Eradicating TB from cattle and badgers – a review of evidence

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Photo by Seth Jackson

Abstract

A review of England's eradication strategy for bovine tuberculosis (TB), chaired by Prof Sir Charles Godfray, will publish its conclusions shortly, and will undoubtedly spark a policy debate. This report, prepared by scientists at the Zoological Society of London (ZSL) aims to inform that debate.

This report focuses on management aimed at badgers, reflecting ZSL's expertise in wildlife health. However, this focus should not eclipse the overwhelming importance of tackling cattle-to-cattle transmission, which is estimated to account for 94% of new herd infections. Such transmission is to be expected when the main diagnostic test is estimated to detect only 50% of infected cattle.

Mass culling of badgers is at the heart of England's TB policy. Nine counties now host large-scale culls; five of these counties have cull zones covering over half of their total land area. Farming leaders envision expanding this cull to a continuous zone from Land's End to the Peak District.

Thus far there is no robust evidence that England's policy of mass culling is reducing cattle TB. A minister's claim that the approach is "*delivering results*" is based upon a government report which states explicitly that it "*cannot demonstrate whether the badger control policy is effective in reducing bovine TB in cattle*". A previous randomised controlled trial suggests that large-scale culling can somewhat reduce cattle TB in the short term, but can contribute little to long-term eradication because it increases TB prevalence in badgers and spreads infection to new areas.

While mass culling is described as "industry-led", it currently costs taxpayers 3-6 times as much as it costs farmers. The government's cost-benefit analysis appears to substantially underestimate the costs of large-scale culling.

Large-scale culling also raises major concerns about animal welfare and environmental impact.

Evidence suggests that small-scale badger culls planned for Cumbria will spread TB rather than control it. Selective culling, and culling combined with vaccination, are being piloted in Wales and Northern Ireland; both are costly and may either increase or reduce cattle TB.

Badger vaccination can potentially reduce TB risks to cattle at least as fast as widespread culling, but firm evidence is limited. Better evidence could be obtained through a large-scale trial, which we estimate could cost less than the government invests in a single average cull zone. Oral vaccination is being developed but may prove neither cheaper nor more effective than injectable vaccination. We therefore identify trialling injectable vaccination as an immediate priority.

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Summary of Key Points

Current policies relating to badgers and TB

- TB control is a devolved issue, with different policies in different UK countries.
- English TB policy includes both extremely large-scale badger culling and small-scale culling. Wales is conducting selective culls targeting test-positive badgers. Northern Ireland is trialling a cull of test-positive badgers with vaccination of test-negative animals. Scotland is officially TB-free, and takes no action against wildlife for TB control purposes.

The role of badgers

- At least 75% (more likely 94%) of TB-affected herds acquire infection from other cattle.
- Badgers can transmit TB to cattle but appear not to act as a reservoir for TB.
- Managing cattle-to-cattle transmission is likely to contribute far more to TB control and eradication than managing badger-to-cattle transmission.

Large-scale badger culling *(currently implemented in England)*

- Despite government claims, there is currently no robust evidence that industry-led badger culls are consistently reducing cattle TB.
- Large-scale nonselective culling may help control cattle TB, but it cannot eradicate TB because it increases prevalence among badgers and spreads TB to cattle in new areas.
- Large-scale badger culling is industry-led, but costs taxpayers 3-6 times as much as it costs farmers.
- The government's value-for-money analysis appears to significantly under-estimate the costs of nonselective culling.
- Nonselective badger culling is the only management approach that raises serious concerns for badger welfare.
- Nonselective badger culling is the only management approach that raises serious concerns about environmental impact.
- Nonselective badger culling is the only approach that raises concerns for public safety.

Small-scale badger culling *(recently licensed in England)*

- There is strong evidence that small-scale nonselective culling increases cattle TB.

Selective culling *(recently commenced in Wales)*

- Selective culling cannot detect and remove all infected badgers; it could either reduce or increase cattle TB.
- Selective culling is very expensive.

Badger vaccination *(not main policy in any UK country but expanding in Republic of Ireland)*

- Vaccination has the potential to reduce TB infection prevalence in the badger population, and hence TB risks to cattle, without the harmful effects associated with culling.
- Badger vaccination, assisted by volunteers, is currently the cheapest control option.
- A replicated field trial would be needed to properly evaluate the effects of badger vaccination on TB in badgers and cattle.
- Oral vaccination is being trialled, but may prove neither cheaper nor more effective than injectable vaccination, and should not delay deployment of injectable vaccine.
- The government could support a trial of injectable badger vaccination on the scale of the RBCT for less than its average financial contribution to a single cull zone.

Test and Vaccinate or Remove (TVR – *trial underway in Northern Ireland*)

- Mathematical modelling suggests that TVR might either reduce or increase cattle TB.
- TVR is very expensive.

Managing contact between badgers and cattle *(not main policy anywhere)*

- It is unclear which forms of farm management might effectively reduce infectious contact between badgers and cattle. Research is needed to identify effective methods.

