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The impact of the bluetongue serotype 3 outbreak on sheep and goat mortality in the Netherlands in 2023

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A R T I C L E I N F O

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A B S T R A C T

In September 2023, bluetongue virus serotype 3 (BTV-3) emerged in the Netherlands, infecting over five thousand livestock farms. In sheep, high morbidity and mortality rates were reported that were unlike previously described bluetongue outbreaks. This study aimed to quantify the impact of BTV-3 in the small ruminant population in the Netherlands in 2023. Sheep and goat movement census data and BTV-3 notification data were available from 2020 until the end of 2023. Data were aggregated to farm and week level and mortality indicators were calculated for lambs (<1 year) and adult animals (≥1 year). Population averaged GEE models with a Negative-binomial distribution and a log-link function correcting for repeated measures per farm in time were used to quantify the association between BTV-3 and mortality. In 2023, 2994 sheep farmers and 89 goat farmers notified clinical signs of BTV-3 to the NVWA. During this BTV-3 outbreak period, an additional 55,000 sheep died compared to the same period in 2020–2022. At flock level a high variety in mortality was observed, with a clear increase in mortality in both flocks that were not notified but that were located in infected areas and in flocks of which the farmer notified clinical signs. During the BTV-3 outbreak period, mortality in infected areas increased 4.2 (95 % CI: 4.0–4.3) times in sheep lambs (<1 year) and 4.6 (95 % CI: 4.4–4.8) times in sheep (≥1 year) compared to BTV-3 free areas. Flocks with a confirmed BTV-3 infection that were notified in September showed a 12.8 (95 % CI: 11.4–14.3) times higher mortality in lambs and a 15.1 (95 % CI: 13.7–16.6) times higher mortality in sheep compared to flocks in BTV-3 areas. In flocks of which the farmer notified clinical signs after September, mortality was 4.6 (95 % CI: 4.2–5.0) and 5.6 (95 % CI: 5.1–6.0) times higher in lambs and sheep compared BTV-3 areas respectively. In goats, around 4000 additional deaths were recorded during the BTV-3 outbreak period. In farms that were notified, mortality of goats (≥1 year) was 1.8 (95 % CI: 1.2–2.8) times higher compared to BTV-3 free areas. Since May 2024, multiple BTV-3 vaccines are available in the Netherlands. In June 2024, the first new infections of BTV-3 were confirmed in Dutch sheep flocks. Hopes are that with the possibility to vaccinate, the spread and impact of BTV-3 in the Netherlands will rapidly decline and that losses as observed in 2023 will no longer be seen.

1. Introduction

Bluetongue (BT) is an infectious, non-contagious arthropod-borne disease of mainly ruminants. BT is caused by bluetongue virus (BTV), a segmented double stranded virus belonging to the genus Orbivirus from the Reoviridae family. BTV is almost exclusively transmitted by midges of the genus *Cullicoides* (Maclachlan et al., 2009, 2015). BTV causes haemorrhagic disease in ruminants (Feenstra and van Rijn, 2017). The disease is characterized by high fever, depression, mucosal lesions in mouth and nose, congestion of the coronary band, hypersalivation, nasal discharge, lameness and mortality. BTV affects most species of wild and domestics ruminants, but clinical signs and mortality are more severe in domestic sheep, compared to cattle and goats (Vellema, 2008).

BTV is listed as a category C disease by the new Animal Health Law

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(AHL, Regulation EU, 2016/429, 2016) and its infection status varies per serotype and per country (Hodnik et al., 2021). More than thirty different BTV serotypes are described and the first 24 are notifiable according to the AHL. BT is also listed by the World Organisation for Animal Health (WOAH) as a multi-species disease with large economic impact. The economic impact of BT is directly caused by a reduction in productivity and increased mortality, and indirectly through trade restrictions of animals and animal products such as semen and embryos (Schwartz-Cornil et al., 2008).

BTV was detected in the Netherlands for the first time in 2006 (Elbers et al., 2008). During this BTV-8 outbreak, increased mortality rates in both sheep and cattle were found, after overwintering of the virus, during the second year of the outbreak in 2007 (Vellema, 2008; Santman-Berends et al., 2011). After a vaccination campaign in 2008, which resulted in a seroprevalence of over 80 %, no cases of BTV were seen from 2009 on and since February 2012 the Netherlands regained its official BTV-free status. In September 2023 BTV was detected in the Netherlands (Holwerda et al., 2023; van den Brink et al., 2023). The virus rapidly spread across the Netherlands in the autumn of 2023 (Van den Brink et al., 2024). At the end of 2023, a number of BTV-3 cases had also been confirmed in Belgium, Germany and the United Kingdom (Van den Brink et al., 2023). In an early stage of the BTV-3 outbreak in the Netherlands, farmers and veterinarians reported severe clinical signs and high mortality rates especially in sheep, but at that time objective data were not yet available. The Netherlands has a high quality data infrastructure including a mandatory identification and registration system for small ruminants in which all movements are registered at individual animal level. These data provided the possibility to quantify the association between the BTV-3 outbreak in small ruminants and mortality on a detailed level for all small ruminant farms in the Netherlands. The aim of this study was to quantify the effect of the BTV-3 outbreak on sheep and goat mortality in the Netherlands in 2023.

