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EVIDENCE PROJECT FINAL REPORT

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Project identification

1. Defra Project code: SE4007

2. Project title: Assessment of tailored farm-level biosecurity strategies for beef suckler farms in England and Wales.

3. Contractor organisation(s): University of Reading
Royal Veterinary College

54. Total Defra project costs (agreed fixed price): £1,743,672.83

5. Project: ....start date: October, 2008
end date ....: February, 2013

6. It is Defra's intention to publish this form.

Please confirm your agreement to do so...YES ☐ NO ☐

(a) When preparing Evidence Project Final Reports contractors should bear in mind that Defra intends that they be made public. They should be written in a clear and concise manner and represent a full account of the research project which someone not closely associated with the project can follow.

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In all cases, reasons for withholding information must be fully in line with exemptions under the Environmental Information Regulations or the Freedom of Information Act 2000.

(b) If you have answered NO, please explain why the Final report should not be released into public domain

Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

The farmer, as a decision maker in relation to livestock management, is a key player in the control of livestock diseases. There are many measures a farmer can take to reduce the likelihood of a disease being introduced and spread on the farm. These measures are encompassed by the broad term 'biosecurity'. Many studies of infectious disease risk factors have highlighted the beneficial effects of biosecurity measures. For example, Tiwari et al. (2009) found that increased *Mycobacterium avium* subsp. *paratuberculosis* (Johne's disease) sero-prevalence on Canadian dairy farms was associated with practices such as purchasing replacement animals, keeping multiple cows in calving pens and housing pre-weaned calves in groups. The effectiveness of biosecurity has been studied in a wide range of situations including the control of tuberculosis (Judge et al. 2011), campylobacter in broiler flocks (Gibbens et al. 2001) and gastroenteritis in rainbow trout (Del-Pozo et al. 2010). It has been studied retrospectively to assess differences in biosecurity practices between farms with and without diseases, for example Newcastle disease in Australia (East et al. 2006). A major challenge is that an effective biosecurity risk management strategy involves multiple factors, with each single factor only having a relatively small effect, and that the relative importance of the various factors included in such a strategy may vary between farms. It is therefore difficult to conceive a single biosecurity strategy concept that will be equally effective on every farm, and therefore be supported by all farmers.

This study was designed to assess the effectiveness of tailored biosecurity advice, provided by veterinary practitioners, in reducing the risk of introduction of infectious diseases on beef suckler farms. Recognising the complexity of the different dimensions that contribute to the potential impact of advice, several outcome measures were used, including an annual disease introduction risk score, changes in infection status for five cattle diseases, and production and economic performance parameters for each farm enrolled in the study. One hundred and sixteen farms were recruited by 10 veterinary practices and followed over a 3 year period. Collaborating veterinarians undertook an annual risk assessment of each farm, from which a disease introduction risk score was calculated. Blood samples from ~50 cattle from each farm were taken annually and tested for bovine viral diarrhoea (BVD) virus, infectious bovine rhinotracheitis (IBR) virus, leptospira and *Mycobacterium avium* subspecies *paratuberculosis* (MAP) antibodies, from which the respective sero-prevalences were estimated. The tuberculosis (TB) (attributed to *Mycobacterium bovis*) status of farms was obtained from the Animal Health and Veterinary Laboratories Agency (AHVLA). Within each veterinary practice, farms were randomly allocated to either intervention or control groups. A specifically-tailored, detailed biosecurity advice package, developed by their veterinary practice, was provided to intervention farms. For ethical reasons, standard general advice was not withheld from control farms, but provided by attending veterinarians in the context of their usual interaction with their farmer clients. The statistical analyses examined the association between intervention/control group

status, as well as other risk factors such as specific risk management measures, and the various outcome variables mentioned above. By the end of the third year of the data collection, 93 farms (46 intervention and 47 control farms) remained enrolled.

Over the course of the study, there was a significant reduction in the proportion of both intervention and control farms sero-positive for leptospira infection, and within-farm prevalence reduced for BVD virus, leptospira and MAP infection. For intervention farms there was a stronger reduction in prevalence of IBR virus (trend towards statistical significance - P=0.08) and MAP infection. Disease introduction risk scores decreased between years one and four for approximately two-thirds of farms suggesting an improvement in biosecurity practices across all study farms. Multivariable regression analysis, taking into account all four years of the project, indicated that irrespective of intervention/ control group status increased direct or indirect exposure to other farms through purchase or over the fence contact with neighbouring farms were associated with increased odds of being seropositive for BVD virus, IBR virus and leptospira infection in terms of farm infection status or within-farm prevalence. By the end of the project, irrespective of intervention or control status, significantly more farmers reported carefully sourcing, isolating and testing new cattle and protecting their buildings from wildlife access than at the beginning of the project. The percentage of farmers who were at least satisfied with their biosecurity increased from 8% in 2009 to 98% in 2011. Qualitative analysis of farmer interviews showed that irrespective of intervention/control group status farmers felt they had benefitted from participating in the project through enhancing their knowledge about biosecurity and many felt there was a need amongst beef farmers in general for a greater understanding of disease control measures.

The study had various limitations which will compromise its external validity. Veterinary and farmer participants were not randomly selected, since the intensive project activities required a good relationship between the veterinary practices and farmers. The study population therefore is neither geographically nor in terms of herd size representative of beef suckler farms in England and Wales. Furthermore, the control group of farms also will have received advice from their veterinarians during the regular visits, although this would not have been based on a structured risk assessment/management programme as the intervention farms did. Another factor adversely affecting the external validity of the study was that intervention and control farmers did not have to cover the costs of the farm visits and diagnostics.

This project has demonstrated the difficulty of providing evidence of impact of tailored biosecurity advice on animal health and farm income. But there have been indications of it potentially being able to reduce farm-level sero-prevalence for BVD, IBR and leptospirosis on beef suckler farms. The research has also identified gaps in knowledge in relation to the epidemiology of MAP infection (Johne's disease) and bovine tuberculosis for these types of farm enterprises. The results further indicate that beef cattle farmers recognise gaps in animal disease-related knowledge and would be willing to learn more about biosecurity. The project emphasized the importance of the communication relationship between veterinarians and farmers. It demonstrated the need to investigate factors influencing farmer behaviour change which, once formally described, should inform the communication between veterinarians and farmers in relation to farm biosecurity as well as any other issues in relation to health and welfare of their livestock.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:

- the objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and
- any action resulting from the research (e.g. IP, Knowledge Exchange).

OBJECTIVES

To determine whether tailored veterinary biosecurity advice can reduce the seroprevalence of four important bovine diseases: BVD (bovine viral diarrhoea virus), IBR (bovine herpes virus-1), leptospirosis (caused by the *Leptospira* serovar *hardjo*) and MAP (Johne's disease caused by *Mycobacterium avium* subspecies *paratuberculosis*) in beef suckler farms. It also assessed the impact of tailored biosecurity advice on the TB (tuberculosis attributed to *Mycobacterium bovis*) status of farms. The impact of biosecurity advice was further assessed through analysing production and economic performance parameters.

MATERIALS AND METHODS

STUDY DESIGN

The impact of biosecurity advice on disease and production in beef suckler farms was assessed through a randomised controlled intervention study. Ten veterinary practices were purposively selected on the basis of willingness to collaborate in the project and having beef suckler farm clients. These in turn selected study farms from their beef clients with which they had a good working relationship and which had at least 50 female cattle at breeding age. The number of farms per veterinary practice was proportionally weighted amongst the study population according to the number of beef suckler clients of each veterinary practice. This process resulted in each recruiting between 8 and 18 farms (see Figure 1). The farms were randomly allocated by the Royal Veterinary College (RVC) and University of Reading, to either the intervention group, which received detailed, specifically-tailored biosecurity advice or the control group, where no specific biosecurity advice was provided unless it was requested by the farmer or provided by the veterinarian as part of the normal consultation process. In total, 57 intervention and 58 control farms were recruited, of which 46 intervention and 47 control farms remained by the end of the four year study period. Data collection commenced in early 2008 and finished in mid 2012. At the start of the study, each participating farm underwent a structured risk assessment, from which a disease introduction risk score was calculated for all five diseases. The risk assessments were conducted by collaborating veterinarians and repeated annually, resulting in 4 risk assessments per farm. In the analyses presented here, year 1 therefore represents the data collected at the start of the study and years 2-4 represent data collected at the end of year 1, 2 and 3 of the study. In addition, blood samples for antibody testing were obtained from approximately fifty animals per farm for bovine viral diarrhoea (BVD) virus, bovine herpes virus-1 (IBR) virus, *Leptospira* serovar *hardjo* (leptospirosis) and *Mycobacterium avium* subspecies *paratuberculosis* (Johne's disease) infection. This resulted in 4% to 100% of cattle on farms being tested annually (median 32% of cattle tested per farm). The blood samples were sent to the NMR (National Milk Records Group) laboratories for analysis. The sensitivities (Se) and specificities (Sp) of the tests used in the study were: 95.9% (Se) and 100% (Sp) for BVD; 98.7% (Se) and 99.9% (Sp) for IBR; 83.7% (Se) and 87.3% (Sp) for leptospirosis, and 64.7% (Se) and 99.2% (Sp) for Johne's disease. These values were obtained from the manufacturers of the tests Linnodee [leptospirosis ELISA (enzyme-linked immunosorbant assay)] and Pourquier (BVD, IBR and Johne's disease ELISAs). Data on the tuberculosis (TB) (attributed to *Mycobacterium bovis*) infection status of farms was obtained from the Animal Health and Veterinary Laboratories Agency (AHVLA), however, not all of the farms had whole herd tests (i.e. every animal within the farm tested) for each year of the study. It is to be noted that some farms vaccinated against some of the infectious diseases investigated in this study (BVD, IBR and leptospirosis), and in such cases vaccinated animals are likely to have produced a positive response in the relevant test (Marshall et al. 1979; Savan et al. 1979; Booth et al. 2013).

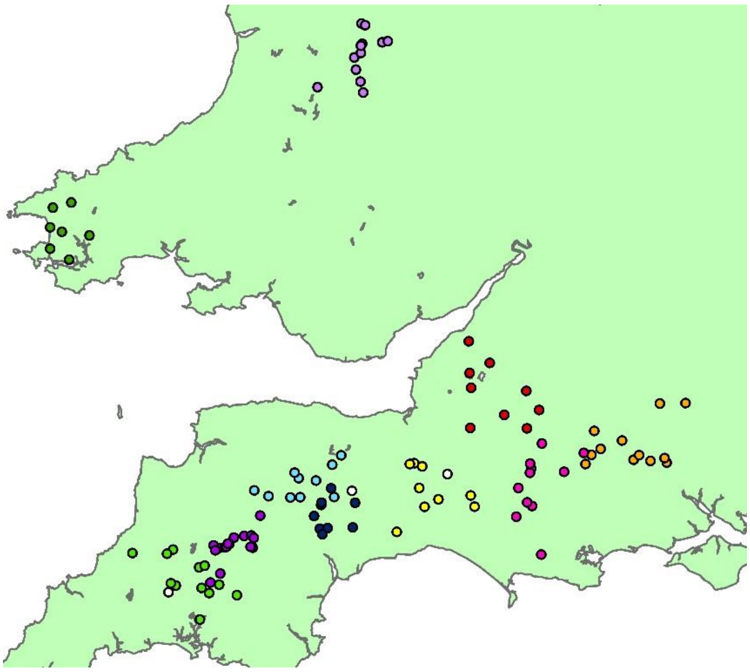

Figure 1: Locations of study farms with colours representing the different veterinary practices

DATA COLLECTION AND ANALYSIS

STRUCTURED RISK ASSESSMENT AND DISEASE INTRODUCTION RISK SCORE

A disease introduction risk score was developed using an expert opinion approach during which the researchers from RVC together with the project veterinarians identified and weighted risk factors. The final output was an agreed list of risk factors and there relative weightings, which then became the basis for the algorithm behind the disease introduction risk score.

