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Quantifying calf mortality on dairy farms: Challenges and solutions

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ABSTRACT

In the Netherlands, the mortality rate of ear-tagged calves <1 yr is one of the indicators that is continuously monitored in census data and is defined as the number of deceased calves relative to the number of calf-days-at-risk. In 2017, yearly calf mortality rates were published in the lay press and resulted in discussions about the calculation of this parameter among stakeholders because the same parameter appeared to be calculated in many different ways by different organizations. These diverse definitions of calf mortality answered different aims such as early detection of deviations, monitoring trends, or providing insight into herd-specific results, but were difficult to understand by stakeholders. The aim of this study was to evaluate several definitions of calf mortality for scientific validity, usefulness for policymakers, and comprehensibility by farmers. Based on expert consultations, 10 definitions for calf mortality were evaluated that assessed different age categories, time periods, and denominators. Differences in definitions appeared to have a large effect on the magnitude of mortality. For example, with the original mortality parameter, the mortality rate was 16.5% per year. When the first year of life was subdivided into 3 age categories, the mortality rate was 3.3, 4.5, and 3.1% for postnatal calves (≤14 d), preweaned calves (15–55 d), and weaned calves (56 d–1 yr), respectively. Although it was logical that these mortality rates were lower than the original, the sum of the 3 separate mortality rates was also lower than the original mortality rate. The reason was that the number of calves present in a herd and the risk of mortality are not randomly distributed over a calf's first year of life and the conditional nature of mortality rates when calculated for different age categories. Ultimately, 4 parameters to monitor calf mortality in Dutch dairy herds were chosen based on scientific value, usefulness for monitoring of trends, and comprehensibility by farmers: perinatal calf mortality risk (i.e., mortality before, during, or shortly after the moment of birth up to the moment of ear-tagging), postnatal calf mortality risk (≤14 d), preweaned calf mortality rate (15–55 d), and weaned calf mortality rate (56 d–1 yr). Slight differences in definitions of parameters can have a major effect on results, and many factors have to be taken into account when defining an important health indicator such as mortality. Our evaluation resulted in a more thorough understanding of the definitions of the selected parameters and agreement by the stakeholders to use these key indicators to monitor calf mortality.

Key words: mortality, dairy calves, monitoring, census data

INTRODUCTION

Heifer calves are very important as future replacement for the milking cows in a dairy herd and should be reared in an optimal way to maximize health, welfare, and future prospective as milking cows (Hultgren and Svensson, 2009; Sandgren et al., 2009; de Vries et al., 2011). An important indicator to evaluate calf health is calf mortality rate, which can be monitored using routinely collected data (Ortiz-Pelaez et al., 2008; Kelly et al., 2013; Santman-Berends et al., 2014).

In the Netherlands, a national cattle health monitoring and surveillance system is in place that entails several components. One of these monitoring components consists of quarterly trend analysis on routine census data to monitor trends in cattle health (Santman-Berends et al., 2016). In the quarterly trend analysis, many indicators are calculated, analyzed, and monitored such as mortality, udder health, fertility, and antimicrobial usage. The mortality rate of ear-tagged calves <1 yr of age is one of the parameters and was defined as the number of deceased calves relative to the number of calf-days-at-risk as described in Dohoo et al. (2003). For monitoring purposes, the calf mortality rate is calculated for each individual Dutch dairy herd and thereafter aggregated to an average on a national level.