1 Introduction

Bovine tuberculosis (TB, caused by *Mycobacterium bovis*) is the most serious chronic infectious disease problem for UK farming. TB is also at the heart of the greatest wildlife controversy in the UK, because some cattle herds acquire infection from badgers, and TB control efforts entail killing badgers on an extremely large scale, despite the species' protected status.

The UK government aims to eradicate TB. In 2018 the Secretary of State for Environment, Food, and Rural Affairs commissioned a review of England's TB eradication policy, chaired by Prof Sir Charles Godfray. Prof Godfray's review is due to be completed at the end of September 2018, and is likely to prompt UK-wide debate among both policymakers and the public.

This report, produced by scientists at the Zoological Society of London (ZSL) aims to inform the debate associated with the forthcoming Godfray review. Reflecting ZSL's expertise in wildlife health, it evaluates the relative importance of badger-to-cattle and cattle-to-cattle transmission, and reviews methods for managing transmission between badgers and cattle. This report has no link to the Godfray review itself.

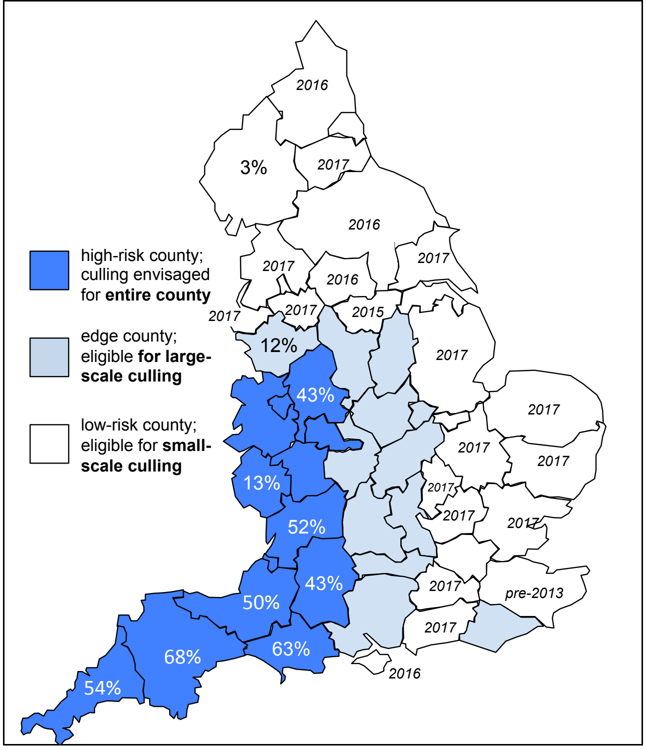
2 Current policies

TB control is a devolved issue and different policies apply in the four countries of the UK.

Scotland is officially TB-free, and maintains that status through regular cattle testing and slaughterhouse surveillance. There is no active management of TB in wildlife in Scotland.

Policymakers have divided **England** into a High-Risk Area in the West, a Low-Risk Area in the East, and an "Edge Area" between the two, reflecting geographical variation in cattle TB incidence (Figure 2.1). While the long-term policy goal is to eradicate TB from the entire country, the shorter-term aim is to reduce TB incidence in the High-Risk Area while preventing it from becoming established in the Low-Risk Area. In recent years, very large-scale (>>100 sq km) badger culls have been conducted in both the High-Risk and Edge Areas, with cull zones covering substantial proportions of entire counties (Figure 2.1). These culls are described as "industry-led" because they are overseen and implemented under licence by cull companies set up by groups of farmers. In addition, small-scale badger culling has recently been authorised for the Low-Risk Area, with the first licence issued in Cumbria in 2018 (Figure 2.1). Some badger vaccination has been conducted in the Edge Area, with a view to reducing TB spread from the High-Risk Area to the Low-Risk Area.

Figure 2.1 *TB Risk Areas of England. Figures indicate the percentage of each county's land area covered by cull zones or, in the Low Risk Area, the year of the most recent confirmed TB incident in cattle.*



Wales is divided into two High-Risk Areas, a Low-Risk Area, and two Intermediate areas. After several years of successfully reducing cattle TB without widespread badger management, Wales recently started a programme of localised selective badger culling on chronically affected farms. It previously completed a pilot programme of large-scale badger vaccination in a single Intensive Action Area.

Like Wales, **Northern Ireland** successfully reduced cattle TB without managing wildlife. However, it is now piloting a Test and Vaccinate or Remove (TVR) approach for badgers.

While this discussion draws mainly on evidence from the UK (due to differences in badger ecology between Britain and the Republic of Ireland[1]) it is worth noting that the **Republic of**

Ireland has recently announced an expanding programme of badger vaccination to replace its established policy of widespread culling[2].

3 How important is *M. bovis* transmission from badgers?

The strongest evidence of badger-to-cattle transmission of *M. bovis* comes from the Randomised Badger Culling Trial (RBCT). In the RBCT, reductions in badger density produced by culling consistently influenced the incidence of cattle TB (although these changes were consistently positive in some circumstances and consistently negative in others)[3-6]. If badgers were not implicated in transmitting *M. bovis* to cattle, RBCT culling would not have altered cattle TB incidence, either negatively or positively.

