Herd-level risk factors for bovine tuberculosis and adoption of related biosecurity measures in Northern Ireland: A case-control study

M.J.H. O'Hagan ^{a,*}, D.I. Matthews ^b, C. Laird ^a, S.W.J. McDowell ^a

^a *Veterinary Sciences Division, Agri-Food and Biosciences Institute, Stoney Road, Belfast BT4 3SD, Northern Ireland*

^b *Biometrics & Information Systems Branch, Agri-Food and Biosciences Institute, 18A Newforge Lane, Belfast BT9 5PX, Northern Ireland*

* Corresponding author. Tel: +44 28 90524388.

E-mail address: Maria.O'Hagan@dardni.gov.uk (M.J.H. O'Hagan).

¹ Present address: Veterinary Epidemiology Unit, Department of Agriculture and Rural Development, Upper Newtownards Road, Belfast BT4 3SB, Northern Ireland.

Abstract

Bovine tuberculosis (bTB) is a zoonotic disease which is endemic in Northern Ireland. As it has proven difficult to eradicate this disease, partly due to a wildlife reservoir being present in the European badger (*Meles meles*), a case-control study was conducted in a high incidence area in 2010-2011. The aim was to identify risk factors for bTB breakdown relating to cattle and badgers, and to assess the adoption of bTB related biosecurity measures on farms. Face-to-face questionnaires with farmers and surveys of badger setts and farm boundaries were conducted on 117 farms with a recent bTB breakdown (cases) and 75 farms without a recent breakdown (controls). On logistic regression at univariable and multivariable levels, significant risk factors associated with being a case herd included having an accessible badger sett within the farm boundaries in a field grazed in the last year (odds ratio, OR, 4.14; 95% confidence interval, CI, 1.79, 9.55), observation of live badgers (OR 4.14; 95% CI 1.79, 9.55), purchase of beef cattle (OR 4.60; 95% CI 1.61, 13.13), use of contractors to spread slurry (OR 2.83; 95% CI 1.24, 6.49), feeding meal on top of silage (OR 3.55; 95% CI 1.53, 8.23) and feeding magnesium supplement (OR = 3.77; 95% CI 1.39, 10.17). The majority of setts within the farm boundary were stated to be accessible by cattle (77.1%; 95% CI 71.2, 83.0%) and 66.8% (95% CI 63.8, 69.7%) of farm boundaries provided opportunities for nose-to-nose contact between cattle. Adoption of bTB related biosecurity measures, especially with regards to purchasing cattle and badger-related measures, was lower than measures related to disinfection and washing.

Keywords: Bovine tuberculosis; *Mycobacterium bovis*; Case-control study; Risk factors; Biosecurity

Introduction

Bovine tuberculosis (bTB), caused by *Mycobacterium bovis*, is a zoonotic disease which is endemic in many species worldwide (Pollock and Neill, 2002). In Northern Ireland, the disease has consequences for animal and human health, alongside being a financial burden for Government. A control programme based on test-and-slaughter (Council Directive 64/432/EEC) has been in place since the 1950s, but has not lead to eradication, possibly due to fragmented farms, dependence on rented pasture, frequent inter-herd cattle movement and the presence of a wildlife reservoir, the European badger (*Meles meles*) (Abernethy et al., 2006).

Many studies have been conducted to assess risk factors for bTB breakdown (Skuce et al., 2012), with cattle movement, bTB outbreaks on neighbouring farms, bTB history and herd size being commonly described herd-level risk factors. Comparisons of studies such as these are complicated by differing outcomes due to variation in farm management, farm structure, regional bTB incidence and wildlife density in the study areas. Although previous studies have focused on biosecurity measures mitigating potential risk factors for bTB transmission (Philips et al., 2003; Ward et al., 2010; Johnston et al., 2011; Judge et al., 2011; Wilson et al., 2011), there is as yet no empirical evidence linking improved biosecurity with reduced risk of bTB breakdown. Furthermore, great variation in uptake of biosecurity measures has been reported previously in Great Britain (Brennan and Christley, 2012; Cresswell et al., 2014), Ireland (Sayers et al., 2013) and further afield (Brandt et al., 2008; Nöremark et al., 2010). No such assessment had ever been conducted in Northern Ireland. Biosecurity measures examined in our work are based on previously suggested management ideas relating to prevention of bTB introduction into the herd by badgers, neighbouring cattle, cattle purchases and indirect transmission (Phillips et al., 2003; Ward et al., 2010).