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From 2009 on, a slight increase in calf mortality in Dutch dairy herds was observed. This resulted in several initiatives and studies to improve the quality of calf rearing and calf health, aiming to reduce calf mortality (Santman-Berends et al., 2014, 2018). At the beginning of 2017, calf mortality rates were published by the lay press and led to discussions on the societal and political level. Even though the definition of the applied parameter was scientifically sound, many farmers did not accept the presented numbers, which were too high in their opinion. An additional complexity when calculating calf mortality in dairy farms is that bull calves leave the farm after approximately 2 or 3 wk to a veal calf operation, and in an increasing number of dairy farms, female calves leave the farm to be raised in a specialized calf rearing facility. As a consequence, numerous different definitions for calf mortality appeared to exist among Dutch veterinarians, agricultural companies, and universities, resulting in differences between calf mortality figures. This finding was in agreement with Compton et al. (2017), who also found that many different definitions, recording methods, and calculation methods are used for evaluating calf mortality in the scientific literature. It is therefore difficult to compare mortality figures between different studies, which is in agreement with Fetrow et al. (2006), who opted for standardized recording of animal removal events. Similarly, farm management programs also calculate incidence rates or risks of mortality and diseases, and in these programs it is not always clear what the precise definition is of these mortality metrics. As a consequence, in most applications, the definition and age categories that are chosen are the result of the aim of the study and are not always comparable.

The differences in calf mortality estimates in the Netherlands resulted in major discussions about the definitions of numerator and denominator, comprehensibility of the definition of calf mortality, age categories, and time periods over which calf mortality should be calculated and monitored. Therefore, the aim of this study was to evaluate several definitions of calf mortality for scientific validity, usefulness for policymakers, and comprehensibility by farmers. Eventually, our aim was to reach agreement with the stakeholders about the ultimate definition and calculation method for parameters to monitor calf mortality in the national cattle health monitoring and surveillance system.

MATERIALS AND METHODS

Study Population and Data Availability

Only dairy herds were included in this study, which were defined as cattle herds that deliver milk for quality control to the national milk quality laboratory (Qlip, Leusden, the Netherlands). For 16,750 Dutch dairy herds that participated in the national cattle monitoring and surveillance system (>98% of all Dutch dairy herds), census data were available from July 1, 2012, to June 30, 2017. The data were provided by the identification and registration system (Rijksdienst Voor Ondernemend Nederland, Assen, the Netherlands), Qlip, and the rendering plant (Rendac, Son, the Netherlands). The data consisted of on- and off-farm animal movements, calving dates, dates of birth and rendering data with date, origin, and age of collected cattle carcasses. In the Netherlands, all carcasses are collected and processed through the rendering plant. On-farm disposal is not allowed and as far as we know is not practiced. Only small fetuses not detected by the farmer may not be rendered.

Two basic mortality rates were calculated from these data that describe the underlying mortality processes. The first rate was the mortality rate per day from the time of birth until 1 yr old in each individual herd, where the numerator consisted of the number of calves (<1 yr) that died on a given day in their first year and the denominator consisted of the number of calves that were present on that specific day in the same herd. The calculation of this first basic rate results in the mortality rate for each day of the calf's life (e.g., the mortality rate for all eligible calves during their first day of life, during their second day of life, and so on). The second rate described the mortality rate per calendar day, where for each calendar day the number of calves that died on that specific date per herd is included as the numerator and the denominator is the number of calves present on that specific calendar day in the same herd. The calculation of this second basic rate results in the mortality rate for each calendar day in a year (e.g., the mortality rate of all eligible calves on January 1, January 2, and so on). The challenge was to correctly reflect these underlying rates per farm, per life time period, and per calendar period in a parameter that is also intuitively valuable to farmers and other stakeholders. For that reason, expert consultation was conducted.

Expert Consultation

Experts were consulted to

(1) ensure that all possible definitions of calf mortality were included in the evaluation;
(2) deduce how to reach understanding about the aspects that need to be taken into account when calculating calf mortality such as age categories, definition of the denominator, fit for purpose, and so on; and

(3) seek support for the final calf mortality parameters of choice (e.g., the calculation method, the definition, age categories, and time periods over which calf mortality should be calculated).

The first expert group consisted of veterinarians and epidemiologists that were employed at GD Animal Health and specialized in longevity of cattle, cattle health, and epidemiological analysis. The advantages and disadvantages of the current parameter for calf mortality were discussed and alternative definitions to monitor calf mortality were generated.

