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Herd-level factors associated with detection of calves persistently infected with bovine viral diarrhoea virus (BVDV) in Irish cattle herds with negative herd status (NHS) during 2017

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ABSTRACT

A compulsory national BVD eradication programme commenced in Ireland in 2013. Since then considerable progress has been made, with the animal-level prevalence of calves born persistently infected (PI) falling from 0.67 % in 2013 to 0.06 % in 2018. The herd-level prevalence fell from 11.3 % in 2013 to 1.1 % in 2018. In the Irish programme, herds in which all animals have a known negative status and which have not contained any PI animals for 12 months or more are assigned a negative herd status (NHS). While considerable progress towards eradication has been made, PI calves have been identified in a small proportion of herds that had previously been assigned NHS. Given this context, a case-control study was conducted to investigate potential risk factors associated with loss of NHS in 2017. 546 herds which had NHS on 1 January 2017 and lost that status during 2017 (case herds) were matched with 2191 herds (control herds) that retained their NHS status throughout 2017. Previous history of BVD infection, herd size, herd expansion, the purchase of cattle including potential Trojan cattle and the density of BVD infection within 10 km of the herd emerged as significant factors in a multivariable logistic regression model. This work adds to the evidence base in support of the BVD eradication programme, particularly establishing why BVD re-emerged in herds which had been free of BVD for at least the previous 12 months prior to the identification of a BVD positive calf. This information will be especially important in the context of identifying herds which may be more likely to contain BVD positive animals once the programme moves to herd-based serology status for trading purposes in the post-eradication phase.

1. Introduction

Bovine viral diarrhoea virus (BVDV) is a member of the genus Pestivirus, family Flaviviridae, and is an economically important pathogen of cattle that is present at high prevalence in many countries around the world (Scharnböck et al., 2018). The ability of the non-cytopathic biotype of the virus to establish persistent infection of the unborn foetus when infection occurs prior to 120 days of gestation is a key feature in the epidemiology of the disease (Nettleton, 1990; Houe, 1999). As a consequence, BVD eradication programmes were initiated in several northern European countries in the 1990s, including Sweden, Norway, Finland and Denmark (Lindberg et al., 2006; Stahl and Alenius, 2012). These programmes were based on initial screening of herds for serological evidence of the presence of persistently infected (PI) animals, followed by further detailed investigation where required to identify and remove any PIs (the so-called Scandinavian eradication model) (Bitsch and Rønsholt, 1995; Lindberg and Alenius, 1999; Houe et al., 2006). This approach, in conjunction with attention to biosecurity and ongoing monitoring, has achieved national eradication in the absence of vaccination (Nagy et al., 2013; Norström et al., 2014).

More recently, the development of sensitive and specific ELISA and RT-PCR tests for detection of BVDV in tissue samples, coupled with the introduction of official identification or management ear tags capable of collecting a punch of ear tissue, has led to the development of an alternative approach to eradication in which annual testing of the entire calf crop is conducted to identify PI calves. First implemented in Switzerland (the Swiss model) (Presi et al., 2011; Presi and Heim, 2010), this approach has now been adopted in other countries and regions, including Germany, Ireland, Belgium and Northern Ireland (Graham et al., 2015; Quinet et al., 2016; Wernike et al., 2017; Byrne, 2018).

In Ireland, losses due to BVDV were estimated at €102 million annually (Stott et al., 2012). As a consequence, a voluntary industry-led eradication programme commenced in 2012 (Graham et al., 2014a, b), progressing to a compulsory national programme, supported by legislation, from 1 January 2013 (Clegg et al., 2016). Initially, the key measure of progress was the prevalence of PI calves born each year, with this declining from 0.67 % in 2013, to 0.12 % and 0.06 % at the

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end of 2017 and 2018, respectively (www.animalhealthireland.ie). In parallel, the prevalence of herds with one or more positive or inconclusive results has fallen from 11.3 % in 2013 to 2.2 % and 1.1 % in 2017 and 2018, respectively.

Herds have been assigned a negative herd status (NHS) based on all cattle in the herd having a known negative status (based either on a direct test for BVDV or indirectly, through dams having produced one or more BVDV-negative calves) and the herd not having contained a PI animal for at least the previous 12 months. By the start of 2017, almost 70,000 (84 % of all) breeding herds had attained NHS. However, a review of the 2017 programme data indicated that 546 (33.8 % of 1612) incident herds in 2017 were NHS at the start of 2017.