Veterinarians visited all farms to complete a risk assessment questionnaire including questions on cattle purchasing, animal contact, visitors, existing biosecurity practices and farm-level vaccination status for BVD, IBR and leptospirosis. From these responses a disease introduction risk score was calculated for BVD, IBR, leptospirosis, Johne's disease and TB. A linear mixed modelling approach was used to examine the pattern of introduction risk scores during the study, including an assessment of any differences between intervention and control groups. In this analysis, veterinary practice and farm nested within veterinary practice were included as random effects and modelled assuming an auto-regressive covariance structure. This analysis was performed using the Stata/SE software version 13.1 (www.stata.com).

VETERINARY ADVICE

Advice consisted of a tailored biosecurity risk management plan developed for each intervention farms based on the risk assessment or in the case of control farms of advice provided at the request of the farmer or as part of a normal consultation. The analysis of the impact of biosecurity advice on the outcome measures consisted of a comparison between intervention and control farms, as well as of that of individual pieces of advice, irrespective of intervention/control group status. Individual pieces of advice were classified into 25 categories. These included the sourcing of cattle, quarantine, post-quarantine vaccination, pre-purchase testing, foot dips, reducing contact with neighbouring cattle, vaccination of existing farm, monitoring of existing farm, reducing wildlife contact, cleaning vehicles, restricting visitor access, not sharing vehicles and the sourcing of feed. The frequency of each piece of advice per farm, per veterinarian and per year was calculated as was whether the advice had been followed and reasons for non-compliance. The F-Test was used to compare the number of different pieces of advice given to intervention and control farms over different years. Each piece of advice recorded by the veterinarian during the questionnaire data collection was treated as a single unit throughout the analyses.

FARM DISEASE STATUS

Changes in positivity at farm level (positive = at least one test positive animal in sample or in the case of TB the farm had at least one confirmed TB reactor during an official herd test) between years one and four of the study were analysed descriptively. Multiple correspondence analysis was used to perform an exploratory analysis of the association between disease status variables and vaccination status, as well as between disease status change variables and intervention/control group. This analysis was performed using IBM SPSS Statistics version 22 (www.spss.com).

The apparent prevalence within each farm was calculated for each of the four years for the four diseases for which serological data was available (BVD, IBR, leptospirosis and Johne's disease). To avoid using samples from the same animal between years and thereby being less likely to detect change in prevalence, the apparent prevalence for each farm was calculated using cattle aged between 9-21 months for BVD, IBR and leptospirosis and cattle aged two years old and over for Johne's disease after removal of duplicate cattle identification numbers. Farms where fewer than five cattle were tested that met the previously stated age profile for the prevalence calculation were omitted to increase the stability of the estimates. Estimated true prevalence (accounting for diagnostic test sensitivity and specificity) and associated CIs were calculated for the serological tests using Bayesian analyses based on equations from Cameron and Baldock 1998 and Branscum, 2004 in WinBUGS (Spiegelhalter et al, 1999) using programming code from UC Davis (http://www.epi.ucdavis.edu/diagnostictests/software.html) that used the hypergeometric distribution to take into account the herd size as well as the sample size. This code enabled the calculation of the probability that a farm was truly seropositive. The median probability of ≥50% that a farm was seronegative was used as a threshold to classify the farm as being negative or positive for antibody. The overall seroprevalence and associated CIs for intervention and control farms were calculated for BVD, IBR, leptospirosis and Johne's disease using Bayesian methods in R with the prevalence package (Devleesschauwer et al. 2013). Some farms had vaccinated their cattle for BVD, IBR and leptospirosis and a positive serological result therefore may be an indication of prior vaccination, since these serological tests do not differentiate between immunological responses resulting from vaccination and infection.

Multivariable analyses were conducted to investigate the association between various risk management factors and both outcome variables, farm disease status and disease prevalence (incidence in case of tuberculosis). The unit of analysis was farm in a particular year of study, so that each farm contributed 4 sets of data records (including the baseline data collected at the start of the project). For farm disease status within year of study as outcome variable, a multilevel mixed effects logistic regression for binary responses was applied separately to each of all five diseases. For prevalence/incidence within farms during each year of the study as outcome variable, a multilevel mixed logistic regression for binomial responses (positives as numerator and number of animals tested as denominator) was applied to each of the five diseases. In the disease status and within-farm disease prevalence/incidence analyses, veterinary practice and farm nested within veterinary practice were considered for inclusion as random effects and modelled assuming an unstructured covariance matrix. The farm's intervention/control status and year were independent variables in the model together with their interactions and other putative risk factors. To explicitly test one of the main hypotheses of this study, a first multivariable analysis was conducted for each disease status/prevalence/incidence outcome variable focussing on the association with intervention/control group, year and their interaction as well as vaccination status. This analysis was based on a backward variable selection process based on $p > 0.05$ to define variable exit using the likelihood ratio statistic. A second multivariable analysis was conducted to evaluate other potential risk factors. In this case, univariable analyses were carried out followed by multivariable analyses where the multi-level mixed logistic regressions were fitted using a forward stepwise method with variable inclusion determined by a significance of p<0.05 and variable exit by p > 0.05 based on the likelihood ratio statistic. The multi-level mixed logistic regression analyses were undertaken using the Stata/SE software version 13.1 (www.stata.com). Classification tree analysis based on the CHAID method was used to explore the dataset further, with the minimum number of observations per parent node set to 30 and 10 per child node. This analysis was conducted using IBM SPSS Statistics version 22 (www.spss.com). Outcome variables in this analysis were the number of different diseases for which a farm was positive within a particular year.

FARM FINANCIAL PERFORMANCE

Between June 2009 and July 2012, 101 farm businesses were visited and data collected face-to-face. On the few occasions that this was not possible, datasheets were completed by the farmer and returned to the University of Reading. Farming systems, physical performance and financial data were collected for four years, relating to the calf crop years 2008 to 2011, with data from 2008 used to determine a pre-study baseline. At the end of year four, 99 businesses remained as participants in this assessment. Whilst 74 were able to provide full financial data for year four (2011), only 62 participants were able to do this for each of the four years.

In 2009 and 2011, participants were also asked a series of questions designed to determine their knowledge of biosecurity measures and their attitudes towards implementing them. The questions were identical between the two years; 99 farmers completed this exercise for both years. In addition, biosecurity expenditure record sheets were sent out quarterly by post in order to capture the previous quarter's specific expenditure on biosecurity measures such as use of rat bait, disinfectant and new fencing; 48 participants completed this for each surveyed quarter of 2009, 2010 and 2011.

The Student's t-test and Wilcoxon matched pairs sign test were used to assess the differences between intervention and control farms with respect to farm systems, physical and financial performances. The Wilcoxon matched pairs sign test was used to compare the frequency of use of biosecurity measures and satisfaction of farmers' current biosecurity measures between years 2009 and 2011. Linear regression was used to assess the contribution of financial performance to the disease introduction risk score.

Great care was taken in the design of the three main data collection instruments used. Pre-pilot and pilot surveys were undertaken and the study complied fully with University of Reading ethical requirements. The data recording sheet and calculation tool employed for financial performance was supplied by EBLEX so that meaningful comparison could be made with published figures from single-suckler beef farms.

FARMERS' ATTITUDES TOWARDS BIOSECURITY

Twenty farmers were selected from study participants for in-depth interview, with the aim of understanding their perceptions of biosecurity and factors influencing their management decisions. As this was a qualitative study, interviewees were purposively selected to reflect a range of characteristics such as intervention or control farm status, biosecurity practices, size of herd and changes in biosecurity practices over the course of the study.

Selected farmers were initially contacted by letter, followed by a telephone call to ask if they would be willing to participate. Those who were willing and able to participate were then sent a letter to confirm the time and place of the interview.

Farmers were interviewed at their farm, over a period of two weeks in July 2012, by one interviewer who was an epidemiology researcher with previous experience working as a veterinarian in mixed veterinary practice. The interviews were recorded and then transcribed and anonymised.

A semi-structured interview schedule was used, which had been pilot-tested during two interviews with farm staff at the RVC. The schedule included questions about the meanings of the word biosecurity, motivations for changing biosecurity practices and farmers' relationships with their veterinarian(s). Interviews were judged to be over when the interviewer had addressed all topics of interest and the interviewee had nothing further to add. The interviews were analysed using thematic analysis: a qualitative method for in-depth exploration of text data.

The study was approved by the RVC Ethics Committee and signed consent was obtained from all participants.

RESULTS

During the study period, 19.3% of 58 control farms and 18.9% of 57 intervention farms were lost to follow-up, for different reasons including the discontinuation of farming. Individual veterinary practices lost between 12.5-50% of their recruited farms.

VACCINATION STATUS

There was no difference in the odds of vaccination for BVD, IBR and leptospirosis between the intervention and control groups (Table 1).

Table 1: Crosstabulation of intervention/control group status against vaccination status (aggregated across the 4 study years, i.e. the same farm can be included up to 4 times)(OR based on multi-level logistic regression analysis including veterinary practice as random effect)

	BVD vaccination		IBR vaccination		Leptospirosis vaccination	
	Yes	No	Yes	No	Yes	No
Intervention group	112 (59.9%)	75	10 (5.3%)	177	85 (45.5%)	102
Control group	107 (56.9%)	81	11 (5.9%)	177	70 (37.2%)	118

OR (95%CI)	1.13 (0.75-1.72)	0.91 (0.37-2.21)	1.43 (0.93-2.2)

BIOSECURITY ADVICE

Four farms did not receive any biosecurity advice from the veterinarians during the study. More individual pieces of advice were provided per farm in year one of the study (mean 2.7) than during year four (mean 0.7) (p <0.05). More pieces of advice were provided for intervention farms than control farms in year 1 (P=0.002) whilst in year 3 more pieces of advice were given to control than intervention farms (P <0.05). The most common pieces of advice concerned vaccination and on-going monitoring of herd health (~19% each). The next most common were: advice regarding the sourcing of cattle (~9%), pre-purchase testing (7%), post-quarantine testing (7%), quarantine (6%) and reducing contact with neighbours' cattle, i.e. installing secure fences (5%). The majority of advice given to control farms concerned vaccination and the monitoring/control of disease within the existing farm, whereas intervention farms had a larger variety of advice provided including the sourcing of cattle, quarantine and testing pre- and post-purchase.

The majority of advice (68% of recorded advice provided by veterinarians) was followed by both intervention and control farms. The pieces of advice that were least followed by intervention farms were: not sharing equipment, not farming other species, fencing-off water courses and pasture management while for control farms the least followed were: end-of-quarantine testing, changing feed origin and reduced contact with other cattle on-farm (<50% farmers complied with these pieces of advice). Reasons provided for not following advice could be grouped into several categories with the two most common (28.4% of all reasons) being that the advice was impractical for the current situation or expensive to follow. Impracticality was the main reason cited by intervention farms whilst for control farms expense was the major factor. Five percent of intervention and 8% of control farms reported that they did not perceive a need to comply with a particular piece of advice, whilst ~5% of intervention and ~3% of control farms reported that they were waiting, e.g. for test results, before taking action, particularly with regard to herd vaccination.

DISEASE INTRODUCTION RISK SCORES

Mixed linear model analysis showed that introduction risk scores for each of the five infectious diseases decreased over the study period. For tuberculosis there was a statistically significant interaction between intervention/control group and year of study, indicating that in year 4 intervention farms experienced a greater reduction in risk score than control farms (p=0.03).

FARM DISEASE STATUS

Farm Disease Status and vaccination

The association between herd disease status and vaccination was explored using a series of two-by-two tables for the relevant diseases, i.e. BVD, IBR and leptospirosis (see Table 2). It shows that of the 290 farms with complete vaccination and disease status data, 169 farms vaccinated their cattle against BVD, and these were slightly more likely to be sero-positive in the sample of 1-2 year old cattle tested. 26 farms reported to vaccinate against IBR, and almost all of those were sero-positive in the sample. 122 farms reported to vaccinate against leptospirosis, and 18% were sero-positive. There was no difference in the likelihood of sero-positivity between vaccinating and non-vaccinating farms.