2. Material and methods

2.1. Study population and available data

For this study census movement data at individual animal level of both sheep and goats were available between 1 January 2020 until 31 December 2023, from the identification and registration system in the Netherlands (Netherlands Enterprise Agency (RVO), Assen, the Netherlands). These data contained individual animal movement records with the unique herd identification number (UHI), individual animal ID, animal species (sheep or goat), date of birth, date of the on-farm movement, on-farm movement code i.e. birth, purchase or import, date of the off-farm movement, off-farm movement code i.e. sale, export, slaughter, and death. Additionally, BTV-3 notification data were available from the Dutch Food and Consumer Product Safety Authority (NVWA), which included all records from farmers that notified clinical signs indicative for a BTV-3 infection in their animals. Notification data contained metadata regarding the UHI of the reporting farm, the species, whether the notification was confirmed by PCR or whether the notification was only based on clinical suspicion, date of notification, location of notification (coordinates) and the date on which the test result was available. Given the large number of notifications, legislation was amended during the outbreak. From the second half of September on, it was also possible to notify suspicions of BTV-3 without the need to confirm the infection by PCR if located in an area that was already severely infected. In case, no blood samples were tested, the notification remained a clinical suspicion.

2.2. Definitions

Classification of herds in relation to the expected influence of BTV-3: Goat and sheep farms were allocated to a BTV-3 classification status on farm and week level. The allocation to the groups depended on i) time, ii) farm location on a two-digit postal code level and iii) whether the farmer notified clinical signs to the authorities. Given that the first outbreak was detected on 3 September 2023 and a serological survey revealed no indications for massive spread in the month prior to this first detection (Holwerda et al., 2023), the whole period before this date was classified as BTV-3 free. For every week between the start of the outbreak at 4 September until the end of December 2023, farms were classified in either one of three disease status groups: 1) BTV-3 free area, 2) BTV-3 infected area or 3) BTV-3 notified farm. Farms were classified as 'BTV-3 free' in every week in which no notifications of clinical signs were made by any farmer (regardless of the species) located in the same two-digit postal code area. When at least one farmer in a two-digit postal code area notified clinical signs of BTV-3, the BTV-3 classification status changed for all farms in that area to 'BTV-3 infected area'. This classification status was maintained for every week until the end of the study period i.e. 31 December 2023, unless the farmer of the herd/flock notified clinical signs of BTV-3 to the authorities. In this case, the farm moved on to the BTV-3 classification status 'BTV-3 notified'. In the majority of notified farms, BTV-3 was confirmed by PCR at the national reference laboratory. However, because of logistic restrains, not all notifications could be sampled and submitted for confirmation in areas with many cases. Nevertheless, because of the high likelihood that the observed clinical signs at that place and time were associated with BTV-3, these farms were classified together with the farms where BTV-3 was confirmed. The BTV-3 notified group therefore consists of farms with a very high probability of infection and is named 'BTV-3 notified' in the remainder of this paper.

Mortality indicators: In this study age specific mortality indicators were calculated for sheep lambs and goat kids (<1 year) and for adult sheep and goats (≥1 year). A dead animal was defined as an animal with an off-farm movement code in the animal movement data (I&R), which indicated that the animal died on farm. The age at the moment of death was defined as the difference between the date of mortality and the birth date. For descriptive purposes both crude number of deaths and mortality rates were calculated.

The mortality rate was calculated as the number of deaths relative to the number of animal days at risk (DAR) and was calculated for each included farm per species (i), age category (j) and period of interest (k). The resulting mortality rate per day was multiplied with the number of days ($ndays$) in the period of interest to calculate the mortality rate for the period of interest i.e. week of year (week number 1–52), four-weekly moving average or whole BTV-3 outbreak period (formula 1).

$$Pmortality\_rate_{ijk} = \frac{n\_dead_{ijk}}{DAR_{ijk}} * ndays_{ijk} * 100\% \tag{1}$$

Where:

i:animal species (i.e. sheep or goat)

j:age category (i.e. <1 year (lambs/ kids) or ≥1 year (sheep/ goats))

k:the period of interest (i.e. week of year (week number 1–52), four-weekly moving average or whole BTV-3 outbreak period)

The mortality rate (*Pmortality_rate*) was subsequently multiplied by hundred and presented per species, age category and period of interest as percentage.

2.3. Analysis

Due to privacy regulations, and to prevent traceability of results to individual farms or animals, all datasets were encrypted by an external encryption company (IntoFocus Data Transformation Services, IDTS, Deventer) before being provided to the researcher. IDTS encrypted all variables in the data containing information traceable to the original source, such as UHI or animal ID. To ensure that data from different sources could be combined for analysis, a corresponding encryption code was used for all datasets. Subsequently, the census small ruminant movement data were validated according to the procedures described in the national monitoring and surveillance system (Dijkstra et al., 2022). In short, standard software scripts in SAS 9.4® (SAS Institute Inc., 2013) were used to check the data for duplicates and biological illogical records, which were removed from the data. Subsequently, movement data were collated on farm and week level. The date of first BTV-3 notification per two-digit postal code were extracted from the notification data and both the regional outbreak date and the farm level notification data were combined with the animal movement data. After validation, the data was transferred to Stata® version 17 (StataCorp, 2019) for further analysis.

Descriptive statistics were used to summarize the notification data and mortality. Crude numbers of deaths per farm and week of the year were summarized for the whole BTV-3 outbreak period and per week of the year in 2023. The results that were possibly influenced by BTV-3 in 2023 were compared to the mean mortality in the three preceding years (2020–2022) for the same group of farms and in the same period/week of the year.

At farm level, mortality rates were calculated on week-level, four-week level and for the whole BTV-3 outbreak period. For descriptive purposes, the mortality rates on week level and for the whole BTV-3 outbreak period were compared to the mortality rates in previous years. The mean difference per week and over the whole BTV-3 outbreak period between 2023 and 2020–2022 was presented stratified to each of the three BTV-3 statuses. For the descriptive statistics at farm level, only data of professional sheep farms (>32 sheep, Dijkstra et al., 2022) were included. This was done to remove extreme results of small scale farms given that one death sheep in a small scale farm often results in a high mortality rate.

