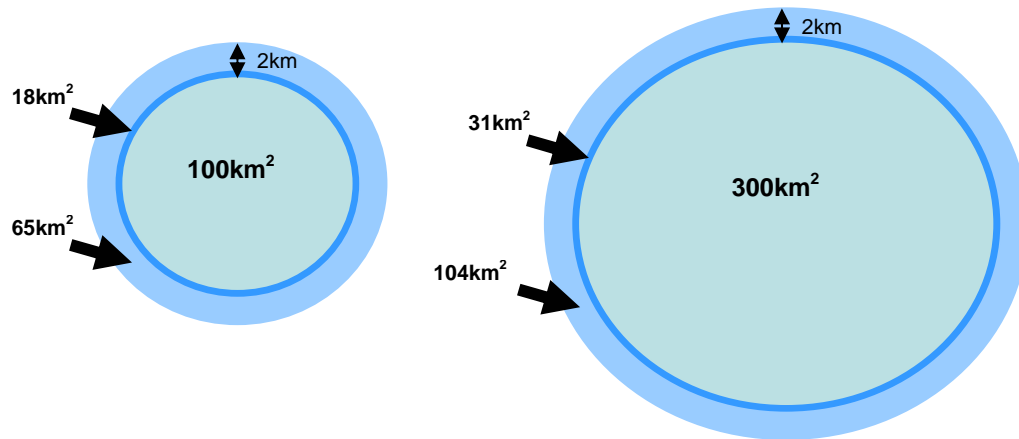
duration of infectiousness. For this reason R is generally lower than R_0 , as transmission is less likely.

An infection can only cause a major outbreak or become epidemic when the number of secondary cases produced by a single primary case is more than one ($R_0 > 1$). Minor outbreaks can still occur when R_0 is less than one, but they will not persist.

ROUTES OF TRANSMISSION OF TB BETWEEN BADGERS AND CATTLE AND THE RELEVANT BASIC REPRODUCTION NUMBERS (R_0)



THE EFFECT OF INCREASING THE AREA OF THE REMOVAL ZONE ON THE AREA OF THE ZONE 2KM OUTSIDE



- Removal zone
- Zone 0–0.5 km outside the removal zone
- Zone 0.5-2 km outside the removal zone

In the RBCT there was some badger removal in the zone 0-0.5 km outside the removal zone; a beneficial effect was reported in this area.

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