Table 2: Crosstabulation of farm disease status against vaccination status (aggregated across the 4 study years, i.e. the same farm can be included up to 4 times)

	BVD		IBR		Leptospirosis	
Vaccinating against relevant disease?	Positive	Negative	Positive	Negative	Positive	Negative
Yes	84	85	14	2	22	100
No	51	70	89	184	32	136
OR (95%CI)	1.36 (0.83-2.23)		14.5 (3.2-132.7)		0.94 (0.49-1.77)	

Figure 2 shows the multivariable association between sero-status for BVD, IBR and leptospirosis, vaccination against these diseases and intervention/control group status generated by a correspondence analysis. Dimension 1 (representing 56% of inertia) of the plot represents good discrimination between farms that vaccinate or don't for BVD, IBR and leptospirosis, whereas dimension 2 (34% of inertia) discriminates between farms with positive and negative sero-status for these infections. An association between IBR vaccination and IBR sero-status is indicated by IBR vaccination having a strong correlation with both dimensions 1 and dimension 2. Neither of the two dimensions discriminates between the intervention and control group farms.

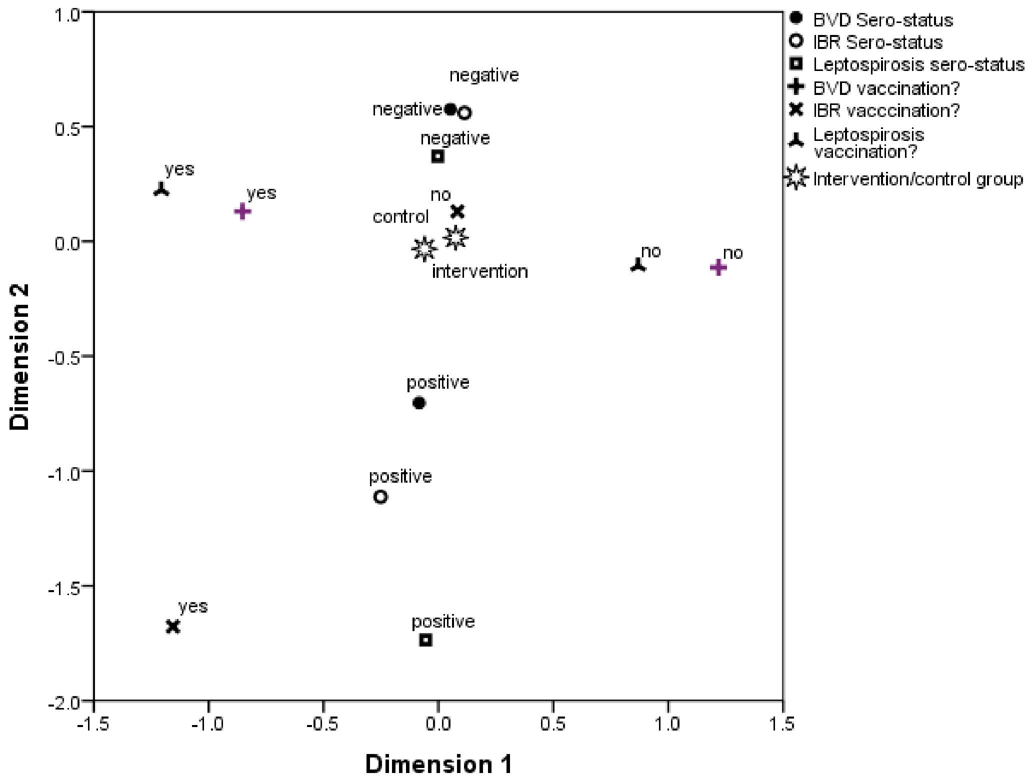

Figure 2: Joint plot of category points generated by multiple correspondence analysis for the variables sero- status for BVD, IBR, leptospirosis, vaccination status for these infections and intervention/control group (aggregated across the 4 study years, i.e. the same farm can be included up to 4 times)

FARM DISEASE STATUS AND DISEASE RISK INTRODUCTION SCORE

An example of a receiver operating characteristic (ROC) curve analyses for the different risk scores as indicator of disease status is disease status is shown in Figure 3 for BVD and Johne's disease. Comparing the areas under the curve for each of the diseases shown in

Table 3 indicates that all risk scoring algorithms perform very similarly independent of the disease they are applied to. The area under the curve is largest for BVD, slightly lower for IBR and leptospirosis and it suggest that the risk scores had little discriminatory value for tuberculosis and none for Johne's disease farm status. The area under the curve does not differ substantially between vaccinating and that for all farms for IBR, but it increases for BVD and even more so for leptospirosis.

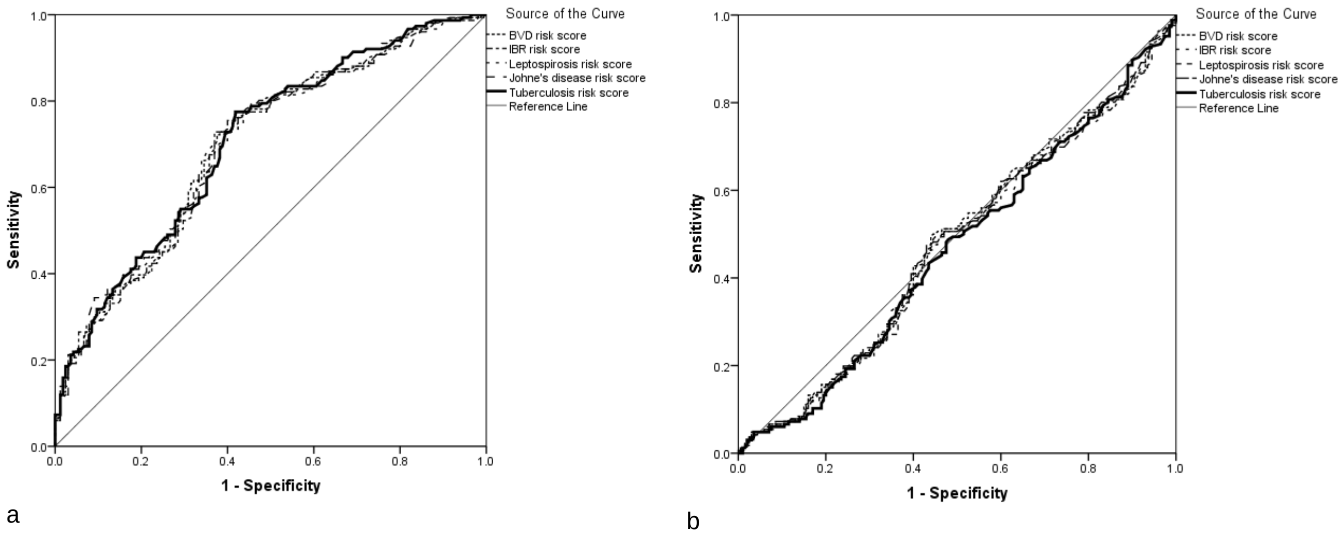

Figure 3: Receiver operating characteristic curves for predictive accuracy of the 5 different disease-specific disease introduction risk scores for BVD (a) and Johne's disease (b) farm sero-status status (aggregated across the 4 study years, i.e. the same farm can be included up to 4 times)

Table 3: Area under the curve for different disease risk introduction score and farm disease status variables (aggregated across the 4 study years, i.e. the same farm can be included up to 4 times)

Introduction risk score for:	BVD sero-status	BVD sero-status (not vaccinating)	IBR sero-status	IBR sero-status (not vaccinating)	Leptospirosis sero-status	Leptospirosis sero-status (not vaccinating)	Johne's disease sero-status	Tuberculosis disease
BVD	0.70	0.73	0.66	0.66	0.64	0.71	0.48	0.56
IBR	0.70	0.73	0.66	0.66	0.64	0.71	0.47	0.56
Leptospirosis	0.70	0.72	0.66	0.67	0.64	0.71	0.47	0.57
Johne's disease	0.70	0.72	0.67	0.67	0.65	0.73	0.48	0.56
Tuberculosis	0.71	0.73	0.67	0.67	0.64	0.70	0.47	0.55

COMPARISON OF FARM DISEASE STATUS BETWEEN INTERVENTION AND CONTROL GROUP

Based on chi-squared tests, there was no statistically significant difference between the intervention and control group in terms of the number of farms changing their disease status between years 1 and 4 of the study (Table 4). There was a trend towards statistical significance in terms of intervention farms being more likely to become sero-negative for leptospirosis.

Table 4: Change in disease status of farms for BVD, IBR, leptospirosis, Johne's disease and TB between years 1 and 4

	Intervention farms				Control farms			Chi-squared
Disease	Became negative	No change	Became positive		Became negative	No change	Became positive	P-value
BVD	14 (43.8%)	13	5	(100%)	4 (18.2%)	14	4	0.14
IBR	7 (21.9%)	14	11		1 (4.8%)	14	6	0.15
Leptospirosis	10 (31.3%)	19	3		3 (13.6%)	19	0	0.08
Johne's disease	4 (12.1%)	19	10		5 (17.1%)	15	9	0.83
Tuberculosis	6 (14%)	28	9		9 (20%)	31	5	0.40

Multiple correspondence analysis was used to examine the association between change in disease status from year 1 to 4 of the study. Outcomes categories were whether a farm became positive or negative or did not change status between years 1 and 4. The results are shown in Figure 4. In this analysis dimension 1 explains 40% of inertia and dimension 2 31.4%. Dimension 1 discriminates well between the two treatment groups, but much less so between the different disease status change variables. Dimension 2 discriminates well between the three outcome categories for tuberculosis. But they are distant from each of the intervention/control group categories, indicating lack of association. All three outcome categories for Johne's disease are close to the origin, therefore also indicating poor discrimination along dimension 1, and limited discrimination along dimension 2. For BVD, IBR and leptospirosis discrimination is moderate to low against both dimensions. The farms which had become sero-negative for BVD, IBR and leptospirosis are clustered around the intervention group category on the plot. Note that the farms which became positive for leptospirosis are also in that same cluster. There is another cluster consisting of farms which either did not change their status or became positive located almost equidistant from the two intervention/control group categories.

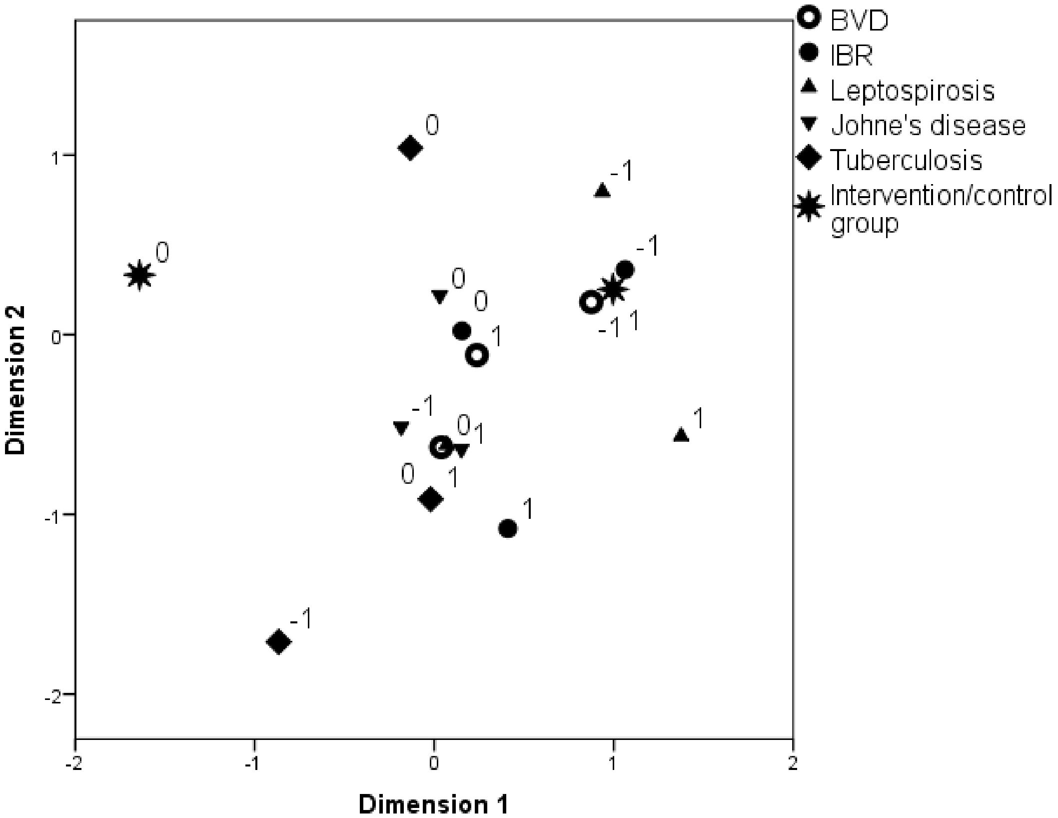

Figure 4: Joint plot of category points generated by multiple correspondence analysis for the change in disease status between years 1 and 4 of the study for BVD, IBR, leptospirosis, Johne's disease and tuberculosis (codes: for BVD, IBR, leptospirosis, Johne's disease and tuberculosis: -1 = farm became negative during study, 0 = there was no change in status, 1 = a negative farm became positive; for intervention/control group: 1 = intervention group, 0 control group)