In the multivariable analyses, all sheep farms were included and herd/flock size, herd/flock type and region were included as potential confounders. Multivariable Population-Averaged Generalized Estimating Equations (PA-GEE) models correcting for repeated measures within farms, with a Negative Binomial distribution and a log-link function were used for analyses. The dependent variable was the number of dead animals per moving four-weekly period and the number of animals at risk (as described as denominator in formula 1) was included as exposure variable. The BTV-3 status was the independent variable of interest. For the independent categorical variables, the mean of the whole population was included as the reference category. Effects of the independent variables are presented by incidence rate ratios (IRR) and results with a P-value<0.05 are deemed statistically significant.

3. Results

3.1. Descriptive population data

In the month of May of every year, Dutch livestock farms are obliged to notify their herd size and the agricultural land to be used to the Netherlands Enterprise Agency (RVO). Based on the identification and registration data, in May 2023, there were over thirty thousand sheep farms and over fifteen thousand goat farms in the Netherlands. The majority of these are small scale or backyard flocks or herds with a median number of seven sheep or three goats in total (Table 1). The professional small ruminant farming sector in the Netherlands consisted of 3932 sheep flocks and 540 goat herds. The professional sheep sector can be categorized into flocks dedicated to fattening and flocks engaged in both breeding and fattening. The average fattening sheep farm had a median flock size of sixty sheep and the other professional flocks had a median size of 125 sheep. The typical professional goat farm primarily prioritized milk production and had a median of 1069 goats in total (Table 1).

The total number of sheep in the Netherlands was 1.22 million sheep (~656,000 adult sheep and ~569,000 lambs) and 692 thousand goats (526,000 adult goats and 122,000 lambs) in May 2023 (Table 1).

Most of the sheep are located in the Northern part of the country (Fig. 2). The highest goat density can be found in the Eastern and Southern part of the Netherlands (Fig. 2).

3.2. Notification data

The first clinical signs of BT were observed in sheep flocks and were notified to the authorities on 4 September 2023. In the first two weeks of the outbreak, only sheep- and cattle farmers notified clinical signs of BT. In the week of 18 September the first goat farmer notified clinical signs (Fig. 3). The peak of the outbreak occurred in week 41 (9 until 16 October). In that week 618 sheep farmers and 11 goat farmers notified clinical signs of BT in their animals. As a result of updated legislation, animals were sampled in 354 out of 629 farms, were BTV-3 was confirmed by PCR (Fig. 3). In total, in 2023, 2994 sheep farmers and 89 goat farmers notified clinical signs to the NVWA, of which on 1885 sheep and 71 goat farms respectively BTV-3 was confirmed by PCR. From December on, the number of new clinical notifications decreased to almost zero and are therefore not presented in Fig. 3.

3.3. Impact of the BTV-3 outbreak in sheep flocks

3.3.1. Sectoral level

During the BTV-3 outbreak period from 4 September (week 36) until the end of 2023 (week 52), in total 35,451 lambs (<1 year) and 46,183 sheep (≥1 year) died. In the same period of the three preceding years (2020–2022) these numbers were 14,904 and 11,573 deaths, respectively (Table 2). This resulted in a difference of in total 55,157 dead sheep during the sixteen week period of the BTV-3 outbreak in 2023 (Table 2). During the first 35 weeks of 2023, such a difference in mortality compared to previous years was not observed (Table 2).

Fig. 4 shows that the difference in number of dead lambs and sheep between 2023 and earlier years is close to zero during the first 35 weeks of 2023. In the first two weeks of the BTV-3 outbreak (week 36 and 37) no increased mortality was observed yet. Between week 38 (3rd week of September) and 49 (First week of December) mortality was increased, which peeked in week 43 (third week of October) (Fig. 4).

Table 1
Descriptive numbers of the Dutch small ruminant population in May 2023.

		Population size			Mean farm size (median)		
	Herd type	Number of farms	Lambs (<1 year)	Sheep/ goats (≥1 year)	Lambs (<1 year)	Sheep/ goats (≥1 year)	Total
Sheep	Small scale flocks	26,649	167,812	191,024	6 (1)	7 (5)	13 (7)
	Professional fattening flocks	92	10,748	1563	117 (48)	17 (9)	134 (60)
	Professional kept flocks	3840	390,933	463,034	102 (62)	121 (61)	222 (125)
	Total	30,581	569,493	655,621			
Goats	Small scale farms	15,324	16,179	50,809	1 (0)	3 (2)	4 (3)
	Professional fattening farms	54	27,570	1254	510 (308)	23 (0)	533 (308)
	Professional farms (mostly dairy)	486	122,203	474,178	251 (194)	976 (831)	1227 (1069)
	Total	15,864	165,952	526,241			

