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1 **Advances and prospects for management of TB transmission between badgers**
2 **and cattle**

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8

9 **Abstract**

10 Bovine tuberculosis (bTB) is the most serious endemic disease facing the livestock
11 industry in the United Kingdom (UK) and Republic of Ireland (RoI), where its
12 management has been confounded by the presence of persistent infection in the
13 Eurasian badger (*Meles meles*). Field evidence suggests that the social structure of
14 badger populations can have an important influence on disease dynamics, and on the
15 outcome of management interventions. Recent, large-scale badger culling experiments
16 in the UK and RoI had complex epidemiological outcomes. In the UK, proactive
17 culling led to reduced bTB incidence in cattle herds inside culled areas, but a
18 temporary increase in adjacent areas. Reactive culling in response to herd breakdowns
19 was associated with an increase in the incidence of bTB in cattle. In contrast, badger
20 culling in RoI was reported to have only beneficial effects on bTB incidence in cattle.
21 The reasons for these differences are not clear. The complexity of the evidence base
22 for culling is highlighted by the different management approaches currently being
23 adopted by the different authorities of the UK and RoI.

24 It is generally accepted that a holistic approach to bTB management, which
25 targets both cattle and wildlife, is necessary. Consequently recent research activities

1 have also focussed on cattle and badger vaccines, and biosecurity on farms. This
2 paper describes recent advances in our understanding of the epidemiology of bTB in
3 badgers and the consequences of culling, and current research to develop approaches
4 for the vaccination of badgers, and methods of managing the risks of contact between
5 badgers and cattle in farm buildings.

6
7 **Keywords:** badger, bovine tuberculosis, wildlife reservoir, transmission, control,
8 management

9
10 **1. Introduction**

11 The eradication of bovine tuberculosis (bTB) from cattle in the UK and Republic of
12 Ireland (RoI) has been compromised by the presence of endemic infection in the
13 Eurasian badger (*Meles meles*). Since the early to mid 1970s when they were first
14 suspected to be sources of infection for cattle, badgers have been culled in both
15 countries under a variety of different strategies. Although badgers have been protected
16 in the UK and RoI since 1973 and 1976 respectively, culling has been employed since
17 1973 as the primary tool for targeting the reservoir of infection in wildlife, as a
18 complement to cattle-based controls (Krebs, 1997). In the areas of cattle herd
19 incidence of the UK, specifically parts of the south-west of England and Wales, an
20 initial decrease in the incidence of herd breakdowns provided some encouragement
21 that culling could be an effective management approach (Zuckerman, 1980).
22 Localised, intensive badger removal operations in England and RoI were also
23 accompanied by reported decreases in cattle herd breakdown incidence (Clifton-
24 Hadley et al., 1995; Ó Máirtín et al., 1998; Eves, 1999). However, since the late

1 1980s, the incidence of TB in cattle has risen against a background of statutory badger
2 culling in England and Wales (Krebs, 1997; <http://www.defra.gov.uk>).

3 Concerns over the increasing incidence and geographic spread of bTB in cattle
4 led in 1997 to the suspension of badger culling as a management policy in England
5 and Wales and the appointment of an independent advisory committee to MAFF
6 (Ministry of Agriculture, Fisheries and Food; Krebs, 1997), the predecessor to the
7 current responsible government department, Defra (Department for Environment,
8 Food and Rural Affairs). The committee recommended a range of scientific research,
9 including a field experiment to determine the efficacy of badger culling in reducing
10 bTB incidence in cattle. The UK government accepted most of the recommendations
11 and in 1998 an Independent Scientific Group on Cattle TB (ISG) was convened to
12 design and oversee the Randomised Badger Culling Trial (RBCT). In their final report
13 the ISG recommended a range of policy options focussing on more stringent cattle
14 control measures, and concluded that “badger culling cannot meaningfully contribute
15 to the future control of cattle TB in Britain” (Independent Scientific Group, 2007).
16 Despite being supported by numerous publications in peer-reviewed journals, the
17 ISG’s conclusions were not universally accepted (More et al., 2007;
18 [http://www.defra.gov.uk/foodfarm/farmanimal/diseases/atoz/tb/documents/badgersrep
19 ort-king.pdf](http://www.defra.gov.uk/foodfarm/farmanimal/diseases/atoz/tb/documents/badgersreport-king.pdf)). Nevertheless, a subsequent inquiry by a House of Commons Select
20 Committee acknowledged the importance of the ISG’s work, which it described as
21 “the only robust evidential basis on which a badger cull could take place”
22 (<http://www.publications.parliament.uk/pa/cm200708/cmselect/cmenvfru/130/130i.pdf>
23 f).

