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The impact of bluetongue serotype 3 on cattle mortality, abortions and premature births in the Netherlands in the first year of the epidemic

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ABSTRACT

In September 2023, bluetongue virus serotype 3 (BTV-3) was identified among sheep and cattle in the Netherlands. Severe clinical signs and increased mortality were reported in sheep and cattle. The aim of this study was to quantify the impact of BTV-3 on mortality, abortions and premature births in cattle in the Netherlands in 2023. Data were available from 1 January 2020–31 December 2023 and were aggregated at herd-month level. Cattle herds were assigned a BTV-3 status for each herd-month: 1) herds that notified clinical signs of BTV-3, 2) herds that did not notify clinical signs but were located in BTV-3 infected areas or 3) herds that were located in BTV-3 free areas (all areas without BTV-3 notifications). Multivariable population-averaged generalized estimating equations models were used to quantify the association between the BTV-3 epidemic and cattle mortality, abortions and premature births. The results showed that from September 2023 until the end of 2023, perinatal calf mortality increased 1.11 (95 % CI:1.06–1.16) and 1.07 (95 % CI: 1.05–1.09) times, in dairy herds with a notified BTV-3 outbreak and in other dairy herds located in outbreak areas, respectively. Premature birth may be one of the explanations of increased calf mortality, as suggested by an odds ratio of 1.39 (95 % CI: 1.26–1.54) for premature births in dairy herds with a notified BTV-3 outbreak compared to dairy herds in BTV-3 free areas. The odds of abortions in infected dairy herds was 1.1 (95 %CI: 1.02–1.20) times higher compared to non-infected herds. Mortality in cattle aged 1–2 years and older than 2 years increased 2.25 (95 %CI: 1.97–2.58) and 1.71 (95 % CI: 1.62–1.81) times respectively, in infected dairy herds. In dairy herds without notification located in BTV-3 infected areas, mortality increased by 1.17 (95 %CI: 1.07–1.27) and 1.22 (95 % CI: 1.19–1.25) times respectively, compared to herds in BTV-3 free areas. In addition, suckler cow herds, beef cattle herds and small scale non-dairy cattle herds with a notified BTV-3 outbreak showed a significantly increased mortality during the BTV-3 epidemic compared to herds in BTV-3 free areas. In conclusion, BTV-3 infections markedly increased abortions, mortality and premature births in cattle herds.

1. Introduction

Bluetongue (BT) is an infectious, non-contagious vector-borne disease that is caused by bluetongue virus (BTV) which mainly affects ruminants. BTV is transmitted by midges of the genus *Culicoides* spp. and is an Orbivirus from the Reoviridae family (Maclachlan et al., 2015), for some strains vertical transmission has been demonstrated (De Clercq et al., 2008; Darpel et al.,2009). BTV infection causes severe damage of endothelial cells of the vasculature resulting in oedemas, hemorrhages, muscular degeneration and necrosis (Maclachlan et al., 2009). Domestic and wild ruminants are mainly affected by BT and sheep develop severest clinical signs with sometimes high mortality rates (Backx et al., 2007; Santman-Berends et al., 2024; van den Brink et al., 2024). Nevertheless, cattle play an important role in transmission and can also show pronounced clinical signs and mortality upon infection (Elbers et al., 2008; van den Brink et al., 2024). BT is listed by the World Organisation for Animal Health (WOAH) as a multispecies disease with significant economic impact (WOAH, 2020), and is categorized as a

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category C+D+E disease under the European Animal Health Law (AHL) (EUregulation, 2016/429). These are diseases that are relevant to Member States and require measures to prevent their spread to other parts of the Union that are officially disease-free or where an eradication program for the listed disease is ongoing. Direct economic losses of BT in cattle are mainly caused by a negative impact on milk production, fertility and mortality (Santman-Berends, 2011). To date, over thirty different BTV serotypes have been identified of which only the first 24 are notifiable to the European Commission and the WOAH (van Rijn, 2019; Saminathan et al., 2020).

BT emerged in the Netherland for the first time in 2006. This epidemic was caused by BTV serotype 8 (BTV-8) and vaccines became available in 2008. High natural and vaccine-induced immunity stopped virus spread and the Netherlands regained its official BTV-free status in 2012. After an official BTV-free period of more than eleven years, BTV serotype 3 (BTV-3) was identified in September 2023 in the Netherlands for the first time (Holwerda et al., 2024). Subsequently, BTV-3 spread rapidly through the Netherlands, affecting over 5000 sheep flocks and cattle herds and, in addition, a limited number of outbreaks were notified in Belgium, Germany and the United Kingdom (van den Brink et al., 2024). Clinical signs observed in cattle included fever, lesions and ulcerations of mucous membranes, nasal discharge and conjunctivitis. Most prominent signs were lameness and a clear drop in milk production. Mortality following severe clinical disease and lung oedema was also reported (van den Brink et al., 2024).

The availability of routine trend analyses within the national Cattle Health Surveillance System (CHSS) (Santman-Berends et al., 2016), offered the opportunity to quantify certain impacts of the BTV-3 epidemic on cattle in the Netherlands. The aim of this study was therefore to quantify the impact of BTV-3 on mortality, abortions and premature births in cattle in the Netherlands in 2023.

2. Material and methods

2.1. Study population

During the epidemic of BTV-3 in 2023, approximately three million cattle (excluding veal calves) located in approximately 30,200 cattle holdings were present in the Netherlands, (van den Brink et al., 2024; RoyalGD, 2023). Fig. 1 shows the distribution of farm categories in the Dutch cattle industry. In our study, we included dairy and non-dairy herds. Veal and youngstock rearing herds were excluded.

2.2. Available data

This study was part of the Trend Analysis Surveillance Component (TASC) within the CHSS, for which, each quarter of the year anonymized routinely collected census data are provided over a five year period by different national organizations. These data include cattle movement data (Dutch enterprise agency (RVO, Assen)), carcass collections (Dutch rendering facility (Rendac, Son)), milk production and quality data (Qlip laboratories, Zutphen), bulk milk delivery data (Milk processing companies), data on antimicrobial use (ZuivelNL, the Hague), herd health statuses (Royal GD, Deventer) and test-day milk production data (Royal Dutch Cattle Syndicate (CRV Holding BV, Arnhem) and (milk control association Nijland, Nijland)). Within TASC, these data are combined and aggregated into various key indicators to monitor developments in cattle health in the Netherlands (Santman-Berends et al., 2016).

BTV-3 notification data were available from the Dutch Food and Consumer Product Safety Authority (NVWA) for all herds of which the farmers notified clinical signs of BTV-3. At the beginning of the epidemic, notification and confirmation by PCR was compulsory. Due to the high volume of notifications, legislation was amended during the epidemic. Starting from the second half of September 2023, it became possible to report suspected cases of BTV-3 without requiring PCR confirmation in areas already heavily affected by the infection. When no PCR result was available, the report was classified as a clinical suspicion. These data included the unique herd identification number (UHI), the animal species in which the clinical signs were observed, whether the report was solely a clinical notification or notified and confirmed by PCR, the date of the report and the location of the report. The final dataset for the study consisted of all herds with either a clinical suspicion and herds in which the clinical suspicion was confirmed with PCR.

2.3. Definitions

2.3.1. Classification of herds in relation to the expected influence of BTV-3

Cattle herds were assigned a BTV-3 status per week based on geographical farm location at the level of two-digit postal code area, and whether the farmer reported any clinical signs to the NVWA. The median size of a 2-digit postal code area in the Netherlands is 370 km^2 (IQR:213–492). The period before September 2023 was for all herds regardless of the area classified as BTV-3 free, given that the first clinical signs were detected on 3 September 2023 and that no indications of BTV-3 infection had been found prior to September 2023 (Holwerda et al., 2024).