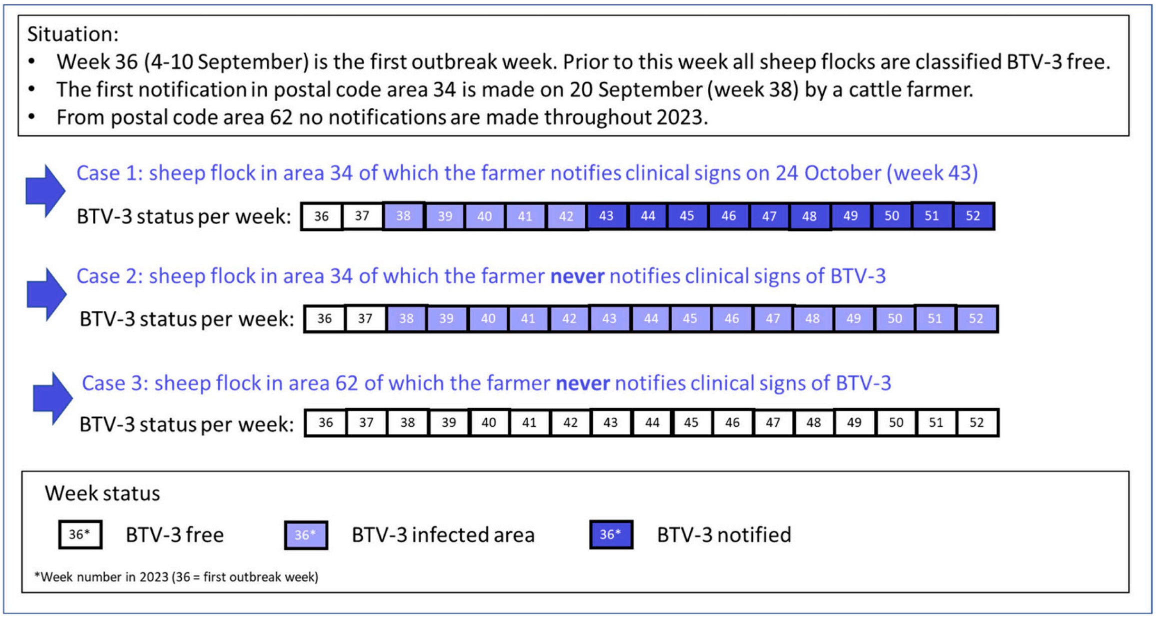


Fig. 1. Three examples of assigning a BTV-3 classification status per sheep/ goat farm per week during the BTV-3 outbreak period in 2023 in the Netherlands.

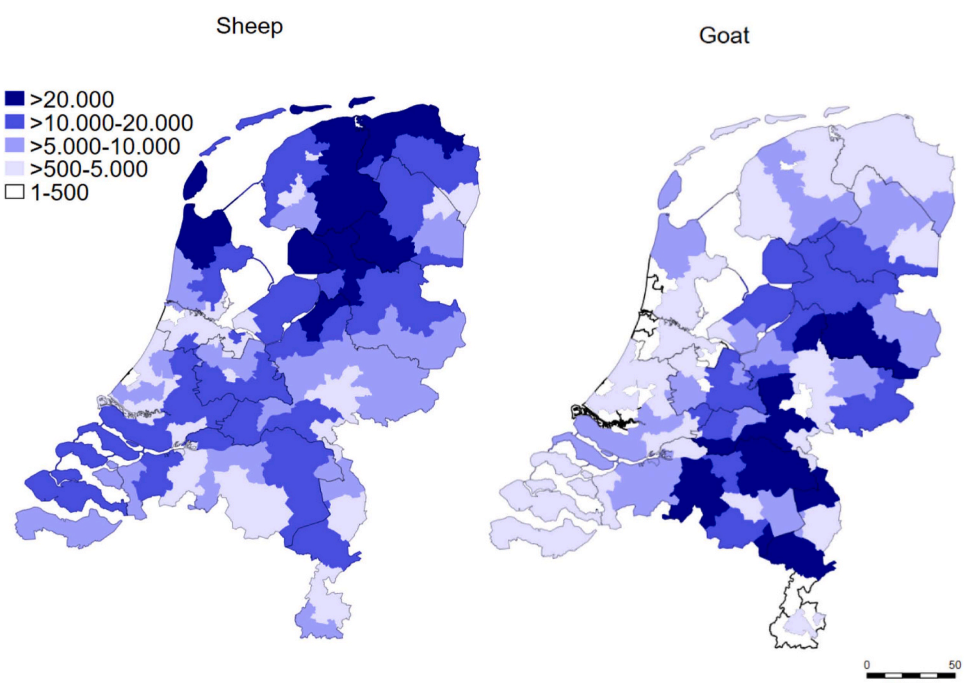


Fig. 2. Population density distribution of sheep and goats per two-digit postal code area in the Netherlands in 2023.

3.3.2. Farm level

During the BTV-3 outbreak period, mortality was not increased in regions that remained BTV-3 free (Fig. 5). In both sheep flock BTV-3 infection strata (infected area and notified flocks), mortality in sheep lambs (<1 year) and sheep (≥1 year) was increased in the BTV-3 outbreak period (week 36–52), compared to the same period in 2020–2022 (Fig. 5a and b). The median mortality during the BTV-3 outbreak period in BTV-3 infected regions was 3.0 % (mean 7.0 %) in lambs and 2.6 % (mean 8.7 %) in sheep. In the same period of 2020–2022 the median mortality in this group of farms was 1.8 % (mean 2.8 %) in lambs and 1.1 % (mean 2.2 %) in sheep, respectively. In BTV-3 notified farms, differences were even more extreme with a median lamb mortality of 8.0 % (mean: 13.8 %) and a median sheep mortality of 9.8 % (mean: 16.6 %) in the period between week 36 and 52 of the year 2023. In the same period of 2020–2022 median mortality in this group of farms was 2.3 % (mean: 3.2 %) in lambs and 1.1 % (mean: 1.9 %) in sheep, respectively (Fig. 5a and b). Additionally, Fig. 5a and b show that there were many farms with an extreme high lamb and or sheep mortality during the BTV-3 outbreak period in 2023. In prior years such extreme mortality percentages were hardly seen.

3.3.3. Multivariable regression model sheep

Corrected for confounding factors such as farm type, flock size, region, and repeated measures within flocks over time, sheep mortality was significant increased in both lambs (<1 year) and sheep (≥1 year) (Table 3).