The observed re-emergence of BVD in herds that had previously been recorded as free of infection became a cause of considerable concern for the group overseeing the implementation of BVD eradication in Ireland. Several risk factor studies from relatively early in the Irish BVD eradication programme have previously been reported (Graham et al., 2016), but were not considered entirely relevant. The national epidemiological situation had changed substantially during the programme, as highlighted by the marked decline in overall infection prevalence. Further, disease control strategies were increasingly robust, particularly from 2016 onwards, with the introduction of restrictions on herds that retained PI animals and the associated notification of neighbouring herds. There was also a need for an understanding of risk factors for a defined sub-population of Irish herds, namely those with no evidence of BVDV circulation for at least 12 months prior to observed re-emergence. Given this context, the current study was conducted to examine risk factors associated with the loss of NHS during 2017 in herds with negative herd status (NHS) at the start of 2017, to inform policy decision-making at this critical stage of the national BVD eradication programme.

2. Materials and methods

2.1. Study herds

Case herds (n = 546) included all Irish herds with NHS on 1 January 2017 but lost that status over the course of 2017 due to the disclosure of a BVD + animal (initial positive or inconclusive BVDV result and either confirmed on re-test or removed without re-testing) over the course of 2017. For each case herd, four control herds were randomly selected from all Irish herds (n = 61,406) with NHS both on 1 January 2017 and throughout 2017 (a total of 2192 control herds).

2.2. Herd-level independent variables

The following independent variables were considered in this study, as potential risk factors for NHS loss in the case herds:

- *Location:* (county)
- *Herd type:* (dairy, beef or dual [beef and dairy enterprises])
- *Year of last BVD + animal:* during the compulsory phase of eradication programme (2013–2015 or none reported, with 2015 representing the most recent year in which a herd could have had a BVD positive animal present in the herd and have had NHS on 1st January 2017)
- *Density of BVD + cattle within 10* km *radius of the herd in 2016:* (the number of BVD positive calculated within a 10 km radius of the centroid of the largest land fragment within the holding)
- *Sheep present:* sheep enterprise recorded on the holding
- *Calf numbers 2013 − 2017:* difference in number of calf births registered between 2013 and 2017 (to reflect herd expansion)
- In addition, the following variables were considered separately for the years 2016 and 2017:
- *Herd size* measured as:
  - o Total number of cattle in the herd on 30 June
  - o Number of cows: females greater than 2 years of age on the 30 June
  - o Number of calves born during the year (also for 2013)
- *Cattle introduced:* total number
- *Mortality rate:* number of cattle deaths/100 cattle on farm, independent of age
- *Calf mortality rate:* Number of calves dying within 28 days of birth/number of calves born
- *Potential Trojan dams introduced:* number of females introduced that were aged 12 months or above on the recorded date of introduction and therefore with the potential to be pregnant.

2.3. Data sources

Most of the data regarding the independent variables and herd BVD status were collated by the Irish Cattle Breeding Federation (ICBF; www.icbf.com). Additional data on the number of land fragments and whether sheep were present on the farm came from the national Land Parcel Identification Scheme (LPIS) and the 2015 sheep census (Department of Agriculture Food and the Marine, 2017) and the Animal Health Computer System (AHCS) of the Department of Agriculture, Food and the Marine (DAFM).

2.4. Data analysis

The outcome of interest was whether the herd was a case herd.

a. Univariable analysis

Each of the independent variables listed above were initially tested in a univariable logistic regression model with case/control status as the outcome variable. All independent variables with some evidence of statistical association ($p \leq 0.20$) with case/control status in the univariable analysis were considered for inclusion in the multivariable model. For continuous variables, the appropriate format of the variable was assessed by plotting the variable against the log odds of the outcome. When a linear relationship or a transformation was not appropriate, a categorical variable was created based on the quintiles of the continuous variable. For risk factors with measurements in more than one year and for correlated risk factors, the risk factor resulting in the lowest Aikake Information Criteria (AIC) in the univariable logistic regression model was retained for further consideration.

b. Multivariable analysis

A logistic regression model was developed, using Stata SE 14 (Statacorp, USA), to model the probability of a herd being categorized as a case rather than a control. A backward selection procedure was used to eliminate non-significant terms ($p > 0.05$) from the model. The potential for confounding and interaction was assessed during the model building process. An assessment for correlation was conducted during model building. The goodness-of-fit of the final model was assessed using the Hosmer-Lemeshow test and examining outliers based on influence statistics.