From the start of the epidemic in September 2023 herds could be classified in one of three disease classification groups:

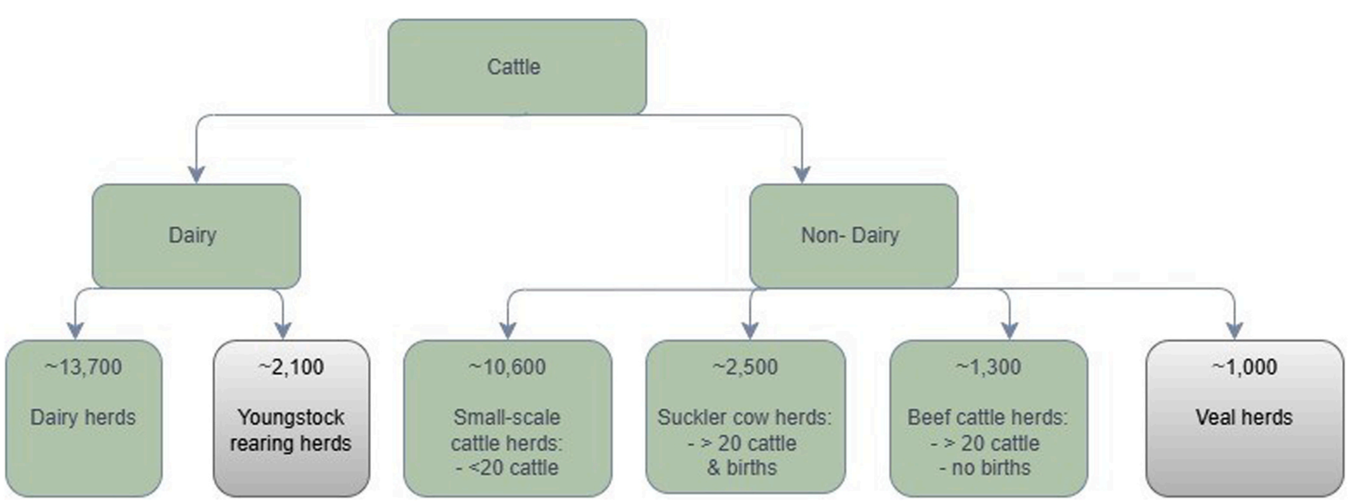

Fig. 1. Break down of the cattle industry in the Netherlands according to farm category.

1. BTV-3 infected herd: Herds of which the farmer notified a clinical suspicion of BTV-3 infection to the authorities.
2. BTV-3 infected area: Herds of which the farmer didn't notify clinical signs to the authorities, but located in two-digit postal code areas where presence of BTV-3 was confirmed (regardless of species involved).
3. BTV-free area: Herds that were located in a two-digit postal code area from which no notifications of clinical signs indicative for BTV-3 were made. In these areas no clinical signs had been notified to the authorities by any farmer of BTV susceptible animals.

The classification was made on week level and in every time period the BTV-3 status could evolve to a higher BTV classification group. Consequently, before September 4, 2023, all herds were classified as being in a 'BTV-free area'. They remained in this category after September 4, 2023, unless a notifications was made within the two-digit postal code area in which the herd was located. If at least one farmer within a two-digit postal code area reported clinical signs of BTV-3 to the authorities, regardless of the species in which clinical signs were observed, the classification for all herds within that 2 digit postal code area changed to 'BTV-3 infected area'. If a farmer notified clinical signs specifically within their own herd, that herd's status changed to the 'BTV-3 infected herd'.

2.3.2. Mortality, premature birth and abortion parameters

Indicators that were analysed were mortality including perinatal calf mortality, abortions and premature births. In this study, different mortality parameters in dairy herds were determined according to definitions that were developed in previous research and that are currently used in CHSS (Santman-Berends et al., 2019): 1) perinatal calf mortality 2) postnatal calf mortality, 3) preweaned calf mortality, and 4) weaned calf mortality. In all four calf mortality parameters, the number of dead animals in a predefined period of time were included as numerator. The number of births and the number of eartagged calves were included as denominator to calculate the mortality risk for 1 and 2, respectively. To calculate the mortality rate for 3 and 4, the number of calves in the specific age category and the time that they were present in the herd were included in the denominator as calf-days-at-risk. The exact definitions and formulas of these four parameters can be found in Santman-Berends et al. (2019). The young stock (1–2 years) and cattle (≥2 years) mortality rates were calculated as the number of dead young stock or cows relative to the number of cattle in the specific age category present in the herd in the same period (cow-days-at-risk). The mortality risk during the start of lactation (Days In Milk (DIM) < 60 days) was defined as the number of dead cows during this period relative to the number of cows present in this period. Finally, the (risk) percentages of abortions (between 180 and 260 days pregnancy) and premature births (between 260 and 265 days pregnancy) were determined and included as the numerator. The number of births were included as denominator.

Mortality in suckler herds was determined for the following groups: perinatal calves, eartagged calves < 1 year and cattle ≥ 1 year and were calculated in the same way as for dairy herds. Additionally, total cattle mortality was determined for beef cattle herds, whereas the occurrence of cattle mortality (yes or no) was determined for small-scale herds.

2.4. Analyses

First, all datasets that are routinely delivered for the CHSS, were encrypted by an external encryption company (IntoFocus Data Transformation Services, IDTS, Deventer) to prevent traceability of results to individual farms or animals. To enable combining data from multiple sources for analysis, the same encryption code was applied across all datasets. Each dataset was subsequently validated following the protocols established in the national monitoring and surveillance system (Santman-Berends et al., 2016). Specifically, scripts in SAS 9.4® (SAS Institute Inc., 2013) were utilized to identify and eliminate duplicate entries and biologically implausible records. Post-validation, all datasets were aggregated at farm and weekly levels, and were merged. The notification dataset was encrypted with the same key as the CHSS dataset and based on these data, the week of the initial BTV-3 notification for each two-digit postal code was extracted and merged with farm-level notification data. These data were subsequently combined with the CHSS dataset and thereafter the complete dataset was transferred to Stata® version 17 (StataCorp, 2019) for statistical analysis.

Descriptive statistical methods were applied to the notification data and mortality data for all farm types. The crude weekly death counts per herd were aggregated for the entire duration of the BTV-3 epidemic in 2023, as well as on a weekly basis for the year 2023.

2.4.1. Multivariable analyses

To quantify the impact of the BTV-3 epidemic, multivariable regression analyses were performed using Multivariable population-averaged generalized estimating equations (PA-GEE) as described by Santman-Berends et al. (2016). For analysis purposes, the weekly mortality data were aggregated on herd-month level over the period of 1 January 2020 to 31 December 2023. All mortality parameters, premature births and abortions were included as dependent variables and the BTV-3 herd status as independent variable of interest. The BTV-free classification group was used as a reference group. Additional explanatory variables that were included as independent variables in the models were: herd size, milk production level, geographical location (province), growth in herd size, replacement rate, milk and meat prices, season (quarter of the year as indicator for winter, spring, summer and autumn), trend in time (month of year) and herd health statuses (for BVD, IBR, salmonellosis, paratuberculosis and leptospirosis). Based on the structure and distribution of the dependent variable, the best fitting distribution and appropriate link function was chosen. In all models, an independent correlation structure was used to correct for repeated measures of herds. Mortality was generally analysed using a Poisson distribution with a log link function and in case of overdispersion of the residuals a Negative Binomial distribution was used. The natural logarithm of the number of animal-days at risk was included as exposure variable. For small scale herds the occurrence of mortality (yes or no) was analysed with a binomial distribution with a logit link function. The impact of BTV-3 on premature births and abortions could only be analysed for dairy herds.