The best available estimates suggest that badger-to-cattle transmission causes between 1% and 25% of new breakdowns, with 6% most likely[7]. Hence, at least 75%, and possibly as many as 99%, of TB-affected herds acquire infection from other cattle herds[7]. This relatively high rate of cattle-to-cattle transmission is readily explained by inadequacies in the testing programme: a recent meta-analysis estimated that the standard TB test detects only 50% of infected cattle[8].

This evidence suggests that reducing cattle-to-cattle transmission of *M. bovis* holds greater potential for TB control than does tackling badger-to-cattle transmission. However, rapid eradication of TB (which is England's policy goal) is likely to require addressing infection in both host species.

Because badgers can transmit *M. bovis* to cattle, they are often misrepresented as a TB "reservoir"[e.g. 9]. A reservoir host is a species within which infection persists indefinitely without outside input. A reservoir host may transmit infection to another "spillover" host species, in which infection does not persist without repeated re-infection from the reservoir[10]. Crucially, in a reservoir/spillover host system, infection cannot be eradicated by targeting the spillover host alone.

The reservoir concept does not accurately describe badger' role in maintaining cattle TB. If badgers were a TB reservoir, most herds would acquire infection from badgers whereas, as discussed above, the best available estimates suggest that 94% of affected herds acquire infection through cattle-to-cattle transmission[7]. Cattle-to-badger transmission[11,12] also appears to play a role in TB persistence: suspension of cattle TB testing for a single year during a national epidemic of Foot-and-Mouth Disease was associated with a 70% increase in badger TB[13]. Indeed, it is not clear whether *M. bovis* infection persists in badger populations in the absence of cattle[14].

Correctly viewing TB as a two-host system[13] rather than a reservoir/spillover host system is important, because it emphasises the need to reduce cattle-to-cattle and cattle-to-badger transmission, as well as badger-to-cattle transmission. Moreover, certain forms of management, such as vaccination of badgers in the "Edge Area" to try to prevent TB spread from the High-Risk Area to the Low-Risk Area, might be effective if badgers were a reservoir host, but may fail where cattle-to-cattle transmission allows long-distance spread of the disease[15].

Key points:

- *At least 75% (more likely 94%) of TB-affected herds acquire infection from other cattle.*
- *Badgers can transmit TB to cattle but appear not to act as a reservoir for TB.*
- *Managing cattle-to-cattle transmission is likely to contribute more to TB control than managing badger-to-cattle transmission.*

4 Comparison of methods for managing *M. bovis* transmission from badgers to cattle

Various methods have been proposed or deployed to reduce *M. bovis* transmission from badgers to cattle. Here we compare these methods against five key criteria: (i) their contribution to TB control and eradication, (ii) cost, (iii) safety, (iv) humaneness, and (v) environmental impact. Societal costs (e.g., divisions in rural communities) are not included due to lack of evidence.Table 4.1 summarises these comparisons.

The amount of evidence available to inform these evaluations varies between management methods (Table 4.1). The evidence base is especially rich for nonselective badger culling, which has been the subject of a randomised controlled trial (the RBCT) and subsequently practised as policy in England. As noted above, this discussion draws mainly on evidence from Britain, since major differences in badger ecology have been documented between Britain and the Republic of Ireland[1].

Table 4.1 *– Summary of badger management methods, evaluated against key criteria. For criteria ranked using stars, methods with more stars rank higher (e.g., lower environmental impact, more humane, less costly). Shading indicates the best score against each criterion. Full details and sources are given in the text.*

Type of badger management	evidence	public safety	humaneness	environmental impact	cost per sq km per year	impact on prevalence in badgers	impact on cattle TB incidence	potential role in TB eradication
Nonselective culling								
localised	***	*	*	*	£679	increases[16]	increases[4,5,17-19]	*
widespread	***	*	*	*	£2,247	increases[11]	increases & reduces[3,5,6,20]	***
Selective culling	*	***	**	**	£112,265	unknown	uncertain[21]	**
Badger vaccination								
volunteer staff	**	***	***	****	£592	likely reduces[22]	uncertain, may reduce[23,24]	****
government staff	**	***	***	****	£3,160	likely reduces[22]	uncertain, may reduce[23,24]	****
Test-vaccinate-remove	*	***	**	**	£9,118	unknown	uncertain[21,25,26]	**
Managing contact	*	***	****	***	£1,536	unknown	uncertain	**

4.1 Contributions to TB control and eradication

4.1.1 Nonselective Culling

The impacts of nonselective badger culling were well-studied in the RBCT[1]. In that trial, large-scale culling reduced cattle TB inside trial areas[3,20]. However, this benefit was undermined by harmful effects. First, nonselective culling consistently increased the prevalence of infection in badgers[11], probably by changing their behaviour so that badger-to-badger transmission increased as density fell[27]. This same behavioural change also meant that each remaining badger was in contact with more cattle herds, potentially spreading disease over larger areas[28]. Cattle TB increased on adjoining land, where badger densities were inadvertently reduced by nearby culling[3,20]. Small-scale RBCT culling likewise increased TB in both badgers[16] and cattle[4,5,17,18].

Overall, the RBCT showed that nonselective badger culling is risky: its ability to control TB is undermined by increased cattle TB on adjoining land, and it can also increase cattle TB inside culled areas if culling is inefficient, patchy, small-scale or short-term[1].

