



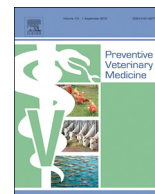
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## Potential infection-control benefit of measures to mitigate the risk posed by Trojan dams in the Irish BVD eradication programme



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### ABSTRACT

In the epidemiology of Bovine Viral Diarrhoea (BVD), Trojan dams (animals that are not persistently infected (PI) with BVD (BVDv) virus but carrying PI fetuses) are a vehicle through which infection can be transmitted. We investigated the degree to which restricting movement of cattle from BVDv infected herds would prevent Trojan births in other herds (effectiveness) and the extent to which this would reduce other, non-Trojan, movements (proportionality). We focussed on Irish herds with BVD + animal(s) present during 2014 and/or 2015. The effect of restricting movements of female animals over 12 months of age from these herds was compared with data collected on Trojan dams that calved in 2015. Four different potential restriction lengths were considered, varying from the period when a BVD + animal was present in the herd, to extending this to 12 months after removal of the last BVD + animal. In terms of effectiveness, none of the four restriction measures evaluated was effective at preventing the movement of all Trojan dams. Between 18.3% and 37.3% of Trojan births in 2015 would have been prevented under the proposed measures, and all Trojan births would have been prevented in between 14.4% and 32.5% of herds with BVD + births. In terms of proportionality, between 4.4% and 15.4% of all females > 12 months of age that moved between herds during 2015 would have been prevented from moving, and between 3.5% and 10.1% of Irish herds with at least one such movement would have been affected. These results show how measures to control the movement of Trojan dams should be targeted in a way that fits the Irish context and reduces the spread of BVDv, without unduly impacting other trade.

### 1. Introduction

The potential role of Trojan dams in the epidemiology of BVD is well recognised internationally. These are pregnant cattle, which are not themselves persistently infected (PI) with bovine viral diarrhoea virus (BVDv), but which are carrying a PI foetus. A PI animal is one that is infected as a calf *in utero* and sheds high levels of virus in all bodily secretions throughout its life (Brownlie et al., 1987). Trojan dams have the potential to introduce infection into a previously non-infected herd. Lindberg and Alenius (1999) and Obritzhauser et al. (2005) identified trade in PI animals and Trojans as the two major routes by which infection can enter a herd.

Concerns about the role played by Trojan dams have been addressed in several national BVD eradication programmes. In the Swiss eradication programme, females that were pregnant at the time of removal of a PI animal were restricted to that holding until after their next calving (Presi et al., 2011). In Sweden, herds under restriction due to evidence

of ongoing or recent infection based on herd-level serological testing were not allowed to sell pregnant animals other than to slaughter until the infection was resolved and the herds had been tested twice for antibodies with an approved result (Hult and Lindberg, 2005). In addition, pre-sale testing of pregnant dams from BVD-free herds was recommended if these dams had not been included in the herd-level serological monitoring (e.g. heifers on remote pasture that may not have been blood tested) (Hult and Lindberg, 2005; Anon., 2006). In Denmark, trade in pregnant cattle from herds not free of BVDv was prohibited in the absence of negative virus and antibody tests within four weeks of the anticipated date of movement (Alban et al., 2001).

In Ireland, a compulsory national BVD eradication programme has been underway since January 2013. The programme is coordinated by Animal Health Ireland (AHI; [www.animalhealthireland.ie](http://www.animalhealthireland.ie)) and implemented through a BVD Implementation Group (BVDIG), with technical advice provided by a BVD Technical Working Group (TWG) (Graham et al., 2014). In an earlier study, Trojan dams were estimated

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to be responsible for 2526 (8.6% of all) birth events of BVD + calves to non-BVD + dams between January 2013 and December 2015 (Reardon et al., 2018). In that study, BVD + calves were defined, based on the results of neonatal tissue tag testing, as either BVDPOS (animals with an initial positive or inconclusive tissue sample test but without a confirmatory re-test being conducted) or BVDPI (animals with an initial positive or inconclusive tissue sample test and a positive confirmatory test). The Trojan status of dams giving birth to the BVD + calves was determined after considering their movement history relative to a defined ‘window of susceptibility’ (WOS; days 30 to 120 of gestation). Results of this study showed that first parity dams and dams calving in small herds (< 46 animals) were more likely to be Trojan. Factors which increased the risk of selling a Trojan dam from a herd with one or more BVD + animals included the number of pregnant animals more than 12 months of age sold and the number of BVD + animals present in the herd. The odds of selling a Trojan dam in herds selling more than 1 pregnant female aged over 12 m was 37 times higher than herds selling 0 or 1 such animals. Herds with > 2 BVD + cattle in the herd in 2014 were 1.6 times more likely to sell a Trojan dam compared to herds with just 1 BVD + in 2014. For further descriptive information see Reardon et al. (2018).

A large number of cattle are traded in Ireland every year, with 2,940,989 cattle movements, either directly from farm-to-farm or via markets, recorded in 2015 (Anon., 2016a). These included 573,886 beef breed and 274,782 dairy breed females aged 12 months and above (of which 406,078 and 98,252, respectively, moved via a market). Given this large volume of trade, there is the potential for movement of a female animal carrying a PI foetus, even when the virus prevalence in the cattle population is low (Damman et al., 2015). Measures aimed at reducing the farm-to-farm spread of BVDv via Trojan dams typically focus on controlling movement of pregnant animals from herds that are known to be infected or of unknown status, rather than controlling movements of pregnant animals from all herds. However, the pregnancy status of cows at the point of sale is often unknown, and rarely certified. It is typically not recorded in databases available to managers of national or regional eradication programmes. Therefore measures to prevent the movement of pregnant females from specified herds may need to address the movement of all females of breeding age from these herds, subject to potential derogations such as their certification as non-pregnant or as both virus- and antibody-negative (Lindberg and Ailenius, 1999; Burciaga-Robles et al., 2010).