24 25 **2. Recent advances in knowledge**

2.1. Epidemiology of bTB in badgers

Bovine TB is a chronic infectious disease caused by the bacterium *Mycobacterium bovis*. It affects a broad range of mammalian hosts including humans, cattle, deer and wild carnivores such as badgers. Although the extent to which badgers contribute to infection in cattle is still unclear, the results of the RBCT suggested they accounted for around 50% in the experimental areas (Jenkins et al., 2008). The precise routes of transmission amongst badgers and between badgers and cattle have yet to be described. The distribution of lesions in badgers at *post mortem* examination and the observation that *M. bovis* is most frequently isolated from sputum during live sampling, suggest that the respiratory route may be most important for badger to badger transmission (Clifton-Hadley et al., 1993; Corner, 2006). Onward transmission to cattle may potentially occur through either direct contact with badgers themselves, or with their excretory products. Incidence and transmission rates appear to be relatively low in badgers and bTB apparently has little detectable impact on badger population size or turnover (see Rogers et al., 1997, 2000). Infected badgers may live for several years, during which time they may continue to breed (Delahay et al., 2005), although individuals with evidence of continual excretion appear to exhibit significantly higher levels of mortality (Wilkinson et al., 2000). Counter-intuitively, recent analyses of a longitudinal study of badgers at Woodchester Park, Gloucestershire, UK revealed a significant negative correlation between population size and the detected incidence of excretion of *M. bovis* (Vicente et al., 2007). This study showed that individual and group-level incidence risks were related to changes in social group size and movement patterns of badgers amongst groups, highlighting the profound importance of social structure in disease transmission dynamics.

1 2.2. *Epidemiological consequences of culling badgers*

2 Past studies from the UK and RoI provided compelling evidence that comprehensive,
 3 localised badger culling operations reduced disease in cattle (see Clifton-Hadley et al.,
 4 1995; Ó Máirtín et al., 1998; Eves, 1999). However, these studies did not incorporate
 5 sufficient experimental controls or replication to provide conclusive scientific
 6 evidence, and did not investigate the potential detrimental effects of culling in
 7 adjoining areas. The RBCT took place between 1998 and 2005 in thirty 100 km²
 8 treatment areas of high bTB incidence in cattle herds in west and south-west England.
 9 The treatment areas were arranged into ten triplets, each of which contained an area
 10 subjected to reactive culling (localised culling in response to a TB outbreak in cattle),
 11 an area of proactive culling (widespread annual culling throughout the treatment area)
 12 and a survey-only area, where no culling was carried out. This acted as an
 13 experimental control against which the results of the other two treatments could be
 14 measured (Independent Scientific Group, 2007).

15 The reactive culling treatment was stopped early by Ministers in November
 16 2003 due to an observed 20% increase in the incidence of bTB in resident cattle herds
 17 compared to survey-only areas (Donnelly et al., 2003). Despite debate over the
 18 magnitude of the detrimental impact of reactive culling, and over the biological
 19 plausibility and statistical treatment of the results (More et al., 2007), the ISG
 20 concluded that reactive culling as carried out in the RBCT was, “unacceptable as a
 21 policy option.” Proactive culling, on the other hand, demonstrated a significant
 22 reduction (23%) in the incidence of cattle TB breakdowns inside culled areas after
 23 approximately five years of culling (Independent Scientific Group, 2007; Donnelly et
 24 al., 2007). This beneficial effect increased to 54% in the post-trial period (from one to
 25 two years after the last proactive cull; Jenkins et al., 2008). However, this was