Importantly, neither large-scale nor small-scale nonselective badger culling can contribute sustainably to TB eradication, because both approaches increase TB prevalence in the badger population[11,16] and spread infection to new areas[3,4,28], increasing rather than reducing the area affected by TB. A recent announcement to allow small-scale culling in Cumbria is likely to spread TB in this area rather than contain it.

The effects of current industry-led culls on cattle TB are not yet clear. The most recent government report[29] presents TB incidence covering four years post-cull from two zones, two years from one zone, and one year from seven zones (17 zone-years). Time trends suggest falling incidence in the first two zones, rising incidence in the third, and no consistent effect in the other seven[29]. However, unlike previous reports, the most recent report presents no statistical comparison with unculled areas. Although a Defra Minister was quoted as saying the findings showed that the approach was "*delivering results*"[9], the report itself remarks that "*these data alone cannot demonstrate whether the badger control policy is effective in reducing bovine TB in cattle*"[29]. Indeed, any attempt to quantify the impact of industry-led badger culling is difficult because farms in the cull zones have greater access to improved cattle testing[74] and biosecurity advice[31] than areas without culling. A previous primary analysis (based on seven zone-years of data) showed no significant difference in cattle TB between areas with and without industry-led culling[30]. A secondary analysis, based on just four zone-years (two areas culled for 2 years each), suggested that cattle TB incidence might be lower inside the culled areas than in comparison areas, after statistically adjusting for a large number of other variables[31]. However, the authors themselves cautioned that "*it would be unwise to use these findings to develop generalizable inferences about the effectiveness of the policy*"[31]. Of the two cull areas, one had significantly lower cattle TB incidence than its comparison areas before culling started, making it difficult to attribute subsequent differences to culling. Sensitivity analyses revealed that results from the second cull area were not statistically robust[31]. Updates of these statistical analyses are to be published in a peer-reviewed scientific journal rather than a government report[29]. However, differing time trends between the first three areas suggest that it is still too early to draw general conclusions about the efficacy of industry-led culling.

Key points*:*

- *Large-scale industry-led badger culling is a key component of current TB policy in England.*
- *Despite government claims, there is no robust evidence that current industry-led badger culls are consistently reducing cattle TB.*
- *Large-scale nonselective culling may help control cattle TB but it cannot eradicate TB because it increases prevalence among badgers and spreads TB to cattle herds in new areas.*
- *There is strong evidence that small-scale nonselective culling worsens the TB problem.*

4.1.2 Selective culling

TB is controlled in cattle by selectively culling individuals which test positive, and a similar approach for badgers has intuitive appeal. However, there are two major impediments to this approach.

First, the best-studied trap-side test for live badgers (BrockTB StatPak) fails to detect roughly half of the infected animals[32-34], suggesting that selective culling would inevitably leave some infected badgers in the wild, as occurred when selective culling was trialled (using an earlier test) in England in 1994-1996[35]. The StatPak test has now been replaced with the DPP test; a recent attempt at selective culling in Wales using this test killed five test-positive badgers; however, two other badgers which were test-negative at the trap-side, and hence released, were found to be test-positive when samples were subsequently re-analysed in the laboratory[36]. None of the five test-positive badgers was confirmed infected when examined *post mortem*. These problems of TB diagnosis, combined with constraints on capture success[37], mean that selective culling is unlikely to remove all infected badgers from a farm.

Leaving infected badgers behind raises the second impediment to selective culling. Evidence suggests that removing even small numbers of badgers may be sufficient to prompt behavioural change, similar to that caused by other types of culling[21]. Strong evidence that small-scale culling increases cattle TB raises the possibility that selective culling might have similar adverse effects. Hence, while selective culling has the potential to reduce cattle TB incidence by removing some infected badgers, it also has the potential to increase cattle TB incidence by altering badger behavior and facilitating disease spread.

Key point*:*

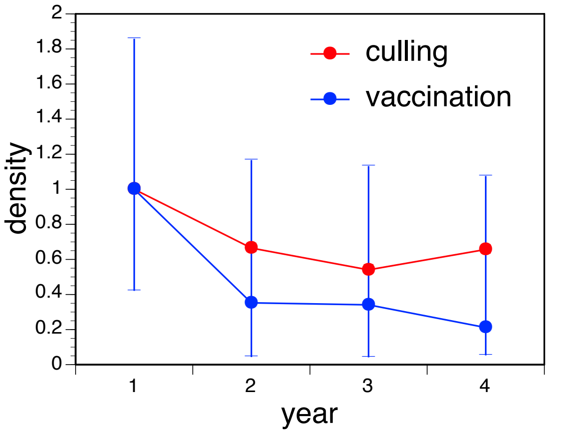
- *Selective culling cannot detect and remove all infected badgers; it could either reduce or increase cattle TB.*

4.1.3 Vaccination

Badger vaccination has the potential to reduce badger-to-cattle transmission by lowering the prevalence of infection in the badger population. Vaccination does not remove infected badgers, but it does reduce their ability to infect other badgers (which are protected by the vaccine). Over time, the infected animals should die off, and the prevalence of infection would be expected to decline.