The current study had the following objectives: (1) to assess the level of adoption of biosecurity measures in Northern Ireland; and (2) to assess the impact of potential bTB biosecurity measures on the risk of bTB breakdown. The results in relation to a third objective (assessing farmers' attitudes toward bTB control) have reported previously (O'Hagan et al., 2016).

Materials and methods

Study area

For logistical reasons and in order to decrease variability, a defined study area was chosen in an area of high bTB incidence. This area consisted of parts (area 27/37/39) of two divisional veterinary office (DVO) areas with an annual bTB herd incidence for 2010 of 4.92% in DVO Newry and 7.86% in DVO Newtownards¹ (Fig 1).

Study population

There were 2281 active herds in the study area based on the fact that they were subjected to the single intradermal comparative cervical skin test (SICCT) in 2008 and/or 2009. Inclusion of herds into the study by location was based on point map references of the main farm house since, for practical purposes, this is the best geo-referencing method (Durr and Froggatt, 2002). As the SICCT used to disclose bTB infected animals is not 100% specific (Clegg et al., 2011), case herds were selected on the basis of the presence of confirmed or multiple reactors. The case definition was therefore 'herds in the study area that, during 2008 and/or 2009, had multiple reactors to the SICCT, or a confirmed bTB breakdown (based on either one or more confirmed reactors to the SICCT, or one or more confirmed

¹ See: <https://www.dardni.gov.uk/sites/default/files/publications/dard/tb-stats-december2010.pdf> (accessed on 22 March 2016).

animals that were detected at post-mortem examination during routine slaughter)’. Confirmation was based on having positive histopathology or bacteriology findings (O’Hagan et al., 2015). The control selection definition was ‘herds in the study area without restricted herd tests or reactors to the SICCT from 2007 to 2009’.

Herd size is a known risk factor in relation to bTB breakdown (Griffin et al., 1996; Olea-Popelka et al., 2004; Green and Cornell, 2005; Abernethy et al., 2010). Background analysis assessing the distribution of active herds in the study area by herd size and case-control status confirmed that large herds were more likely to be cases. Therefore, cases were selected by stratified random sampling based on herd size category (see Appendix: Supplementary Table 1) and DVO area. Small herds (< 10 animals) were excluded from the study. Subsequently, controls were selected on a group-matched basis (1:1 match).

Data collection

Data were gathered from face-to-face questionnaires and from surveys of badger setts and farm boundaries, with answers referring to the 12 months prior to the bTB breakdown for case farms and the 12 months prior to the survey taking place for control farms (see Appendix: Supplementary questionnaire). Staff involved in data collection were trained in completing the questionnaires, conducting badger sett surveys, reading farm maps, use of camera/global positioning system (GPS) and recording of field boundaries. The majority of farms were visited by two members of staff to ensure consistency.

Two surveys of badger setts were conducted per farm; one survey evaluated the existence of badger activity within the farm boundary and a similar survey assessed the area within a 250 m radius around the farm buildings (see Appendix: Supplementary badger

survey form). Badger setts were classified according to Thornton (1998) (see Appendix: Supplementary Table 2). Farm boundaries were defined as any place of contact with a contiguous neighbour; they were described by the participating farmers and boundary surveys were conducted for verification purposes. This resulted in an assessment of the possibility of nose-to-nose contact with cattle from the neighbouring farm, taking into account the farmer's statement on whether cattle were grazed on both sides of the boundary over the 12 month period either prior to the bTB breakdown (cases) or over the 12 months prior to the survey taking place (controls) (risk assessment score 1 to 5; Table 3). If more than one boundary type was present between the study farm and a contiguous farm, they were recorded separately. In November 2010, a pilot study was conducted on eight farms, resulting in minor alterations to the questionnaire. The field study commenced in December 2010 and finished in June 2011.