Multiple correspondence analysis was used to perform an exploratory analysis of the association between different diseases and their respective number of years with positive disease status, and intervention/control group category. The results are shown in Figure 5. Dimension 1 explains 53% of inertia and dimension 2 the remainder. The joint plot of category points shows that there is no discrimination between the two intervention/control group categories, and very limited discrimination for BVD, IBR and leptospirosis. Dimension 1 discriminates primarily between farms that never had any Johne's disease positive animals in the sample examined and the other three categories (1 to 4 years with positive disease status). Dimension 2 discriminates between Johne's disease categories 3 and the other 3 categories, but it primarily discriminates farms which were TB positive during 3 of the four study years and those with 0-2 years (note that there were no farms which were TB positive in all 4 years).

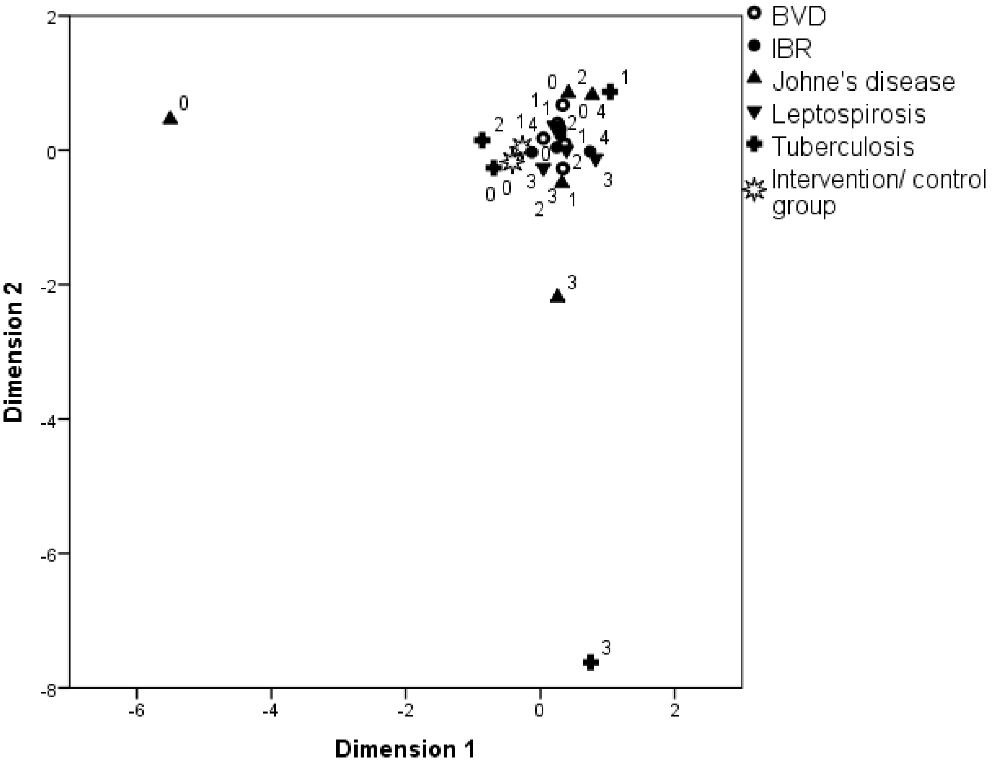

Figure 5: Joint plot of category points generated by multiple correspondence analysis for number of disease positive years in study for BVD, IBR, leptospirosis, Johne's disease and tuberculosis (codes: for BVD, IBR, leptospirosis, Johne's disease and tuberculosis: count of years with positive disease status, 1 = a negative farm became positive; for intervention/control group: 1 = intervention group, 0 control group)

Table 5 shows that only a small number of farms were negative to BVD, IBR or leptospirosis in all four study years. The number were higher for leptospirosis, particularly amongst control farms. Over half of the farms with complete data were negative or tuberculosis in all four study years. No farm for which data was available for all four years was free from all 5 diseases in all four study years (data not presented here).

Table 5: Cross-tabulation of number of years being positive for one of the five infectious diseases (only includes farms for which disease data was available for all four study years)

	BVD		IBR		Leptospirosis		Johne's disease		Tuberculosis	
Years positive	Intervention	Control	Intervention	Control	Intervention	Control	Intervention	Control	Intervention	Control
0	1	4	4	5	8	14	4	4	21	25
1	8	3	7	8	9	1	8	8	15	12
2	7	2	6	1	4	0	10	7	6	5
3	6	4	3	1	1	2	6	6	1	2
4	0	5	2	2	0	0	4	3	0	0
Total	22	18	22	17	22	18	32	28	43	44

The multivariable multilevel mixed logistic regression analysis results are presented in

Table 6. There was no statistically significant effect of intervention/control group as a main effect or as an interaction with year of study on any of the five diseases. Vaccination status was significant for BVD and IBR, but not for leptospirosis. There was a decrease across both study groups in the odds of a farm being positive for leptospirosis from the start of the study to the end.

Table 6: Results of multivariable multilevel mixed logistic regression analysis of the association between intervention/control group and disease status (farm nested within veterinary practice was included as random effect in all analyses, except for TB where a random effect based on only veterinary practice improved model fit) (aggregated across the 4 study years, i.e. the same farm can be included up to 4 times)

Risk factor	BVD (OR and p-value)	IBR (OR and p-value)	Leptospirosis (OR and p-value)	Johne's disease (OR and p-value)	Tuberculosis (OR and p-value)
Intervention/ control group	1.32 (0.70)	1.30 (0.72)	1.12 (0.90)	1.03 (0.96)	0.40 (0.22)
Year of study	0.77 (0.17)	1.17 (0.42)	0.43 (0.01)	1.03 (0.86)	0.88 (0.50)
Interaction Intervention/control group * year	0.76 (0.30)	1.01 (0.98)	1.47 (0.32)	1.10 (0.68)	1.45 (0.16)
Vaccination (relevant to particular disease)	2.03 (0.06)	22.5 (<0.01)	0.96 (0.94)	NA	NA

In an additional analysis, farms were categorised within years with respect to being positive for at least one of the different disease combinations within a particular study year. For none of the combinations was there a statistically significant association with intervention/control group.

COMPARISON OF WITHIN-FARM PREVALENCE/INCIDENCE BETWEEN INTERVENTION AND CONTROL GROUP

Across intervention and control groups, the average of the within-farm sero-prevalence Bayesian estimates in year 4, amongst the cattle that met the inclusion criteria for intervention and control farms, was lower compared with year 1 of the project, for BVD and leptospirosis, and similar in both years for IBR (Table 7). For Johne's disease, it was lower in year 4 than in year 1 in the intervention group, and reverse was the case for the control group (Table 7). The 95% credible intervals for Johne's disease sero-prevalence in the control group do not overlap between years 1 and 4 indicating that the increase in prevalence was statistically significant (Table 7). All other 9% credible intervals overlapped, suggesting there was no statistically significant difference between years 1 and 4 of the study.

Table 7: Mean within-farm sero-prevalence Bayesian estimates (in %) with credible intervals (CI), for years one and four of the project, for BVD, IBR, leptospirosis and Johne's disease.

Disease	BVD		IBR		Leptospirosis		Johne's disease	
Year	1	4	1	4	1	4	1	4
Intervention farms sero-prevalence	2.62	0.70	3.32	3.09	2.03	0.92	2.71	1.42
95% CI	(0.24-5.20)	(0.03-2.04)	(2.11-4.76)	(1.60-4.85)	(0.14-4.08)	(0.04-2.53)	(0.47-4.64)	(0.09-3.06)
Control farms sero-prevalence	3.82	1.66	3.41	3.19	1.26	1.18	2.05	11.93
95% CI	(0.90-6.77)	(0.08-4.08)	(2.07-5.05)	(1.87-4.83)	(0.07-2.89)	(0.06-2.80)	(0.18-3.92)	(7.58-17.59)

The multivariable multilevel mixed logistic regression analyses results for within-farm prevalence/incidence are presented in Table 8. For BVD, leptospirosis and Johne's disease, there was a reduction in the odds of infection (=sero-positivity) over the study period for both the intervention and control group. For IBR this effect only applied to the intervention group and for Johne's disease the reduction was stronger in intervention farms. Infection risk (=sero-positivity) was increased in vaccinating IBR farms. There was no statistically significant association between intervention/control group status, year of study and incidence of tuberculosis.

Table 8: Results of multivariable multilevel mixed logistic regression analysis of the association between intervention/control group and within-farm infection prevalence/incidence (farm nested within veterinary practice was included as random effect in all analyses) (aggregated across the 4 study years, i.e. the same farm can be included up to 4 times)

Risk factor	BVD (OR and p-value)	IBR (OR and p-value)	Leptospirosis (OR and p-value)	Johne's disease (OR and p-value)	Tuberculosis (OR and p-value)
Intervention/ control group	1.11 (0.85)	1.56 (0.40)	2.04 (0.14)	1.29 (0.34)	0.40 (0.22)
Year of study	0.47 (<0.01)	1.01 (0.92)	0.57 (<0.01)	0.80 (<0.01)	0.88 (0.50)

Interaction Intervention/Control Group * Year of study	0.97 (0.79)	0.78 (0.06)	0.94 (0.69)	0.82 (0.04)	1.45 (0.16)
Vaccination (relevant to particular disease)	1.06 (0.74)	7.63 (<0.01)	1.28 (0.31)	NA	NA

RISK FACTORS ASSOCIATED WITH FARM DISEASE STATUS

The results from the multivariable multilevel mixed logistic regression analyses for identifying risk factors associated with farm disease status within different study years are shown in Table 9. The odds of being positive for BVD, IBR and Leptospirosis increased with farm size. Increased numbers of purchased animals increased the odds of a farm being positive for IBR. In the case of Johne's disease and IBR, potential exposure to other livestock was associated with a reduced odds of being serologically positive. For BVD and leptospirosis, the odds of being seropositive decreased over the study period. Farms that used IBR vaccination were more likely to be seropositive for IBR. None of the risk factors was statistically significantly associated with TB status.