The preliminary results of the evaluation of the default and alternative parameters for calf mortality were presented and discussed with a second expert group that consisted of representatives of (1) the dairy industry [i.e., representatives of farmers organizations (Land en Tuinbouw Organisatie), the Dutch dairy association (Nederlandse Zuivel Organisatie), and the committee of sustainable dairy (Duurzame Zuivelketen)], and (2) representatives of the ministry of agriculture (Ministerie van Landbouw, Natuur en Voedselkwaliteit), which are all located in The Hague, the Netherlands. The definitions were further specified, additional definitions and age categories for calf mortality were suggested, and the advantages and disadvantages of each of the developed parameters for calf mortality were discussed. Factors that were taken into account when evaluating calf mortality parameters were (1) scientific soundness of the calculation method, (2) whether the definition of the parameter was comprehensible by farmers, and (3) usefulness in monitoring trends in calf mortality over time. With the latter expert group, ultimate agreement was reached about the ultimate parameters for calf mortality used to monitor calf mortality in Dutch dairy herds.

Data Validation and Analysis

Procedures for anonymization of the data were described by Santman-Berends et al. (2016). In short, to ensure confidentiality, the raw data that were provided by Rendac, Qlip, and Rijksdienst Voor Ondernemend Nederland were sent to an external firm (IntoFocus Data Transformation Services, Deventer, the Netherlands). IntoFocus Data Transformation Services encrypted all variables in the data that might link the data back to the original source, such as the unique herd identification number of the farms and the identification code of individual cattle. The same encryption code was used for all data sets to ensure that the data sets from the different organization could still be combined.

The data sets were combined and validated. During the validation process, the data were checked for biologically impossible values (such as cattle born before 1980 who were still alive in 2017 according to the data), repeated observations, and outliers. Based on the results of the expert consultations, for each herd and for each predefined period, the numerator and denominator were calculated for each definition of calf mortality and each of the selected age categories of calves. The different mortality categories included perinatal calf mortality [i.e., mortality before, during, or shortly after the moment of birth up to the time of ear-tagging (required within 3 d after birth)], mortality of ear-tagged calves $\leq$14 d, mortality of ear-tagged calves $\leq$21 d, mortality of calves from 15 to 55 d, and mortality of calves from 56 d up to 1 yr of age. As an initial starting point, the number of deceased and present calves in each of the age categories was determined for each individual herd at each specific day during the analyzed period. Thereafter, the daily numbers were combined to the period of interest (i.e., day, quarter of the year, or annual level).

Evaluated Definitions of Calf Mortality

Definitions of calf mortality that were included in this study were (1) currently applied by Dutch organizations to calculate calf mortality, (2) calculated in herd management programs, (3) used in practice by veterinarians and farmers, or (4) included based on the discussions with the experts. Based on these expert discussions, it was agreed to divide the first year of life of the calves into multiple age periods and to evaluate the possibility of using the number of calves as the denominator (preferred by the stakeholders) instead of calf-days-at-risk (scientifically preferred).

For each of the evaluated parameters, the period of interest daily, quarterly, or annually was evaluated. Eventually, 10 parameters to monitor calf mortality were assessed. For illustrative purposes, an easy example of calculating calf mortality is provided in Appendix Figure A1.

Current Definition: Mortality Rate in Ear-Tagged Calves (<1 yr; Parameter 1). The first parameter, "the mortality rate of cattle <1 yr," was formerly used in the monitoring system, and was based on data of the rendering plant that only distinguished between ear-tagged calves (<1 yr) or cattle ($\geq$1 yr). In this parameter, the numerator was the number of deceased calves <1 yr during a given time period. The number of calf-days-at-risk [$DARc$(<1 yr)] during that same time period was calculated based on National Identification and Registration data on the individual and daily level, and calf-days-at-risk was included as the denominator (formula [1]):

$$\text{mortality rate}(\text{calves} < 1\,\text{yr})_{ij} = \frac{\text{no. of deceased ear-tagged calves}(<1\,\text{yr})_{ij}}{DARc(<1\,\text{yr})_{ij}}. \quad [1]$$