3. Results

3.1. Study herds and univariable analyses

There were no case herds in county Dublin, therefore this county was combined with the neighbouring county of Wicklow for further analysis. Otherwise, the number of case herds per county ranged from 4 (1.0 %, Carlow and Dublin/Wicklow) to 52 (9.5 %, Cork), while the number of control herds per county ranged from 20 to 238 (Carlow and Cork, respectively) (Table 1).

Case herds were most commonly categorized as beef (52.4 % of cases), followed by dairy (41.2 %) and dual herds (6.4 %) (Table 2), while 71.7 %, 23.9 % and 4.3 % of the control herds were categorized as beef, dairy and dual respectively. Dairy herds were more frequent

Table 1
Number of BVD case and control herds, and percentage of all case and control herds, by county.

County	Number of herds			% of all case herds	% of all control herds
	Case	Control	Total		
Carlow	4	20	24	1	0.9
Cavan	27	105	132	4.9	4.8
Clare	19	156	175	3.5	7.1
Cork	52	238	290	9.5	10.9
Donegal	17	122	139	3.1	5.6
Galway	36	226	262	6.6	10.3
Kerry	23	132	155	4.2	6.0
Kildare	11	17	28	2	0.8
Kilkenny	15	66	81	2	3.0
Laois	22	45	67	4	2.1
Leitrim	12	59	71	2	2.7
Limerick	34	88	122	6.2	4.0
Longford	13	39	52	2	1.8
Louth	5	15	20	1	0.7
Mayo	34	220	254	6.2	10.0
Meath	35	31	56	6.2	1.4
Monaghan	36	66	102	6.2	3.0
Offaly	13	58	71	2	2.6
Roscommon	32	104	136	5.8	4.7
Sligo	11	82	93	2	3.7
Tipperary	43	117	160	7.8	5.3
Waterford	13	35	48	2.4	1.6
Westmeath	20	47	67	3.6	2.1
Wexford	25	64	89	4.6	2.9
Dublin/Wicklow[a]	4	40	44	1	1.8
Total	546	2192	2738		

[a] Data combined due to absence of case herds in Dublin.

Table 2
Number of BVD case and control herds, and percentage of all case and of all control herds, by herd type and presence of sheep on farm. The univariable associations between herd status (case, control) and either herd type or sheep present were calculated using a univariable logistic regression analysis.

	Number of herds			% of all case herds	% of all control herds	P-value
	Case	Control	Total			
Herd Type						
Beef	286	1572	1858	52.4	71.7	0.001
Dairy	225	524	749	41.2	23.9	
Dual	35	96	131	6.4	4.4	
Sheep present						
Yes	102	455	557	18.7	20.8	0.273
No	443	1717	2160	81.1	78.3	
No data available	1	20	21	0.2	0.9	
Total	546	2192	2738			

among case compared to control herds (41.2 %/23.9 % = 1.7) in comparison to either beef (0.73) or dual (1.5) herds.

Information on the presence of sheep was not available for 21 herds (0.2 %), all but one of which were control herds. Otherwise sheep were present on 102 case (18.7 %) and 455 control herds (20.7 %), respectively (Table 2), and the presence of sheep was not a significant factor in the univariable analysis (P = 0.273).

Independent variables relating to herd size, numbers of cows, number of calves born, introductions, mortalities and introductions are summarized in Table 3. The mean value of the case variable was greater than that of the controls in all instances. Data on the year of the most recent BVD + birth are summarized in Table 4. Results were not available for 22 herds, all but two of which were controls. The majority of both case and control herds had not had a BVD + result in the years 2013-2015.

Table 3
Mean (standard deviation) of independent variables relating to size, births, introductions and mortality in the BVD case and control herds.

Risk factor	Case		Control	
	Mean	SD	Mean	SD
Herd size (all cattle) (2016)	133.5	143.7	71.1	79.9
Herd size (all cattle) (2017)	139.5	158.8	72.7	84.5
Number of cows in 2016	63.9	83.3	44	40.2
Number of cows in 2017	66.9	89.6	45	42.1
Number of calves born in 2016	58.2	82.7	29.6	39.4
Number of calves born in 2017	61.4	89.3	29.6	40.9
Number of calves born in 2013	49.1	67.6	26.8	33.4
Change in calf numbers 2013 and 2017	14.2	34.1	3.8	14.1
Cattle introduced in 2016	34.9	115.9	17.5	81.8
Cattle introduced in 2017	38	125.5	18	96.0
Mortality rate in 2016	1.3	0.71	1.25	0.71
Mortality rate in 2017	1.8	1.3	1.8	1.2
Calf mortality in 2016	6.3	17.2	3.4	5.7
Calf mortality in 2017	5.8	13.3	3.4	5.8
Potential Trojans introduced in 2016	6.8	12.6	3.7	5.1
Potential Trojans introduced in 2017	6.6	10.5	3.4	4.5

Table 4
Number of BVD case and control herds, and percentage of all case and of all control herds, by year of last BVD + animal. The univariable association between herd status (case, control) and year since last BVD + animal was calculated using a univariable logistic regression analysis.