Estimates are presented as incidence rate ratios (IRR) (for models in which a Poisson or negative binomial distribution was used) or odds ratios (OR) (for models with a binomial distribution). Results are considered statistically significant at a P-value < 0.05.

Model fit was evaluated using the quasi-likelihood under the independent model criterion (QIC) (Pan, 2001; Cui, 2007) and the amount of variance explained by the model (R^2).

3. Results

3.1. Descriptive data Cattle (dairy and non-dairy)

The differences in the number of cattle per week that died in the total cattle sector stratified to different age categories between 2023 and the previous period (2020–2022) are presented in Fig. 2 as a four-weekly moving average. The largest increase in mortality was seen in the age group of cattle ≥ 2 years of age and a modest increase of eartagged calves ≤ 14 days. During the BTV-3 epidemic in 2023 (week 36–52), approximately 1400 eartagged calves ≤ 14 days, 1000 calves between 56 days and 1 year, 600 young stock between 1 and 2 years and 6500 cattle ≥ 2 years additionally died compared to the average in the same period in the three previous years (2020–2022). The mortality rate of calves between 15 and 55 days old could not be compared to the numbers from previous years. Mortality in this age category is influenced by the fact that imported veal calves from Germany (>500,000/year) were on average 30 days old at the time of arrival in the

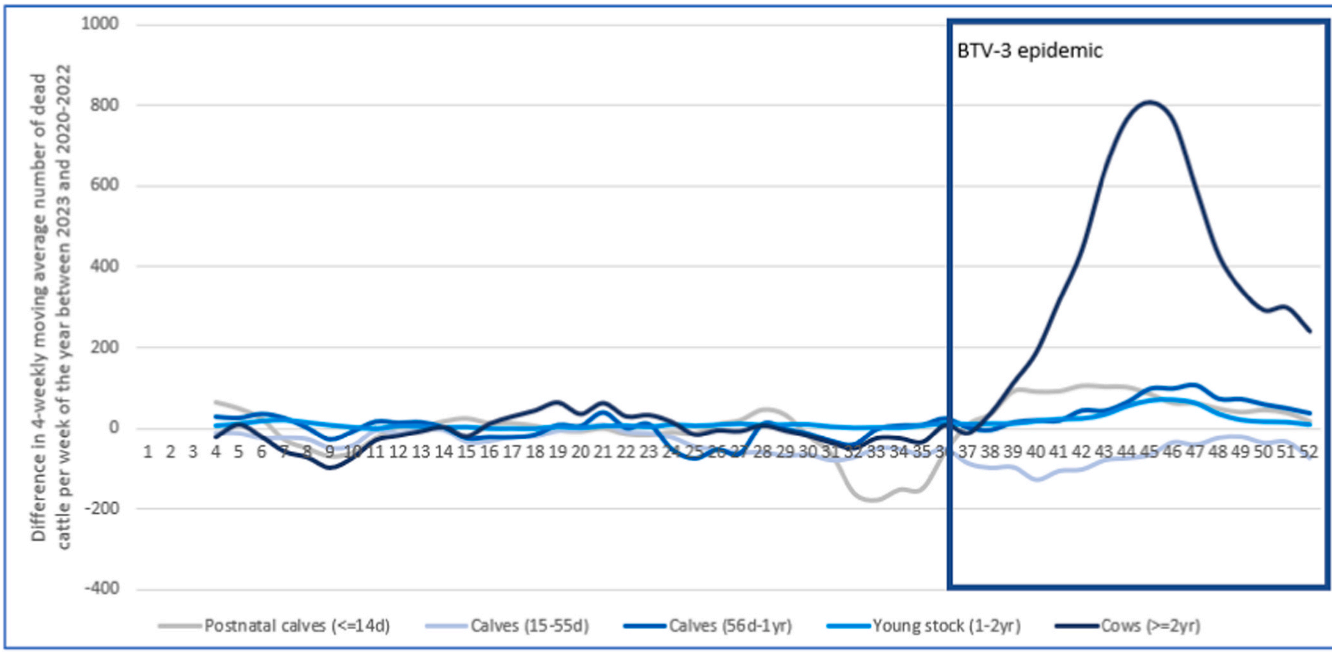

Fig. 2. Difference in the number of cattle deaths per week in 2023 compared to the average number of deaths in the same week during the BTV-free years (2020–2022). The data is presented as a four-week moving average and categorized by age group.

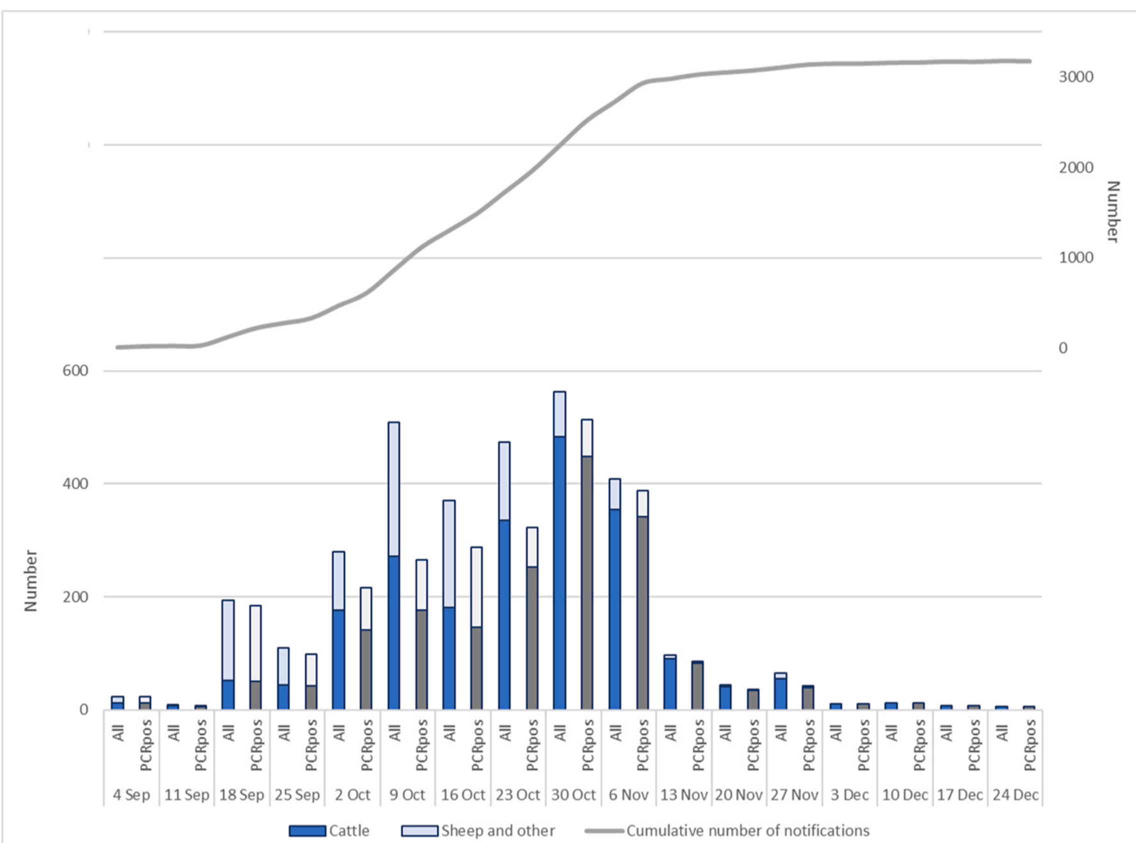

Fig. 3. The number of notifications (clinically and PCR confirmed) per week originating from cattle farms, regardless of the animal species were the notification originated from, along with the cumulative number of reports over time.