In a study in Gloucestershire, wild badgers vaccinated with injectable BCG were 76% less likely to subsequently test positive for TB than were unvaccinated controls[38]. Moreover, unvaccinated cubs were less likely to test positive when the adults in their social groups had been

Figure 4.1 – Density of infected badgers (relative to the start) over 4 years of RBCT proactive culling and Wales vaccination. Figures for vaccination are calculated from the proportion of road-killed badgers testing positive, assuming constant population size; error bars show exact binomial 95% confidence intervals and are wide due to small sample size. Figures for culling show the simple numbers killed in RBCT proactive culls so have no error bars.



vaccinated[38]. The Gloucestershire study was not suitable to assess changes in population prevalence over time, as vaccinated and unvaccinated social groups were interspersed. However, in a large, contiguous, vaccination area in Wales, prevalence in a sample of road-killed badgers declined from 19% to 4% over four years of vaccination (Figure 4.1)[22]. This latter result must be interpreted with great caution as it is derived from a very small sample size (as indicated by the large error bars in Figure 4.1); nevertheless it might represent a reduction in the density of infected badgers at least as great as the average observed in the RBCT proactive culling areas[1] (Figure 4.1). Importantly, this reduction in the density of infected badgers need entail no reduction in the overall badger density; hence vaccination causes no change in badger behaviour[39,40] and thus avoids the harmful effects associated with culling.

Vaccination does not lead badgers to shed live vaccine into the environment[40].

There have been no replicated studies to evaluate the effects of badger vaccination on cattle TB. Incidence in cattle was observed to fall within single badger vaccination areas in both England[23] and Wales[24], but in both studies incidence also fell in unvaccinated comparison areas. Both of these single-site studies had low statistical power and their findings should be interpreted with caution. A 2018 policy announcement in the Republic of Ireland noted that "*The most recent research has… demonstrated that a badger vaccine programme… has a similar effect to badger removal with regard to reducing the risk of TB transmission from badgers to cattle*"[2], but the associated research has not yet been published in the scientific literature.

If badger vaccination can contribute to reducing cattle TB, it could be a powerful tool to aid TB eradication, because it would reduce infection in both host species (unlike large-scale culling, which reduces TB incidence in cattle[3,20] but increases prevalence in badgers[11]). The effects of badger vaccination are thus worth investigating. Effects on prevalence in badger populations could be measured in a relatively small study (e.g., 200 sq km over four years) but sufficient statistical power to detect effects on the incidence of cattle herd breakdowns would require a larger study, comparable in size with the RBCT (which covered 1,000 sq km per treatment over five years)[41]. Such a trial might compare vaccinated areas with untreated controls, and/or with culled areas.

As well as reducing the prevalence of infection in chronically infected populations, vaccination might be used where cattle TB is detected in otherwise low-risk areas, to reduce the risk of TB becoming established in badger populations through cattle-to-badger transmission.

To date, only injectable badger vaccine has been used in the UK. An oral delivery system is under development, raising the hope of remotely-delivered mass vaccination similar that used to control wildlife rabies in mainland Europe and North America. While this idea is appealing, oral vaccination may prove neither cheaper nor more effective than injectable vaccination. Oral rabies vaccination of wildlife can be achieved by scattering vaccine baits widely in the environment, often by aircraft. However, this approach is not appropriate for TB vaccine. At £35 per injectable dose in 2018, the TB vaccine is too expensive to be scattered freely. Moreover, to avoid other species consuming the baits (which in cattle might cause sensitisation to the tuberculin test, prompting false herd breakdowns), vaccine baits need to be hand-delivered to badger setts. To ensure sufficient vaccine uptake, it is likely that badgers would need to be habituated by repeated pre-baiting with non-vaccine baits, requiring multiple sett visits. Moreover, since free-ranging badgers can consume multiple baits, achieving sufficient vaccine coverage is likely to require careful deployment of relatively large numbers of (expensive) baits. Since oral vaccination might prove no cheaper, and reach no more badgers, than injectable vaccine, it is worth considering the immediate large-scale use (or trial) of injectable vaccine, rather than waiting for oral vaccination to become available.

Key points:

- *Badger vaccination has the potential to reduce* M. bovis *infection prevalence in the badger population, and hence TB risks to cattle, without the harmful effects associated with culling.*
- *A replicated field trial would be needed to properly evaluate the effects of badger vaccination on TB in badgers and cattle.*
- *Oral vaccination is being developed, but may prove neither cheaper nor more effective than injectable vaccination and should not delay deployment of injectable vaccine.*

4.1.4 Test and Vaccinate or Remove (TVR)

Test and Vaccinate or Remove (TVR) is a variant of selective culling in which test-positive badgers are killed, while test-negative animals are vaccinated and released. TVR is currently being piloted in Northern Ireland, and the outcomes of that study (expected in 2019[42]) should help determine its potential effectiveness.

Like selective culling, TVR is likely to be impacted by the difficulties of capturing and correctly identifying all infected badgers. Mathematical modelling suggests that the outcome of TVR may depend upon whether it prompts surviving badgers to change their behaviour as observed in nonselective culls[25]. If there is no behavioural change, TVR is predicted to reduce TB risks to cattle but, if it were to induce behavioural change, it has the potential worsen cattle TB risks[25].