The prevalence of BVD + births in Ireland has fallen from 0.66% of approximately 2.1 million births in 2013 to 0.16% of approximately 2.3 million births in 2016 (Animal Health Ireland, 2017). While the BVD TWG has issued specific biosecurity advice (Animal Health Ireland, 2015) to herd owners and their veterinary practitioners to minimise the risk of purchasing a Trojan dam, measures to address their movement have not yet been incorporated into the legislation that governs the programme (Anon., 2017). While the prevention of movement of a female carrying a PI calf only determines the location rather than the number of each associated PI birth, a recent modelling study (Thulke et al., 2018) has demonstrated the beneficial impact, in terms of shortening the time to eradication, of measures to stop their movement. However, this presupposes that all such movements can be prevented, and that the measures required to do so are acceptable to the industry.

The objectives of the current study were to assess the effectiveness of movement restrictions for varying periods following the removal of PI animals from infected herds in preventing Trojan births in other herds, and the proportionality of such measures in terms of the total number of herds and animals affected by the movement restrictions. The current study was therefore undertaken to provide an evidence base to inform discussions within the BVDIG regarding the introduction of measures to minimise the role of Trojan dams in spreading BVDv between herds.

## 2. Materials and Methods

### 2.1. Definitions

The study period was from 1 January 2014 to 31 December 2015 inclusive.

#### 2.1.1. Animal-level definitions and statuses

**BVD + animal:** For the purposes of this study, a BVD + animal was any animal (whether a calf or older animal) assigned one of the following statuses based on test results from the programme database provided by the Irish Cattle Breeding Federation ([www.icbf.com](http://www.icbf.com)):

- **BVDPOS:** animals with an initial positive or inconclusive tissue sample test but without a confirmatory re-test being conducted.
- **BVDPI:** animals with an initial positive or inconclusive tissue sample test and a positive confirmatory test.
- **OFFPI:** an untested animal that is the offspring of a PI dam and therefore must itself be PI.

**Eligible animals:** All female animals greater than 12 months of age that move, except to slaughter or a knackery (by definition, these animals will not subsequently produce a calf) or return to the herd of origin from a market (i.e., unsold).

**The window of susceptibility (WOS):** The stage of gestation during which transient infection of a dam with BVDv may lead to the development of a PI calf. In this study, the WOS was assumed to be from day 30–120 of gestation (Brownlie et al., 1998; Charleston et al., 2001; Lanyon et al., 2014).

**Trojan dam:** A Trojan dam is the dam of a BVD + calf and satisfies each of the following three conditions:

- she was introduced to the birth herd while pregnant,
- she was carrying a BVD + foetus on introduction, and
- she was not herself a PI animal.

**Study Trojan dam:** For the purposes of this and an accompanying paper (Reardon et al., 2018), a study Trojan dam was defined as a non-BVD + dam of a BVD + calf that either moved into the herd where that calf was born (the birth herd) between days 30 and 120 of gestation (except in those situations where a source of infection was identified in the birth herd only) or a dam that moved into the birth herd after 120 days of gestation (i.e. after the end of the WOS). These animals were identified after considering both the history of movement and potential BVDv exposure relative to WOS of all non-BVD + dams that gave birth to BVD + calves during the period of interest. See Reardon et al. (2018) for further information. The number of study Trojan dams was 2526 (8.6% of 29,422 BVD + birth events), comprising 938 (7.1%), 841 (9.2%) and 747 (10.6%) in 2013, 2014 and 2015, respectively. In 2015, there were 272 study Trojan births (9.1% of all BVD + birth events) in dairy herds, 380 (11.4%) in beef herds and 95 (13.2%) in dual purpose herds.

**Trojan birth:** The birth of a BVD + calf (or calves, if multiple births, all of which had the same BVD status) to a Trojan dam.

**A non-Trojan dam:** In this study, all dams giving birth to a BVD + calf except Trojan dams.

#### 2.1.2. Herd-level definitions

**Study (restriction) herd:** Any herd which contained a BVD + animal (or animals) at any point between 1 January 2014 and 31 December 2015 inclusive.

**BVD + herd:** A herd was considered to be BVD + for the period that an identified BVD + animal was present in the herd.

**Duration of positivity (DOP):** The length of time that a BVD + animal or animals were present in a study (restriction) herd. These animals could be present concurrently, consecutively or intermittently, or a

mixture of all three in cases where multiple BVD + animals were present over an extended time period. The start date was taken as the date the BVD + animal entered the herd and not the date the animal was tested.

**Birth herd:** The herd into which a BVD + calf was born.

**Source herd:** Any herd in which the Trojan dam was present during the pregnancy of interest prior to entering the birth herd.

**The herd of infection:** The source herd in which the dam was considered most likely to have been exposed to BVD<sub>v</sub>, leading to the subsequent birth of a Trojan calf.

**The herd of origin:** The birth herd of the dam (which may also be a source herd).

## 2.2. Study design

### 2.2.1. Overview

In this paper, we have focused on ‘study Trojan dams’, but use the term ‘Trojan dams’ subsequently.

Related investigations were conducted to evaluate both animal- and herd-level estimates of the effectiveness and proportionality of each of four potential control measures to restrict animal movement from known BVD + herds, as described below.

- **Control measure 1 (CM<sub>1</sub>):** Herds are restricted and eligible animals are unable to move while any BVD + animal is present in the herd.
- **Control measure 2 (CM<sub>2</sub>):** Herds are restricted and eligible animals are unable to move, while any BVD + animal is present in the herd, and for 4 months (120 days) after the last BVD + animal has been removed.
- **Control measure 3 (CM<sub>3</sub>):** Herds are restricted and eligible animals are unable to move, while any BVD + animal is present in the herd, and for 9 months (270 days) after the last BVD + animal has been removed.
- **Control measure 4 (CM<sub>4</sub>):** Herds are restricted and eligible animals are unable to move, while any BVD + animal is present in the herd, and for 12 months (365 days) after the last BVD + animal has been removed.

Within the study herds, key animals of interest included all of the BVD + animals that were present in these herds at any point during the study period, all eligible animals that moved from these herds during 2015, and all Trojan dams that gave birth in 2015. Study herds were eligible for restriction from 01 January 2014 to 31 December 2015.