Table 9: Results of multivariable multilevel mixed logistic regression analysis of the association between various risk factors and disease status (farm nested within veterinary practice was included as random effect in all analyses, except for TB where a random effect based on only veterinary practice improved model fit) (aggregated across the 4 study years, i.e. the same farm can be included up to 4 times)

Variable type	Risk factor	BVD (OR and p-value)	IBR (OR and p-value)	Leptospirosis (OR and p-value)	Johne's disease (OR and p-value)	Tuberculosis (OR and p-value)
Herd size	Herd size	1.01 (<0.01)	1.01 (<0.01)	1.01 (0.03)		
Purchase behaviour	Categorised number of animals introduced in past 12 months		1.99 (<0.01)			
Exposure to other herds	Animals grazed away from main premises and have direct contact with other livestock				0.35 (0.02)	
	Frequency of over the fence contact with other cattle		0.73 (<0.01)			
Other	Year of study	0.72 (<0.01)		0.58 (<0.01)		
Vaccination titre?	Vaccination against relevant disease		19.9 (<0.01)			

The results for the multivariable analysis to identify risk factors associated farms categorised within years with respect to being positive for at least one of different disease combinations within that particular study year are presented in Table 10. The odds of a farm being positive for at least one of the 5 infectious diseases increased with herd size. If a herd was closed it reduced the odds of being positive for at least one of the five diseases. Increased opportunity for over the fence contact to neighbouring cattle reduced the odds of being sero-positive for either BVD, IBR or leptospirosis. The odds of a farm being sero-positive for at least one of these three diseases reduced during the study period. None of the risk factors considered was statistically significantly associated with a farm being positive for either Johne's disease or tuberculosis in a particular study year.

Table 10: Results of multivariable multilevel mixed logistic regression analysis of the association between various risk factors and being positive for eat least one of different disease combinations (farm nested within veterinary practice was included as random effect in all analyses) (aggregated across the 4 study years, i.e. the same farm can be included up to 4 times)

Variable type	Risk factor	BVD or IBR (OR and p-value)	BVD or IBR or Lepto (OR and p-value)	BVD or IBR or Lepto or Johne's disease (OR and p-value)	BVD or IBR or Lepto or Johne's disease or Tuberculosis (OR and p-value)	Johne's disease or Tuberculosis (OR and p-value)
Herd size	Herd size	1.01 (<0.01)	1.01 (<0.01)	1.01 (<0.01)	1.01 (0.03)	
Purchase behaviour	Closed herd	0.44 (0.01)	0.44 (0.02)	0.44 (0.05)	0.40 (0.03)	
Exposure to other herds	Frequency of over the fence contact with other cattle		0.70 (<0.01)			
Other	Year of study		0.67 (0.02)			

The classification tree analysis results are only presented for one outcome variable due to lack of space, and the resulting tree is presented in Figure 6. It shows that amongst the total of 315 farm observations included in this particular analysis, 104 farms were negative for BVD, IBR and leptospirosis in a particular year of the study (note that the same farm will be included up to four times in this dataset, except if the diagnostic test results were missing). Amongst the farms with > 83 cattle less 12 months old, 9.4% of the farms had no positivity to any of these diseases, whereas 39% did so amongst those with less than that number of youngstock. In this latter group of 251 farms, 49 had more than 47 cattle >= 12 and < 24 months of age, of which 41% had not been positive to any of the three diseases in a particular year of the study. And if amongst farms with less than 47 cattle >= 12 and < 24 months of age they did not purchase any cattle in that same age group in this year of study, 57% were not positive for any of the three diseases.

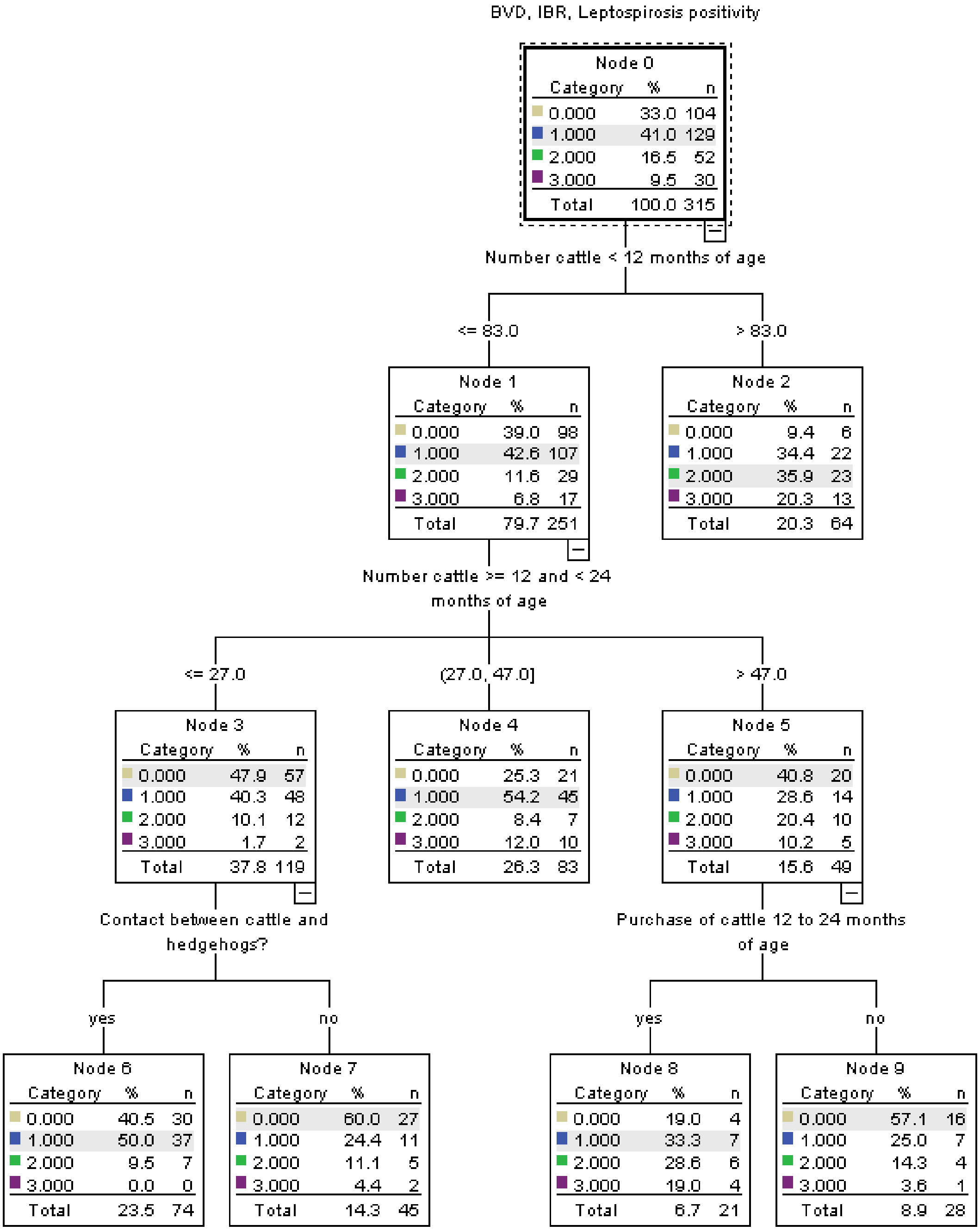

Figure 6: Classification tree showing the risk factors associated with the number of different diseases (BVD, IBR and leptospirosis) for which a farm is sero-positive during a particular study year (based on CHAID method) (aggregated across the 4 study years, i.e. the same farm can be included up to 4 times)

RISK FACTORS ASSOCIATED WITH WITHIN-FARM PREVALENCE/INCIDENCE

The multivariable multilevel mixed logistic regression analyses results for the association between various potential risk factors and within-farm prevalence/incidence are presented in Table 11. Herd size or having more adult animals increased the odds of animal sero-positivity for BVD and IBR. In the case of tuberculosis, an increasing number of 1-2 year old cattle was associated with a decrease in incidence. An increasing number of cattle introductions was associated with an increased within-farm prevalence for IBR and leptospirosis. Grazing animals away from the main premises where they had opportunity for direct or indirect contact with other livestock reduced the odds of Johne's disease animal sero-positivity. An increasing frequency of over the fence contact with cattle from neighbouring farms was associated with an increased odds of animal positivity for BVD, leptospirosis, Johne's disease and tuberculosis. If ruminants other than cattle had access to cattle feed or feed stores the odds of animal sero-positivity for IBR increased. The odds of Johne's disease animal sero-positivity reduced if the neighbouring farms had arable land at the boundary. Visits by agricultural supplies representatives increased the odds of animal sero-positivity for IBR. In the case of tuberculosis, visit by non-livestock owning friends or family increased the incidence whereas using borrowed vehicles and equipment for slurry or cattle transport was associated with a decreased incidence. Prevalence for BVD and leptospirosis decreased throughout the study period. For IBR, this was only the case in the intervention group. Farms that vaccinated against IBR had an increased odds of animal sero-positivity for BVD and leptospirosis. If they vaccinated against BVD, animals were more likely to be sero-positive for IBR and leptospirosis. IBR vaccination was associated with an increased odds of animals being positive for IBR.

Table 11: Results of multivariable multilevel mixed logistic regression analysis of the association between various risk factors and disease prevalence (farm nested within veterinary practice was included as random effect in all analyses) (aggregated across the 4 study years, i.e. the same farm can be included up to 4 times)

Variable type	Risk factor	BVD (OR and p-value)	IBR (OR and p-value)	Leptospirosis (OR and p-value)	Johne's disease (OR and p-value)	Tuberculosis (OR and p-value)
Herd size	Herd size	1.01 (<0.01)				
	No of animals >=2yrs		1.003 (<0.01)			
	No. of animals 1-2 yrs					0.99 (0.04)
Purchase behaviour	Categorised number of animals introduced in past 12 months		1.81 (<0.01)	2.21 (<0.01)		
Exposure to other herds	Animals grazed away from main premises and have direct contact with other livestock				0.52 (0.02)	
	Animals grazed away from main premises and have indirect contact with other livestock				0.69 (0.04)	
	Frequency of over the fence contact with other cattle	1.65 (<0.01)		1.16 (0.03)	1.16 (<0.01)	1.14 (0.04)
Other	Ruminants other than cattle have access to cattle feed / feed stores		4.44 (<0.01)			
	Pastures adjacent to neighbouring farms arable land				0.72 (0.03)	
	Visits by agricultural supplies representatives		2.56 (<0.01)			
	Visits by non-livestock owning friends/family					1.90 (0.03)
	Borrows vehicles for slurry and cattle transport					0.56 (0.02)
	Intervention compared with control group		1.81 (0.31)		1.57 (0.12)	
	Year of study	0.61 (<0.01)	1.31 (0.04)	0.57 (<0.01)	0.93 (0.40)	
	Interaction Intervention/control group * Year of study		0.66 (0.02)		0.77 (0.02)	
Risk management through vaccination	Vaccination against IBR	44.6 (<0.01)		8.20 (<0.01)		
	Vaccination against BVD		2.07 (0.01)	2.31 (<0.01)	0.70 (0.03)	
Vaccination titre?	Vaccination against relevant disease		17.9 (<0.01)		NA	

FARMING SYSTEMS AND PRODUCTION PERFORMANCE

Table 12 summarises the farming system and animal production performance of control and intervention group farms for the base year 2008, and for the three years following the introduction of tailored biosecurity advice on the intervention farms. Both intervention and control farms are somewhat larger than the national average in terms of both the area farmed and beef herd size (Defra, 2013) and the age of the occupier is around 10 years lower than the average for the UK.

In all years it can be seen that the intervention farms were, on average, 20-30 ha smaller in size than the control group and with a smaller grassland area. However, despite this area difference, the average herd size for the two groups was very similar, as the intervention group operated with higher average stocking rates and N fertilizer application rates, strongly suggesting that intervention group farms were either on more favourable land, or were better at managing their grassland. Intervention farms used less concentrate feed per cow than the control farms, suggesting greater use of home-produced forage. There were no significant differences between intervention and control farms in the number of barren cows, calves born alive, calves died and calves reared, all calculated per 100 cows.