Key point:

- *Mathematical modelling suggests that TVR might either reduce or increase cattle TB.*

4.1.5 Managing contact

In principle, the simplest way to reduce pathogen transmission between two host species would be to reduce contact between them. Unfortunately, prospects for managing badger-to-cattle transmission in this way are hindered by uncertainty about how, where and when infectious contact occurs. While there is growing evidence that transmission occurs through the environment[43-46], uncertainty remains as to precisely where in the environment transmission is most likely to occur.

Interventions have been developed to exclude badgers from farm buildings[47], but evidence suggests that transmission is likely to occur at pasture as well as in buildings[48]. Various methods have been recommended to reduce contact at pasture (e.g., raising troughs, fencing badger latrines) but their effectiveness at reducing transmission is unknown.

Badgers can be excluded from fields using specific forms of electric fencing[49]; however such fences require frequent maintenance. Since cattle pasture is essential foraging habitat for rural badgers[43,50], excluding badgers from large tracts of pasture may have significant ecological (and, in the short term, welfare) consequences. In other wildlife species, exclusion from key resources intensifies fence transgressions[51], and can lead to animals becoming stuck on the wrong side of the fence. In principle, badgers might be excluded temporarily from specific fields while cattle were grazing but, since transmission appears to occur through contamination of the shared environment, this approach might have little impact on the risk of transmission between species.

Ongoing research should help to identify more targeted interventions, aimed at specific locations (e.g. troughs, latrines) where transmission between species is most likely.

Key point:

- *It is unclear which forms of farm management might effectively reduce infectious contact between badgers and cattle. Research is needed to identify effective methods.*

4.2 Costs

4.2.1 Costs of nonselective culling

The costs of England’s current policy of nonselective badger culling are shared between taxpayers and farmers. Reported costs to taxpayers in 2013-7 are summarised in Table 4.1: they total over £27 million[52-54] (excluding expenditure on effectiveness monitoring, which might not form part of a sustained policy) over 14,282 sq km-years[55], averaging £1,929/sq km/year. Approximately half of the cost to taxpayers has been for policing (Table 4.1).

Table 4.1 *– Costs* ***to taxpayers*** *of industry-led badger culling, as published by Defra*[52,53]

Year:	2013	2014	2015	2016	2017	Cumulative total
Number of areas culled	2	2	3	10	21	38
Total area culled (sq km)	567	567	790	3,803	8,555	14,282
Total badgers killed	1,879	615	1,467	10,886	19,537	34,384
Costs to taxpayers (£)						
Licensing & compliance monitoring	859,000	1,036,000	1,003,000	1,284,000	1,289,000	£5,471,000
Equipment, *post mortems*, etc*	3,124,000	2,014,000	776,000	1,091,000	1,283,000	£8,288,000
Policing	3,524,000	1,392,000	1,803,247	3,029,998	4,046,561	£13,795,806
TOTAL	*7,507,000*	*4,442,000*	*3,582,247*	*5,404,998*	*6,618,561*	*£27,554,806*
Cost per badger killed (£)	3,995	7,223	2,442	497	339	£801
Cost per sq km per year (£)	13,240	7,834	4,534	1,421	774	£1,929
Estimated cost per sq km per year from Defra Value-for-Money analysis[57]						£205

*excludes efficacy monitoring, which might not be part of a long-term policy

Costs to farmers are not a matter of public record: they are set by local cull companies and presumably vary between cull areas. However, a recent *Farmers Guardian* article reported farmer contributions which are summarised in Table 4.2. By this estimate, farmer contributions average approximately £318/sq km/year. Added to the cost to taxpayers, this gives a total cost of nonselective culling of £2,247/sq km/year on average.

Table 4.2 *– Estimated costs* ***to farmers*** *of industry-led badger culling, as published by the Farmers Guardian*[58]*.*

Cost	Unit cost	Cost/sq km/year	Annual cost for 457 sq km
Acreage cost	£4/ha for 4 years	£100	£45,700
Cost per head of cattle	£9/head for 4 years	£218*	£99,626
Total cost		*£318*	*£145,326*
Estimate from Defra Value-for-Money analysis[57]		*£61*	

*assuming 97 cattle per sq km, the mean for counties in the south-west[59].

Curiously, when Defra evaluated the value-for-money of culling[56], it provided estimates of costs to taxpayers (£468,000 per 570 sq km area for four years, or £205/sq km/year) and farmers (£140,000 per 570 sq km area for four years, or £61/sq km/year) which are markedly lower than those estimated, from reliable sources, in Tables 4.1 and 4.2. Hence, the value-for-money analysis is based on an estimate of the total cost to taxpayers and farmers (£266/sq km/year) which is just 12% of the estimated amount actually spent in 2013-7 (£2,247/sq km/year). This discrepancy raises questions about the estimation of value-for-money as reported by Defra.