Herds were categorised as dairy, beef or dual purpose based on ICBF categorisation. Where data was not available from this source, data from the Animal Identification and Movement (AIM) System database of the Department of Agriculture, Food and the Marine was used. A small number of herds did not have an assigned category on either database. These were categorised as null and excluded from herd type specific analyses.

### 2.2.2. The effectiveness study

Effectiveness addresses the impact of each proposed control measure on preventing the movement of Trojan dams, identified as giving birth to a BVD + calf in Ireland in 2015 in the previous paper (Reardon et al., 2018), into purchasing herds in Ireland during 2015. Animal- and herd-level estimates for effectiveness were calculated as follows:

- **Animal-level:** Two animal-level estimates of effectiveness were calculated:
  - **% of Trojan births prevented:** the number of Trojan dams that would have been prevented from entering the birth herd in 2015 if the potential control measure had been applied (numerator) divided by the total number of Trojan births in 2015 (denominator).
  - **% of all BVD + births affected:** the number of Trojan dams that

would have been prevented from entering the birth herd in 2015 if the potential control measure had been applied (numerator) divided by the total number of BVD + births in 2015 (denominator). In 2015, there were 7372 BVD + birth events (7445 BVD + calves born), including 3113 birth events in dairy herds, 3512 in beef herds and 747 in dual herds.

- **Herd-level:** two herd-level estimates of effectiveness were calculated:
  - **% of breeding herds with all Trojan births prevented:** the number of herds where all Trojan births would have been prevented in 2015 if the potential control measure had been applied (numerator) divided by the number of herds with at least one Trojan birth in 2015 (denominator). There were 535 herds with at least one Trojan birth in 2015, including 138 in dairy herds, 330 in beef herds and 67 in dual herds.
  - **% of breeding herds with all BVD + births prevented:** the number of herds where all BVD + births would have been prevented in 2015 if the potential control measure had been applied (numerator) divided by the number of herds with at least one BVD + birth in 2015 (denominator). There were 4251 herds with at least one BVD + birth in 2015, including 1551 in dairy herds, 2332 in beef herds and 368 in dual herds. Of the 4023 herds with at least one BVD + birth to a non-BVD + dam in 2015, there were 432 herds where all births were to Trojan dams.

### 2.2.3. The proportionality study

Proportionality addresses the impact of each proposed control measure on the movement of eligible animals from study (restriction) herds relative to the movement of eligible animals from all Irish herds during 2015. Animal- and herd-level estimates for proportionality for each control measure were calculated as follows:

- **% of eligible animals in Ireland that would have been prevented from moving (animal-level):** the total number of eligible animals that moved from study (restriction) herds in 2015 and would have been restricted if the potential control measure had been in place (numerator) divided by the total number of eligible animals with at least one registered movement from Irish herds during 2015 (denominator).
- **Of Irish breeding herds with at least one eligible movement, % where at least one movement would have been restricted (herd-level):** the total number of study (restriction) herds where the movement of at least one eligible animal would have been prevented in 2015 if the potential control measure had been in place (numerator) divided by the total number of Irish herds from which at least one eligible animal moved in 2015 (denominator).

### 2.2.4. Potential infection-control benefit

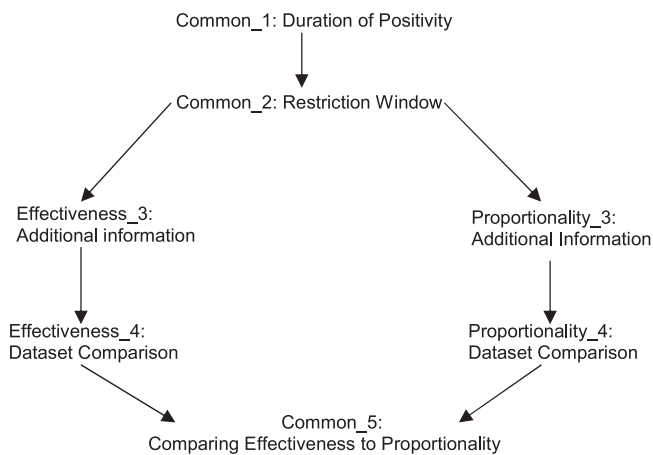
For each control measure, the potential infection-control benefit was evaluated by separately comparing animal- and herd-level estimates of effectiveness and proportionality, by control measure and herd type.

## 2.3. Data

Data were obtained from either the database of the Irish Cattle Breeding Federation (ICBF) (identification of all BVD + animals and related herds during 2014 and 2015) or the Animal Identification and Movement (AIM) System database of the Department of Agriculture, Food and the Marine (DAFM; movements of all eligible animals during 2015 and movement of dams giving birth to BVD + calves in 2015).

## 2.4. Data analysis

Five steps were undertaken during data analysis, with the first two steps (*Common\_1*, *Common\_2*) being common to both the effectiveness and proportionality calculations. The interrelationship of these steps is



**Fig. 1.** Interrelationships between the different stages of data analysis in the effectiveness and proportionality studies. Further detail is available in the text.

illustrated in Fig. 1.

For both studies:

**Common\_1. Duration of positivity in BVD + herds.** We identified the DOP for each BVD + herd during the study period. Where there was more than one BVD + animal in a given herd, the DOP for each was calculated individually. Where these overlapped, a single extended DOP was calculated. Otherwise, separate DOPs were determined. The dates of entry and exit of each BVD + animal was left censored at 01 January 2014 and right censored at 31 December 2015, as appropriate.

**Common\_2. Restriction window(s) in BVD + herds.** Separately for the effectiveness and proportionality studies, and for each of the control measures outlined in Section 2.2, restriction windows were applied for each of the four potential control measures, based upon the DOP, right censored at 31 December 2015. Where there were two or more distinct DOPs in a herd, leading to more than one restriction window, each window was calculated individually. Where these overlapped, a single, extended restriction window was calculated. Otherwise sequential, discrete restriction windows were determined and applied. Under each control measure, eligible animals were free to move while the herd was not within a restriction window. A separate restriction window was calculated for each control measure for each herd (that is, there were four restriction windows for each herd in total).