1 accompanied by a 25% increase in the incidence of bTB breakdowns in a 2 km wide
2 buffer zone around the proactive areas (Independent Scientific Group, 2007; Donnelly
3 et al., 2007), which subsequently disappeared in the post-trial period, 1-2 years after
4 culling ceased (Jenkins et al., 2008). Also, within the culled areas there was a
5 tendency for the incidence of herd breakdowns to increase with proximity to the
6 boundary, although these negative effects of culling diminished with successive
7 annual culls (Donnelly et al., 2007). Ongoing analyses in the post-trial period continue
8 to produce complex results. After three years since the end of culling, benefits inside
9 culled areas were no longer detectable. However, repeating this analysis using a
10 further six months of cattle testing data indicated that the beneficial effects observed
11 within trial areas in the first year post-trial had unexpectedly reappeared, with
12 confirmed breakdowns being 37% lower than survey-only areas (Jenkins et al., 2010).
13 Despite these complex outcomes, the experiment demonstrated that proactive badger
14 culling sustained for several years on a relatively large scale resulted in a positive
15 impact on herd breakdown incidence. However, the overall benefits in terms of the
16 number of breakdowns prevented were considered “modest”, and several years of
17 post-culling benefits would be required to offset the costs involved in carrying out the
18 culling (as conducted in the RBCT; Independent Scientific Group, 2007). Another
19 large-scale study in RoI compared the effects of two different culling strategies on the
20 control of bTB in four paired study areas (Griffin et al., 2005). The probability of a
21 cattle herd breakdown was significantly lower in areas where badgers were
22 proactively culled (removal areas) than in paired ‘reference areas’ where they were
23 only locally culled in response to a severe herd breakdown. Although the reference
24 areas did not represent a strict experimental control, the magnitude of the relative
25 beneficial effect of culling in the removal areas was compelling. In practice, very few

badgers were removed from the reference areas and there was no evidence that such small-scale culling led to an increase in herd breakdowns as had been observed following localised culling in the RBCT. This suggests that the negative effects associated with culling on the UK mainland may not necessarily occur in Ireland, where agricultural practices, landscape composition and badger density and ecology may differ. This notion is supported by research from County Laois in RoI which showed that badger removal following herd breakdowns was associated with a beneficial impact on the time to future breakdowns for both index and surrounding farms (Olea-Popelka et al., 2009).

2.2.1. Unravelling the wider significance of badger sociality to disease control

The temporary negative impacts of badger culling on herd breakdown rates observed in the RBCT were attributed to disruption caused to otherwise stable badger populations. There is a substantial body of evidence from the RBCT itself and other studies in the UK and RoI that culling badgers may result in increased immigration into culled areas, disruption of territoriality, increased ranging by individuals and mixing of social groups, which may persist for many years (reviewed in Carter et al., 2007). Such “social perturbation” may potentially lead to an increased risk of disease transmission amongst badgers and between badgers and cattle. Culling during the RBCT resulted in significant disruption of badger territories (Woodroffe et al., 2006a) and was associated with an increase in the prevalence of infection in badgers (Woodroffe et al., 2006b; Independent Scientific Group, 2007). Comparable disruption of social structure was observed in previous studies of badger removal operations in England and RoI (Cheeseman et al., 1993; O’Corry-Crowe et al., 1996; Tuytens et al., 2000). In an intensively studied, undisturbed population, strong

1 associations were identified between badger movement patterns and the risks of bTB
 2 infection (Rogers et al., 1998; Vicente et al., 2007).

3 The observed differences between the outcomes of badger culling in RoI and
 4 mainland UK are intriguing. The absence of an increase in herd breakdowns in the
 5 Irish Four Areas project (Griffin et al., 2005) may in part be due to its design, being
 6 deliberately located in areas where natural barriers such as rivers, mountain ranges
 7 and sea inlets are likely to have impeded the immigration of badgers from surrounding
 8 areas. Another factor may be the lower density of badger populations in Ireland
 9 compared to those in the bTB affected areas of Britain (Independent Scientific Group,
 10 2007). Between 0.76 and 2.77 badgers were culled per km² in the proactive areas of
 11 the RBCT, compared to 0.29 – 0.48 badgers per km² in the Four Areas project. At
 12 medium to high densities, typical of south-west England and Wales, badgers tend to
 13 reside in discrete social groups with well-defined territories and low rates of dispersal
 14 (Kruuk and Parish, 1982; Woodroffe et al., 1993; Rogers et al., 1998). At low
 15 densities however, badgers may adopt a more flexible social structure (Cheeseman et
 16 al., 1993; Revilla and Palomares, 2002). Under these circumstances, it is possible that
 17 lower density, associated reduced immigration pressure and the less marked spatial
 18 structure may reduce the potential epidemiological consequences of culling. It
 19 remains to be seen to what extent future developments in ‘trap-side’ diagnostics may
 20 open the door to selective, and hence potentially less disruptive culling strategies,
 21 perhaps also in combination with vaccination.