Importantly, while the estimates in Tables 4.1 and 4.2 differ from those provided in Defra's value-for-money analysis, both sets of estimates indicate that while culling is "industry-led", it costs taxpayers far more than it costs farmers, with the government contribution exceeding the farmer contribution by a factor of three (according to Defra's value-for-money analysis) or six (according to Tables 4.1 & 4.2).

4.2.2 Costs of localised nonselective culling

The costs of small-scale nonselective culling can be cautiously extrapolated from the costs of widespread culling. In the RBCT, reactive culls covered approximately 20% of each trial area each year, suggesting that field costs might be roughly 20% those of widespread culls. However, the average cost of licensing might be closer to 80% those of widespread culls because, while widespread culls require a single licence for four years (averaging 25% of the costs annually), small-scale culls would require licensing a different 20% of the area each year (and 20% is 80% of 25%). These figures give a combined total of £679/sq km/year on average.

This relatively low cost of small-scale culling needs to be set against the high probability of harmful effects discussed above.

4.2.3 Costs of selective culling

The costs of small-scale selective culling in Wales have been reported as £383,112 in a single year for three farms[36]. The size of the individual farms was not reported, but the average size of cattle holdings in Wales[60] is 0.65 sq km, suggesting a cost of approximately £196,468/sq km/year. However, this figure includes a large cost of associated scientific research; the cost of field operations is reported as £218,916, or roughly £112,265/sq km/year. This very high cost is likely to reflect the fact that this was the first year of implementation.

4.2.4 Costs of badger vaccination

The cost of badger vaccination varies between programmes, depending mainly upon the type of labour used. A professional-led programmes in Wales cost £4.6 million to vaccinate 288sq km for 5 years[61], or £3,194/sq km/year, while another in Devon cost approximately £250,000 to vaccinate 20 sq km for 4 years[62], or £3,125/sq km/year. By contrast, a programme in Derbyshire which used volunteers to do much of the work cost £59,163 to vaccinate 46 sq km for three years, or £429/sq km/year on average[63]. The Derbyshire programme benefited from collaboration between farming and wildlife NGOs with well-established volunteer networks.

Table 4.3 compares the estimated costs of volunteer-led badger vaccination with those of industry-led badger culling. The field estimates reported above do not include the cost to taxpayers of licensing and monitoring badger vaccination; in Table 4.3 these costs are tentatively estimated based on the proportion of Natural England cull compliance visits concerned with cage trapping versus free shooting[64]. These estimates suggest that volunteer-led vaccination has an overall cost markedly lower than that of industry-led culling. The difference is great enough that the cost to taxpayers of culling a single average-sized area (457 sq km in 2018) would be sufficient to vaccinate nearly 1,500 sq km, if the Derbyshire model could be scaled up to this extent (Table 4.3). This observation is important because it suggests that, in principal, the government could support a trial of the effects of injectable badger vaccination on cattle TB, on the scale of the RBCT (in which 1,000 sq km was allocated to each treatment), for less than its investment in a single average cull zone.

***Table 4.3** – Comparison of costs of industry-led badger culling and volunteer-led badger vaccination. Estimates are calculated per square kilometre per year.*

Cost (in £ per sq km per year)	**Industry-led culling**	**Volunteer-led vaccination**
Costs currently borne by taxpayers (from Table 4.1)		
Licensing & compliance monitoring	£383	£163†
Equipment, *post mortems*, etc	£580	£429¶
Policing	£966	£0
Total cost to taxpayers per sq km per year	*£1,929*	*£592*
Costs currently borne by farmers (from Table 4.2)		
Acreage cost	£100	£0
Cattle cost	£218	£0
Total cost to farmers per sq km per year	*£318*	*£0*
Total cost per sq km per year	**£2,247**	**£592**
Annual cost to cover an average 457 sq km cull area	£1,027,033	£270,544
Area that could be covered each year for the **total** annual cost of implementing the **opposite** approach across an average 457 sq km cull area	120 sq km	1,735 sq km
Area that could be covered each year for the annual cost **to taxpayers** of implementing the **opposite** approach across an average 457 sq km cull area	140 sq km	1,489 sq km

†estimated as cost of licensing and compliance monitoring of culling multiplied by 77/181 to reflect report that 77 of 181 compliance visits by Natural England concerned cage trapping in 2017[64].
¶costs incurred by Derbyshire Badger Vaccination Programme; note that under current policy a large proportion of these costs were covered by charities.

4.2.5 *Costs of Test-Vaccinate-Remove*

The costs of TVR in Northern Ireland have been reported as £3,647,000 over 4 years for a 100 sq km area[42], averaging £9,118/sq km/year. This cost is roughly three times that of vaccination performed by government staff and 15 times that of vaccination conducted by coordinated volunteers (Table 4.1).

4.2.6 *Costs of managing contact*

The cost of managing contact between badgers and cattle is difficult to estimate, since uncertainty about the efficacy of various interventions makes it unclear what combination of measures might be appropriate for the average farm. As a starting point, the cost of excluding badgers from farm buildings has been estimated as £3,840 per farm on average[47]. This figure can be tentatively taken to represent a cost of approximately £1,536/sq km/year, assuming a farm density of 1.1 farms/sq km (the mean density of cattle farms in RBCT areas)[1], an equipment lifetime of 5 years, and an annual maintenance cost equivalent to 20% of the capital cost.