Subsequently, for the effectiveness study:

**Effectiveness\_3. Additional information.** Data on the 2015 Trojan dams as reported in the previous paper (Reardon et al., 2018) were examined to determine:

- movements of these dams during the nine months prior to the Trojan births, including the identity, location and enterprise type of the source herds that each of these dams were in during the gestation of interest,
- the duration of time that the dam spent in each of these herds.

Further detail is provided in Reardon et al. (2018).

**Effectiveness\_4. Dataset comparison.** The movement records during pregnancy of Trojan dams that calved in 2015 were examined to determine if one or more source herds were also BVD + . Where this was the case, movement records of Trojan dams were compared with the restriction periods generated from analysis of DOPs, to identify overlapping time period(s) between dates that a Trojan dam was present in, and left, a particular source herd that contained one or more BVD + animals, and dates when movement of eligible animals from that herd would have been restricted. This comparison was used to identify at the individual animal-level, which, if any Trojan dams giving birth in 2015 would have been prevented from reaching their birth herds if these restrictions had been in place while they were pregnant

with the BVD + csalf. At the herd-level, these analyses were used to determine how many of the herds that had Trojan births in 2015 would have had fewer or no Trojan births if these measures had been applied from 01 January 2015. A subset of these herds were identified as having had only a Trojan BVD + birth or births in 2015, and therefore prevention of the introduction of all Trojan dams into these herds would have resulted in their having had no BVD + births in 2015.

Subsequently, for the proportionality study:

**Proportionality\_3. Additional information.** Movement records from Irish breeding herds in 2015 were examined to identify the number of eligible animals that moved from study (restriction) herds and the dates of such movements.

**Proportionality\_4. Dataset comparison.** The movement records of each of the eligible animals from *Proportionality\_3*. were compared with the restriction windows from *Common\_2*. Separately for each of the potential restriction windows, the number of eligible females that would have been prevented from moving during 2015 if the restriction windows determined in *Common\_2* had been introduced on 01 January 2015 and applied to any herd with an identified BVD + animal since 01 January 2014 was calculated. It should be noted that herds could be restricted in 2014 without affecting movements in 2015, depending on the period of the restriction. Thus, 01 January 2014 was chosen as the earliest date on which the presence of a BVD + animal could potentially lead to restrictions in 2015 if a 12 month restriction window was applied (CM\_4). The duration for which a herd would be restricted and the numbers of animals that this would affect were determined. The number of BVD + herds subject to control measures from which movement of eligible animals were not prevented (either because none actually occurred, or those that did occur all took place outside the restriction window(s)) were also calculated.

For both studies:

**Common\_5. Infection-control benefit**

Animal- and herd-level measures of effectiveness and proportionality were presented in tabular form, by control measure and herd type, to allow comparison.

### 3. Results

#### 3.1. Study (restriction) herds

Of the 78,380 breeding herds (that is, those herds that registered the birth of at least one calf in 2015), there were a total of 11,061 (14.1%) study (restriction) herds (with at least one BVD + animal in the herd at any point between 01 January 2014 and 31 December 2015). For 9028 (81.6%) of the study herds, there was a single DOP where one or more BVD + animals were present, including 2960 (26.8%) herds where more than one BVD + animal was present and where the DOPs overlapped. The median length of DOP (between 01 January 2014 and 31 December 2015) in these herds was 85 days (min = 1 day, max = 729 days, SD 189.7) in 2014 and 2015. For the remaining 2033 (18.4% of study herds) herds, there was more than one DOP, with 1621 (14.7% of study herds) having two such periods and 412 herds (3.7%) having more than two. The maximum number of separate DOPs in an individual herd was seven, for four herds, all incorporating periods in both 2014 and 2015.

#### 3.2. Effectiveness

##### 3.2.1. Animal-level

In 2015, between 137 Trojan dams (18.3% of all 747 Trojan dams in 2015) (under CM\_1) and 279 (37.3%) Trojan dams (under CM\_4) would have been prevented from reaching the birth herd under the proposed control measures. Of the eligible animals that moved and would have been subject to restriction, the number (%) that calved within 9 months of movement (and therefore were pregnant at the time of movement, making them all potential Trojan dams) was 3979 (13.3%) and 15,763

**Table 1**

Effects of four potential control measures on the prevention of movement(s) of the 2015 Trojan dams during the pregnancy of interest, for all herds and by birth herd type.

Control measures <sup>a</sup>	Herd type <sup>b</sup>			All herds
	Dairy	Beef	Dual	
Number of movements of Trojan dams that would have been prevented				
CM <sub>1</sub>	78	66	6	147
CM <sub>2</sub>	109	106	27	242
CM <sub>3</sub>	128	137	32	297
CM <sub>4</sub>	131	137	32	303
Number (and %) of Trojan dams (n = 747) that would have been prevented from moving from the first source herd containing one or more BVD + animals during pregnancy <sup>c</sup>				
CM <sub>1</sub>	65 (23.9)	66 (17.4)	6 (6.3)	137 (18.3)
CM <sub>2</sub>	96 (35.3)	104 (27.4)	25 (26.3)	225 (30.1)
CM <sub>3</sub>	111 (40.8)	135 (35.5)	27 (28.4)	273 (36.5)
CM <sub>4</sub>	114 (41.9)	135 (35.5)	27 (28.4)	279 (37.3)
Of the eligible animals that moved and would have been subject to restriction, the number (%) that calved within 9 months of movement				
CM <sub>1</sub>	2,282 (13.2)	1060 (11.9)	666 (17.2)	3979 (13.3)
CM <sub>2</sub>	4,665 (14.7)	2394 (12.2)	1215 (16.8)	8206 (14.1)
CM <sub>3</sub>	7,049 (16.3)	4318 (13.2)	2024 (18.2)	13,240 (15.4)
CM <sub>4</sub>	8,274 (16.0)	5384 (13.0)	2331 (18.2)	15,763 (15.1)
Number (%) of herds with at least one Trojan birth in 2015 (n = 535) where all Trojan births would have been prevented <sup>d</sup>				
CM <sub>1</sub>	23 (16.7)	51 (15.5)	3 (4.5)	77 (14.4)
CM <sub>2</sub>	41 (29.7)	80 (24.2)	15 (22.4)	136 (25.4)
CM <sub>3</sub>	49 (35.5)	106 (32.1)	17 (25.4)	172 (32.1)
CM <sub>4</sub>	50 (36.2)	106 (32.1)	18 (26.9)	174 (32.5)
Number (%) of herds with at least one BVD + birth in 2015 (n = 4251) where all BVD + births would have been prevented <sup>e,f</sup>				
CM <sub>1</sub>	15 (1.0)	46 (2.0)	2 (0.5)	63 (1.5)
CM <sub>2</sub>	29 (1.9)	67 (2.9)	11 (3.0)	107 (2.5)
CM <sub>3</sub>	35 (2.3)	91 (3.9)	13 (3.5)	139 (3.3)
CM <sub>4</sub>	36 (2.3)	91 (3.9)	14 (3.8)	141 (3.3)