Year of last BVD + animal	Number of herds			% of all case herds	% of all control herds	P-value
	Case	Control	Total			
No history of BVD	355	2027	2402	65.0	87.7	0.001
2012	14	9	23	2.5	0.4	
2013	63	37	100	11.5	1.7	
2014	46	86	132	8.4	3.9	
2015	66	13	79	12.1	0.6	
Missing values	2	20	22	0.4	0.9	
Total	546	2192	2738			

3.2. Multivariable results

The final multivariable logistic regression model (Table 5) included the following risk factors: county, herd-size (total cattle), change in calf birth numbers 2013–2017, cattle introduced in 2017, mortality rate in 2016, calf mortality in 2017, potential Trojans introduced in 2017, density of BVD + cattle in 2016 and the year of birth of the last BVD + animal.

The odds of being a case increased as overall herd size increased, where the odds of losing NHS among herds with more than 131 animals was almost four times those of herds with less than 19 animals. Herd expansion, as evidenced by an increase in the number of calves born in 2017 compared to the number born in 2013 was significant in the final model. The odds of losing NHS was 1.75 times greater among herds where there were 9 calves or more born in 2017, compared to those herds where there were three or fewer calves born in 2017 relative to the number of calves born in 2013. The odds of losing NHS increased when six or more cattle had been introduced to the herd in 2017. In addition, the odds of being a case herd among herds that purchased potential Trojan animals were over twice that of herds which did not purchase potential Trojan animals. The odds of being a case herd increased by 0.04 for each percentage increase in overall herd mortality in 2016. Herds with a 2017 calf mortality rate greater than 5.8 % had

Table 5
Parameter estimates from the final multivariable logistic regression model of the probability of an Irish herd with BVD NHS losing its status due to a BVD + birth in 2017.

	Odds Ratio	P-value	95 % Confidence Interval	
			Lower	Upper
County				
Carlow	Referent			
Cavan	1.04	0.95	0.28	3.84
Clare	0.64	0.50	0.17	2.39
Cork	0.73	0.63	0.21	2.56
Donegal	2.09	0.28	0.55	7.96
Galway	1.06	0.93	0.30	3.76
Kerry	0.94	0.92	0.25	3.47
Kildare	2.75	0.19	0.61	12.42
Kilkenny	0.66	0.55	0.17	2.57
Laois	1.46	0.58	0.39	5.53
Leitrim	2.56	0.19	0.63	10.35
Limerick	1.49	0.55	0.41	5.43
Longford	1.20	0.81	0.28	5.15
Louth	1.47	0.65	0.29	7.51
Mayo	1.44	0.57	0.40	5.20
Meath	2.90	0.13	0.73	11.44
Monaghan	2.52	0.16	0.69	9.21
Offaly	0.81	0.77	0.20	3.25
Roscommon	2.04	0.28	0.56	7.43
Sligo	1.23	0.77	0.31	4.96
Tipperary	1.10	0.89	0.31	3.89
Waterford	1.89	0.37	0.47	7.69
Westmeath	1.34	0.67	0.35	5.19
Wexford	1.26	0.73	0.33	4.79
Dublin/Wicklow	0.52	0.44	0.10	2.75
Herd size				
< 19	Referent			
19–37	2.40	< 0.01	1.44	3.99
38 – 68	2.73	< 0.01	1.63	4.57
69 – 131	2.89	< 0.01	1.69	4.94
> 131	3.98	< 0.01	2.24	7.06
Change in calf numbers 2013 and 2017				
3 or more fewer calves	Referent			
Between 0 and 2 fewer	1.11	0.64	0.73	1.67
1 – 3 more calves born	1.31	0.18	0.88	1.94
4 – 9 more calves born	1.56	0.02	1.09	2.25
> 9 more calves born	1.76	0.02	1.22	2.52
Cattle introduced in 2016				
0 or 1	Referent			
2–5	0.80	0.18	0.57	1.12
6 – 16	1.31	0.11	0.95	1.81
≥17	1.34	0.09	0.95	1.88
Mortality rate in 2016	4.74	0.09	1.31	17.23
Calf mortality rate in 2017				
0 – 5.8%	Referent			
> 5.8 %	2.96	< 0.01	2.32	3.77
Potential Trojan dams introduced in 2017				
No	Referent			
Yes	2.20	< 0.01	1.69	2.86
Density of BVD + cattle within 10 km of herd in 2016				
0 – 0.0152	Referent			
0.0153 – 0.0266	1.78	< 0.01	1.16	2.75
0.0267 – 0.0384	1.88	< 0.01	1.22	2.89
0.0385 – 0.0538	1.73	0.01	1.12	2.68
> 0.0538	2.67	< 0.01	1.71	4.15
Year last BVD + animal born in the herd				
No history of a BVD + animal	Referent			
2012	6.96	< 0.01	2.78	17.44
2013	7.26	< 0.01	4.45	11.76
2014	2.04	< 0.01	1.33	3.13
2015	23.55	< 0.01	11.81	46.72