The mortality rate was calculated at the individual herd level (i) for the defined period (j), and the mean of all individual herds was calculated to represent the mortality rate for all dairy herds. The resulting mortality rate represented the rate per day in a predefined period and was translated into a rate per period at risk (maximum 365 d) per defined time period (i.e., day, quarter, or year; formula [2]). For readability and intelligibility purposes, the mortality rate for period j was presented as percentages by multiplying them by 100:

$$\%\ \text{mortality}(\text{calves} < 1\,\text{yr})_{ij} = \left(\frac{\text{no. of deceased ear-tagged calves}(<1\,\text{yr})_{ij}}{DARc(<1\,\text{yr})_{ij}}\right) \times n\,days_j \times 100, \quad [2]$$

where $n\ days$ equals 1, 90.4, or 365 depending whether the period of interest was day, quarter, or year. It should be noted that $n\ days$ cannot exceed the maximum period at risk for a certain age category of calves. So for the calculation of calf mortality <14 d, the maximum value of this parameter is 14.

Postnatal Calf Mortality Relative to the Number of Ear-Tagged Calves (Parameter 2 to 4). An alternative parameter that was extensively used by farmers was calf mortality risk (<1 yr). This parameter was only calculated on an annual basis and was calculated similarly to the definition of mortality rate of calves (<1 yr), but differed with respect to the denominator. The denominator for calf mortality risk was the number of calves that were ear-tagged in a given time period j instead of the calf-days-at-risk. Calf mortality risk was calculated by dividing the number of deceased calves from age group a (≤14 or ≤21 d) for herd i in period j by the number of ear-tagged calves that were present for at least 1 d in the respective age group, herd, and period (formula [3]). By multiplying the rate by 100, the rates were presented as percentage. Subsequently, the mean calf mortality risk for all dairy herds per age category and time period j (quarter, year, or both) was calculated:

$$\text{calf mortality risk}_{aij} = \frac{\text{no. of deceased ear-tagged calves}_{aij}}{\text{no. of ear-tagged calves}_{aij}} \times 100. \quad [3]$$

The numerator and denominator are not necessarily connected in this calculation method of calf mortality. A calf can be born in, and survive the first quarter and die in the second quarter. When the mortality is calculated on a quarterly basis, such a calf would contribute to the numerator (deaths) in the second quarter, whereas it only contributes to the denominator (which is based on the moment the respective calf was ear-tagged) in the first quarter.

This farmers' definition is closer to an incidence risk rather than an incidence rate as it does not take into account the fact that calves that die or are moved off-farm, are lost to follow-up, and thus have a different period at risk compared with calves that survive and stay in the herd. In our study we reproduced the parameter used by the farmers and evaluated this for postnatal calf mortality in the age groups of ≤14 d and ≤21 d old (≤14 d and ≤21 d). Both parameters were calculated on a quarterly and yearly level. The threshold of 14 d was based on the European Union council regulation 1/2005 (EC, 2005) that states that newborn calves are not allowed to be moved off-farm until 14 d old. The threshold of 21 d was based on expert evaluation because this was expected to be the age when all calves that were sold to veal herds had left the dairy herds.

Calf Mortality Rate Stratified to Multiple Age Groups (Parameter 5 to 8). Calf mortality rate was defined as the number of deceased calves in different age categories a relative to the number of calf days at risk in the specific age category ($DARc_a$; formula [4]). Similar to calf mortality risk, the calf mortality rate was calculated for postnatal calves up to 14 and 21 d old. Additionally, mortality rates for calves in the age categories 15 to 55 d and 56 d up to 1 yr old were determined:

$$\text{calf mortality rate}_{aij} = \frac{\text{no. of deceased ear-tagged calves}_{aij}}{DARc_{aij}}. \quad [4]$$

The calf mortality rate per age category for each individual herd i was calculated per day and averaged into a mean per period j (i.e., day, quarter, or year). For presentation purposes, the rate was multiplied by 100 and presented as a percentage.