Table 1
Results of the multivariable population averaged negative binomial regression model for the mortality, premature birth and abortion in 13,700 Dutch dairy herds from 1 January 2020 to 31 December 2023. Significant IRR and OR are bold (P < 0.05).

Dairy herds Parameter		IRR/OR	95 % Confidence interval	P-value (Z- test)
Abortions	BTV−3 free	Reference		
(180–260 days) (OR)	BTV−3 infected area	**1.04**	**1.00–1.07**	**0.04**
	BTV−3 infected herd	**1.10**	**1.02–1.20**	**0.02**
Premature birth	BTV−3 free	Reference		
(260–265 days) (OR)	BTV−3 infected area	1.01	0.96–1.06	0.82
	BTV−3 infected herd	**1.39**	**1.26–1.54**	**< 0.001**
Perinatal calf mortality	BTV−3 free	Reference		
(IRR)	BTV−3 infected area	**1.07**	**1.06–1.09**	**< 0.001**
	BTV−3 infected herd	**1.11**	**1.06–1.16**	**< 0.001**
Postnatal calf mortality	BTV−3 free	Reference		
(≤14 days) (IRR)*	BTV−3 infected area	1.01	0.98–1.05	0.38
	BTV−3 infected herd	1.03	0.95–1.11	0.44
Preweaned calf mortality	BTV−3 free	Reference		
(15–56 days) (IRR)	BTV−3 infected area	**0.92**	**0.88–0,96**	**< 0.001**
	BTV−3 infected herd	0.99	0.90–1.10	0.88
Weaned calf mortality	BTV−3 free	Reference		
(56 days−1 year) (IRR)	BTV−3 infected area	1.01	0.96–1.08	0.73
	BTV−3 infected herd	**1.13**	**1.02–1.31**	**0.02**
Cattle mortality	BTV−3 free	Reference		
(1–2 yr) (IRR)	BTV−3 infected area	**1.17**	**1.07–1.27**	**< 0.001**
	BTV−3 infected herd	**2.25**	**1.97–2.58**	**< 0.001**
Cattle mortality	BTV−3 free	Reference		
(≥2 yr) (IRR)	BTV−3 infected area	**1.22**	**1.19–1.25**	**< 0.001**
	BTV−3 infected herd	**1.71**	**1.62–1.81**	**< 0.001**
Start lactation mortality	BTV−3 free	Reference		
(0–60 DIM) (IRR)	BTV−3 infected area	**1.30**	**1.25–1.35**	**< 0.001**
	BTV−3 infected herd	**1.93**	**1.79–2.09**	**< 0.001**

* All newborn calves in the Netherlands must be eartagged and registered by the third day after birth.

Netherlands in 2023, compared to an average of twenty days old in 2020–2022, due to changed German regulations.

From the start of the epidemic on 4 September 2023, until 31 December 2023, 3180 cattle farmers notified a clinical BT suspicion (regardless of the species involved in their farm) and/or submitted samples to the authorities (Fig. 3). In total, from 2506 farms, samples were submitted for confirmation and tested positive for BTV-3 by PCR. Fig. 3 lists the number of notifications (both clinically and PCR confirmed) per week, along with the cumulative incidence of the number of reports over time. The peak of the epidemic in cattle was in week 44 (30 October until 5 November). In that week 562 farmers notified a clinical suspicion of BT in either cattle (n = 484) or other animal species in their farm (n = 78). Seventy percent of the notifications originated from dairy herds, 18 % came from small-scale cattle herds, 9 % were from suckler cow herds, and 3 % from beef cattle herds. From November onwards, the number of new clinical notifications decreased rapidly to less than ten notifications per week.

3.2. Impact of the BTV-3 epidemic in dairy

3.2.1. Multivariable regression model dairy cattle

In Table 1 the associations between i) abortions, ii) premature births, iii) mortality, and the BTV-3 infection status is presented. The full results of the PA-GEE models for dairy cattle are presented in appendix A1 and A2.

In BTV-3 infected herds, the odds of premature births was 1.39 times higher compared to herds in the BTV-3 free area and period. The odds ratio was not significantly different between herds in BTV-3 infected areas and in BTV-3 free areas. The odds of abortions (between 180 days and 260 days of gestation) in infected dairy herds was 1.1 (95 % CI: 1.02–1.20) times higher compared to non-infected herds.

Perinatal calf mortality in dairy herds in BTV-3 infected areas was significantly higher (IRR 1.07) compared to those in BTV-3 free areas (Table 1). In BTV-3 infected herds this mortality rate was 1.11 times higher. In contrast, postnatal calf mortality was not significantly different in BTV-3 infected herds (Table 1). However, mortality of young stock (1–2 years) and cows older than 2 years was significantly increased in both herds in infected areas as in BTV-3 infected herds.

Mortality in cattle aged 1–2 years and older than 2 years increased 2.25 and 1.71 times respectively, in BTV-3 infected dairy herds. In dairy herds located in BTV-3 infected areas, mortality increased 1.17 and 1.22 times respectively, compared to herds in BTV-3 free areas. Mortality was also higher during the first 60 DIM, 1.93 times higher in BTV-3 infected herds relative to BTV-3 free herds.

3.3. Impact of the BTV-3 epidemic non-dairy

3.3.1. Multivariable regression model non-dairy

In addition to increased mortality observed in dairy herds, a significantly increased mortality was observed in cattle (≥1 year) in suckler

Table 2
The results of a multivariable population averaged negative binomial regression model for the mortality rate in Dutch non-dairy cattle herds (10,600 small scale herds, 2500 suckler cow herds, 1300 beef cattle herds) between January 2020 and December 2023. Significant IRR and OR are bold (P < 0.05).

Non dairy herds Parameter		IRR/OR	95 % Confidence interval	P-value (Z test)
Suckler cow herd: perinatal calf mortality (IRR)	BTV−3 free	Reference		
	BTV−3 infected area	0.95	0.81–1.13	0.74
	BTV−3 infected herd	0.79	0.56–1.11	0.18
Suckler cow herd: eartagged* calf mortality (<1 year) (IRR)	BTV−3 free	Reference		
	BTV−3 infected area	**1.15**	**1.02–1.28**	**0.018**
	BTV−3 infected herd	1.08	0.73–1.61	0.7
Suckler cow herd: cattle mortality (≥1 yr) (IRR)	BTV−3 free	Reference		
	BTV−3 infected area	**1.32**	**1.15–1.52**	**< 0.001**
	BTV−3 infected herd	**2.62**	**1.86–3.69**	**< 0.001**
Beef cattle herds: mortality (IRR)	BTV−3 free	Reference		
	BTV−3 infected area	1.06	0.88–1.29	0.52
	BTV−3 infected herd	**2.86**	**1.27–6.47**	**0.01**
small scale cattle herds: mortality^ (OR)	BTV−3 free	Reference		
	BTV−3 infected area	**1.35**	**1.23–1.49**	**< 0.001**
	BTV−3 infected herd	**2.23**	**1.71–2.91**	**< 0.001**

* All newborn calves in the Netherlands must be eartagged and registered by the third day after birth.
^ presence or absence of mortality

cow herds, small scale cattle herds and beef cattle herds. This increased mortality was present both in herds located in BTV-3 infected areas and in BTV-3 infected herds (Table 2).

In suckler cow herds in BTV-3 infected areas, mortality in cattle (≥1 year) was 1.32 times higher, and in BTV-3 infected herds, mortality was 2.62 times higher compared to those in BTV-3 free areas. However, no significant increase in calf mortality associated with BTV-3 was observed in suckler cow herds.