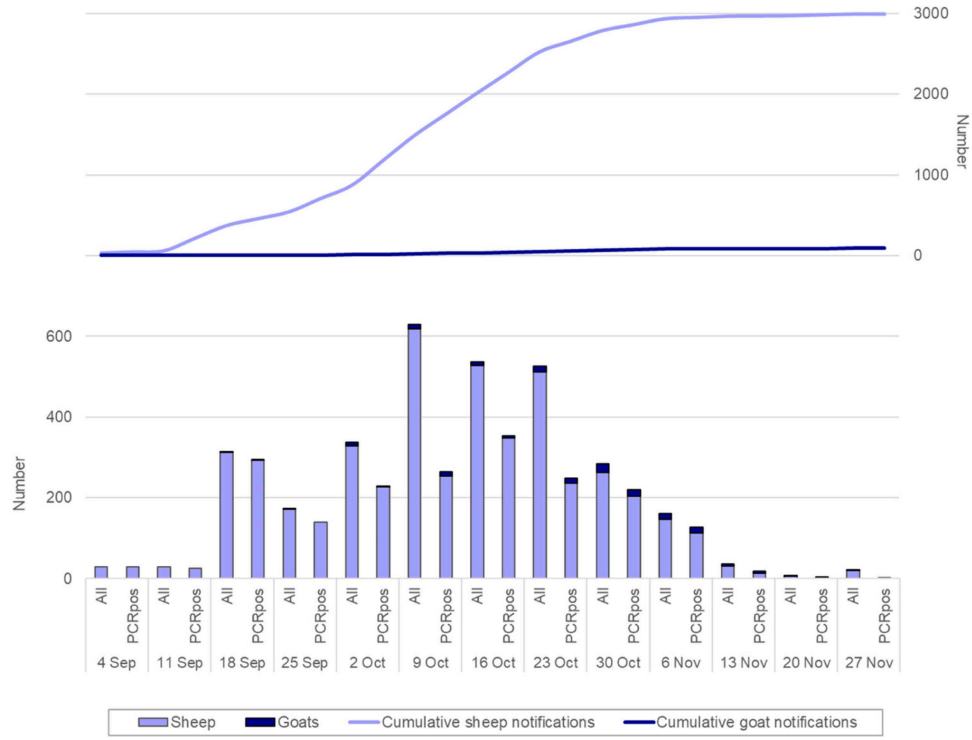
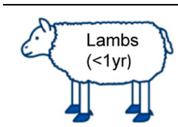
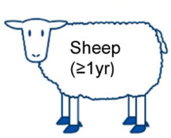


Fig. 3. The number of sheep flocks and goat herds of which the farmer notified clinical signs of BTV-3 to the authorities, the number that were sampled and in which BTV-3 was confirmed and the cumulative number (sampled + clinical notifications that were not followed up) of cases during the BTV-3 outbreak per week in 2023.

Table 2
Descriptive results of the number of dead sheep per age category in the period of the year before BTV-3 and during the BTV-3 outbreak in 2020–2022 (BTV-3 free during the whole year) and 2023.

Age category	Period	Total number of dead sheep		Difference
		2020–2022	2023	
 Lambs (<1yr)	Week 1–35: BTV−3 free	31,551	29,350	−2201
	Week 36–52: BTV−3 outbreak period in 2023	14,904	**35,451** *	**20,547***
 Sheep (≥1yr)	Week 1–35: BTV−3 free	38,657	39,480	823
	Week 36–52: BTV−3 outbreak period in 2023	11,573	**46,183** *	**34,610***

[*] Assumed to be influenced by the BTV-3 outbreak

Flocks that were located in BTV-3 infected two-digit postal code area of which the farmer did not notify clinical signs had a 4.2 (95 % CI: 4.0–4.3) times higher sheep lamb (<1 year) mortality compared to BTV-3 free sheep flocks. In flocks of which the farmer notified clinical signs, lamb mortality was 12.8 (95 % CI: 11.4–14.3) times higher in flocks that were already notified in September. On farms where BT like symptoms were notified in October of November, lamb mortality was 4.6 (95 % CI: 4.2–5.0) times higher compared to the lamb mortality on farms located in BTV-3 free areas.

Farmers that did not notify clinical signs related to BT in their sheep flock, but that were located in a two-digit postal code area from which notifications were made, had an IRR of 4.6 (95 % CI: 4.4–4.8) times higher sheep (≥1 year) mortality compared to BTV-3 free farms. Mortality was highest in flocks of which the farmer already notified clinical signs in September, the month in which the midges was not yet a limiting factor. In these flocks mortality was 15.1 (95 % CI: 13.7–16.6) times higher compared to BTV-3 free flocks. In flocks where clinical signs were notified in later months, sheep mortality was still significantly increased, although less extreme (IRR=5.6, 95 % CI: 5.1–6.0).

3.4. Impact in goat farms

During the BTV-3 outbreak period in 2023, 4709 goat kids (<1 year) and 16,431 goats (≥1 year) died. These numbers were comparable (difference: −23 kids) or higher (difference: 4294 goats) compared to the same period in 2020–2022. However, in the first 35 weeks of 2023 the number of dead kids and goats were both lower compared to previous years.

In professional goat farms located in BTV-3 infected areas of which the farmer did not notify clinical signs, mortality during the BTV-3 outbreak period in 2023 (week 36–52) was fairly comparable to mortality in the three preceding years in both goat kids (<1 year) and goats (≥1 year). In goat herds of which the farmer notified clinical signs median mortality during the BTV-3 outbreak period was comparable in kids, and seemed slightly increased in goats (≥1 year). The median mortality during the BTV-3 outbreak period in this group of farms was 2,8 % (mean: 4,4 %) compared to 2.3 % (mean: 3.4 %) in the same period of 2020–2023.

