Using Quantitative Risk Assessment To Inform Decision Making For The Control of Badger-to-Cattle Transmission Of *Mycobacterium bovis*

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ABSTRACT

A Quantitative Risk Assessment (QRA) model was developed in order to estimate the risk of badger-to-cattle transmission of *Mycobacterium bovis (M. bovis)*. The QRA allowed the quantification of the risk of badger-to-cattle transmission but importantly also allowed the effect on this risk to be investigated following the implementation of control strategies. Outputs from the QRA indicate that *M. bovis* shedding badgers pose a significant risk to cattle and a reduction in the number of shedding badgers present on a field reduces the risk of badger-to-cattle transmission. A reduction in the daily probability of shedding of *M. bovis* and the number of *M. bovis* shed will also reduce the risk of transmission. In addition, the QRA outputs show that badgers in the early stages of disease were less likely to pose a risk to cattle. This implies that a policy of vaccination, using a vaccine that prevents formation of lesions and reduces the number and frequency of shedding of *M. bovis* would be a successful strategy in reducing the risk of badger-to-cattle transmission of *M. bovis*. Furthermore, practical on-farm control policies, such as the prevention of cattle access to badger latrines and a reduction in cattle stocking density, would be effective in reducing the risk of badger-to-cattle transmission of *M. bovis*.

INTRODUCTION

Various policies have been implemented since badgers were first hypothesised as a source of *M. bovis* infection in cattle. Such policies have focussed on investigations aimed at establishing an epidemiological link between *M. bovis* infection in badgers and cattle. Although, studies have been undertaken for over thirty years, there is currently no conclusive evidence that badger-to-cattle transmission of *M. bovis* exists (Krebs, 1997). However, a strong association in the occurrence of the disease between the two species has been established by laboratory and field studies. In addition, a recent review of Department of Environment, Food and Rural Affairs (Defra) policies has recommended that future policies should be formulated with the assumption that badgers are involved in transmission of *M. bovis* to cattle (Godfray, 2004).
A variety of bovine tuberculosis control policies have been implemented, however, these policies have not been successful in eradicating *M. bovis* infection in cattle or badgers. The need to develop and implement effective policies for the control of *M. bovis* infection in badgers is now recognised as a prerequisite for the eradication of the disease in the cattle population (Gormley, 2000). A QRA has been developed in order to estimate the risk of badger-to-cattle transmission of *M. bovis* and investigate various control strategies and scenarios in order to inform policy and decision-making.

METHODS

The QRA was developed as a lattice-based discrete event simulation model which describes the release of *M. bovis* infected badger excreta on to a field, the exposure of cattle to *M. bovis* in the badger excreta and the probability of cattle infection given this exposure.
A simplified random field was spatially represented by the lattice structure and comprises of 2 co-planar lattice grids, representing cattle grazing area and a badger latrine area. The model evolves over time, in 24-hour steps with badger and cattle activities on the lattices being simulated.
The following events occur during each time step:

- Badgers enter the field and infected and shedding badgers shed *M. bovis* in their excreta (bronchial secretions, urine, faeces and exudate from bite wounds)
- The population of *M. bovis* in the badger excreta declines according to a survival model

- Cattle enter the field, grazing on the grazing lattice and investigating the badger latrine lattice
- Cattle exposed to *M. bovis* become infected according to a dose response model

The QRA was implemented using Visual Basic for Applications® (VBA, Microsoft Corp.). Multiple iterations (1,000) of the QRA were simulated using @RISK simulation software (Palisade Corp.) to represent the randomness associated with location and quantity of *M. bovis* shedding, survival of *M. bovis* and infection patterns. During each iteration the dynamics of the QRA are simulated for a period of 1 year. It was assumed that at *t*=0, the field is clear of *M. bovis*, that the herd has just had a clear tuberculin test and undisclosed infection is not present within the herd. The model is therefore representative of a herd in an annually tested parish, which is the most commonly applied test regimen in the south-west of England, a hot-spot for both badger and cattle infection with *M. bovis* in England. In addition, it was assumed that the herd is closed, therefore no cattle are bought in or removed from the herd within the year. The mean annual probability that infection in cattle occurs due to exposure of *M. bovis* in badger excreta is generated on each run of the QRA. The QRA was run firstly using baseline parameter estimates (Table 1). Various scenarios and control strategies were then investigated in subsequent simulations by altering particular parameter estimates (Table 2).