Data handling and statistical analyses

Data were checked and entered on a SQL Server database. Data analyses were conducted using R (2.15.0; The R foundation for Statistical Computing) and SPSS Statistics version 19 (IBM). A comparison between farms that participated and the rest of the study population was conducted by location and herd size in order to assess response bias. There was no significant difference between participating case and control farms in relation to DVO area ($\chi^2 = 5.5703$; $P = 0.061$), but there was a significant difference in relation to herd size (two-sample t test; $P = 0.012$). Therefore, a univariable logistic regression model, with herd size added as an a priori confounder, was used to determine whether each variable was significantly associated with case-control status (dependent variable) for progression to multivariable analysis. Multivariable logistic regression was conducted, with variables with P values < 0.20 in the univariable analysis (based on the likelihood ratio test) being considered

for inclusion (Mickey and Greenland, 1988; Katz, 2011). The decision whether to treat independent variables as continuous or categorical was determined by plotting each variable against the dependent variable. Collinearity between variables was assessed using correlation matrices (cut-off point 0.8; Katz, 2011). Final model selection was based on assessment of Akaike Information Criteria (AIC), model fit was assessed using the Hosmer-Lemeshow goodness-of-fit test ($P \leq 0.05$ indicating significant lack of fit to the data) and sensitivity analyses were conducted. Variables with low numbers in any of the categories (and where it was not possible to combine categories) were excluded (Katz, 2011). Biologically plausible two-way interactions between variables were added to the model and tested for significance ($P < 0.05$). A forward stepwise approach was used to build the final multivariable model. This approach is preferred for relatively small data sets containing large numbers of variables (Dohoo et al., 2009; Katz, 2011).

Results

An a priori sample size calculation (power = 0.8, ratio cases:controls = 1, precision = 0.95, predicted exposure in controls = 0.2, odds ratio, OR, detected = 2) resulted in a preferred sample size of 175 cases and 175 controls. Invited farmers ($n = 547$; 294 cases, 253 controls) received two follow-up telephone calls and one follow-up letter to encourage participation. In total, 192 farmers agreed to enrol, thus representing participation of 37.4% ($n = 117$) for cases and 32.4% ($n = 75$) for controls (see Appendix: Supplementary Fig. 1). Permission to conduct a farm boundary survey was obtained on 183 farms (95.3% of the total; 109 cases, 74 controls). Participating farms are described in Supplementary Table 3 (see Appendix).

Key descriptives

Overall, 6.0% (95% confidence interval, CI, 2.7, 12.0) of case farmers and 9.3% (95% CI 4.3, 18.3) of control farmers actively looked for badger activity (see Appendix: Supplementary Fig. 2). Surveyors found that the majority of farmer-reported badger setts were true badger setts (positive predictive value 81.4%; 95% CI 74.9, 86.5). Although 34.9% of farmers reported no badger setts on their farm, this was the case on only 17.2% of farms (negative predictive value 49.3%; 95% CI 37.7, 60.9). Of the setts within the farm boundary, most were stated to be accessible by cattle on case farms (82.0%; 95% CI 75.7, 86.9) and control farms (69.4%; 95% CI 58.9, 78.2; $\chi^2 = 5.3293$, $P = 0.021$). In total, 96.6% (95% CI 92.2, 98.8) of setts on case farms and 91.5% (95% CI 81.3, 96.7) of setts on control farms were in fields grazed by cattle in the year prior to the bTB breakdown (cases) or in the 12 months prior to the survey (controls) (Table 1; see Appendix: Supplementary Fig. 3).