3.4.1. More detailed results are presented in the supplementary materials

3.4.1.1. Multivariable regression model goats. Results of the multivariable model showed no significant increased kid (<1 year) mortality associated with BTV-3 (Table 4). In adult goats (≥1 year) a slight but significant increase in mortality was found (Table 4). In goat herds in infected areas, goat mortality was 1.4 (95 % CI: 1.2–1.6) times higher compared to the BTV-3 free period. In goat herds of which the farmer notified clinical signs, mortality in goats (≥1 year) was 1.8 times higher (95 % CI:1.2–2.8) (Table 4).

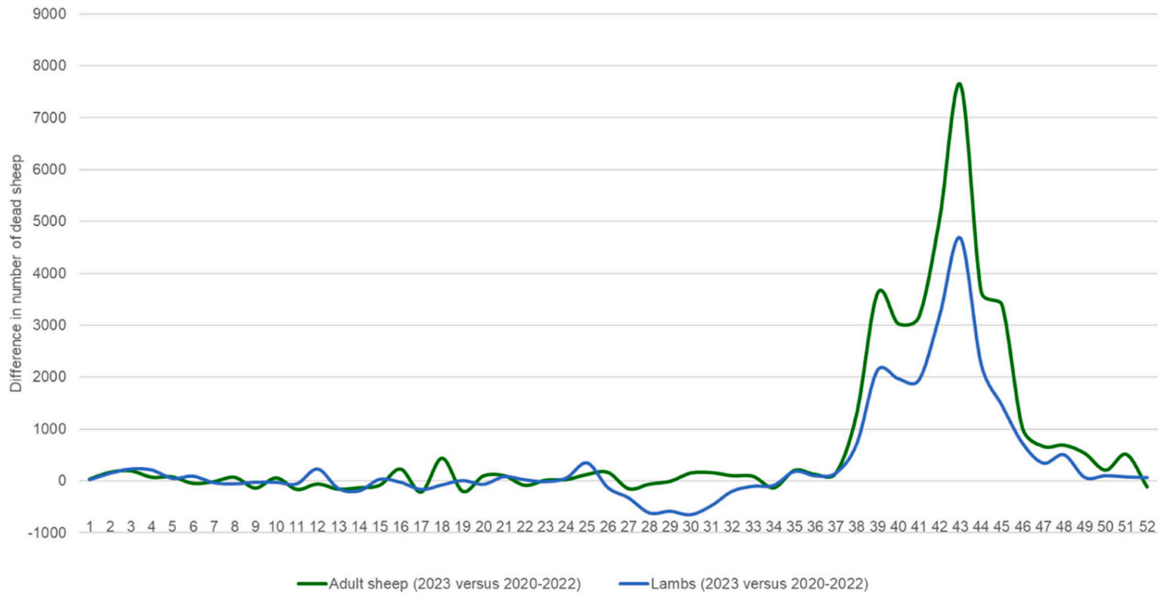


Fig. 4. Difference in number of dead lambs (<1 year) and sheep (≥1 year) between 2023 and the three preceding years (2020–2022) per week of the year, before the BTV-3 outbreak (wk1–35) and during the BTV-3 outbreak period (wk36–52).

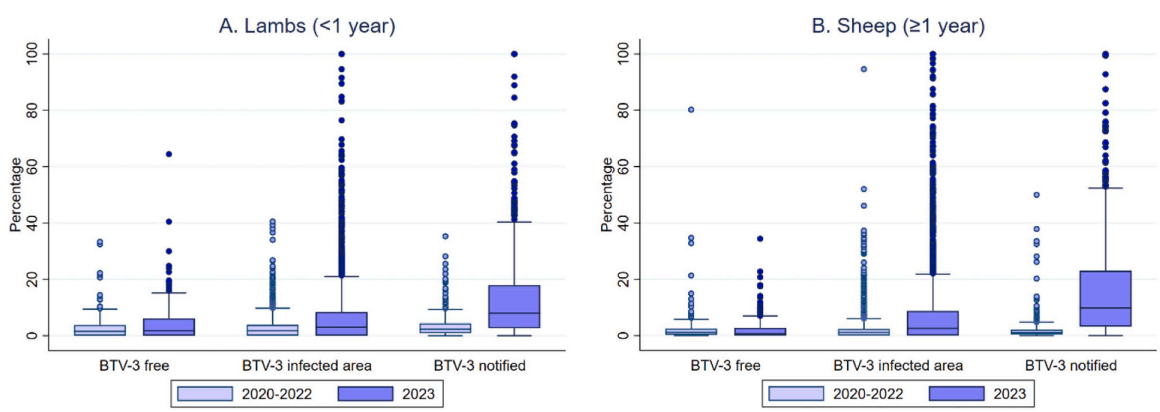


Fig. 5. Boxplots presenting the lamb (<1 year) and sheep (≥1 year) mortality in 3840 professional sheep flocks during the BTV-3 outbreak period in 2023 (week 36–52) and in the same period of the three preceding years (2020–2022).

4. Discussion

In this study we aimed to quantify the effect of BTV-3 on mortality in the small ruminant population in the Netherlands in 2023. We found a major increase in sheep mortality, both in lambs (<1 year) and in sheep (≥1 year), and a slight increase in mortality of goats (≥1 year). An increased mortality was detected from two weeks after the initial outbreak and on. This is probably due to the fact that the number of notified flocks was limited during the first two weeks of the outbreak and the fact that many of the infected sheep did not die immediately after infection. During the previous BTV-8 outbreak in the Netherlands in 2006, mortality in sheep was also significantly increased (Elbers et al., 2008), but that increase was only a fraction of what was observed during the current outbreak. The same was observed in cattle. During the BTV-3 outbreak, BT like symptoms were also notified in >2000 cattle herds. The first impact analyses indicated that a BTV-3 infection was associated with an 1.8 times higher mortality in cows (>1 year) (Van den Brink et al., in preparation), which was higher compared to the BTV-8 outbreak (IRR: 1.4, Santman-Berends et al., 2011).