22 The effects of social perturbation present a significant challenge to the
 23 management of infection risks from a reservoir in wildlife, and such problems are not
 24 unique to badgers and bTB. There is also evidence that culling-induced social
 25 perturbation may have hampered the control of rabies in red fox (*Vulpes vulpes*)

1 populations (Macdonald, 1995) and of Classical Swine Fever in wild boar (*Sus scrofa*;
2 Maillard and Fournier, 1995).

3

4 **3. Current research directions**

5 *3.1. Vaccination of badgers*

6 The vaccination of badgers and cattle has long been viewed as an attractive disease
7 control option. The basic aim of a badger vaccination strategy is to reduce the risk of
8 onward transmission of bTB from badgers to cattle. Inherent attractions of vaccination
9 as a disease management tool are that, unlike culling, it is not expected to disrupt
10 badger social behaviour and is unlikely to be opposed by conservationists, welfare
11 groups and the general public. However, the development of an effective vaccine,
12 with an appropriate strategy for its delivery, and its realisation as a commercially
13 available, licensed product involves considerable technical and regulatory challenges
14 (Blancou et al., 2009). Options for vaccinating badgers include capture and manual
15 delivery of the vaccine either directly into the oral cavity or by intra-muscular
16 injection, or oral delivery through deployment of bait without the need to capture
17 animals.

18 BCG (Bacille Calmette-Guerin) is presently the only candidate vaccine and
19 has been shown to be safe when administered parenterally to captive badgers
20 (Lesellier et al., 2006). A field study in the UK to evaluate the safety of intramuscular
21 delivery of BCG in badgers and to collect supporting data on vaccine immunogenicity
22 and efficacy was completed in November 2009. This study of approximately 90
23 contiguous badger social groups in south-west England began in 2006 and results are
24 anticipated by mid-2010. Badger social groups were allocated to either vaccination or
25 control treatments. Individuals captured in vaccinate groups were injected with 2-8 x

1 10^6 colony forming units (cfu) of BCG. All captured badgers were uniquely marked,
 2 physically examined and had a suite of clinical samples taken to determine disease
 3 status and to detect the presence of *M. bovis* or BCG in clinical samples. The safety of
 4 the vaccine was assessed by comparing vaccinated badgers with unvaccinated
 5 controls in terms of body temperature following injection and local reactions at the
 6 vaccination site on recapture. Samples were also taken for histological examination
 7 from any vaccinated animals found dead in the study area.

8 Laboratory studies have been conducted in the UK and RoI on captive badgers
 9 to determine the efficacy of BCG delivered via several routes. Evidence of a
 10 protective effect, measured in terms of the immunological response and the severity of
 11 pathology observed at *post-mortem* examination following experimental infection in
 12 uninfected badgers, has been demonstrated (Corner et al., 2008; Lesellier et al., 2006,
 13 2009). The results of the above field and laboratory studies formed the basis of an
 14 application submitted to the Veterinary Medicines Directorate (the UK veterinary
 15 medicines licensing body) in 2009 to obtain a Marketing Authorisation (MA) for the
 16 intramuscular administration of BCG Danish 1331 to wild badgers. This was granted
 17 in March 2010.

18 The UK Government began using the licensed injectable vaccine in the Badger
 19 Vaccine Deployment Project in July 2010 (BVDP;
 20 <http://www.defra.gov.uk/fera/bvdp>). This is a six-year project to deploy vaccine to
 21 wild badgers in a bTB-affected area in England. Badgers are captured in cage traps
 22 and vaccinated in the field by government staff on up to 100 km² of predominantly
 23 cattle land. Unlike other components of the vaccine programme this is neither a
 24 research project nor a regulatory study, but rather aims to provide training for lay-
 25 vaccinators, assess the viability of field application of an injectable badger vaccine,

1 and build industry confidence in the principle and practicalities of wildlife
 2 vaccination. It is intended that the project will provide valuable information on the
 3 true costs and practicalities of large-scale vaccine deployment. It will also provide an
 4 opportunity to engage the farming community, and potentially, to begin to make a
 5 positive impact on a badly affected area before an oral vaccine formulation is
 6 available. A social science study is also being conducted with participating and non-
 7 participating farmers, to establish levels of farmer confidence in the use of vaccination
 8 before, during and after vaccine deployment.