The key farm management and biosecurity descriptives are shown in Table 2. Most farmers bought cattle in the last three years; case farmers bought a mean of 64 cattle and control farmers bought a mean of 44 cattle. There were means of 8.9 (range 2-33) boundaries per case farm and 8.2 (range 1-26) boundaries per control farm. On the basis of the surveyor's risk assessment, 66.8% of farm boundaries (case farms: 66.5%; 95% CI 62.7, 70.1; control farms: 67.4%; 95% CI 62.4, 72.1) provided opportunities for nose-to-nose contact (allowance of a minimum gap between cattle < 3 m) if cattle were grazed in fields on both sides of the farm boundary, which was in almost perfect agreement with the farmers' assessment (κ statistic = 0.788) (Landis and Koch, 1977). However, for 59.9% of boundaries as stated by the farmer (case farms: 57.3%; 95% CI 54.2, 60.4; control farms: 64.2%, 95% CI 60.3, 68.1) no direct nose-to-nose contact with neighbouring cattle was possible, taking into account whether cattle were grazed at the same time on both sides of the boundary in the last

year (Table 3). This finding was also in near perfect agreement with the surveyors' assessments (κ statistic = 0.833).

Multivariable analyses

The final multivariable logistic regression model is displayed in Table 4. The model fitted the data well (Hosmer-Lemeshow test: $P > 0.05$) and the sensitivity was 76.1%. The statistical significance of farms that used contractors to spread manure or slurry on their farm having higher odds of being a case was particularly based on spreading slurry (41.0% of cases vs. 21.3% of controls) rather than manure (23.9% of cases vs. 17.3% of controls). Few farmers (27.1% of cases; 31.8% of controls) stated that contractors that they used washed their equipment before arrival on the farm.

Discussion

Although the knowledge of risk factors in relation to bTB breakdown is vast (Skuce et al., 2012), there is, as yet, no empirical evidence linking improved biosecurity with reduced risk of bTB breakdown. The current study therefore focussed on risks that could be mitigated by improved bTB related biosecurity and furthermore assessed the uptake of such measures by farmers in Northern Ireland. It was not possible to assess bTB history as a risk factor within this study, as identified in previous studies (Olea-Popelka et al, 2004; Porphyre et al., 2008; Abernethy et al., 2010), since bTB history was used to select cases and controls.

The purchase of beef cattle was highlighted as a risk factor in the final model. Since only 24% of farmers stated that they had a closed farm and because pre-movement testing is not compulsory and seldom conducted, the purchase of cattle is a plausible potential source of bTB introduction into a herd, consistent with previous studies (Barlow et al., 1998;

Goodchild and Clifton-Hadley, 2001; Gilbert et al., 2005; Gopal et al., 2006; Clegg et al., 2008; Green et al., 2008).

The use of contractors to spread slurry or manure was also associated with being a case farm, consistent with findings by Griffin et al. (1993) and Wolfe et al. (2010). This is plausible, since *M. bovis* can survive in faeces for several months, aerosol can be created by slurry and few farmers stated that contractors wash and disinfect their equipment after use.

Contact with neighbouring cattle (Phillips et al., 2003) was possible for 66.8% of farm boundaries in our study and 79% in a previous study (Denny and Wilesmith, 1999). However, we found no significant association between being a case farm and the number of boundaries per farm, as well as mean risk scores based on nose-to-nose contact and farm boundary nature; this is in contrast to findings reported by Denny and Wilesmith (1999), Munroe et al. (1999), Karolemeas et al. (2010) and Johnston et al. (2011). Since the current study examined the overall effect of contact with neighbouring herds, instead of focussing on neighbouring herds with bTB breakdowns, there may have been a dilution of the possible association between the risk of bTB breakdown and contact with contiguous herds.

No significant association was found between the presence of deer and the risk of being a case farm, consistent with previous findings by Denny and Wilesmith (1999). The prevalence of *M. bovis* in wild deer in Northern Ireland is known to be low (~2%²). Farmers that kept poultry or lambs as well as cattle were at a lower and higher risk, respectively, of being a case farm, for which the explanation is unclear.

² See: <https://www.dardni.gov.uk/articles/wild-deer-tb-surveillance-200809> (accessed 22 March 2016).