The fact that a high mortality was found in sheep, is in concordance with the impact during previous BT outbreaks of various serotypes. During the BTV-4 outbreak in Greece in 2014, the average mortality and case fatality in sheep were 4.5 % (95 % C.I. 1.5–7.6 %) and 32.0 % (95 % C.I. 18.1–42.9 %), respectively (Katsoulos et al., 2016). In Portugal the median mortality associated with BTV-1 infections was estimated at 2.2 % and the case fatality was 29.8 % in sheep in 2004 (Allepuz et al., 2010). In that study, an increase in goat mortality of 1.2 % and a case fatality of 45 % in goats was reported, while during the BTV-3 outbreak in the Netherlands this increase appears limited so far. This finding is in accordance with the BTV-8 outbreak in the Netherlands (Backx et al., 2007; Elbers et al., 2008), where only sporadic cases of BT were notified in goats. However, experimentally it was possible to cause clinical BT in goats (Backx et al., 2007). At that time, possible explanations for the fact that (almost) no notification of clinical illness in goats was notified were that 1) the indoor husbandry systems of goats is less preferred by the vector and 2) infected goats showed no or only mild clinical signs and were not tested

In our study, the highest increase in mortality was detected in sheep flocks and goat herds of which the farmer notified clinical signs. However, also mortality was increased in farms without notification that were located in infected regions. We know from farmers and veterinarians in the field that some underreporting has occurred during the peak of the outbreak. This will have led to some misclassification bias in the BTV-3 infection groups. In our study, we were only sure about the BT

Table 3
Results of a multivariable population averaged negative binomial regression model for the mortality rate of lambs or sheep in >30,000 Dutch sheep flocks between January 2020 and December 2023.

Parameter	Sheep lambs (<1 year)			Sheep (≥1 year)		
	Incidence rate ratio (IRR)	95 % confidence interval	*P-value* (Z-test)	IRR	95 % confidence interval	*P-value* (Z-test)
Farm type						
Average NL	Reference			Reference		
Professional (≥32 sheep)	1.35	1.21–1.50	<0.001	0.98	0.94–1.01	0.22
Small scale (<32 sheep)	0.93	0.89–0.97	<0.001	1.02	0.99–1.07	0.22
Total flock size						
Average NL	Reference			Reference		
25 % smallest (≤4 sheep)	1.24	1.18–1.31	<0.001	1.01	0.97–1.05	0.68
25–50 % smaller (5 – 9 sheep)	0.94	0.90–0.98	0.002	0.82	0.79–0.85	<0.001
50–75 % larger (9 – 26 sheep)	0.92	0.89–0.95	<0.001	0.94	0.91–0.97	<0.001
75–90 % larger (27 – 76 sheep)	0.93	0.90–0.95	<0.001	1.08	1.05–1.11	<0.001
10 % largest (≥77 sheep)	1.02	0.95–1.08	0.63	1.19	1.12–1.27	<0.001
Region						
Average NL	Reference			Reference		
North	1.02	0.98–1.05	0.32	1.02	0.99–1.05	0.24
Central	1.01	0.98–1.04	0.46	1.04	1.02–1.07	0.001
South	0.97	0.94–1.00	0.09	0.94	0.92–0.97	<0.001
Bluetongue serotype 3 status						
BTV−3 free	Reference			Reference	Reference	
BTV−3 infected area, farmer did not notify	4.15	3.97–4.33	<0.001	4.59	4.41–4.77	<0.001
BTV−3 infected flock (notification made in September)	12.77	11.43–14.28	<0.001	15.11	13.73–16.64	<0.001
BTV−3 infected flock (notification made in October-November)	4.59	4.21–5.00	<0.001	5.55	5.13–6.01	<0.001

Table 4
Results of a multivariable population averaged negative binomial regression model for the mortality rate of kids or goats in >15,000 Dutch goat farms between January 2020 and December 2023.

Parameter	Goat kids (<1 year)			Goat (≥1 year)		
	Incidence rate ratio (IRR)	95 % confidence interval	*P-value* (Z-test)	IRR	95 % confidence interval	*P-value* (Z-test)
Farm type						
Average NL	Reference			Reference		
Professional (≥32 goats)	0.83	0.73–0.95	0.008	0.73	0.78–0.97	<0.001
Small scale (<32 goats)	1.20	1.05–1.37	0.008	1.37	1.22–1.54	<0.001
Total herd size						
Average NL	Reference			Reference		
25 % smallest (≤4 goats)	1.66	1.42–1.94	<0.001	1.27	1.19–1.36	<0.001
25–50 % smaller (5 – 9 goats)	0.91	0.79–1.05	0.21	0.96	0.88–1.03	0.25
50–75 % larger (9 – 26 goats)	0.84	0.75–0.94	0.002	0.88	0.80–0.96	0.006
75–90 % larger (27 – 76 goats)	0.72	0.64–0.81	<0.001	0.89	0.83–0.96	0.003
10 % largest (≥77 goats)	1.10	0.95–1.26	0.21	1.05	0.94–1.16	0.40
Region						
Average NL	Reference			Reference		
North	1.07	0.91–1.26	0.43	1.01	0.91–1.13	0.83
Central	1.04	0.90–1.22	0.56	1.15	1.04–1.28	0.009
South	0.89	0.77–1.04	0.15	0.86	0.79–0.94	0.001
Bluetongue serotype 3 status						
BTV−3 free	Reference			Reference		
BTV−3 infected area, farmer did not notify	1.14	0.90–1.43	0.28	1.37	1.20–1.57	<0.001
BTV−3 notified farm	1.38	0.83–2.31	0.22	1.80	1.16–2.80	0.009