9 It is generally recognised that delivery of vaccine in oral baits holds the best
 10 long-term prospect for deployment to badgers over a wide area (see Delahay et al.,
 11 2003). The large-scale eradication of sylvatic rabies in Europe through the vaccination
 12 of red foxes using oral baits (Brochier et al., 1991) represents an important precedent
 13 for the wide-scale vaccination of badgers in the UK and RoI. The success of such an
 14 approach will depend on how many badgers consume the baits and the effectiveness
 15 of the vaccine. Collaborative research and development studies are currently
 16 underway in both countries towards a common aim of identifying how this might be
 17 achieved in practice. Work has already taken place on bait delivery systems for
 18 badgers (e.g. Delahay et al., 2000) and on identifying the most palatable baits. Current
 19 research is aimed at identifying the most appropriate bait formulation to ensure that
 20 BCG remains viable for prolonged periods in the bait, is not incapacitated by acidic
 21 conditions in the stomach, but can be delivered where it is most likely to induce
 22 protective immunity to *M. bovis*. A recent study in New Zealand achieved an
 23 estimated efficacy of 95% in wild brush-tail possums (*Trichosurus vulpecula*) using a
 24 lipid-formulated oral vaccine containing 10^7 cfu BCG delivered to the rear of the oral
 25 cavity (Tomkins et al., 2009). In light of these promising results, a large field trial

began in 2009 in RoI, designed to measure the protection generated by BCG
 vaccination in wild badgers, and to estimate vaccine efficacy by comparing the
 prevalence of *M. bovis* infection in vaccinated and non-vaccinated badgers (Corner et
 al., 2009). Badgers are trapped in an area comprised of three zones, in which 100%,
 50%, or none of the captured badgers are vaccinated using the lipid formulation
 delivered directly into the pharynx under general anaesthetic. These proportions were
 selected such that effects on vaccine efficacy due to changes in the force of infection
 as a result of vaccination could be estimated (Corner et al., 2009). Badgers will be
 vaccinated annually for three years, at which point the area will be depopulated and
 all captured badgers submitted for *post mortem* examination, histology and bacterial
 culture.

Field studies to determine the optimum deployment method for an oral vaccine
 bait began in England in May 2010. The relative uptake rates of the most promising
 candidate baits, devoid of vaccine, will be assessed at different times of year. The
 study will also investigate variations in bait uptake rates relative to deployment of bait
 above and below ground (i.e. down sett entrances), and the duration of bait provision.
 The aim is to identify the most cost-effective and practical strategy for maximising
 bait uptake by badgers. Alongside this, studies will be conducted on the efficacy of
 the oral vaccine under experimental, controlled conditions. The results of this work
 are expected by 2012 at which point it will be necessary to conduct regulatory studies
 to demonstrate safety of the final product to both captive and wild animals. The
 earliest anticipated date for a licensed oral vaccine is 2015. In addition to the science,
 there are a number of key policy, legal, commercial, regulatory and manufacturing
 issues surrounding the implementation of a vaccine against bTB.

1 3.2. Farm biosecurity

2 The principal routes of *M. bovis* transmission between badgers and cattle are unclear.
3 Badgers forage for earthworms on grassland and their preference for grazed pasture
4 creates opportunities for cattle to come into direct contact with them and their
5 excretory products (Muirhead et al. 1974; MAFF 1979; Wilesmith et al. 1982). Direct
6 contact between live badgers and cattle on pasture has been documented (Böhm et al.,
7 2009), and there are anecdotal reports of cattle investigating badger carcasses. Most
8 research on potential transmission risks has in the past concentrated on the
9 contamination of cattle pasture with badger faeces and urine, particularly at latrines
10 (Benham, 1985; MAFF, 1979; Cheeseman and Mallinson, 1981; Benham and Broom,
11 1989; Hutchings and Harris, 1997; 1999). However, evidence suggests that badger
12 visits to farm buildings might also give rise to opportunities for transmission (MAFF,
13 1979; 1981; 1987; Cheeseman and Mallinson, 1981; Benham, 1985; Kruuk and
14 Parish, 1985; Shepherdson et al., 1990; Brown, 1993; Sleeman and Mulcahy, 1993).
15 Studies using intensive nocturnal observations, radio tracking, video and camera
16 surveillance revealed that badger visits to buildings on some farms occurred on over
17 50% of nights investigated (Garnett et al., 2002; 2003; Tolhurst, 2006; Ward et al.,
18 2008). Visiting badgers used a variety of resources including feed stores, silage
19 clamps and cattle housing. Badgers, including known infected individuals, were
20 recorded defecating and urinating in buildings, sometimes directly onto feed and
21 regularly came within 2m of housed cattle (Garnett et al., 2002; Roper et al., 2003,
22 Tolhurst, 2006). These studies highlighted the potential for this phenomenon to be an
23 important risk factor for disease transmission on some farms, although the
24 contribution of such behaviour to cattle herd breakdown rates has not been quantified.
25 Nevertheless, it is clear that the development of practical means of managing badger-