almost three times the odds of being a case herd compared to those herds where the 2017 calf mortality rate was less than 5.8 %. The odds of being a case increased as the density of PIs in the locality in 2016 increased, although not linearly. Herds that had a BVD + calf in 2015 had 23 times the odds of being a case herd compared to those that no history of a BVD + animal. The risk was significant but lower for herds with BVD + calves in 2012–2014, with the lowest odds for those herds with the last BVD + in 2014, although the risk of being a case herd was still twice that compared to herds with no history of a BVD + animal. The Hosmer–Lemeshow test ($p = 0.334$) and residual analysis indicated that there was no significant lack of fit in the model.

4. Discussion

This study has highlighted a number of factors which are associated with the discovery of BVDV-positive calves in Irish herds which have been free of BVD for a minimum of the previous 12 months. Previous history of BVD infection, herd size, herd expansion, the purchase of cattle including potential Trojan cattle and the density of BVD infection within 10 km of the herd emerged as significant factors in the final multivariable logistic regression model.

4.1. Previous infection history

A previous history of BVD in the herd emerged as a significant predictor of a future outbreak, particularly in the year preceding the achievement of negative herd status (NHS), where the odds of a future breakdown were 23 times that of a herd with no history of BVD during the eradication programme. To have NHS status on 1 January 2017, the herd needed to have NHS granted prior to 1 January 2016. Of the 546 herds that lost NHS in 2017, 66 (12 %) had evidence of BVD infection in 2015. These 66 herds represented 0.09 % of all herds with NHS (unpublished data). While the loss of status was a relatively rare event in the context of the overall national population (accounting for 0.78 % of herds), the fact that almost an eighth of herds which lost their NHS status in 2017 had evidence of BVD infection within the previous 24 months is a noteworthy finding. In this study, it is not possible to determine if this was due to residual infection within the herd or if there were management practices conducive to the introduction of BVD. In any case this study highlights that these herds are at a greater risk of repeat breakdowns and may require continued intensive surveillance for at least 12 months after they regain negative herd status. The retention of BVD positive cattle has been found to significantly increase the probability of creating BVD positive calves in the subsequent calving season (Graham et al., 2014a, b). In the national programme, more stringent restrictions have been applied to herds which had retained BVD positive cattle since January 2017, which has accelerated progress. In the post-eradication surveillance scenario, it may be necessary to continue tissue tagging calves for up to two years after the identification of the last BVD positive animal in a herd.

4.2. Biosecurity and management

Increased herd size was also significantly associated with the loss of NHS in 2017. As herd size increased, the odds of losing NHS also increased from 2.40 for herds between 19 and 37 cattle to 3.98 for herds of greater than 131 cattle, compared to herds with ≤ 19 cattle. Previous studies in Ireland (Graham et al., 2016) and Switzerland (Presi et al., 2011) have identified herd size as a risk factor in the epidemiology of BVD. Consistent with the association between increased risk and herd size was the finding that an increase in the number of calves born between 2013 and 2017 was also found to be significantly associated with the loss of NHS, with this being 1.75 times more likely in herds where more than 9 additional calves were born in 2017 relative to those where the number decreased (Table 5).