Table 1 Summary of baseline estimates of parameters investigated

Parameter	Parameter estimate
Herd size (*C*)	74
Number of infected shedding badgers present (*B*)	1
Probability infected and shedding badger sheds on a day (intermittent shedding) (p_E)	0.01
Number of *M. bovis* that cattle are exposed to per bronchial secretion deposit (m_1)	1000
Number of *M. bovis* that cattle are exposed to per defaecation (m_2)	1.09×10^4
Number of *M. bovis* in urine that cattle are exposed (m_3)	1.25×10^3
Number of *M. bovis* in bite wound exudate that cattle are exposed (m_4)	5000
Probability cattle investigate latrine during grazing (*p*)	0.33
Dose-response model parameter (*r*)	4.1795×10^{-5}

RESULTS

The QRA results indicate that the greatest reduction in the mean annual probability that at least one cow in a herd is infected (11% to 1%) is achieved by reducing the daily probability that a badger is shedding *M. bovis*, or reducing the infectivity of *M. bovis*. Furthermore, it can be seen that this probability is also reduced to 1% if the badger present is in the early stages of disease (shedding only via bronchial secretions). Reducing the overall number of *M. bovis* shed by an infected badger also decreases this probability to 2%. Reducing the herd size and restricting cattle access to latrines have similar effects: both slightly reduce the risk of infection from 11% to 8% per year. When considering reduction in herd size and restricting cattle access to latrines the risk of infection is reduced to 5%. The effect of the number of shedding badgers present is also evident; if all 7 badgers are shedding there is a 52% probability of at least one cow becoming infected whereas if only 1 badger is excreting the risk per year is 11%.

Table 2 Mean annual probability that at least one cow in a herd is infected with *M. bovis* under differing scenarios

Scenarios investigated	Estimates for parameters investigated	Mean annual probability that at least one cow in the herd is infected with *M. bovis*
Baseline	*B*=1, *C*=74, *p*= 0.33, m_1= 1.0×10^3, m_2= 1.09×10^4, m_3=1.25×10^3, m_4 =5.0×10^3, *r*=4.1795×10^{-5}, p_E= 0.01	0.11
Reduction in the number of *M. bovis* shed by badger	m_1= 1.0×10^2, m_2= 1.09×10^3, m_3=1.25×10^2, m_4 =5.0×10^2	0.02
Reduction in the daily probability that badger sheds *M. bovis*	p_E= 0.001	0.01
Reduction in the infectivity of *M. bovis*	*r*=4.1795×10^{-6}	0.01
Reduction of cattle herd size	*C*=60	0.08
Restriction of cattle from badger latrine sites	*p*=0	0.08
Reduction of cattle herd size and restriction of cattle from badger latrine	*C*=60, *p*=0	0.05

sites		
Badger in early stage of disease	m_1= 1.0x10^2, m_2= 0 m_3=0, m_4 =0	0.01
Increase in the number of badgers present	*B*= 3	0.29
	B = 5	0.45
	B = 7	0.52

DISCUSSION

Historically, the implementation of policies relating to badger-to-cattle transmission of *M. bovis* has been fraught with difficulties. Increasing scientific evidence implicates badgers in the transmission of *M. bovis* to cattle and a recent review of research recommended that future Defra policy should be based on the assumption that transmission occurs (Godfray *et al*, 2004). The QRA outputs add to the weight to the evidence that badger-to-cattle transmission occurs.

Although badger-to-cattle transmission of *M. bovis* has been hypothesised for over 30 years, there are still important gaps in our understanding of the process. The use of risk analysis methods to study badger-to-cattle transmission of *M. bovis* is novel and is particularly advantageous. Risk analysis presents decision-makers with an objective, transparent and documented assessment of the system and is a convenient platform to investigate practical control policies aimed at reducing the risk of badger-to-cattle transmission.

Practical policy decisions can be made based on the results of the scenarios investigated using the QRA. The QRA results indicate that reducing the number of badgers present in an area and consequently the number of *M. bovis* present in their excreta that cattle are subsequently exposed to could be achieved by removing shedding badgers. However, the culling of badgers has proven to be unacceptable to the general public and therefore may not be a practical control strategy.

In order to reduce the number of *M. bovis* shed and effects of P_E, strategies to reduce the probability of badgers shedding *M. bovis* can be employed. Vaccination of badgers against *M. bovis* could be used as an effective method of reducing shedding. However, although currently under development, a badger vaccine is unlikely to become available within the near future. The dose response model used within the QRA represents the probability that one *M. bovis* organism causes infection in a cow. In order to reduce this probability and therefore the effect of *r*, the number of *M. bovis* the cattle are exposed to and/or the number of *M. bovis* required to cause cattle infection must be increased. The number of *M. bovis* the cattle are exposed to could be reduced by vaccinating badgers against *M. bovis*. The number of *M. bovis* required to cause cattle infection may be reduced by vaccinating the cattle against *M. bovis* infection, however, a cattle vaccine is not currently available.

The QRA outputs may be used by policy makers to make decisions related to the implementation of the most appropriate control policies to reduce the risk of badger-to-cattle transmission of *M. bovis* from badger excreta on pasture. Importantly the use of the QRA to investigate these control policies enables policy and decision makers to assess the effectiveness of control strategies before applying them in the real world.

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