Perinatal Calf Mortality Risk (Parameter 9). The current definition of calf mortality exclusively include mortality of ear-tagged calves. Perinatal calf mortality that consists of aborted calves (>100 d in gestation), stillbirths, and mortality before the time of ear-tagging are not included in the calculation of this parameter. Perinatal calf mortality risk was calculated by dividing the number of dead perinatal calves including abortions, stillbirths, and mortality before ear-tagging by the number of calves delivered (formula [5]). A calving was defined as giving birth to a calf irrespective of the survival status of that calf (i.e., aborted, dead, or alive). Thus, for this calculation it may be assumed that all calvings with a deceased calf as a result are also part of the denominator.

$$\text{perinatal calf mortality risk}_{ij} = \frac{\left(\sum \text{abortions, stillbirths, deceased newborn calves}\right)_{ij}}{\text{no. of calves delivered}_{ij}} \times 100. \quad [5]$$

The average perinatal calf mortality risk for each individual dairy herd i per period j was combined into the mean perinatal calf mortality for all dairy herds in that specific period.

Young Calf Mortality Risk: Combination of Perinatal and Postnatal Mortality (≤14 d; Parameter 10). In this definition, perinatal and postnatal calf mortality are combined to estimate a mortality parameter of young calves that is insensitive to the time of ear-tagging in newborn calves. In the Netherlands, it is mandatory to ear-tag and register newborn calves at most at 3 d after birth. In general, calves are ear-tagged on the first day after birth. There is, however, variation between farmers in the moment at which calves are ear-tagged, which may bias the herds' mortality figures. The young calf mortality risk is defined as the sum of aborted calves, stillbirths, newborn, and young ear-tagged calves (≤14 d) relative to the number of calves delivered per herd i and period j (formula [6]):

$$\text{mortality of calves}\left(\le 14\,\text{d}\right)_{ij} = \frac{\left(\sum \text{abortions, stillbirths, deceased calves} \le 14\,\text{d}\right)_{ij}}{\text{no. of calves delivered}_{ij}} \times 100. \quad [6]$$

Similar to the calculation of calf mortality risk, the numerator and the denominator are not necessarily connected in this calculation. A deceased calf can contribute to the numerator in quarter j while it is born and thus contributes to the denominator in quarter $j - 1$. Again, the mean of all dairy herds was calculated per period of interest and the risk was multiplied by 100 to enable presentation as a percentage.

Evaluation

All definitions were applied to Dutch census data and the results were calculated and presented for the predefined time periods. For each defined mortality parameter, the formula, the advantages and disadvantages, and the results at different levels (i.e., day, quarter, or year) were evaluated and discussed with the 2 groups of experts. Each of the parameters was qualitatively scored on 3 different indicators:

(1) The parameter resulted in a correct estimation of calf mortality (the calculation of the numerator and denominator are epidemiologically correct). Parameters that were scientifically incorrect were not recommended for use in the monitoring program.
(2) The parameter and subsequent result are comprehensible for farmers. When farmers do not comprehend the results or the calculation method, they will not agree with their own calf mortality figures and will not improve their management to reduce calf mortality. Incomprehensible mortality parameters would receive a negative recommendation by the policymakers and industry representatives for inclusion in the monitoring program.
(3) The parameter should have value to monitoring trends in calf mortality.

The qualitative results of the 3 scoring indicators resulted in an overall recommendation for implementation, which could vary from incorrect ("recommend not to use") to good ("recommend to use").

RESULTS

The basic mortality rates were calculated for each day of the life of a calf (Figure 1) and for each calendar day in the year 2016 (Figure 2). For the latter, a moving average per 7 d was calculated to remove fluctuations in mortality due to administrative issues (e.g., farmers are more likely to report deaths at the end of the week at the time they are doing their administrative tasks).

Figure 1 shows that the probability to die is highest just after birth and rapidly declines during the first month of life. In Figure 2, seasonal fluctuations in calf mortality are visible with higher mortality rates in winter months and lower in summer.