Table 12: Farming system and animal production performance characteristics of study farms by intervention/control group and study year (means)

	2008		2009	
FARMING SYSTEMS	Control	Intervention	Control	Intervention
Sample size	49	50	49	50
Total area farmed (ha)	184.2	162.69	183.1	149.01
Herd size (head) of sample	77.1	81.04	67.8	66.12
Grassland area (ha)	130.96	126.3	146.34	114.32
Age of farmer	47.84	47.08	48.84	48.08
ANIMAL PRODUCTION PERFORMANCE				
Barren cows per 100	9.6	9.57	9.18	9.45
Calves born alive per 100	92.32	91.27	92.69	90.75
Calves died per 100	4.33	3.77	6	4.05
Calves reared per 100	95.66	96.23	96.66	98.38
Total concentrates (kg per cow)	209.11	198.8	198.29	176.23
N Fertiliser use (kg per ha)	44.57	49.38	33.66	37.5
Stocking rate (LSU per ha)	0.68	0.72	0.69	0.72
		2010		2011
FARMING SYSTEMS	Control	Intervention	Control	Intervention
Sample size	49	50	49	50
Total area farmed (ha)	184.27	151.28	189	149.97
Herd size (head) of sample	73.61	76.22	77.63	78
Grassland area (ha)	133.79	116.26	137.18	115.71
Age of farmer	49.84	49.08	50.84	50.08
ANIMAL PRODUCTION PERFORMANCE				
Barren cows per 100	10.04	10.26	10.08	10.74
Calves born alive per 100	92.09	92.08	90.35	92.19
Calves died per 100	5.91	6.48	6.15	6.7
Calves reared per 100	94.09	93.51	93.84	92.3
Total concentrates (kg per cow)	166.03	124.62	126.24	93.39
N Fertiliser use (kg per ha)	37.09	45.54	37.4	41.9
Stocking rate (LSU per ha)	0.66	0.73	0.67	0.7

FINANCIAL PERFORMANCE

Table 13 summarises the financial performance of control and intervention farms. Financial measures are presented following the conventions of Defra and Levy-board farm economists, viz: ‘output’ from calf sales has ‘variable costs’ deducted to provide a ‘gross margin’ per cow. Then, ‘fixed costs’ are deducted to arrive at a ‘net margin’ figure, which is a form of enterprise profit. The payments farmers received from the EU Common Agricultural Policy, namely the Single Farm Payment and Less-Favoured Area payments, are not included in the calculations since they can be considered as ‘transfer payments’ to farmers from taxpayers.

Table 13: Financial performance of the study farms by intervention/control group and study year (means)

Farm costs	2008			2009		
	Control	Intervention		Control	Intervention	
No of farms	49	50	Sig	49	50	Sig
OUTPUT (£)	508.11	554.75	p>0.1	596.20	582.50	p>0.2
VARIABLE COSTS (£)	264.17	262.86		320.00	323.20	
GROSS MARGIN (£)	243.94	291.89	p>0.6	276.20	259.30	p>0.6
FIXED COSTS (excluding non-cash costs) (£)	358.88	299.22	p>0.1	417.50	407.60	p>0.1
NET MARGIN (excluding non-cash costs) (£)	-114.94	-7.33	p>0.1	-141.30	-148.30	p>0.1
NON-CASH COSTS (£)	289.29	206.50	p>0.1	337.30	171.90	p>0.1
NET MARGIN (Including non-cash costs) (£)	-404.23	-213.83	p>0.1	-478.60	-320.20	p>0.2
Farm costs	**2010**			**2011**		
	Control	Intervention		Control	Intervention	
No of farms	49	50	Sig	49	50	Sig
OUTPUT (£)	592.29	612.68	p>0.3	685.10	718.17	p>0.8
VARIABLE COSTS (£)	275.70	340.40		357.80	328.10	
GROSS MARGIN (£)	316.59	272.28	p>0.6	327.30	390.07	p>0.6
FIXED COSTS (excluding non-cash costs) (£)	379.00	375.10	p>0.1	419.60	407.70	p>0.1
NET MARGIN (excluding non-cash costs) (£)	-62.41	-102.82	p>0.1	-92.30	-17.63	p>0.1
NON-CASH COSTS(£)	241.90	251.00	P>0.1	312.20	296.00	p>0.1
NET MARGIN (Including non-cash costs) (£)	-304.31	-353.82	p>0.3	-404.50	-313.63	p>0.8

Also excluded from the calculations are compensation payments received for slaughter of *Mycobacterium bovis* (TB) reactors. Consequently, the data capture the true (societal) financial impact of TB breakdowns (per farm) and any real loss avoidance that may arise from improved biosecurity. The inclusion of subsidy payments would mask both of these impacts. However, the number of TB reactors is low and incidence is very similar in control and intervention groups, as well as being relatively constant over time. Incidence of TB reactors was also unrelated to disease introduction risk score. Exchequer costs for TB slaughter compensation payments was £80.65 per farm averaged over all farms in the control group (many of whom had no TB reactors), and £94.88 in the intervention group.

The figures from Table 8 show that, for each of the four years, on average, beef enterprises on intervention and control farms made a substantial (three figure) loss per cow based on the net margin measure (before subsidy). In general, there was very little difference in financial performance of beef enterprises on intervention and control farms over the study period. Calf output differences between intervention and control farms in 2008, 2010 and 2011 were not statistically significant enterprise gross margin differences between the intervention and control farms were also non-significant There were no significant differences in 'net margin including non-cash costs', the nearest to a profit figure if subsidies are ignored, between intervention and control farms

SPECIFIC EXPENDITURE ON BIOSECURITY MEASURES

Table 14 below highlights a selection of specific biosecurity items together with the division of costs between the intervention and control farms. Study farmers were surveyed for eight quarterly periods to determine their precise expenditure on biosecurity measures both by item and by labour time. Overall, the majority of farms spent considerably less than £250 per year. On intervention farms, expenditure on rat bait and disinfectant was significantly higher than that on control farms *(p=0.03).*

Table 14: Mean expenditure per study quarter per farm on specified biosecurity items for intervention and control farms

	Status	N	Mean	Std. Deviation	t	Significance
Disinfect & iodine	Control	35	2.97	4.581	-1.151	P≤0.490
	Intervention	41	3.97	7.355		
Fencing	Control	35	54.23	113.869	0.508	P≤0.668
	Intervention	41	41.99	131.562		
Washing yards & maternity areas	Control	35	24.55	100.070	1.132	P≤0.236
	Intervention	41	3.91	17.529		
Rat bait & pest control products	Control	35	22.04	20.300	-3.161	P≤0.003
	Intervention	41	47.20	47.673		

DISEASE INTRODUCTION RISK SCORES AND FINANCIAL PERFORMANCE

The risk score was regressed on a range of key animal production and financial performance indicators referenced in the intervention/control group analysis above. The regression analysis showed no significant relationship between any of the variables and risk score in any year. However, it is possible that the impacts of improved biosecurity actions taken in any year might be felt in subsequent years. To test for this type of relationship, a lagged regression analysis was undertaken, exploring the relationship between animal production and financial performance in years 3 and 4 and risk scores in earlier years. Model R^2 values were generally low, typically less than 10%, indicative of weak explanatory power, with the only nearly statistically significant relationship found being that between risk score (year 3) and net margin (year 4) (P=0.055). Analyses of the impact of farm expenditure on biosecurity measures and animal production and financial performance (i.e. comparing the top third of farmers spending most per head of cattle with the bottom third spending the least) found two statistically significant relationships, showing that higher expenditure on biosecurity in year 3 was associated with a reduced number of barren cows in year 4 (p<0.05) but also an overall reduction in net margin in year 4 (p<0.05).

FARMERS' ATTITUDE TOWARDS BIOSECURITY

In 2009 and 2011, all study farmers were asked a series of questions relating to the biosecurity measures they implemented, and their views and level of satisfaction with these measures. Table 15 records the frequency with which eight biosecurity measures were undertaken by study farmers using the categories 'always', 'sometimes' and 'never'. Control and intervention group data are aggregated in this analysis as there was no significant difference between the two groups in either year on any single measure (2009, P=0.1; 2011, P=0.2). Responses to four of the items differed significantly between the two years. These were that: by 2011 more farmers were ensuring that bought-in cattle were disease free/accredited; by 2011 fewer farmers were using isolation boxes for positive/sick cases; by 2011 more farmers were isolating and blood testing bought-in cattle; and by 2011 more farmers were protecting buildings from wildlife access.

Table 15: Frequency of use of biosecurity measures on study farms, 2009 and 2011

Biosecurity measures	2009 (% of n= 99)			2011 (% of n= 96)			Wilcoxon Signed rank
	Always	Sometimes	Never	Always	Sometimes	Never	
Ensure that bought in cattle are disease free / accredited	41	37	22	50	41	9	P = 0.02
Keep my cattle away from other cattle / neighbours	54	32	14	55	36	9	P = 0.48
Breed my own replacements	52	39	9	48	42	10	P = 0.28
Use AI	8	34	58	7	33	60	P = 0.62
Use isolation boxes for positive / sick cases	53	41	6	4	58	38	P <0.01
Use disinfectants in buildings and on vehicles / visitors	19	68	13	21	71	8	P = 0.16
Isolate and blood test bought-in cattle	16	23	61	34	30	36	P <0.01
Protect buildings from wildlife access	4	41	55	16	44	40	P <0.01

Farmers were also asked how satisfied they were with their current biosecurity measures (Table 16). By 2011 a much higher proportion of the farmers were satisfied with their biosecurity measures than in 2009 (P≤0.0001).

Table 16: How satisfied are you with your current biosecurity measures?

Farmer satisfaction with current biosecurity measures	2009 (% of n=99)	2011 (% of n=96)
Very satisfied	0	6
Satisfied	8	92
Indifferent	24	1
Unsatisfied	65	1
Very unsatisfied	3	0

S = -1914; P <0.0001

The study farmers were then presented with a set of 11 statements concerning disease and biosecurity and asked to indicate their level of agreement with them. For nine of these statements, there were no statistically significant differences between the two years. However, significantly more farmers in 2011 than in 2009 agreed with the statements 'My farm has a high risk of disease' (P=0.0006), and 'My friends and colleagues in the beef industry would be supportive of my use of enhanced biosecurity measures' (P=0.05).

SEMI-STRUCTURED INTERVIEW STUDY OF FARMERS' ATTITUDES TOWARDS AND PERCEPTIONS OF BIOSECURITY

Of the twenty farmers selected for interview, one declined to take part, one initially agreed to take part but later declined because he had decided to sell his farm, one wanted to take part but was unavailable and two could not be contacted. The interviews lasted between 20 and 70 minutes. Several themes emerged from the interviews, detailed discussion of which is beyond the scope of this report, so a brief description of key themes follows. A more detailed account will be submitted for publication.

1. *Most of the farmers valued very highly the deeper level of understanding gained from participating in the project.*

   Interviewee 2: "He [another farmer] wanted to spread slurry on our land. And since doing the biosecurity [project] there is no way we would have let them do it. Before? Yes, sure. That's brilliant. That's a great way of getting PNK into the soil and so on. Whereas now, you're like no, no, no..... but you didn't realise it until you actually went into it."

2. *Many farmers felt that there was a need amongst fellow farmers for education – in particular applied knowledge- on disease control.*

   Interviewee 6 [regarding BVD control]: "My hubby he wouldn't know exactly what to do. But I'm probably more interested. But I, you know... It is quite difficult to get your head around some of these things, really."

3. *In most, if not all interviews, the local vet was seen as the ultimate authority and most reliable source of disease control advice. Their knowledge of local conditions was perceived as important.*

   Interviewee 3: "Well, you trust the vets! You don't challenge their knowledge because they're far more qualified than I am."

4. *Many farmers expressed unwillingness to accept the need to cull test-positive animals that appear to be healthy – even farmers who were clearly convinced by epidemiological principles.*

   Interviewee 1: But it's difficult to cull them because they're in calf and you know at the moment they don't show any signs of the disease...if they started to show signs we would cull them.

5. *Several farmers tended strongly towards individual interpretation of tests even when the tests had poor sensitivity.*

   Interviewee 9: It [Johne's] was a disease I was conscious of but never had a case. Yes, we'd tested the odd cow and saying, "Gosh," the vet comes on and says it's a classic case of Johne's, you know. And I'd say well let's test it. And of course, we've done that I suppose three or four times in our lifetime and never found a case. So, that was comforting.