The positive and negative predictive values of farmers identifying badger setts correctly were 81.4% and 49.3%, respectively, compared to the values of 95% and 30% reported by Menzies et al. (2011). The odds of being a case farm were significantly increased by the presence of accessible badger setts and the observation of live badgers on the farm. Badgers are attracted by food and feed supplements, and have been reported to visit feed stores and cattle houses (Phillips et al., 2003; Tolhurst et al., 2009; Ward et al., 2010; O'Mahoney, 2014)³. Significantly fewer case farmers stored processed grain on their farm in comparison with control farmers, but there was no difference in how they stored this grain and how accessible it was to badgers. Case farmers were significantly more likely to feed magnesium supplement and meal on top of the silage, which may attract badgers. However, case farmers were more confident that their cattle houses and feeding troughs were badger proof, although they did not report putting more badger proofing measures in place in comparison with control farmers.

In line with findings by Ward et al. (2014), there was a lack of adoption of biosecurity measures by farmers, especially in relation to badgers. Although most study farms used raised feed and water troughs, they were likely to have been installed for reasons other than increasing biosecurity (e.g. to prevent cattle defecating into troughs). Little was done (pre- or post-movement testing, maintaining a closed herd) on both case and control farms to reduce the risk of bTB introduction by cattle purchase. Isolation, washing and disinfection were better adopted.

Since the current study had a lower than anticipated level of farmer participation, there may be a possibility of participation bias and reduced study power. However, the

³ See: <https://www.dardni.gov.uk/publications/badger-cattle-interactions-rural-environment-implications-bovine-tuberculosis> (accessed 22 March 2016).

participation rates of invited case and control farmers were similar. Participating farms were compared to the study population and a significant difference in mean herd size between cases and controls was evident; this was accounted for by adding herd size to all derived models as an a priori confounder.

The risk of response bias was mitigated by the use of surveying staff, who verified farmers' responses (presence of badger setts and nature of farm boundaries), which showed a high level of agreement. Furthermore, several survey questions overlapped, allowing additional validation. The majority of farms were visited by two members of staff, which further ensured consistency. Some response bias was suspected on the basis of some of the answers to the questionnaire by case farmers, perhaps related to a reluctance to attribute responsibility for bTB breakdowns on their farms.

Since the questionnaires were based on answers referring to the 12 months prior to the bTB breakdown for case farms, but the last 12 months for control farms, the time period for recall for case farmers was longer than for control farmers, possibly leading to recall bias. However since bTB breakdowns for the case farms were relatively recent (2008/2009) compared to the survey being conducted (2010/2011), this is not likely to have a major impact. Furthermore, some minor changes in the classification of some of the setts may have occurred between the time badger setts were surveyed (2010-2011) and the time of the bTB breakdowns (2008-2009) on case farms.

Conclusions

The risk of several significant factors associated with being a bTB case farm potentially can be reduced by adopting suitable biosecurity measures, particularly in relation

to cattle purchases (e.g. keeping a closed herd and pre-movement testing) and badger proofing of farms. The results of the current study should be applicable to other locations with farming practices that are similar to Northern Ireland, such as other areas of the British Isles.

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Table 1

Mean number and range of setts of different sett classifications found within the farm boundary and within a 250 m radius from farm buildings in a case-control study of 117 farms with a bovine tuberculosis breakdown and 75 farms without a breakdown in Northern Ireland in 2008/2009.

	Case		Control		<i>P</i>
	Mean	Range	Mean	Range	(Two sample <i>t</i> test)
Setts found within farm boundary	1.56	0-7	1.13	0-4	0.301
Active setts found within farm boundary	1.16	0-7	0.81	0-4	0.313
Main setts found within farm boundary	0.41	0-3	0.21	0-2	0.151
Sett density (setts/ha farm land)	0.03	0-0.39	0.03	0-0.20	1.000
Active sett density (active setts/ha farmland)	0.01	0-0.39	0.02	0-0.08	1.000
Main sett density (main setts/ha farmland)	0.02	0-0.27	0.01	0-0.15	1.000

Table 2

Key descriptives in relation to farm management and biosecurity measures in the 12 months prior to the bovine tuberculosis (bTB) breakdown (cases) or in the 12 months prior to the survey taking place (controls) in a case-control study of 117 farms with a bTB breakdown and 75 farms without a breakdown in Northern Ireland in 2008/2009.