<sup>a</sup> The control measures were as follows: (1) CM<sub>1</sub>, herds are restricted and eligible animals are unable to move whilst any BVD + animal is present in the herd, (2) CM<sub>2</sub>, herds are restricted and eligible animals are unable to move, whilst any BVD + animal is present in the herd, and for 4 months (120 days) after the last BVD + animal has been removed, (3) CM<sub>3</sub>, Herds are restricted and eligible animals are unable to move, whilst any BVD + animal is present in the herd, and for 9 months (270 days) after the last BVD + animal has been removed, (4) CM<sub>4</sub>, herds are restricted and eligible animals are unable to move, whilst any BVD + animal is present in the herd, and for 12 months (365 days) after the last BVD + animal has been removed.

<sup>b</sup> Herds are categorised as dairy, beef or dual purpose where herd type could be established. Herds where herd type could not be established are not included in the herd type subdivisions but are included in the 'all herds' figure. Please see Discussion.

<sup>c</sup> Some dams had more than one movement during this period, for example, through several source herds before moving into the birth herd. In all cases this is also the number (%) of Trojan births prevented.

<sup>d</sup> The number of herds where all Trojan births would have been prevented in 2015 if the potential control measure had been applied (numerator) divided by the number of herds with at least one Trojan birth in 2015 (denominator), expressed as a percentage.

<sup>e</sup> That is, regardless of the BVD status of the dam.

<sup>f</sup> The number of herds where all BVD + births would have been prevented in 2015 if the potential control measure had been applied (numerator) divided the number of herds with at least one BVD + birth in 2015 (denominator), expressed as a percentage.

(15.1%) under CM<sub>1</sub> and CM<sub>4</sub>, respectively (Table 1). This animal-level measure of effectiveness, in targeting potential Trojan dams, was generally lower in beef compared to dairy herds with each of the control measures.

### 3.2.2. Herd-level

In herds with at least one Trojan birth in 2015, all Trojan births

**Table 2**

Details of Irish herds in 2015, including number of herds from which at least one eligible animal moved, total number of eligible animals with at least one registered movement and total number of movements of eligible animals.

Herd type	All herds			
	Dairy	Beef	Dual	
Total number of herds from which at least one eligible animal moved in 2015				
	16,108	50,101	4,179	71,163
Total number of eligible animals with at least one registered movement from a herd in 2015				
	282,250	378,566	71,558	684,890
Total number of movements of eligible animals from herds in 2015				
	314,851	442,337	74,398	842,076

would have been prevented in 14.4% and 32.5% of these herds, under CM<sub>1</sub> and CM<sub>4</sub>, respectively. In herds with at least one BVD + birth in 2015, all BVD + births would have been prevented in 1.5% and 3.3% of herds under CM<sub>1</sub> and CM<sub>4</sub>, respectively (Table 1).

### 3.3. Proportionality

#### 3.3.1. Animal-level

During 2015, there were 842,076 movements of 684,890 eligible animals from 71,163 of 78,380 (90.7%) Irish breeding herds (Table 2). If imposed, CM<sub>1</sub> and CM<sub>4</sub> would have prevented the movement of 30,082 (4.4%) and 105,921 (15.4%) of eligible animals from study (restriction) herds (Table 3). Dairy animals were more likely to be affected by these control measures (Table 3). The median number of movements prevented per animal was 1, ranging from 1 to 4 for all control measures.

#### 3.3.2. Herd-level

The number of study (restriction) herds affected by the control measures varied between 2477 (22.4% of all study (restriction) herds) and 7186 (65.0%), for CM<sub>1</sub> and CM<sub>4</sub>, respectively (Table 3). Of Irish herds with at least one eligible movement, at least one of these movements would have been restricted for 3.5% and 10.1% of these herds, under CM<sub>1</sub> and CM<sub>4</sub>, respectively (Table 3). The median number of movements restricted per herd varied from 5 for CM<sub>1</sub> to 7 for CM<sub>4</sub>, with up to 2557 movements in a single herd restricted for CM<sub>2</sub> to CM<sub>4</sub> (Table 3).

### 3.4. Infection-control benefit

A comparison of animal and herd-level measures of effectiveness and proportionality are presented in Table 4. At the animal-level, the respective effectiveness (% of Trojan births prevented) and proportionality (% of eligible animals that would have been prevented from moving) were 18.3% and 4.4% under CM<sub>1</sub> and 37.3% and 15.4% under CM<sub>4</sub>, respectively. Both the percentage of Trojan births prevented and the percentage of animals prevented from moving were higher in dairy animals compared to beef or dual purpose. At the herd-level, the respective effectiveness (% of herds with all Trojan births prevented) and proportionality (% of herds with at least one animal movement restricted) were 14.4% and 3.5% under CM<sub>1</sub> and 32.5% and 10.1% under CM<sub>4</sub>, respectively. The percentages of herds with all Trojan births prevented and with movement restrictions was higher in dairy than in beef or dual purpose herds.

## 4. Discussion

This study, based on detailed analysis of animal- and herd-level patterns of movements and BVDv test results generated during the Irish national BVDv eradication programme, represents the first published

**Table 3**

For each of four control measures, the number of movements from study (restriction) herds that would have been prevented, the number of study (restriction) herds that would have been affected, the median number (range) of eligible animals per farm whose movement would have been prevented, and the median number (range) of movements per eligible animal that would have been prevented, in total and by herd type. Cases where no herd type was available for the herd are excluded from the break down by herd type but included in the data for all herds.