Current Definition of Calf Mortality

From July 1, 2012, to June 30, 2017, the mean mortality rate of ear-tagged calves (parameter 1), which was presented as percentage was 0.04% per day, 4.3% per quarter, and 16.5% per year on 16,750 Dutch dairy herds (Table 1). The mean yearly percentage was high-

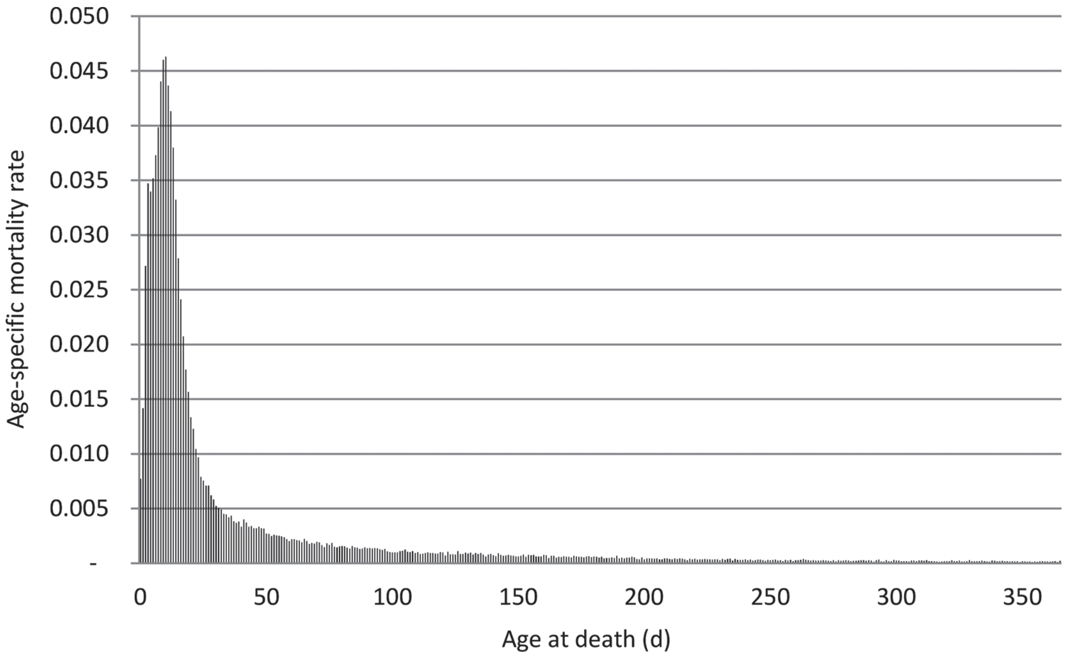

Figure 1. Mortality rate of Dutch dairy calves <1 yr relative to age in days.

er than the median value given the somewhat skewed distribution of calf mortality across Dutch dairy herds.

The farmers perceived the presented mean mortality rate as too high. They estimated the calf mortality in their herds at approximately 5% per year based on parameter 2 (Table 1). The farmers underestimated the yearly calf mortality rate (<1 yr) in their herds because they were unaware that this rate was highly influenced by the first 14 d of life of calves. During this first 14 d of life, the mortality rates are highest (Figure 1). In addition, the proportion of calves that were born in the herd that were still present and thus at risk of dying was also highest during this first 14-d period (Figure 3). In Figure 3 we visually present calves that stay on the farm during their first year of life. It shows that over 50% of calves born on the farm, which mainly represent bull calves that are destined for the veal industry, are moved off-farm between 2 and 4 wk of age. This means that most calves are present in the herd when they are at highest risk of dying, which results in a high annual calf mortality rate (<1 yr).