Mortality in BTV-3 infected beef cattle herds was 2.86 times higher compared to those in BTV-3 free areas. Additionally, small-scale cattle herds infected with BTV-3 had a 2.23 higher odds that cattle mortality occurred compared to those in BTV-3 free areas. Also in small-scale cattle herds in BTV-3 infected areas that did not report clinical signs of BTV-3 to the authorities, mortality was observed more often, though less frequent than in BTV-3 infected herds (OR: 1.35).

4. Discussion

Since September 2023, BTV-3 spread rapidly, affecting over 5000 sheep and cattle herds in the Netherlands. Severe clinical signs among cattle were reported, as well as decreased milk production and increased mortality (van den Brink et al., 2024). Mortality and severity as a result of BT infections depend among others, on the serotype (Breard et al., 2004). The aim of this study was to quantify the impact of the BTV-3 epidemic on 1) mortality and 2) abortions and 3) premature births in cattle in the Netherlands in 2023. The descriptive analyses indicated that BTV-3 was associated with higher mortality in adult cattle. However, the descriptive analyses did not account for factors that can influence these parameters. In the multivariable models, associations between BTV-3, mortality, abortion and premature birth were quantified, correcting for explanatory variables such as seasonal effects, regional differences and management practices. The 2023 BTV-3 epidemic was associated with significantly higher perinatal mortality, abortions and mortality in young stock (1–2 years) and in cattle ≥ 2 years old. Perinatal mortality included late abortions, stillbirths, and calves born alive that died before eartagging, which is compulsory within three days after birth in the Netherlands. The significant rise in abortions and perinatal calf mortality suggests an increase in abortions, stillbirths or births of weak calves during the acute phase of the epidemic. This aligns with the finding that the percentage of premature births (between 260 and 265 days gestation) was also significantly higher in BTV-3 infected herds than in BTV-3 free herds.

Previous studies on BTV-8, found that vertical transmission of the virus from mother to calf can occur (Wouda et al., 2009; De Clercq et al., 2008). In 2024, vertical transmission of BTV-3 was observed in infected herds, resulting in fetal abnormalities (non-published results Royal GD). A transplacental infection may have contributed to an increase in abortions, premature births, the birth of weaker calves, and higher perinatal mortality. Additionally, infections in dams may have led to the birth of weaker calves as a result of maternal fever and sickness during the acute phase of the disease. Given that the epidemic started in September 2023 and our data covers up to December 2023, all BTV infected cows that calved during this period would have been infected during the second half of their gestation. Consequently, fetal abnormalities would not yet be expected in 2023 (Wouda et al., 2009). The most plausible explanation for the increased premature births and perinatal calf mortality is the birth of less vital calves due to maternal illness or vertical transmission. It seems unlikely that this increased impact is the result of a new infection of the calf due to bites of BTV-3 infected *Culicoides* spp.

In dairy herds, there was an increased mortality rate in weaned calf mortality (56days-1year) in infected herds, young stock (1–2 years) and cows (≥2 years) (both in infected herds and infected areas). Remarkably, calf mortality between 15 and 55 days in dairy herds was even significantly decreased in infected areas (IRR: 0.92; 95 % CI 0.88–0.96). It may be that weaker calves already died before reaching the age of 15 days. The fact that the highest increased mortality was observed in young stock and adult cattle but not in calves can have several reasons. Adult cows, due to lactation, may have more severe expression of clinical signs. Additionally, calves are often kept indoors, while youngstock, pregnant heifers and lactating cows have daily access to pasture on many Dutch farms, and might therefore be bitten more often by

Culicoides spp. In 2023, 82.8 % of Dutch dairy farms implemented grazing practices (Doornewaard, 2024). Previous studies in the Netherlands for BTV-8 and Schmallenberg virus have shown that keeping cattle indoors was associated with a lower seroprevalence (Veldhuis et al., 2014; Santman-Berends et al., 2010). Thus, calves housed indoors in the fall of 2023 may have been less exposed to BTV-3. This hypothesis is supported by the fact that a higher mortality associated with BTV-3 was also observed in suckler cow herds, beef cattle herds and small-scale cattle herds, where cattle are mainly kept outdoors.

BTV infections in cattle are known to increase mortality, stillbirths, and abortions (Maclachlan et al., 2009; Gethmann et al., 2020; Saminathan et al., 2020). Additionally, BT can shorten gestation periods and cause fetal abnormalities (Osburn, 1994; De Clercq et al., 2008; Rushton and Lyons, 2015). The associations between mortality and BTV-3 infections are similar to those observed during the BTV-8 epidemic from 2006 to 2008 in the Netherlands. During that period, a notable increase in mortality in dairy cattle was also observed (Santman-Berends et al., 2011b). No clear effect of BTV-8 was seen on abortion rates (Santman-Berends et al., 2010). However, the association between BTV-3 infections and cattle mortality in dairy herds showed a higher increase compared to the BTV-8 epidemic in 2007, highlighting a relatively higher increase in mortality associated with BTV-3. While perinatal calf mortality was comparable, postnatal calf mortality in dairy herds did not show a clear association with BTV-3. In contrast, during the second year of the BTV-8 epidemic in 2007, postnatal calf mortality was 1.3 times higher (Santman-Berends et al., 2011b).

Some misclassification of the BTV-3 infection status at herd level likely has occurred. Some herds in areas with confirmed BTV-3 outbreaks may have been infected despite not reporting clinical signs, as non-reporting herds in affected areas also experienced higher mortality and reduced milk production. Similarly, some herds in areas classified as BTV-3-free may not have been free of infection, as this classification was based on the absence of clinical reports. Therefore misclassification may have led to a slight underestimation of the association between BTV-3 infections and cattle mortality, premature births and abortions. We used a P-value threshold of < 0.05 for our large dataset, which increase the risk of identifying significant associations with effect sizes that may not be relevant. Consequently, the relevance of some small but significant effects at $P < 0.05$ is disputable. For example, while the odds ratio of 1.04 for abortions in infected dairy cattle areas is statistically significant, the increase in odds is minimal. BTV-3 infected herds confirmed by PCR testing were indeed infected, but not all cattle on these farms may have been infected with BTV-3. A clinical study in five dairy cattle herds (van den Brink et al., 2024) showed that even in confirmed infected herds, within-herd prevalence was still low by the end of 2023. During the BTV-8 epidemic in 2006/2007, more significant health effects were observed in the second year of the epidemic as more cattle became infected.

Our study showed a significant increase in premature births, consistent with findings for other BTV serotypes (Osburn, 1994; Veldhuis et al., 2016; Saminathan et al., 2020). To assess the full impact of BTV-3 epidemic in 2023, the association between BTV-3 and fertility and milk production, as observed for BTV-8 (Santman-Berends et al., 2011a; Zientara and Sanchez-Vizcaino, 2013; Gethmann et al., 2020) should be further investigated. A significant association between BTV-8 and reduced fertility was observed in dairy herds during the BTV-8 epidemic, but for BTV-3, it is too early to assess this at this stage, as reduced fertility due to BTV-3 infection can first be evaluated based on 2024 data.