Key points:

- *England's policy of large-scale nonselective badger culling is "industry-led", but it costs taxpayers 3-6 times as much as it costs farmers.*
- *The government's value-for-money analysis appears to significantly under-estimate the costs of nonselective culling.*
- *Selective culling and TVR are very expensive.*
- *Badger vaccination, drawing on volunteer workforces, is the cheapest control option.*
- *The government could support a trial of badger vaccination on the scale of the RBCT for less than its financial contribution to a single cull zone.*

4.3 Safety

Nonselective badger culling raises concerns about public safety. In particular free shooting, a method used in the English culls, is conducted at night with high-powered rifles, without informing local people. While there have been no documented cases of injury to the public, several unsafe encounters between anti-cull protestors and marksmen have been reported to the police.

Selective culling and TVR raise fewer safety concerns because badgers are killed either by gunshot in traps or by lethal injection while immobilised, in daylight. Vaccination and managing contact entail no public safety concerns.

Key point:

- *Nonselective badger culling is the only approach that raises concerns for public safety.*

4.4 Humaneness

Nonselective culling raises serious concerns about badger welfare. An Independent Expert Panel cautioned that free shooting – a key component of industry-led culling – caused serious pain and suffering to an unacceptably high proportion of badgers[65]. The British Veterinary Association has called for free shooting to be discontinued on welfare grounds[66].

There are no published evaluations of the welfare of badgers shot in cages under licence. Annual independent audit of the Randomised Badger Culling Trial concluded that shooting caged badgers at short range, as conducted by trained government staff, was humane[67]. However, these annual independent audits have not been implemented for licensed culls, which is a cause for concern.

Both culling and vaccination entail confining badgers to cage traps, which can potentially lead to injury, stress, dehydration, hypothermia, and over-heating. Minor injuries (e.g. abrasions of the paws) were observed on 8% of badgers trapped in the RBCT, with more serious injuries (e.g. tooth breakage) less frequent[68]. Careful trap deployment and timing of trapping can minimise harmful effects.

Managing contact could have welfare implications if it excluded badgers from key resources for long periods; however more localised interventions aimed at managing contact between badgers and cattle would have little or no welfare cost for badgers.

***Key point**:*
- *Nonselective badger culling is the only management approach that raises serious concerns for badger welfare.*

4.5 Environmental impact

The RBCT showed that large-scale nonselective badger culling had impacts on farmland ecosystems, including marked increases in fox numbers, a possible decline in hare numbers, and localised increases in hedgehog numbers[69-71]. Such impacts are to be expected from the removal of the largest native carnivore remaining in Britain.

While current licensing conditions for industry-led culls entail safeguards intended to avoid localised extinction of badgers (*i.e.* a 100% reduction in badger density), the RBCT revealed multiple ecological consequences from a 70% reduction in badger density[69-71]. Current industry-led culls are much more extensive than RBCT culls, and also more prolonged; hence they may have environmental impacts which were either not investigated or too variable to be detectable in the RBCT. Importantly, culling is permitted on most European Protected Sites, RAMSAR Sites, and Sites of Special Scientific Interest[72], as well as in National Parks. Natural England advice on mitigating the environmental impact of badger culling includes habitat management to deter fox predation, as well as shooting and fencing out foxes[73]. Hence, badger culling could potentially have broader environmental impacts on ecological processes, both on agricultural land and within England's protected area network.

Other forms of badger management entail minimal environmental impact, although attempting to exclude badgers from pasture would also be likely to impact other species.

Key point
- *Widespread culling is the only approach likely to have marked environmental impacts.*

5 Conclusions

The available evidence suggests that reducing cattle-to-cattle transmission of *M. bovis* is the most important action required to improve TB control. However, achieving eradication in a timely manner is likely to require some intervention to reduce transmission from badgers.

The available evidence raises significant concerns about the current policy of large-scale nonselective badger culling. The policy goal is to eradicate cattle TB, but nonselective badger culling contributes little to this goal because it increases the prevalence of infection in badgers and spreads TB to herds in new areas. Hence, while culling may contribute somewhat to TB control in the short term, its effects are not sustainable in the long term. Large-scale badger culling also raises very significant concerns relating to cost, animal welfare, and environmental impact.

Small-scale badger culling increases cattle TB and can contribute nothing to eradication efforts. Information is currently too limited to determine the extent to which selective badger culling, TVR, or the management of badger-cattle contact might contribute to TB eradication. Selective culling and TVR are very expensive.

Badger vaccination is a potentially valuable tool in TB eradication, held back by incomplete evidence. The evidence available suggests that vaccination could reduce the risk of TB transmission from badgers to cattle without the harmful side-effects of culling, potentially making a more sustainable contribution to the long-term goal of TB eradication. Moreover, vaccination can be much cheaper than culling, even though badgers must currently be captured and hand-injected. Additionally, vaccination entails none of the concerns relating to safety, welfare, or environmental impact that are associated with culling. A field trial of the impact of injectable badger vaccination on cattle TB could cost less than the government invests in a single culling area, and we consider such a trial to be an immediate priority.

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