	Case (<i>n</i> = 117) % in category (95% confidence interval)	Control (<i>n</i> = 75) % in category (95% confidence interval)	<i>P</i> value ^a
Farm management			
Farm type			0.920
Beef farm	65.8% (56.8, 73.8)	78.7% (68.0, 86.5)	
Dairy farm	17.1% (11.3, 25.0)	9.3% (4.3, 18.3)	
Mixed farm	17.1% (11.3, 25.0)	12.0% (6.2, 21.5)	
Let out land as conacre ^b	10.3% (5.8, 17.2)	13.3% (7.2, 23.0)	0.661
Take land as conacre ^b	83.8% (75.9, 89.4)	78.7% (68.0, 86.5)	0.821
Purchase cattle in the last 3 years	87.2% (79.8, 92.2)	90.7% (81.7, 95.7)	0.821
House cattle during the winter period only	94.0% (88.0, 97.3)	94.7% (86.7, 98.3)	0.375
Straw bedded accommodation for indoor housing available	79.5% (71.2, 85.9)	78.7% (68.0, 86.5)	0.566
Slatted accommodation for indoor housing available	76.1% (67.5, 82.9)	74.7% (63.7, 83.2)	0.313
Central feeding passage or feeding passage with enclosed sides	79.5% (71.2, 85.9)	73.3% (62.3, 82.1)	0.909
Rotational/paddock grazing	78.6% (70.3, 85.1)	78.7% (68.0, 86.5)	0.488
Feed big bales grass silage	75.2% (66.6, 82.2)	84.0% (73.9, 90.8)	0.381
Feed grass silage clamp	68.4% (59.5, 76.1)	62.7% (51.3, 72.8)	0.337
Feed meal at housing	94.9% (89.0, 97.9)	93.3% (85.0, 97.5)	0.859
Feed meal at grass	82.9% (76.1, 89.7)	76.0% (66.3, 85.7)	0.458
Feed meal in troughs at housing	76.9% (68.5, 83.7)	77.3% (66.6, 85.4)	0.455
Feed meal in troughs at grass	68.4% (59.5, 76.1)	65.3% (54.0, 75.1)	0.894
Observation of wild deer on the farm	29.1% (21.6, 37.9)	22.7% (14.6, 37.2)	0.290
Biosecurity measures			
<i>Badger related</i>			
Use of electric fence to prevent badger access to clamps	0% (0, 3.8)	0% (0, 5.8)	-
Fence off badger latrines	5.1% (2.1, 11.0)	0% (0, 5.8)	-
Install solid gates/fencing around farmyard ^c	7.7% (3.9, 14.2)	8.0% (3.4, 16.7)	0.988
Fence off badger setts	11.9% (7.1, 19.2)	4.0% (0.9, 11.6)	0.091
Have solid doors which would prevent badger access to housing	38.5% (30.1, 47.5)	26.7% (17.9, 37.7)	0.083
Use raised water troughs at pasture ^c	61.5% (52.5, 69.9)	60.0% (46.7, 70.4)	0.906
Use raised feed troughs at pasture ^c	65.0% (56.0, 73.0)	64.0% (52.7, 74.0)	0.822
Badgers can access farmyard at night	95.7% (90.1, 98.4)	96.0% (88.4, 99.1)	0.998
Badgers can access feeding passage at night	72.2% (63.9, 79.9)	89.3% (80.1, 94.7)	0.035
<i>Farm management related</i>			
Arrangements with neighbours to avoid grazing contiguous fields	21.4% (14.9, 29.7)	17.3% (10.3, 27.6)	0.523
Maintain closed herd (i.e. no cattle purchases)	23.9% (17.1, 32.5)	24.0% (15.7, 34.9)	0.427
Avoid grazing boundary fields	52.1% (43.2, 61.0)	52.0% (40.9, 62.9)	0.740
Visitors have to wash/disinfect before entry	56.4% (47.4, 65.1)	48.0% (37.1, 59.1)	0.219
Routinely washing/disinfecting of cattle houses after emptying	86.3% (78.8, 91.5)	82.7% (72.4, 89.7)	0.436
Separate collection area for fallen livestock available ^c	88.0% (80.8, 92.9)	84.0% (73.9, 90.8)	0.633
No sharing of livestock equipment with other farmers ^c	88.0% (80.8, 92.9)	92.0% (83.3, 96.6)	0.191
Isolation accommodation for sick animals available	97.4% (92.4, 99.5)	98.6% (92.1, 100)	0.637
<i>Measures related to only herds that purchase cattle ^d</i>			
	<i>n</i> = 89	<i>n</i> = 57	
Carry out post-movement test for bTB	2.2% (0.1, 8.3)	1.8% (0.0, 10.2)	0.751
Ask for pre-movement test for bTB	11.2% (6.0, 19.6)	8.8% (3.4, 19.4)	0.770
Isolation of purchased cattle for at least 21 days	40.4% (30.9, 50.8)	42.1% (30.2, 55.0)	0.984
Check bTB status prior to purchase	51.7% (41.5, 61.8)	49.1% (36.6, 61.7)	0.807