BTV-3 also caused significant damage in sheep (Santman-Berends et al., 2024). The increase in sheep mortality in 2023 exceeded that of the previous BTV-8 epidemic (2006–2008). While cattle mortality rates during the 2023 BTV-3 epidemic were lower than in sheep, the overall impact of BTV-3 associated mortality in the Dutch cattle population remains substantial. Quantifying mortality, abortions, and premature births in cattle may help farmers in Europe understand the potential consequences of a BTV-3 infection for their herds, which may help them decide on management practices (e.g. keeping cattle indoors and vaccination). After the first year of the BTV-3 epidemic in 2023, the average within herd prevalences for BTV-3 appeared relatively low (data not shown). This means that a large proportion of the cattle population is still susceptible to BTV-3 in 2024, and therefore the impact of BTV-3 in 2024 can also be substantial to the cattle industry in the Netherlands and in other European countries. The importance of a high immunity in populations of susceptible ruminants, as result of a combination of natural immunity and a high vaccination degree, has been shown effective when eradication of BTV is the goal (Zientara et al., 2010; Zientara and Sanchez-Vizcaino, 2013). In May 2024, three BTV-3 vaccines became available. So far it remains unclear to what extent farmers decided to vaccinate in 2024. Nevertheless, the results of our study showed the importance of immunization to avoid mortality associated with BTV-3 infections as observed in 2023 in the Netherlands.

5. Conclusion

The BTV-3 epidemic in 2023 in the Netherlands had a large impact on cattle health in dairy-, suckler cow-, beef cattle- and small scale herds. This study showed a significant rise in abortions, premature births and mortality, associated with BTV-3 infections in cattle in the Netherlands in 2023.

CRediT authorship contribution statement

van den Brom R.: Writing – review & editing, Supervision. **Stegeman A.:** Writing – review & editing, Supervision. **Lam T.J.G.M.:** Writing – review & editing, Supervision. **Santman-Berends I.M.G.A.:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Spierenburg M.A.H.:** Writing – review & editing, Data curation. **van Schaik G.:** Writing – review & editing, Supervision, Conceptualization. **Brouwer-Middelesch H.:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Formal analysis, Data curation, Conceptualization. **van den Brink K. M. J.A.:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

With this statement all authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table A 1

Full results of the population averaged regression models to evaluate factors associated with calf mortality in 13,700 Dutch dairy herds with complete data from 1 January 2020 to 31 December 2023. Significant parameters are bold (P < 0.05)

Parameter	Perinatal calf mortality		Postnatal calf mortality		Pre-weaned calf mortality		Weaned calf mortality	
	IRR	95 % confidence interval	IRR	95 % confidence interval	IRR	95 % confidence interval	IRR	95 % confidence interval
Herd health status								
IBR-free (relative to a non-free status)	**0.98**	**0.96 - 0.99**	0.98	0.95 - 1.01	**0.91**	**0.88 - 0.94**	**0.90**	**0.86 - 0.93**
BVD-free (relative to a non-free status)	0.99	0.98 - 1.01	**0.90**	**0.87 - 0.93**	**0.82**	**0.79 - 0.86**	**0.80**	**0.77 - 0.84**
Salmonella-unsuspected (relative to a herds with an indication of a Salmonella infection according to the bulk milk results)	**1.04**	**1.01 - 1.07**	1.02	0.96 - 1.07	**1.18**	**1.12 - 1.25**	**1.17**	**1.08 - 1.25**
Paratuberculosis unsuspected relative to a herds with an indication of a Paratuberculosis infection according to the bulk milk results)	**0.98**	**0.96 - 0.99**	**0.93**	**0.91 - 0.96**	**0.89**	**0.86 - 0.93**	**0.88**	**0.84 - 0.92**
Month, trend in time	**1.00**	**1.00 - 1.00**	**1.00**	**1.00 - 1.00**	**1.00**	**1.00 - 1.01**	**1.01**	**1.00 - 1.01**
Price for a dairy calf at 14d of age	**1.00**	**1.00 - 1.00**	**1.00**	**1.00 - 1.00**	**1.00**	**1.00 - 1.00**	**1.00**	**1.00 - 1.00**
Growth in herd size								
Dutch average	Reference		Reference		Reference		Reference	
10 % lowest	0.99	0.98 - 1.01	0.99	0.97 - 1.02	1.05	1.01 - 1.08	1.02	0.98 - 1.06
40 % lower	0.99	0.99 - 1.00	**0.95**	**0.94 - 0.96**	**0.96**	**0.94 - 0.98**	**0.95**	**0.93 - 0.97**