status of farms in which the BT notification was confirmed by diagnostic testing. Nevertheless, part of the farms that were not notified were also infected and even in regions that were classified as BTV-3 free, some infections might have occurred. In our analyses we tried to acknowledge this misclassification bias due to underreporting, by distinguishing three BTV-3 infection statuses i.e. BTV-3 free, `being located in a BTV-3 infected region and being BTV-3 notified instead of only two (free versus notified). The results supported this choice as sheep mortality was significantly increased in both the BTV-3 notified stratum as in the located in a BTV-3 infected region stratum. It was not possible to correct for possible misclassification of BTV-3 free regions during the BTV-3 outbreak period in 2023. However, we would expect that the number of infections in those areas would have remained very limited, otherwise at least some notifications from these areas would have been made. Additionally, not all BT notifications were confirmed by PCR and even though the far majority of these will probably have been truly infected, it may be that the detected signs were in some cases not the result of BT. The misclassification in the group statuses may have resulted in an underestimation of the impact of BTV-3 on mortality given that some BTV-3 infected farms were wrongly classified as BTV-3 free, and, to lesser extent, some herds were wrongly classified as BTV-3 infected.

We found a significantly higher mortality in sheep flocks that were notified in September compared to flocks that became notified in later months. A possible explanation for this could be the declining midge activity towards colder months: The transmission by *Cullicoides* spp. was not yet a limiting factor in BTV-3 transmission in September, while

Cullicoides spp. became less active from October on. The average daily (24 h) temperature in the Netherlands in September was 17.5∘C (Dutch meteorological institute), which is within the preferred temperature range of *Cullicoides* spp. according to El Moustaid et al. (2021). In October and November the average daily temperature in 2023 in the Netherlands dropped to 13.2∘C and 7.8∘C, respectively, which is below the temperature range in which BTV outbreaks are more likely to occur (El Moustaid et al., 2021). This hypothesis was further supported by the finding that the seroprevalence in the winter of 2023/2024 was still low in five sheep flocks that were monitored 13 weeks after BTV-3 was introduced in October 2023. In these flocks, of the sheep that became infected and expressed BT like symptoms, many died resulting in a case fatality of over 70 percent. However, in these five herds the majority of sheep that remained clinically healthy, appeared to not have been infected according to a prevalence estimation in fifty sheep in January 2024 (van den Brink et al., submitted). Additionally, a first prevalence survey in cattle herds of which the farmer notified clinical signs also indicates that within herd prevalences greatly varied between herds, but could still be low in the winter of 2023/2024, even in herds that already notified BT like symptoms in September (personal communication).

During the first outbreak of BTV-8 in the Netherlands in 2006, hopes were that the virus would die out in winter. However, from July 2007 the virus started to spread rapidly and in that year, infected the majority of ruminant farms in the country (Santman-Berends et al., 2010). Since the previous outbreak, Dutch winters have become milder. Additionally, during the current outbreak, over five thousand livestock farms were already infected in 2023 and vertical transmission from the virus from dam to her offspring is also already proven for BTV-3 in sheep and cattle (van den Brink, 2024). This results in many potential virus reservoirs and subsequently in a high probability that the virus will survive the 2023/2024 winter and will start spreading again in summer 2024. Since May 2024 BTV-3 multiple vaccines are available. Given the major impact in 2023 combined with low seroprevalence in live sheep in spring of 2024, many sheep farmers decided to vaccinate their animals to protect them from BT in 2024. Nevertheless, it is unsure whether the majority of cattle and goat farmers are also willing to vaccinate given that vaccination is voluntary. In cattle and goats the impact of BTV-3 in 2023 was less severe compared to sheep and especially in regions were only few herds were infected, cattle and goat famers are not always convinced that the costs of vaccination outweigh the losses due to BTV-3 infections. Given that cattle are the preferred host of *Cullicoides* and are therefore important in the epidemiology of BT, it remains unsure whether the degree of vaccination will be high enough to stop the spread of BTV-3. In June 2024, overwintering was proven since the first new BTV-3 infections in sheep were detected in the Netherlands. Both the degree of vaccination and the renewed presence of BTV-3 in the Netherlands will influence the incidence, spread and impact of BTV-3 in 2024.

5. Conclusion

In September 2023 BTV-3 emerged in the Netherlands for the first time, infecting more than five thousand cattle, sheep and goat farms in the subsequent three months. These infections resulted in a significantly increase in mortality in small ruminants, especially in sheep. At the end of 2023, the first BTV-3 outbreak year, it seems that the majority of the small ruminant population is still susceptible for BTV-3 infection. Since May 2024, multiple registered BTV-3 vaccines are available and in June 2024, the first BTV-3 cases of 2024 were confirmed in two sheep notified. Depending on the availability of vaccines, the capacity of the veterinarians to vaccinate and the willingness of farmers to vaccinate their animals, the impact of BTV-3 in 2024 may hopefully remain limited.

CRediT authorship contribution statement

I.M.G.A. Santman-Berends: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **K.M.J.A. van den Brink:** Writing – review & editing, Formal analysis, Data curation, Conceptualization. **E. Dijkstra:** Writing – review & editing, Project administration, Methodology, Funding acquisition, Conceptualization. **G. van Schaik:** Writing – review & editing, Conceptualization. **M.A.H. Spierenburg:** Writing – review & editing. **R. van den Brom:** Writing – review & editing, Supervision, Investigation, Funding acquisition, Formal analysis, 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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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2024.106289.

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