6. *The term 'biosecurity' lacked a universally-understood meaning and had negative connotations in particular with the 2001 foot and mouth disease outbreak.*

   Interviewer: If I can ask you to think back to when you think you first heard the word 'biosecurity', when do you think that was?

   Interviewee 5: Foot and mouth ... we were culled ... It was unbelievable ... I was coming out the gate and the vet was there and there was a bit of dirt on my hat; I had a hat on. He said, "woah, woah, stop! There's some shit on your hat!" And I had to take my hat off and he put it in a plastic bag and wrapped it up. God. I thought, "this is getting a bit extreme."... Biosecurity was drummed into us then soon enough!

7. *Family were frequently involved in on-farm decisions.*
8. *There was a sense amongst many farmers that a certain level of biosecurity was futile.*
9. *There was a sense amongst some farmers that other farmers lacked motivation to improve biosecurity because of either a lack of understanding of the hidden costs of disease, or because a lack of financial incentive.*
10. *There was evidence that farmers trusted underlying guiding principles or traditions to inform their decisions. For example, prevention was seen as a good practice in general.*
11. *Tangible evidence or experience was an important driver to improving biosecurity. No evidence of disease was frequently seen as justification for not improving biosecurity.*

    Interviewee 2: Dad ... had a few cases and vaccinated for [blackleg]. We didn't have blackleg then for however long they were vaccinated for. Then thought they didn't need to vaccinate for blackleg, then lost a few with blackleg. And it's sort of that mentality in farmers, you know? It's almost trying to get the money out of them to prevent the problem rather than we will only spend money when we see the problem. Hard to get a farmer to pay for the vet's call-out [fee] anyway when they can see the problem.

12. *Some farmers felt disease was stigmatising.*

    Interviewee 9: And also, I think TB is less of a sort of bogieman type of thing now because so many people have got it it's not just the dirty ones but they've got it, you know. So, we've moved up a level now, not just the scum. You're part of a sort of middle class majority! So, it's not quite so bad.

13. *Some farmers felt it was impossible to create beef-cattle proof boundaries whereas others in areas where earth banks were traditional felt their boundaries were extremely effective.*

DISCUSSION

GENERAL

For many farmers, veterinarians are the primary source of biosecurity information (Heffernan et al. 2008). There is therefore potential for veterinarians to develop this role further, as long as farmers perceive this advice as being practical and efficient to use, as has been demonstrated by a focus-group study by Gunn et al. (2008). The impact of tailored biosecurity advice was compared between control and intervention farms based on three different outcomes: 1) Disease-specific introduction risk scores determined by annual risk assessments, 2) infection prevalence estimated annually using serological testing of a sample of cattle from each farm and 3) an economic assessment. A dual approach of scoring risk and testing animals has been described by several studies including those by Pillars et al. (2011) and Espejo et al. (2012). Advice provided by the veterinarians during this study was based on a structured approach applied to each farm in the intervention group. It consisted of a standardised risk assessment which then informed risk management advice tailored to the specific risk characteristics of the farm. A similar approach has also been used by Sorge et al. (2010). Rather than focussing on individual risk factors or their combination, in the current project the veterinarians developed a set of recommendations tailored to the individual farm and the farmer personality as a result of linking the information gathered through the structured risk assessment with qualitative observations, including the veterinarian's perception of the specific farmer's behavioural characteristics and decision-making priorities. The risk assessments led to disease-specific (e.g. fencing off water courses to reduce the risk of leptospirosis) and generic (e.g. careful sourcing of new cattle, serological monitoring and removing infected animals to reduce both BVD and Johne's disease) advice. The evidence base for the risk assessment and risk management/advice was based on information published in the scientific literature (e.g. Coetzer and Tustin 2005; Radostits et al 2006; Villarroel et al. 2007).

METHODOLOGY

One of the methods for measuring impact was the serological infection status for BVD, IBR and leptospirosis. Some of the farms vaccinated their cattle against these diseases, which will have resulted in them being classified as sero-positive as a result of vaccine-induced antibodies rather than infection. It is therefore somewhat unexpected that only in the case of IBR was there a statistically significant association between vaccination and farm sero-status. The multiple correspondence analysis results also indicate that there is an association between IBR vaccination and sero-status but no association between vaccination and sero-status for BVD and leptospirosis. It therefore has to be suspected that vaccination strategies for the latter two diseases varied substantially between study farms, in terms of which age group and what percentage of animals was actually vaccinated. In the case of IBR, 16 farms vaccinated and 14 of them were sero-positive (note that that these counts may include individual farms up to 4 times). The analyses associated with farm sero-status which are discussed below need to be interpreted taking into account that sero-positivity may have been the result of vaccination.

It should be noted that the study allowed little differentiation between prevalent and incident disease, and therefore also between factors facilitating introduction of infection and within-farm spread following successful introduction. The assumption was made that the diseases had been introduced at some stage, and that subsequent within-farm spread influenced the likelihood of detection. We therefore continue to refer to risk factors influencing risk of introduction.

The study used a longitudinal approach, in that the same farms were visited during each year of the study, and some of the cattle were sampled repeatedly. As a consequence, the statistical analyses needed to account for non-independence in the data, such as more than one farm working with a single veterinary practice and repeated (annual) data from the same farm. This issue was addressed by incorporating random effects representing 'veterinary practice' and 'farm nested within veterinary practice' into the multivariable logistic regression analyses.

A key factor in this study was to perform the data collection through the veterinarians who have these farms as regular clients. Although this introduces a variety of biases, it allows for a more realistic assessment of the intervention. As part of this it had to be accepted that veterinarians would also provide advice to control farms in the context of their usual interaction with their farmer clients. To be able to deal with this bias in the analyses, veterinarians were asked to record any advice they provided.

In conclusion, this study was based on a complex data collection process, with veterinary professional opinion and trust-based relationships with farmers at its core. This was both integral to the main study hypothesis and a source of bias in the investigation. The use of different outcome variables and advanced multivariable statistical analysis methods was helpful, but did not obviate the need to apply very careful and considered interpretation to the results.

BIOSECURITY ADVICE AND FARMER UPTAKE

Almost all study farms received biosecurity advice from their veterinarians. This included advice on vaccination, and in year 1 it tended to be a more comprehensive package of different pieces of advice for intervention farms than for control farms, but in year 3 more pieces of advice were provided to control farms compared with intervention farms. It should be noted that the study originally had only been set up for two years of data collection, and therefore veterinarians may have become more proactive in year 3 in providing advice to control farms. But it has to be acknowledged that as a result of the regular frequent interaction with their veterinarians as part of the annual data collection for this project which also resulted in biosecurity advice being given, the control farms included in this study will not have been representative of the biosecurity behaviour of typical beef farmers within the farm populations in the study area. Consequentially, the likelihood of the study being able to show a statistically significant difference between intervention and control farms if it did indeed exist (e.g. its statistical power) will have been much lower than planned in the study design phase.

A key factor in the effectiveness of any advice provided by veterinarians to farmers is whether farmers are actually prepared to follow it. Across both treatment groups, 68% of advice was followed by farmers, which will have resulted in a reduction of the ability of the study to demonstrate impact of the intervention. It seems that a substantial proportion of farmers were reluctant to change their biosecurity management for a number of reasons, including it being impractical or too expensive.

In conclusion, the difference in terms of the extent of tailored biosecurity advice provided by veterinarians between the intervention and control group was smaller than intended as part of the study design. In addition, the uptake of individual pieces of advice by farmers was very variable, and only a few farmers accepted the complete biosecurity package. Both these aspects will have reduced the ability of the study to detect a difference between the intervention and control group.

FARM DISEASE STATUS

Most study farms were positive for at least one of the five diseases in at least one of the four study years. A small number of farms was positive for either BVD, IBR or Johne's disease in all four study years. This shows that some of these farms are able to maintain freedom from single infectious diseases, specifically from leptospirosis and tuberculosis, assuming that the age group sampled in this study was representative of farm infection status. None of the farms managed to be free from all five infections across all four study years. This most likely reflects the variation in risk factors influencing the occurrence of different infectious diseases examined in this study.

In conclusion, the five diseases investigated in this study are prevalent in the study population and appear to vary in their occurrence within the same farm between study years, which may be a result of farm management, population sampling or imperfect diagnostic tests.

FARM DISEASE STATUS AND RISK ASSESSMENT SCORES

The risk assessment which was conducted at the beginning of the study and then again at the end of each study year resulted in a farm-specific disease introduction risk score at each of these occasions. Its predictive ability was assessed against the farm status for the different infectious diseases considered here. These analyses show that the different disease-specific introduction scores correlate very highly, and there seems little value in separating them by disease. As predictors of farm infection status, they performed moderately well for BVD, IBR and leptospirosis, but poorly for tuberculosis and Johne's disease. This suggests that the various risk factors contributing to the score have little or no influence on the latter two diseases.

In conclusion, the risk scoring algorithm appears to reflect generic mechanisms of infection risk for BVD, IBR and leptospirosis, but not for Johne's disease and tuberculosis.

FARM DISEASE STATUS/ WITHIN-FARM PREVALENCE AND INTERVENTION/CONTROL GROUP

The observed pattern of change in farm infection status suggests that there was a trend towards statistical significance with the intervention farms being more likely to become sero-negative for leptospirosis by the end of the study than control farms (P=0.08). Numerically the percentage of farms becoming negative for IBR and leptospirosis was also higher in the intervention than in the control group, but this association was not statistically significant (P=0.15 and P= 0.08, respectively). For Johne's disease and tuberculosis the percentage of farms becoming negative was very similar between control and intervention farms. The mixed model analysis indicates that the intervention did not influence the likelihood of a farm being positive for any of the five diseases, accounting for year of study, and vaccination where relevant. The Bayesian prevalence estimates are not indicative of any specific treatment effect, except for Johne's disease where control farms experienced an increase in prevalence. The mixed model analysis shows that prevalence reduced throughout the study for BVD, leptospirosis and Johne's disease. For IBR and Johne's disease, intervention farms experienced a significantly higher reduction in prevalence than control farms during the study. Vaccination was included as a potential confounder in these analyses.

In conclusion, the analyses suggest that there has been a slightly higher reduction in disease risk for intervention compared with control farms throughout the duration of the study. This effect was significant for within-farm prevalence of IBR and Johne's disease. This is an encouraging result, particularly given that control farms had also been exposed to biosecurity advice and the resulting reduction in statistical power for this study.

FARM DISEASE STATUS/WITHIN-FARM PREVALENCE AND RISK FACTORS

Various risk factors were associated with farm disease status or within-farm prevalence. Increased farm size or increased numbers of animals older than 12 months were associated with an increased disease risk for BVD, IBR and leptospirosis, but not for Johne's disease and tuberculosis. The classification tree analysis emphasizes this further, in that 48% of 119 farm study years (note that the same farms will be counted multiple times) which had fewer than 83 cattle < 1 year old and fewer than 27 between the ages of 1-2 years were negative for BVD, IBR and leptospirosis. In contrast, if they had the same number of youngstock but between 27 and 47 animals in the age category of 1-2 years, only 25% of 83 farm years were negative for these three infections. Increasing numbers of cattle purchased also increased the risk of a farm being positive or having a higher prevalence for IBR or leptospirosis. Increasing farm size increased the odds of a farm being positive for at least one of the infectious diseases examined in this study, whereas being a closed farm reduced the odds of infection. Increased opportunity of contact with cattle from neighbouring increased disease risk, although it appeared that Johne's disease risk decreased for farms grazed away from the main premises. The greater reduction in IBR and Johne's disease risk during the study period for intervention compared with control farms was also significant in the risk factor analysis, while controlling for several other risk factors. The other statistically significant risk factors are difficult to link to epidemiological factors, and may be proxies for other unmeasured variables or spurious associations.