Control measure <sup>a</sup>	Herd type			All herds
	Dairy	Beef	Dual	
Number of movements of eligible animals from study (restriction) herds that would have been prevented				
CM_1	18,012	8981	3884	30,885
CM_2	33,838	19,783	7294	60,923
CM_3	45,905	33,154	11,248	90,316
CM_4	54,738	42,288	12,957	110,008
Number (%) of eligible animals (n = 684,890) that would have been prevented from moving from study (restriction) herds <sup>b,c</sup>				
CM_1	17,301 (6.1)	8900 (2.4)	387 3(5.4)	30,082 (4.4)
CM_2	31,803 (11.3)	19,545 (5.2)	7245 (10.1)	58,601 (8.5)
CM_3	43,321 (15.3)	32,612 (8.6)	11,117 (15.5)	87,059 (12.7)
CM_4	51,768 (18.3)	41,343 (10.9)	12,785 (17.9)	105,921 (15.4)
Number (%) of study (restriction) herds (n = 11,061) that would have been affected				
CM_1	942 (26.9)	1250 (19.1)	284 (32.9)	2477 (22.4)
CM_2	1,520 (43.4)	2229 (34.1)	399 (46.3)	4149 (37.5)
CM_3	1,934 (55.2)	3265 (49.9)	533 (61.8)	5734 (51.8)
CM_4	2,502 (71.4)	4077 (62.3)	603 (70.0)	7186 (65.0)
Number (%) of Irish herds (n = 71,163) with at least one eligible movement, where at least one movement would have been restricted				
CM_1	942 (5.8)	1250 (2.5)	284 (6.7)	2477 (3.5)
CM_2	1,520 (9.4)	2229 (4.4)	399 (9.5)	4149 (5.8)
CM_3	1,934 (12.0)	3265 (6.5)	533 (12.7)	5734 (8.1)
CM_4	2,502 (15.5)	4077 (8.1)	603 (14.4)	7186 (10.1)
Median number (range) of eligible animals per study (restriction) herd whose movement would have been prevented				
CM_1	8 (1-1549)	4 (1-84)	7 (1-290)	5 (1-1549)
CM_2	9 (1-2557)	5 (1-263)	9 (1-696)	6 (1-2557)
CM_3	11 (1-2557)	5 (1-580)	11 (1-1116)	7 (1-2557)
CM_4	11 (1-2557)	5 (1-766)	11 (1-1116)	7 (1-2557)
Median number (range) of movements per eligible animal that would have been prevented				
CM_1	1 (1-4)	1 (1-3)	1 (1-2)	1 (1-4)
CM_2	1 (1-4)	1 (1-3)	1 (1-2)	1 (1-4)
CM_3	1 (1-4)	1 (1-3)	1 (1-2)	1 (1-4)
CM_4	1 (1-4)	1 (1-3)	1 (1-2)	1 (1-4)

<sup>a</sup> The control measures were as follows: (1) CM\_1, herds are restricted and eligible animals are unable to move whilst any BVD + animal is present in the herd, (2) CM\_2, herds are restricted and eligible animals are unable to move, whilst any BVD + animal is present in the herd, and for 4 months (120 days) after the last BVD + animal has been removed, (3) CM\_3, Herds are restricted and eligible animals are unable to move, whilst any BVD + animal is present in the herd, and for 9 months (270 days) after the last BVD + animal has been removed, (4) CM\_4, herds are restricted and eligible animals are unable to move, whilst any BVD + animal is present in the herd, and for 12 months (365 days) after the last BVD + animal has been removed.

<sup>b</sup> The total number of eligible animals where movement from study (restriction) herds would have been prevented in 2015 if the potential control measure had been in place (numerator) divided by the total number of eligible animals with at least one registered movement from Irish herds during 2015 (denominator), expressed as a percentage.

<sup>c</sup> The total number of animals moving from study (restriction) herds is less under each restriction measure than that indicated here. The numbers were 29,956, 58,175, 87,059 and 104,627 under each respective measure. This is because the above table may count the same animal twice if it moved from two different herd types.

report of the impact of a range of movement controls on herds in which BVD + births have occurred on the prevention of subsequent Trojan births as a consequence of pregnant animals moving from these herds. Measures to restrict the movement of potential Trojan dams have been applied in eradication programmes in other countries (Alban et al., 2001; Hult and Lindberg, 2005; Presi et al., 2011). While intuitively it might be expected that appropriate measures would succeed in preventing all Trojan births, the outcomes of these measures have not been described.

The current study was therefore undertaken to retrospectively investigate the impact of four different control measures on restricting the movement of Trojan dams in 2015 in the context of the Irish national BVDv eradication programme, and in so doing to provide an evidence base to inform policy decisions regarding the introduction and nature of movement controls to prevent Trojan births. While the total number of Trojan births in Ireland has decreased from 2013 (938) to 2015 (747), they represent an increasing proportion of all BVD + births, rising from 7.1% to 10.6% over the same period. Three key pillars dictating the usefulness of these measures were evaluated: (i) their effectiveness in preventing the movement of Trojan dams, (ii) their proportionality with respect to their impact on general trade in eligible animals from restricted herds and (iii) their potential control-benefit, being a comparison of the effectiveness and proportionality of the proposed control measures.