40 % higher	1.00	0.99 - 1.01	**0.98**	**0.96 - 0.99**	**0.96**	**0.95 - 0.98**	**0.97**	**0.95 - 0.99**
10 % highest	1.02	1.00 - 1.03	**1.09**	**1.06 - 1.11**	**1.03**	**1.01 - 1.06**	**1.07**	**1.04 - 1.11**
Replacement percentage cows> 2 years/year								
Dutch average	Reference		Reference		Reference		Reference	
10 % lowest	**0.93**	**0.91 - 0.94**	**0.85**	**0.82 - 0.87**	**0.88**	**0.84 - 0.91**	**0.87**	**0.84 - 0.91**
40 % lower	**0.97**	**0.96 - 0.98**	**0.94**	**0.93 - 0.96**	**0.93**	**0.91 - 0.95**	**0.92**	**0.89 - 0.94**
40 % higher	**1.03**	**1.02 - 1.04**	**1.07**	**1.05 - 1.09**	1.02	1.00 - 1.05	1.00	0.97 - 1.03
10 % highest	**1.08**	**1.06 - 1.11**	**1.17**	**1.14 - 1.21**	**1.20**	**1.15 - 1.25**	**1.25**	**1.19 - 1.32**
Purchase of cattle in the past 12 months								
yes	Reference		Reference		Reference		Reference	
No	**0.97**	**0.96 - 0.99**	**0.91**	**0.89 - 0.94**	**0.86**	**0.83 - 0.89**	**0.77**	**0.74 - 0.80**
Sporadic	1.02	1.00 - 1.04	0.96	0.92 - 1.00	**0.93**	**0.89 - 0.97**	**0.84**	**0.79 - 0.89**
Antimicrobial use (relative to no use)	X		**1.21**	**1.18 - 1.24**	**1.20**	**1.17 - 1.24**	**1.21**	**1.17 - 1.25**
Season								
Dutch average	Reference		Reference		Reference		Reference	
Winter	1.00	0.99 - 1.00	**1.09**	**1.08 - 1.10**	**1.22**	**1.20 - 1.24**	**1.07**	**1.05 - 1.09**
Spring	**1.03**	**1.02 - 1.04**	**0.84**	**0.83 - 0.85**	**0.87**	**0.86 - 0.89**	**0.90**	**0.84 - 0.87**
Summer	1.01	1.00 - 1.01	**1.09**	**1.08 - 1.10**	**0.91**	**0.90 - 0.93**	0.95	0.96 - 1.00
Autumn	**0.97**	**0.96 - 0.97**	1.00	0.99 - 1.01	**1.03**	**1.01 - 1.05**	**1.10**	**1.09 - 1.15**
Milk production level (presented in € cow/lactation)								
Dutch average	Reference		Reference		Reference		Reference	
10 % lowest production	**1.06**	**1.03 - 1.09**	**1.19**	**1.15 - 1.26**	**1.31**	**1.24 - 1.38**	**1.51**	**1.43 - 1.60**
40 % lower production	**1.03**	**1.01 - 1.04**	**1.11**	**1.09 - 1.15**	**1.11**	**1.08 - 1.15**	0.99	0.96 - 1.03
40 % higher production	**0.98**	**0.96 - 0.99**	0.98	0.95 - 1.00	**0.91**	**0.88 - 0.94**	**0.83**	**0.80 - 0.86**
10 % highest production	**0.97**	**0.95 - 0.99**	**0.85**	**0.82 - 0.88**	**0.73**	**0.70 - 0.76**	**0.74**	**0.71 - 0.78**
Unknown	0.97	0.94 - 1.00	**0.91**	**0.86 - 0.95**	1.03	0.98 - 1.10	**1.08**	**1.02 - 1.14**
Herd size								
Dutch average	Reference		Reference		Reference		Reference	
10 % smallest herds	**0.96**	**0.94 - 0.98**	**0.77**	**0.74 - 0.81**	**0.76**	**0.72 - 0.80**	**0.80**	**0.75 - 0.86**
40 % smaller herds	**1.02**	**1.01 - 1.04**	**1.08**	**1.06 - 1.11**	**1.05**	**1.02 - 1.08**	**0.89**	**0.86 - 0.92**
40 % larger herds	**1.02**	**1.01 - 1.03**	**1.14**	**1.11 - 1.16**	**1.12**	**1.09 - 1.16**	**1.05**	**1.02 - 1.08**
10 % largest herds	1.00	0.98 - 1.02	**1.06**	**1.02 - 1.09**	**1.12**	**1.08 - 1.17**	**1.34**	**1.28 - 1.40**
Province								
Dutch average	Reference		Reference		Reference		Reference	
Drenthe	**1.07**	**1.04 - 1.11**	**1.17**	**1.10 - 1.25**	1.05	0.97 - 1.13	**1.13**	**1.05 - 1.21**
Flevoland	**1.12**	**1.06 - 1.18**	1.06	0.95 - 1.19	1.02	0.89 - 1.16	1.07	0.93 - 1.23
Friesland	**1.09**	**1.07 - 1.11**	**1.19**	**1.14 - 1.23**	**1.14**	**1.09 - 1.19**	0.98	0.93 - 1.03
Gelderland	**0.96**	**0.93 - 0.98**	1.02	0.98 - 1.06	1.05	1.00 - 1.10	1.03	0.98 - 1.09
Groningen	**1.09**	**1.06 - 1.13**	1.01	0.95 - 1.08	**1.11**	**1.03 - 1.20**	1.03	0.96 - 1.11
Limburg	0.99	0.95 - 1.03	**0.86**	**0.80 - 0.92**	**0.89**	**0.82 - 0.97**	1.06	0.90 - 1.25
Noord Brabant	0.99	0.97 - 1.01	0.97	0.94 - 1.02	0.95	0.90 - 1.00	**1.07**	**1.01 - 1.13**
Noord Holland	1.02	0.98 - 1.05	**0.90**	**0.84 - 0.96**	0.94	0.87 - 1.01	**0.90**	**0.82 - 0.98**
Overijssel	**0.93**	**0.91 - 0.95**	**1.10**	**1.06 - 1.14**	**1.07**	**1.02 - 1.12**	**1.07**	**1.01 - 1.12**
Utrecht	**0.90**	**0.86 - 0.93**	0.95	0.89 - 1.01	0.98	0.91 - 1.04	**0.90**	**0.83 - 0.98**
Zuid Holland	**0.87**	**0.85 - 0.90**	**0.84**	**0.79 - 0.89**	**0.88**	**0.82 - 0.95**	**0.81**	**0.75 - 0.87**
Zeeland	1.01	0.96 - 1.07	1.00	0.87 - 1.14	0.97	0.84 - 1.12	1.01	0.89 - 1.16
BTV−3 infection status								
BTV-free	Reference		Reference		Reference		Reference	
BTV infected area	**1.07**	**1.05 - 1.09**	1.01	0.98 - 1.05	**0.92**	**0.88 - 0.96**	1.01	0.96 - 1.08
BTV infected farm	**1.11**	**1.06 - 1.16**	1.03	0.95 - 1.11	0.99	0.90 - 1.10	**1.13**	**1.02 - 1.31**
Intercept	**0.43**	**0.30 - 0.63**	**0.00**	**0.00 0.01**	**0.00**	**0.00 - 0.00**	**0.00**	**0.00 - 0.00**