In conclusion, the multivariable analyses indicate that larger farms are more likely to be infected with BVD, IBR or leptospirosis, and being a closed farm or introducing only small numbers of cattle reduces the odds of infection. Given the lack of an association between vaccination and sero-positivity (except for IBR) and that similar results have been reported elsewhere it seems justified to assume that vaccination only had a very limited confounding effect on these results. The findings therefore support the view that it is more difficult to prevent introduction and spread of infection in larger farms. It is probable that larger farms also buy more livestock from a potentially larger number of different sources, and that once infection is introduced there is more opportunity for spread to other animals in the larger farm. There also appeared to be a beneficial effect of the intervention in terms of disease risk for IBR and Johne's disease, which was not associated with vaccination bias. This finding suggests the potential usefulness of an individually-tailored biosecurity strategy, at least from a disease-risk perspective. Tuberculosis and Johne's disease risk appeared to be associated with different sets of risk factors compared with BVD, IBR and leptospirosis. In the case of Johne's disease, the epidemiology is very complex, involving various transmission mechanisms, including environmental contamination. It should also be noted that the diagnostic method used here for Johne's disease has poor sensitivity. For bovine tuberculosis, it is quite surprising that no clear risk factor patterns emerged. In this case, it should also be noted that a lot more animals were tested than for the other 4 diseases where only a sample of 1-2 year old cattle from each farm was used to determine the farm's status.

FINANCIAL PERFORMANCE

The general lack of differences in financial performance between farms with the lowest risk scores and those with the highest risk scores is perhaps due to the higher costs associated with improving biosecurity (for example, perhaps by culling infected animals) and the lack of net benefit to financial performance within the relatively short timescale considered. These results suggest that, within the study period at least, there was no statistically significant impact of biosecurity measures on financial performance. It needs to be recognised that economic returns to improved biosecurity are likely to occur over many years given that the impact is through reduced effects of disease on production over time. However, during each year of the study period there was a substantial rise of both feed wheat and soya prices that may not be compensated by a reduction in costs due to improved animal health.

In conclusion, the study period was too short to be able to demonstrate an economic benefit as a result of developing a tailored biosecurity strategy, if indeed there would be one. It also needs to be noted that, as part of the annual risk assessment visits, control farms also received some level of biosecurity advice from their visiting veterinarian and that simply by being in the project farmers may have improved their biosecurity. Both of these effects will have reduced the likelihood of a significant difference in financial performance between intervention and control farms.

FARMERS' ATTITUDE TOWARDS BIOSECURITY

Probably the most important factor influencing the outcome of this study has been the attitude of individual farmers towards behaviour change in general and biosecurity specifically. It was therefore decided to include a component to the study which used intensive semi-structured interviews, on a smaller sample of farms, to describe farmers' attitudes, in addition to requesting information about this from all farmers through a questionnaire. It is notable that there was no difference between the intervention and control group farmers with respect to attitudes towards biosecurity, further emphasizing that the difference in the advice component of the project that both groups of farmers were provided with was smaller than had been intended. The likelihood of farmers adopting a range of biosecurity measures, such as only buying cattle from accredited low disease risk farms or using quarantine or blood tests for purchased cattle, increased during the study, across both study groups. This is very likely to be a direct or indirect result of the educational influence of the veterinarians, whether relating to specific recommendations made by veterinarians or increased awareness of the importance of biosecurity among participating farmers. In this same context, farmers' satisfaction with their biosecurity risk management significantly improved during the study. While this also applied to both study groups, it also is likely to be attributable to the exposure to biosecurity advice from their veterinarians in the context of the project.

The sub-sample of farmers involved in the semi-structured interview study in general valued very highly the role of the veterinarian in providing advice. This corroborates a study in Ireland (Sayers et al. 2012), which found that farmers preferred obtaining biosecurity advice from veterinarians than from the government, media and farm assurance/quality schemes. The strong association between the word biosecurity and the 2001 foot and mouth disease outbreak has been noted in other studies, for example by Heffernan et al. (2008). Both the semi-structured interviews and the risk assessments suggested that a lack of finances or time to invest in improved biosecurity, even when it was likely to be cost-effective, were constraints to farmers' willingness to change their biosecurity policy. Both intervention and control farms were making a net financial loss, when subsidies and compensation for TB reactors were not taken into account, emphasizing the importance of evaluating the cost-effectiveness of changes made to biosecurity policy. However, other complex factors affecting behaviour were perceived to be important, such as being unwilling to accept the need to cull an apparently healthy animal, or to place too much confidence in negative results generated by poorly sensitive tests. Time was a major reason for not being able to carry out the advice provided by veterinarians. Studies by Gunn et al. (2008) and Sayers et al. (2012) indicate that expense and time constraints were major limitations to applying biosecurity measures.

In conclusion, the role of farmers' perceptions in relation to the importance and effectiveness of biosecurity risk management should not be underestimated, particularly when dealing with disease risks that are affected by a multi-factorial causal web. Education of farmers is important, but it is also necessary to generate credible evidence of the cost-effectiveness of enhanced biosecurity. The study demonstrated the value of semi-structured interviews which, even though conducted with a much smaller sample of farmers, provided additional information that was extremely valuable for appreciating the complexity of the factors influencing farmers' behaviour.

STUDY LIMITATIONS

It needs to be emphasized that the study population included in this intervention study was neither geographically nor in terms of herd size representative of beef suckler herds in England and Wales. The veterinary practice and farm selection process was entirely purposive to maximise the chances of effective collaboration throughout the project, so that the study could focus on testing its main hypotheses. The study farms were also required to have at least 50 breeding female cattle to allow meaningful blood sampling and this number is above the median herd size in England and Wales ((http://www.eblex.org.uk/wp/wp-content/uploads/2014/02/m_uk_yearbook13_Cattle110713.pdf).

One important study limitation was that control farms also received biosecurity advice, as it was ethically and professionally not possible to withhold information if the farmer requested it or it was clearly needed. However, control farms were not subjected to a structured risk assessment and a tailored package of risk management advice, and therefore will have been provided with a narrower range of independent pieces of biosecurity advice. The inability to withhold advice from control farmers will have reduced the statistical power of the study, which may explain why there were few significant differences between intervention and control farms with regards to both the financial performance and sero-positivity. It is also important to realise that the farmers who agreed to take part in the study are likely to be more interested in research and/or the question of the effect of biosecurity on disease risk and farm income than many non-participating farmers. The veterinarians did in fact note that the farmers were interested in the risk assessment and through this asked for advice that could not be refused (personal communication).

The initial risk score took into account existing biosecurity measures. However, there was no initial assessment of the farmers' initial biosecurity knowledge or where original advice or access to advice may have first appeared. If the farmers in the study had already made changes to biosecurity based on advice prior to the study, this may have caused an under-estimation of the impact of providing tailored biosecurity advice in this study.

For some farms there were a number of repeatedly tested cattle, which meant that there were not enough cattle to meet the inclusion criteria of having results from at least five cattle to use for calculating the within-farm prevalence. This means that we could not follow the sero-status of all farms throughout the project.

As stated earlier, vaccination performed as a risk management measure by the farmer will have confounded the disease status data for BVD, IBR and leptospirosis. In addition, it may have been possible for an unvaccinated or uninfected farm to appear positive for a particular disease if sero-positive cattle were brought in from another farm.

It is also important to realise that the data collection by the veterinarians on the farms was paid for by the project, as were the blood tests. This means that the approach used here, i.e. for veterinarians to develop a tailored biosecurity risk management plan informed by an on-farm structured risk assessment, cannot be translated immediately into a recommendation for veterinarians and farmers. As farmers would have to pay for such a service, there would first have to be clear evidence of its cost-effectiveness.

In conclusion, this study was affected by a number of important biases which need to be considered when interpreting the results. One important factor is the limited external validity of the study results, as the farmers involved in this study were unlikely to be representative of beef farmers in England and Wales, and because the costs of the risk assessment, development of the risk management plan and diagnostic testing were covered by the project, rather than the farmers themselves. Furthermore, both the intervention and control group both received biosecurity advice from the veterinarians, rather than just the intervention group as had been the intention when designing the study.

MAIN IMPLICATIONS OF THE FINDINGS

This study has provided new insights into how tailored biosecurity advice may be delivered to cattle beef farms by veterinarians. The effectiveness of tailored biosecurity advice for beef farm enterprises depends on its epidemiological appropriateness, its economic benefit and its technical feasibility, while the likelihood of its adoption depends on farmers' perceptions with respect to cost-effectiveness, farmers' willingness to change and the effectiveness of the communication between veterinarian and farmer. As a result, farmers were very selective in translating advice provided by their veterinarians into action.

The project facilitated more intensive communication between veterinarians and farmer clients, and as a consequence biosecurity risk management improved on the study farms. It needs to be acknowledged that the cost of the communication between veterinarians and farmers was covered by the project, as was the diagnostic testing of the cattle herds. It is very encouraging that as a result of the more intensive interaction with veterinarians farmers demonstrated both a greater understanding of disease risk and biosecurity, with improved biosecurity measures. The farmers were receptive to biosecurity advice and emphasised the importance of the role of veterinarians. The majority of participating farmers believed that better biosecurity could greatly reduce the risk of disease and improve profitability.

The study was not able to demonstrate cost-effectiveness of a tailored biosecurity management strategy. This result needs to be interpreted with some caution, since the study period was too short to expect a measurable economic benefit and the control group of farms in this study received more biosecurity advice than the study plan had intended, thereby reducing the chances of being able to detect a difference between the two groups.

The slightly more intensive interaction between veterinarians and farmers in the context of improving biosecurity management on intervention compared with control farms appeared to reduce disease risk for IBR and leptospirosis.

An important observation was that current understanding of risk factors for disease introduction, which was the basis of the risk assessment scoring tool, seemed effective for IBR, BVD and leptospirosis, but not for Johne's disease or tuberculosis. This was confirmed in the biosecurity risk factor analyses where it was possible to identify a range of factors that influence risk of BVD, IBR and leptospirosis, which are consistent with current knowledge about disease risk management. However most of these factors did not influence risk of Johne's disease and tuberculosis. While there was the potential for vaccination interfering with the diagnostic test result (i.e to produce false positives) for BVD, IBR and leptospirosis, our analyses should have controlled for such an effect to a significant extent. Assuming that this is indeed the case, the study emphasizes epidemiological differences between BVD, IBR and leptospirosis on the one hand and Johne's disease and tuberculosis on the other. It is therefore a challenge for veterinarians and farmers to identify and implement control methods effective for Johne's disease and tuberculosis, and the risk factors for each of these two diseases are likely to be different from each other.

POSSIBLE FUTURE WORK

The project findings suggest a number of future research activities aimed at improving biosecurity of beef farms, and therefore reduced risk of disease introduction.

1. *It is concerning that the risk factors examined in this project did not seem to influence the risk of bovine tuberculosis. It should therefore be a priority to conduct further investigations of factors influencing tuberculosis occurrence on beef farms, and it may indeed be useful to explore the situation on the study farms further through additional data collection.*
2. *The project identified that farmers were very selective in the adoption of the advice provided by veterinarians. It would therefore be appropriate to investigate the communication relationship between veterinarians and farmers and to develop appropriate farmer behaviour-change models. The study population of farmers and veterinarians involved in this study could be used for this purpose. As part of this, a follow-up study could be conducted to examine the long-term impact of the study on the veterinarian-farmer relationship, farmers' biosecurity behaviours/attitudes, and farm economic performance.*
3. *The risk assessment tool developed in this project appeared to be effective at assessing the risk environment of these beef farms in relation to BVD, IBR and leptospirosis. The tool could be developed further so that it could be made available to veterinarians, or to farmers as a biosecurity self-assessment tool. It could also be implemented using different state-of-the-art electronic delivery platforms, including Android apps etc.*

ANY ACTION RESULTING FROM THE RESEARCH (E.G. IP, KNOWLEDGE EXCHANGE)

The project has produced several tangible outputs. Notably it has confirmed and further emphasized the importance of several risk factors for infectious diseases such as BVD, IBR and leptospirosis and that it is possible to perform structured risk assessments that provide an objective impression of the risk environment on a beef farm for these particular diseases. These findings should be communicated to veterinarians and farmers.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

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