For the effectiveness study, a range of potential restriction lengths, including those longer than the DOP, were chosen based on knowledge of bovine gestation length and the pathology of BVDv in pregnant bovines. CM\_1 limits the movements of eligible females to the period while there is an identified BVD + animal on farm and as such represents the minimum period for which one would consider restricting movements in an eradication programme. However, it recognised PIs may remain *in utero* at the point when the BVD + animal is removed and therefore three additional restriction periods were evaluated. In Ireland, the majority of herds have a seasonal calving pattern, particularly in dairy herds, with the majority of calves born in spring, with the expectation that the majority of calves would be born within a 12–16 week period (Butler, 2016). CM\_2 therefore extended the restriction period for four months after the last BVD + animal leaves the farm. CM\_3 extends the restriction period for nine months after the departure of the last BVD + animal, with the expectation that all animals that were in calf at that time, except those in the first days post-service, would have calved by that point. It is possible that in the aftermath of removing a PI animal that there would still be transient infections circulating in the herd or residual contamination of equipment such as common feeders, nose tongs, boots and the environment that could result in the creation of further PI calves (Niskanen et al., 2002; Lanyon et al., 2006). Therefore CM\_4 extended the period of restriction for a further three months to a full calendar year. The calendar year of 2015 was chosen because it had the most complete data available at the start of this study. During this year, 98% of all bovines in breeding herds had a status on the national BVD database (unpublished data), with only 2% having an unknown status, minimizing (but not completely abolishing) the likelihood of misclassification of herds that contained unidentified PI animals. To capture information on the movement history during gestation of all Trojan dams and allow for a potential restriction period of 12 months from removal of last BVD + animal from study (restriction) herds, the status of herds in both 2014 and 2015 were examined. In the proportionality study, the focus was on the wider cattle population and movements, specifically those from BVD + herds. Due to the seasonal differences in cattle trade and to avoid associated bias, it was decided to choose a single calendar year for analysis. Again, the most comprehensive information available on BVD + herds was for 2015.

From an effectiveness perspective, the perfect control measure would prevent all Trojan movements into birth herds which would ideally have no BVD + births from any source in that year. However,

**Table 4**

Animal- and herd-level measures of effectiveness and proportionality, by herd type and for all herds, for four different control measures to limit the movement of Trojan dams in Ireland during 2015.

Control measure <sup>a</sup>	Herd type						All herds	
	Dairy		Beef		Dual		Effectiveness <sup>b</sup>	Proportionality <sup>c</sup>
	Effectiveness <sup>b</sup>	Proportionality <sup>c</sup>	Effectiveness <sup>b</sup>	Proportionality <sup>c</sup>	Effectiveness <sup>b</sup>	Proportionality <sup>c</sup>		
<b>Animal-level measures</b>								
CM_1	23.9	6.1	17.4	2.4	6.3	5.4	18.3	4.4
CM_2	35.3	11.3	27.4	5.2	26.3	10.1	30.1	8.5
CM_3	40.8	15.3	35.5	8.6	28.4	15.5	36.5	12.7
CM_4	41.9	18.3	35.5	10.9	31.6	17.9	37.3	15.4
<b>Herd-level measures</b>								
CM_1	16.7	5.8	15.5	2.5	4.5	6.7	14.4	3.5
CM_2	29.7	9.4	24.2	4.4	22.4	9.5	25.4	5.8
CM_3	35.5	12.0	32.1	6.5	25.4	12.7	32.1	8.1
CM_4	36.2	15.5	32.1	8.1	26.9	14.4	32.5	10.1

<sup>a</sup> The control measures were as follows: (1) CM\_1, herds are restricted and eligible animals are unable to move whilst any BVD + animal is present in the herd, (2) CM\_2, herds are restricted and eligible animals are unable to move, whilst any BVD + animal is present in the herd, and for 4 months (120 days) after the last BVD + animal has been removed, (3) CM\_3, Herds are restricted and eligible animals are unable to move, whilst any BVD + animal is present in the herd, and for 9 months (270 days) after the last BVD + animal has been removed, (4) CM\_4, herds are restricted and eligible animals are unable to move, whilst any BVD + animal is present in the herd, and for 12 months (365 days) after the last BVD + animal has been removed.

<sup>b</sup> Animal-level: % of Trojan births prevented (from Table 1); Herd-level: % of herds with at least one Trojan birth where all Trojan births prevented (from Table 1).

<sup>c</sup> Animal-level: % of eligible animals in Ireland that would have been prevented from moving (from Table 3); Herd-level: of Irish herds with at least one eligible movement, % where at least one movement would have been restricted (from Table 3).

even were all movements of Trojan dams to be stopped, it is recognised that some herds could still have one or more other BVD + births attributable to non-Trojan dams. A key finding was that only a minority of Trojan dams were prevented from moving (Table 1), ranging from 18.3% with CM\_1 to 37.3% with CM\_4. Comparison of the results obtained indicated that there was little benefit in extending the restriction period from 9 months (CM\_3) to 12 months (CM\_4), with only a further 6 Trojan dams being prevented from moving (Table 1), whereas an additional 18,862 (that is, 105,921 minus 87,059) eligible animals would have prevented from moving from study (restriction) herds (Table 3). For a substantial number of Trojan dams, it was not possible to identify a BVD + source herd where the Trojan dam became infected. There are a number of possible explanations for this. Firstly, while the presence or absence of animals of unknown status was not investigated for each source herd, some may have contained animals of unknown status that were in fact PI and which subsequently died or left the herd without being tested. Secondly, it is also possible that unidentified PIs (aborted, stillborn or calves that die as neonates without being tagged) may have served as an unidentified source of infection in some source herds even after the removal of any known PIs (Lindberg and Houe, 2005). Thirdly, source herds may have contained animals which had a false negative test result, leaving a PI animal in the herd. However, consistent with findings from Switzerland (Presi et al., 2011), ongoing monitoring of programme results in Ireland indicates that this occurred very rarely (unpublished data). Finally, it is possible that in fact there was no PI animal present in the source herd which resulted in the creation of a Trojan dam. Rather, the dam was exposed to BVDv in the source herd as a result of a breach of biosecurity. Investigations of over 1100 herds with BVD + births in 2016 carried out by trained private veterinary practitioners as part of a targeted advisory service on animal health (TASAH), and funded by the Rural Development Programme 2014–20, have identified direct contacts at boundaries, and indirect contacts through either the herd owner themselves or other personnel as being the most plausible transmission pathways in such cases (unpublished data). These findings highlight the importance of effective application of biosecurity measures in all herds. While the emphasis for infected herds is clearly on biocontainment to prevent spread to other herds, by Trojan dams or otherwise, the importance of the application of appropriate bioexclusion measures by herds that are not infected cannot be overemphasized. When evaluated at herd-level,

effectiveness, as measured by the percentage of herds where all Trojan births would have been prevented, was slightly lower than at animal-level (a maximum of 174 herds [32.5%] under CM\_4, Table 1). When measured in terms of all BVD + herds where all BVD + births (Trojan and non-Trojan) were prevented in 2015, a maximum reduction of 3.3% was observed under CM\_4 (Table 1).