^a *P* value based on likelihood ratio adjusted for herd size.

^b Conacre is the letting/taking of portions of land by or from a tenant.

^c These measures will improve biosecurity on the farm but may not necessarily be put in place by the farmer for that particular reason.

^d 89 case farms and 57 control farms purchased cattle stated not to be 'closed' herds (i.e. they purchased cattle).

Table 3

Distribution of the risk assessment scores for the farmer's and surveyor's assessment of the risk of nose-to-nose contact in the 12 months prior to the bovine tuberculosis (bTB) breakdown (cases) or in the 12 months prior to the survey taking place (controls) in a case-control study of 117 farms with a bovine tuberculosis breakdown and 75 farms without a breakdown in Northern Ireland in 2008/2009.

Risk score ^a	Nose-to-nose contact ^a	Description of farm boundary in relation to nose-to nose contact ^a	Farmer's risk assessment			Surveyor's risk assessment		
			Case (n = 999)	Control (n = 584)	P value ^b	Case (n = 711)	Control (n = 454)	P value ^b
1	No direct nose-to-nose contact possible (minimum gap between cattle $\geq$ 3 m)	Road or river of sufficient size to prevent nose-to-nose contact. Double fenced boundary with $\geq$ 3 m gap with or without an intervening hedge or other barrier.	527 (52.8%)	352 (60.3%)	<0.001	423 (59.5%)	293 (64.5%)	0.167
2	No direct nose-to-nose contact possible (minimum gap between cattle < 3 m)	Double fenced boundary with $\geq$ 2 m gap with or without an intervening hedge or other barrier Thorn or other hedge with no obvious gaps, minimum width $\geq$ 2 m Laneway used by cattle, no obvious gaps	46 (4.6%)	23 (3.9%)		32 (4.5%)	25 (5.5%)	
3	Rare nose-to-nose contact possible	Laneway used by cattle, some gaps allowing direct nose-to-nose contact Thorn or other hedge with no obvious gaps, minimum width < 2 m	217 (21.7%)	132 (22.6%)		130 (18.3%)	74 (16.3%)	
4	Occasional nose-to-nose contact possible	Thorn or other hedge with occasional gaps allowing direct nose-to-nose contact (< 1% of hedge length) Thorn or other hedge with some gaps allowing direct nose-to-nose contact (1-10% of hedge length)	143 (14.3%)	65 (11.1%)		85 (12.0%)	47 (10.4%)	
5	Frequent nose-to-nose contact possible	Thorn or other hedge with frequent gaps allowing direct nose-to-nose contact (10-49% of hedge length) Fence only, with no or minimal hedging (hedge < 50% of length)	66 (6.6%)	12 (2.1%)		41 (5.8%)	15 (3.3%)	

^a Farm boundaries were defined as any place of contact with a contiguous neighbour. The risk score of the farm boundary was described/assessed taking into account whether cattle had been grazed on both sides of the boundary over the 12 month period either prior to the bTB breakdown (cases) or the last 12 months prior to the survey taking place (controls). If more than one boundary type was present between the study farm and a contiguous farm they were separately recorded.