Table A2
Full results of the population averaged regression models to evaluate factors associated with mortality and abortion in 13,700 Dutch dairy herds with complete data from 1 January 2020 to 31 December 2023. Significant parameters are bold (P < 0.05)

Parameter	cattle mortality 1–2 year		cattle mortality ≥ 2 year		mortality start lactation (0–60 days)		premature births (260–265 days)		abortions (180–260 days)	
	IRR	95 % confidence interval*	IRR	95 % confidence interval*	IRR	95 % confidence interval*	IRR	95 % confidence interval*	IRR	95 % confidence interval*
Herd health status										
IBR-free (relative to a non-free status)	0.96	0.93 - 1.00	**0.96**	**0.94 - 0.97**	**0.96**	**0.93 - 0.98**	1.00	0.98 - 1.03	1.01	0.98 - 1.04
BVD-free (relative to a non-free status)	**0.90**	**0.86 - 0.94**	**0.89**	**0.87 - 0.91**	**0.88**	**0.86 - 0.91**	0.99	0.96 - 1.02	**0.96**	**0.94 - 0.99**
Salmonella-unsuspected (relative to a herds with an indication of a Salmonella infection according to the bulk milk results)	1.06	0.99 - 1.14	**1.09**	**1.06 - 1.13**	**1.10**	**1.03 - 1.17**	1.02	0.96 - 1.07	1.00	0.95 - 1.05
Paratuberculosis unsuspected relative to a herds with an indication of a Paratuberculosis infection according to the bulk milk results)	**0.91**	**0.88 - 0.95**	**0.93**	**0.91 - 0.94**	**0.92**	**0.90 - 0.95**	**0.94**	**0.91 - 0.97**	**0.94**	**0.91 - 0.97**
Month. trend in time	1.00	0.99 - 1.01	**1.01**	**1.01 - 1.01**	1.00	1.00 - 1.00	**1.00**	**1.00 - 1.00**	1.00	1.00 - 1.00
Growth in herd size										
Dutch average	Reference		Reference		Reference		Reference		Reference	
10 % lowest	1.01	0.96 - 1.05	**1.07**	**1.05 - 1.09**	**1.07**	**1.04 - 1.10**	0.99	0.96 - 1.02	0.98	0.95 - 1.00
40 % lower	**0.98**	**0.96 - 1.01**	**0.96**	**0.95 - 0.97**	**0.95**	**0.94 - 0.97**	0.97	**0.96 - 0.99**	**0.97**	**0.95 - 0.98**
40 % higher	**0.96**	**0.94 - 0.99**	**0.95**	**0.94 - 0.96**	**0.94**	**0.93 - 0.96**	1.00	0.98 - 1.01	0.99	0.97 - 1.00
10 % highest	1.05	1.01 - 1.09	**1.02**	**1.01 - 1.04**	**1.04**	**1.02 - 1.06**	1.04	**1.01 - 1.07**	**1.07**	**1.05 - 1.09**
Replacement percentage cows> 2 years/year										
Dutch average	Reference		Reference		Reference		Reference		Reference	
10 % lowest	**0.85**	**0.81 - 0.90**	**0.91**	**0.89 - 0.93**	**0.89**	**0.86 - 0.92**	**0.88**	**0.85 - 0.91**	**0.88**	**0.86 - 0.90**
40 % lower	**0.93**	**0.90 - 0.96**	**0.95**	**0.94 - 0.96**	**0.94**	**0.92 - 0.95**	**0.96**	**0.94 - 0.98**	**0.94**	**0.93 - 0.96**
40 % higher	**1.04**	**1.01 - 1.07**	**1.02**	**1.00 - 1.03**	1.02	1.00 - 1.04	**1.04**	**1.02 - 1.06**	**1.05**	**1.04 - 1.07**
10 % highest	**1.21**	**1.15 - 1.27**	**1.14**	**1.12 - 1.17**	**1.18**	**1.13 - 1.22**	**1.14**	**1.10 - 1.18**	**1.14**	**1.11 - 1.18**
Purchase of cattle in the past 12 months										
yes	Reference		Reference		Reference		Reference		Reference	
No	**0.76**	**0.73 - 0.79**	**0.89**	**0.87 - 0.90**	**0.88**	**0.86 - 0.90**	0.98	0.95 - 1.00	0.97	0.94 - 1.00
Sporadic	**0.89**	**0.84 - 0.94**	**0.92**	**0.90 - 0.95**	**0.95**	**0.92 - 0.98**	1.08	**1.03 - 1.13**	**1.15**	**1.10 - 1.20**
Antimicrobial use (relative to no use)	0.98	0.95 - 1.02	**0.97**	**0.95 - 0.99**	X		X		X	
Milk price	X		**1.00**	**1.00 - 1.00**	X		1.00	1.00 - 1.00	1.00	1.00 - 1.00
Season										
Dutch average	Reference		Reference		Reference		Reference		Reference	
Winter	1.01	0.98 - 1.04	**0.94**	**0.94 - 0.95**	**0.95**	**0.94 - 0.97**	**0.85**	**0.84 - 0.87**	**0.93**	**0.92 - 0.94**
Spring	**0.94**	**0.92 - 0.97**	**0.95**	**0.94 - 0.96**	**1.04**	**1.03 - 1.06**	**1.05**	**1.03 - 1.07**	**1.09**	**1.08 - 1.11**
Summer	**1.05**	**1.02 - 1.08**	**1.13**	**1.12 - 1.14**	**1.13**	**1.11 - 1.14**	**1.19**	**1.17 - 1.21**	**1.05**	**1.04 - 1.06**
Autumn	1.00	0.97 - 1.02	0.99	0.98 - 1.00	**0.89**	**0.88 - 0.91**	**0.93**	**0.91 - 0.95**	**0.94**	**0.93 - 0.96**
Milk production level (presented in € cow/lactation)										
Dutch average	Reference		Reference		Reference		Reference		Reference	
10 % lowest production	**1.26**	**1.19 - 1.33**	**1.10**	**1.06 - 1.13**	**1.14**	**1.10 - 1.18**	**0.91**	**0.86 - 0.96**	1.03	0.98 1.07
40 % lower production	1.02	0.99 - 1.05	**1.04**	**1.03 - 1.06**	**1.07**	**1.05 - 1.09**	1.02	1.00 - 1.05	**1.07**	**1.04 - 1.10**
40 % higher production	**0.92**	**0.89 - 0.95**	**0.95**	**0.93 - 0.97**	**0.95**	**0.93 - 0.97**	1.04	**1.02 - 1.07**	1.02	1.00 - 1.05
10 % highest production	**0.85**	**0.81 - 0.89**	**0.92**	**0.90 - 0.94**	**0.87**	**0.84 - 0.89**	1.03	1.00 - 1.07	**0.94**	**0.91 - 0.98**
Unknown	1.00	0.95 - 1.06	1.00	0.97 - 1.03	X		1.00	0.93 - 1.07	0.94	0.88 - 1.01
Herd size										
Dutch average	Reference		Reference		Reference		Reference		Reference	
10 % smallest herds	**0.84**	**0.79 - 0.91**	**0.93**	**0.90 - 0.96**	1.02	0.98 - 1.07	**0.84**	**0.80 - 0.89**	**0.84**	**0.81 - 0.87**
40 % smaller herds	0.96	0.93 - 1.00	1.02	1.00 - 1.03	1.01	0.99 - 1.03	0.99	0.96 - 1.01	**0.96**	**0.93 - 0.98**
40 % larger herds	**1.06**	**1.02 - 1.09**	**1.03**	**1.01 - 1.04**	0.98	0.96 - 1.00	1.05	**1.03 - 1.08**	**1.06**	**1.03 - 1.08**
10 % largest herds	**1.16**	**1.12 - 1.21**	**1.03**	**1.01 - 1.05**	0.98	0.95 - 1.01	1.14	**1.11 - 1.18**	**1.18**	**1.14 - 1.21**
Province										
Dutch average	Reference		Reference		Reference		Reference		Reference	
Drenthe	**1.12**	**1.05 - 1.19**	**1.15**	**1.11 - 1.19**	**1.19**	**1.14 - 1.25**	1.05	1.00 1.09	**1.10**	**1.05 - 1.15**
Flevoland	**1.17**	**1.04 - 1.30**	**1.15**	**1.08 - 1.23**	**1.14**	**1.05 - 1.24**	1.11	**1.03 - 1.20**	**1.10**	**1.01 - 1.21**
Friesland	0.97	0.92 - 1.01	**1.07**	**1.04 - 1.10**	1.04	1.00 - 1.07	0.97	0.94 - 1.00	**1.05**	**1.01 - 1.09**
Gelderland	0.95	0.90 - 1.00	**0.93**	**0.91 - 0.96**	**0.91**	**0.88 - 0.94**	**0.90**	**0.87 - 0.93**	**0.89**	**0.86 - 0.92**
Groningen	1.04	0.98 - 1.11	**1.06**	**1.02 - 1.10**	1.05	1.00 - 1.10	0.95	0.91 - 1.00	**1.07**	**1.02 - 1.13**
Limburg	1.08	0.99 - 1.18	**1.08**	**1.02 - 1.15**	1.16	**1.04 - 1.28**	1.06	0.99 - 1.13	0.95	0.89 - 1.02
Noord Brabant	0.96	0.92 - 1.01	**0.96**	**0.93 - 0.99**	1.01	0.98 - 1.05	**1.05**	**1.02 - 1.08**	**0.95**	**0.92 - 0.98**
Noord Holland	0.97	0.91 - 1.04	**0.93**	**0.90 - 0.97**	**0.91**	**0.87 - 0.96**	0.93	0.88 - 0.98	1.02	0.96 - 1.07
Overijssel	**0.94**	**0.90 - 0.98**	**0.93**	**0.91 - 0.96**	**0.92**	**0.89 - 0.95**	0.93	0.90 - 0.96	**0.93**	**0.89 - 0.96**
Utrecht	**0.87**	**0.81 - 0.95**	**0.83**	**0.80 - 0.86**	**0.78**	**0.75 - 0.82**	**0.99**	**0.94 - 1.05**	0.97	0.91 - 1.03
Zuid Holland	**0.87**	**0.81 - 0.93**	**0.80**	**0.77 - 0.84**	**0.76**	**0.72 - 0.80**	**0.92**	**0.87 - 0.97**	0.90	0.86 - 0.95
Zeeland	1.11	0.99 - 1.25	**1.19**	**1.09 - 1.30**	**1.27**	**1.13 - 1.41**	1.17	**1.07 - 1.28**	**1.11**	**1.01 - 1.23**
BTV−3 infection status										
BTV-free	Reference		Reference		Reference		Reference		Reference	
BTV infected area	**1.17**	**1.07 - 1.27**	**1.22**	**1.19 - 1.25**	**1.33**	**1.28 - 1.38**	1.01	0.96 - 1.06	1.04	1.00 - 1.07
BTV infected farm	**2.25**	**1.97 - 2.58**	**1.71**	**1.62 - 1.81**	**1.93**	**1.79 - 2.09**	**1.39**	**1.26 - 1.54**	**1.10**	**1.02 - 1.20**
Intercept	**0.00**	**0.00 - 0.05**	**0.00**	**0.00 - 0.00**	**0.02**	**0.01 - 0.07**	**0.00**	**0.00 - 0.01**	**0.01**	**0.01 - 0.03**

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