The proportionality component of the study was undertaken to investigate the impact of the application of control measures on trade from both study (restriction) herds and more generally. The first key observation was that not all BVD + herds would in fact be affected due to the absence of movements during the restriction period. Depending on the control measure, the number and percentage of study (restriction) herds that would have been affected, ranged between 2477 (22.4%) to 7186 (65.0) (Table 3). This represents between 3.5%–10.1% of the 71,163 breeding herds that moved eligible animals in 2015 (Table 4). At the animal-level, the total number of eligible animals in affected study (restriction) herds whose movements would have been prevented ranged from 30,082 (CM\_1) to 105,921 (CM\_4, Table 3) representing between 4.4% and 15.4% of all eligible animals that moved from breeding herds in 2015. When considered at the individual herd-level, the median numbers of animals prevented from moving from restricted herds were relatively modest, ranging from 5 (CM\_1) to 7 (CM\_4) overall (Table 3). However, a small number of herds had much larger numbers of movements (maximum 2557). While a detailed analysis of movement patterns and pregnancy status is beyond the scope of the current study, the previous finding (Reardon et al., 2018) that the odds of selling a Trojan dam in herds selling more than one eligible pregnant animal was 37 times higher compared to herds selling 0 or 1 such animals highlights the risks posed by movements from such herds. The present study evaluated proportionality based on 2015 data. During this year, the overall prevalence of PI births was 0.33% (Animal Health Ireland, 2017), but since then has reduced by over three-fold to 0.1% for 2017 (year to 1 September). Assuming that this reduction in prevalence would be reflected in a similar reduction in the number of study (restriction) herds should control measures be introduced for 2018, it is reasonable to assume that the proportionality of such measures would also be markedly improved, with the proportion and number of herds affected being reduced by approximately three-fold also. There are also several measures that could be taken to potentially improve the proportionality further, by reducing the numbers of

eligible animals affected in restricted herds and the actual number of restricted herds. As indicated in Table 1, the proportion of restricted eligible animals that were in fact pregnant ranged between 13.3% (CM\_1) and 15.1% (CM\_4). Therefore permitting restricted animals to move based on a negative pregnancy status would reduce the number of restricted animals by approximately seven-fold. In addition, while serological tests cannot be reliably used to identify pregnant dams carrying PI fetuses (Lindberg et al., 2001), a negative serological and virological status in advance of movement provides strong evidence that the dam is naïve and therefore her calf is not PI. At this stage of the eradication, given that animals in the 12–24 month age range account for a significant proportion of eligible animals that move each year (Anon., 2016b), and the progress made in the eradication programme to date, it is anticipated that the majority of eligible animals would be seronegative. While there would be a cost associated with a blood test and pregnancy diagnosis, it would further improve the proportionality of control measures and minimize the impact on farm businesses.

The proportionality study ran until the end of 2015, corresponding to a period when the number of BVD + animals in Ireland was declining relative to previous years (Animal Health Ireland, 2017). Therefore, towards the end of the study period, the number of herds and animals restricted was lower than at the beginning. The effectiveness study included all animals that calved in 2015, but looking back nine months to the herds through which they had moved. At this time, the number of BVD + animals was higher, making it more likely that there would be a BVD + animal identified in a source herd, leading to an effective restriction. Further, in this earlier period, information about animal-level BVD status was less complete, making it possible that there were unidentified PI(s) in the source herds leading to infection. When comparing effectiveness and proportionality therefore, we estimate that this nine-month time difference will lead to a slight distortion in the number of Trojan births prevented per movement stopped. In the effectiveness study, the effectiveness of each control method is measured at the herd-level on the basis of herds where one or all BVD + births in 2015 would have been prevented. It is possible that in some herds, a Trojan dam which entered at the start of 2015 and calved early in the year could have led to BVD + births later that year. For example if the Trojan birth happened at the end of January and the PI calf came in contact with a naïve pregnant animal towards the end of the WOS in February, then a resultant PI birth could occur in July. With this in mind, it is possible that the figure we use for herds where all BVD + births would have been prevented is an underestimate.

Care is needed when interpreting the results at the herd-level. Where herds are subdivided into herd type, the three individual values for beef, dairy and dual purpose may not add up to the total, as these only include herds where herd type could be established, while the total number includes all herds. In the section on animal movements (Table 3), this trend is confounded by the fact that each category may add up to more than the total number as each dam may move more than once, through more than one herd type. While these differences do necessitate care in interpreting the tables, they do not affect any of the trends described.

## 5. Conclusions

While the application of control measures to BVD + herds is effective in preventing the movement of Trojan dams from such herds, it is demonstrated that in fact only the minority of Trojan dams originate from BVD + herds. Therefore measures to minimize their movement must focus both on BVD + herds and on improved biosecurity to prevent accidental introduction of infection into other herds. The alternative would be to apply control measures to all programme herds. In the absence of such a decision, not all BVD + herds would be impacted by these control measures, and those that would could reduce their impact through demonstration of negative pregnancy status and seronegativity for BVDv. The progress made in the BVD eradication

programme since 2015 would further contribute to the reduction in the number of herds that would actually be subjected to control measures. The findings of this study on the effectiveness and proportionality of measures to prevent the movement of Trojan dams provides new information for policy makers in deciding on both the necessity and nature of measures to address the issue of Trojan dams. Appropriate controls will become particularly important should a decision be taken to introduce a serological testing option of BVD-free herds, since the birth of a Trojan calf in such herds could go undetected for several months, with significant negative consequences. However, in the meantime the continued application of tag testing of calves born to purchased, pregnant dams, with the rapid removal of any PI calves detected, appears to be the most effective and proportionate means of addressing the issue of Trojan dams.

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