^b P value based on likelihood ratio.

Table 4

Multivariable logistic regression model for risk factors for occurrence of recent bovine tuberculosis (bTB) breakdown in cattle herds in case-control study of 117 farms with a bTB breakdown and 75 farms without a breakdown in Northern Ireland in 2008/2009.

Variable	Cases (n = 117)		Controls (n = 75)		Odds ratio	95% Confidence interval	P value Wald test	P value Likelihood ratio
	n	%	n	%				
Herd size ^a								0.003
Per animal increase					1.01	1.00, 1.01	0.006	
Accessible badger sett within farm boundaries and in a field grazed in the last 12 months ^b								
Not present	48	41.0%	48	64.0%	1.00	-	-	< 0.001
Present	69	59.0%	27	36.0%	4.14	1.79, 9.55	< 0.001	
Live badgers								
Not observed in the last 3 years ^c	54	46.2%	46	61.3%	1.00	-	-	0.019
Observed in the last 3 years ^c	63	53.8%	29	38.7%	2.51	1.15, 5.48	0.021	
Feeding troughs in housing								
Not accessible to badgers	74	63.2%	41	54.7%	1.00	-	-	0.005
Accessible to badgers	43	36.8%	34	45.3%	0.31	0.14, 0.73	0.007	
Does farmer feel badgers could access the house/feeding passage at night								
No	29	24.8%	8	10.7%	1.00	-	-	0.022
Yes	88	75.2%	67	89.3%	0.30	0.11, 0.88	0.028	
Purchase of store/beef cattle in last 3 years ^c								
No	89	76.1%	62	82.7%	1.00	-	-	0.003
Yes	28	23.9%	13	17.3%	4.60	1.61, 13.13	0.004	
Use of contractors to spread slurry or manure on the farm								
No	58	49.6%	52	69.3%	1.00	-	-	0.011
Yes	59	50.4%	23	30.7%	2.83	1.24, 6.49	0.014	
Storage of processed grain or compound meal on the farm								
No	16	13.7%	5	6.7%	1.00	-	-	0.002
Yes	101	86.3%	70	93.3%	0.12	0.03, 0.52	0.004	
Meal fed on top of silage in housing								
No	66	56.4%	52	69.3%	1.00	-	-	0.002
Yes	51	43.6%	23	30.7%	3.55	1.53, 8.23	0.003	
Magnesium fed as a supplement								
No	84	71.8%	63	84.0%	1.00	-	-	0.006
Yes	33	28.2%	12	16.0%	3.77	1.39, 10.17	0.009	
Lambs on the farm								
Not present	97	82.9%	70	93.3%	1.00	-	-	0.004
Present	20	17.1%	5	6.7%	5.47	1.58, 19.02	0.007	
Poultry on the farm								
Not present	113	96.6%	61	81.3%	1.00	-	-	< 0.001
Present	4	3.4%	14	18.7%	0.14	0.04, 0.49	0.002	

^a Included in the model as a continuous variable.

^b In the last 12 months refers to the 12 months prior to the bTB breakdown for cases and to the 12 months prior to the survey taking place for controls.

^c In the last 3 years refers to the 3 years prior to the bTB breakdown for cases and to the 3 years prior to the survey taking place for controls.

492 **Figure legend**

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494 Fig. 1. Map of the study area used for a case-control study of 117 farms with a bovine
495 tuberculosis breakdown and 75 farms without a breakdown in Northern Ireland in 2008/2009.

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Figure 1