1 cattle interactions is likely to be more achievable in and around farm buildings than
2 on pasture.

3 A recent field experiment employing a factorial design investigated the effects
4 of a series of badger exclusion measures on 32 farms in south-west England
5 (Unpublished Defra report). Badger-proofed gates, feed stores and doors, and electric
6 fences, were deployed on cattle feed stores, cattle housing and silage clamps (all of
7 which were known to be visited by badgers) and monitored using remote camera
8 surveillance. The results yielded unequivocal evidence that when exclusion measures
9 were employed and adequately maintained they provided 100% protection of feed
10 stores and cattle housing from badger incursions. However, levels of farmer
11 compliance varied widely, suggesting the existence of cultural/behavioural barriers in
12 the farming community to changing established working practices.

13 The costs of badger exclusion are likely to vary widely, depending on the
14 characteristics of the particular farm in question. As the contribution of such measures
15 to a reduced risk of experiencing a cattle herd breakdown is unknown, their cost-
16 effectiveness cannot be quantified or communicated to farmers at present. Therefore
17 presenting a convincing argument for the value of investing time and money in
18 improved biosecurity measures is a significant challenge. Given the potential disease
19 risks associated with badgers visiting farm buildings, encouraging farmers to take
20 steps to reduce this risk has obvious value. In an attempt to address this, the Welsh
21 Assembly Government established a biosecurity Intensive Treatment Area (ITA) in a
22 high incidence area of west Wales (G. Enticott, 2008) with the aim of raising
23 awareness, understanding, and adoption of biosecurity measures. Local veterinarians
24 visited farms, assessed the existing biosecurity arrangements and provided advice on

practical improvements. Farmers appeared to respond positively and improvements in biosecurity were observed (G. Enticott, 2008).

4. Translating science into policy

Bovine TB continues to have a devastating impact on the farming industry in some parts of the UK and RoI, as well as on the public purse. However, owing to the chronic nature and complexity of the disease, translating our scientific understanding into effective policy is not a straightforward task. It is clear that bTB risks to cattle are multi-faceted, requiring an integrated approach including both cattle and wildlife-based controls. The compulsory test and slaughter of positive (reactor) cattle and associated movement restrictions remain the principal method of controlling bTB in cattle herds in the UK and RoI. While vaccination of cattle is seen as a potential important longer-term policy option in the UK, the eradication of bTB from cattle in high-incidence areas of both countries is unlikely to be achieved without addressing potential re-infection from badgers. The three main ways in which this may be addressed are culling, vaccination and bio-security measures to prevent or at least reduce contact between badgers and cattle. The complexity of this problem is highlighted by the different management approaches currently being adopted by the respective authorities of the UK where bTB is a problem (England, Wales and Northern Ireland), and in and RoI. In light of a range of considerations including the ISG's conclusions from the RBCT, the previous UK Government decided that licences would not be issued to farmers to cull badgers for bTB in England, and increased investment in research into vaccination for badgers, as well as cattle. In RoI routine reactive culling continues to form part of government policy, supported by evidence from field studies, in particular the Four Areas project. Reactive culling has

1 been conducted throughout RoI since the early 1990s where it is viewed as an interim
2 wildlife control strategy. Badgers are removed under licence within a 1-2 km radius
3 around a farm that has suffered a herd breakdown and where badgers are suspected to
4 be the source of infection. The Welsh Assembly Government (WAG; the devolved
5 government of Wales) announced in 2009 that in addition to a range of bTB control
6 measures nationally, proactive badger culling would be conducted alongside more
7 stringent cattle controls within an Intensive Action Pilot Area (IAPA) in Wales. In
8 Northern Ireland (NI), limited badger removal remains a potential option, in the
9 context of investigating badger-related risk factors on farms with and without bTB
10 infection. The Department of Agriculture and Rural Development in NI recently
11 funded a national survey, establishing that there had been little change in badger
12 distribution and population size in NI since an initial baseline survey in the early
13 1990s (Reid et al., 2008).