In 2015, milk quotas were abolished in the EU and this has resulted in marked expansion of dairy herds in Ireland. The mean increase in calf numbers between 2013 and 2017 in case herds was over three times that seen in control herds (14.2 compared to 3.8; Table 3). The increase in breeding herd size was achieved through breeding more replacements and/or buying in heifers, some of which would have been pregnant at the time of purchase. The introduction of potentially pregnant female cattle increased the odds of losing NHS by 2.2. Several authors internationally have highlighted the role of so-called Trojan cows in the epidemiology of BVD (Houe, 1999; Hult and Lindberg, 2005; Presi et al., 2011). The role of Trojan cattle in the epidemiology of BVD in Ireland has been recognised as a significant risk factor since the start of the current programme. The relative importance of Trojans has been considered to become more significant as a programme progresses (Hult and Lindberg, 2005), and this finding was confirmed in the Irish context, where one or more BVDV-positive calf births were attributable to Trojan dams in 7.8 %, 9.2 % and 10.7 % of BVD positive herds in 2013, 2014 and 2015 respectively (Reardon et al., 2018a). However, further analysis showed that only a minority of these births to Trojan dams could be prevented by imposing movement controls on females of breeding age from known infected herds, emphasizing the importance of measures to manage the risk in the purchasing herd. In the context of the Irish programme, the prompt tissue tag testing of calves born to these dams contributed significantly to this (Reardon et al., 2018b).

The inward movement of cattle was also retained in the final model, although the association was not as marked as previously described in earlier stages of the programme. It is not surprising that the relative importance of this risk factor has diminished as the national prevalence has fallen. However, the impact of purchase tended to be greatest as the number of introduced animals increased in this study.

Increased density of PIs within 10 km of the herd in the year previous to the loss of NHS for that herd was also found to be a significant risk factor with the odds increasing with increased density of infection. In a previous study (Graham et al., 2016) found that the birth of one or more PI calves in a herd in one year was significantly associated with the birth of PI calves in contiguous herds the previous year. However, it was not possible to state whether this was as a result of direct contact across boundaries or due to indirect contacts favoured by proximity. The findings of the current study, which highlight the risk over a wider, but local area, point strongly to spread at local level through indirect transmission pathways including movement of personnel and equipment.

4.3. Other risk factors

Histories of increased overall mortality in 2016 (OR 4.7) and in calf mortality in 2017 (OR 2.956) were significantly associated with the loss of NHS. The presence of active BVD infection is known to predispose to mortality rather than a cause of BVD infection and has been previously described in Ireland and Switzerland (Presi et al., 2011). This association is not likely to be causative and is likely to as a result of BVD infection or reflects management practices which are more likely to lead to the introduction of BVD and increased mortality overall.

There was no association between the presence of sheep on the farm and loss of NHS. A recent serological survey of lambs slaughtered in 2017, found evidence of seroconversion in 1.9 % of flocks surveyed (Fagan et al., Personal Communication), which is consistent with this finding (Graham et al., 2014a, b; Gunn et al., 2004).

4.4. Limitations/points of caution

While associations were identified, these are not necessarily causal. In particular, factors such as mortality may be a consequence of BVD infection rather than a risk factor for infection. Increased mortality may create a need to purchase more replacements, which in turn could lead to an increased risk of introducing infection. The design of the study did not allow us to determine impact of farm management practices on the outcome. Neither was it possible to determine whether a BVD positive animal was due to persistent or transient infection. Nonetheless, we were satisfied that BVD virus was circulating in the herds where NHS was lost.

4.5. Implications

This work adds to the evidence base in support of the Irish BVD eradication programme. The work helps to clarify why BVD has re-emerged in herds which had been free of BVD for at least the previous 12 months prior to the identification of the BVD positive calf. This information will be especially important in the context of identifying herds which may be more likely to identify BVD positive animals once the programme moves to herd-based serology status for trading purposes in the post-eradication phase. The identification of these risk factors may provide a basis for the identification of herds which will need increased more intensive surveillance in the post-eradication scenario.

The importance of a previous infection history within the herd demonstrates the crucial role of PI cattle in the epidemiology of BVD. It may also indicate that such farms may be pursuing management practices which facilitate re-infection, particularly relating to biosecurity and the purchase of potential Trojan pregnant cattle. This issue is central to eradication success and may require further investigation. The study highlighted the importance of a neighbourhood effect where there is an increased risk of a breakdown through either direct or, more likely, indirect contacts. This may indicate that herds within the vicinity of a known breakdown herd should be subjected to more intensive investigation and surveillance.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.prevetmed.2020.104990.

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