14 The vaccination of badgers is seen as an important potential policy option for
15 reducing the risk of bTB in cattle throughout the UK and RoI. This is reflected in the
16 significant portions of the respective bTB research budgets that have been allocated to
17 these approaches. Within Defra, the total investment in vaccine development for
18 badgers and cattle exceeded £30 million from 1998 up until April 2010. The UK
19 general election in May 2010 resulted in a change in Government. At the time of
20 writing, the new Government is reviewing options for wildlife TB research and
21 management in the light of background economic pressures and their own policy
22 position. Early outcomes of this process include a reduction in the scope of the BVDP
23 from six target areas to one, and renewed consideration of culling as well as
24 vaccination options.

25

1 **5. Conclusion**

2 Bovine TB is the most serious endemic disease currently facing livestock in the UK
 3 and the RoI, and its cost to the farming industry and the taxpayer is unsustainable. It is
 4 widely recognised that a sustainable solution can only be reached through a multi-
 5 faceted approach using a variety of available tools, targeting both cattle and wildlife.
 6 Such an approach is likely to include continued improvements in cattle testing,
 7 enhanced farm biosecurity and the deployment of cattle and badger vaccines as they
 8 become available. In the meantime badger culling continues in the RoI, is planned to
 9 start in a targeted area of Wales, is still under consideration in Northern Ireland, and is
 10 under review in England by the new UK Government.

11 Recent research in the UK and RoI has significantly increased our knowledge
 12 of the role of the badger in the dynamics of bTB infection in cattle, and in the
 13 outcome of strategies for intervention. It has become clear that aspects of badger
 14 ecology may significantly influence the outcomes of culling. How differences in the
 15 prevailing density and social structure of badger populations might influence the
 16 outcome of culling operations remains unknown. Other crucial gaps in our knowledge
 17 include the precise route of transmission of *M. bovis* between badgers and cattle, and
 18 the extent to which badgers with advanced disease may exhibit behavioural traits that
 19 increase the likelihood of onward transmission. Nevertheless, strategies to reduce
 20 disease transmission among badgers and cattle will have to be developed in the
 21 absence of complete knowledge.

22 Practical steps to improve biosecurity have been shown to be sufficient to
 23 exclude badgers from farm buildings. However, the cost of such activities in terms of
 24 both money and time is a deterrent to farmers. In the absence of proof that improving
 25 biosecurity reduces the risks of herd breakdowns, convincing farmers of the value of

1 implementing such measures remains a significant challenge of communication for
 2 government and the veterinary profession.

3 Vaccination of cattle and badgers is still considered to have the potential to
 4 contribute significantly to a long-term solution to the bTB problem. A wide-ranging
 5 research program is underway in the UK and RoI, aimed at developing vaccine
 6 products and deployment protocols for the wide-scale vaccination of badger
 7 populations. In parallel with this research, badgers are being vaccinated in a badly
 8 affected area of England from 2010, and it is intended that the practical lessons learnt
 9 will inform future vaccination policy for when an oral vaccine bait becomes available.

10 It is clear that management of bTB in badgers and cattle is a considerable
 11 veterinary and ecological challenge. Management of the disease in cattle by reducing
 12 badger population densities through culling has mixed, unpredictable and in some
 13 cases undesirable outcomes. The ISG's findings in particular highlight the need to
 14 consider the ecological complexities of wild animal populations when taking
 15 decisions on disease management. Indeed, owing to the complex ecology of not only
 16 badgers, but also the characteristics of *M. bovis*, the effectiveness of bTB management
 17 may continue to be constrained by an imperfect knowledge of the wildlife host or host
 18 community. Going forward, management of bTB will require input from
 19 veterinarians, epidemiologists and ecologists, mathematical modellers, economists
 20 and others. The current efforts to develop cost-effective vaccine deployment strategies
 21 for badgers are promising examples of such a multi-disciplinary approach.

22

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Conflict of Interest Statement

The authors have not declared any conflict of interest.

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