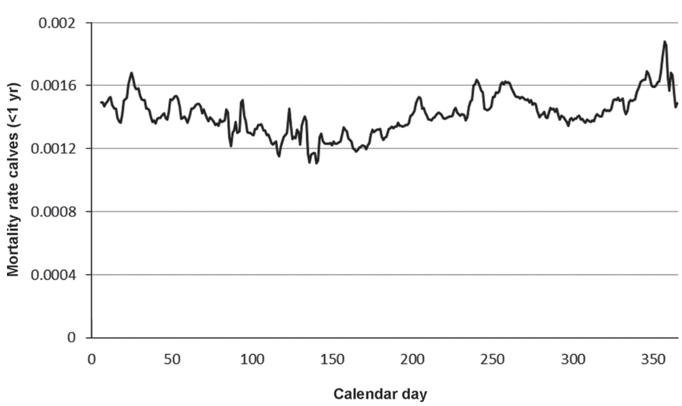

Figure 2. Weekly moving average of the daily mortality rate of Dutch dairy calves <1 yr for each calendar day in 2016.

Alternative Definitions for Ear-Tagged Calf Mortality

The calf mortality risk relative to the number of ear-tagged calves (parameter 3) and calf mortality rate relative to the calf days at risk (parameter 5) was similar up to the age of 14 d with, respectively, 3.3 and 3.2% per quarter or year, when the rates were presented as percentages (Figure 4a). When a cut-off age of 21 d was applied, the results of the calf mortality risk (parameter 4) and the calf mortality rate (parameter 6) differed (Table 1, Figure 4b). Postnatal calf mortality risk ≤21 d (parameter 4) was 4.0% per quarter or year, whereas it was 4.6% per quarter or year for the calf mortality rate (parameter 6). Even though calf mortality according to both parameter 4 and 6 showed similar trends in time, the mortality was underestimated with parameter 4 due to the fact that this definition did not take off-farm movements between d 14 and 21 into account.

For calculation of calf mortality for the 2 age categories 15 to 55 d and 56 d until 1 yr, calf-days-at-risk was the only option for use as the denominator. During these life periods calves could be moved on- and

Table 1. Ten definitions for calf mortality from July 1, 2012, to June 30, 2017, calculated per day, quarter, or year in 16,750 Dutch dairy herds[1]

Parameter	Denominator	Average mortality (%) per day (D), quarter (Q), year (Y)	Epidemiologically correct	Comprehensible by farmers	Usefulness for monitoring
1. Calf mortality rate (<1 yr)	No. of calf-days at risk	D: 0.04 Q: 4.3 Y: 16.5	+	−	+
2. Calf mortality risk (<1 yr)	No. of ear-tagged calves	Y: 5.3	−	−	−
3. Postnatal calf mortality risk (≤14 d)	No. of ear-tagged calves	Q: 3.2 Y: 3.2	+/−	+	+/−
4. Postnatal calf mortality risk (≤21 d)	No. of ear-tagged calves	Q: 4.0 Y: 4.0	−	+/−	+/−
5. Postnatal calf mortality rate (≤14 d)	No. of calf-days at risk	D: 0.2 Q: 3.3 Y: 3.3	+	+/−	+
6. Postnatal calf mortality rate (≤21 d)	No. of calf-days at risk	D: 0.2 Q: 4.6 Y: 4.6	+	+/−	+
7. Preweaned calf mortality rate (15 to 55 d)	No. of calf-days at risk	D: 0.1 Q: 4.5 Y: 4.5	+	+/−	+
8. Weaned calf mortality rate (56 d to 1 yr)	No. of calf-days at risk	D: 0.01 Q: 0.9 Y: 3.1	+	+/−	+
9. Perinatal calf mortality risk (<3 d)	No. of calves delivered	D: 8.5 Q: 8.5 Y: 8.5	+	+	+
10. Peri- and postnatal calf mortality risk (≤14 d)	No. of calves delivered	Q: 11.5 Y: 11.5	+/−	+	+/−

[1]+ = good/comprehensible/useful for monitoring; +/− = useful but not optimal, comprehensible with additional explanation; − = incorrect/unexplainable for farmers/not useful for monitoring.

off-farm and thus the figures had to be corrected for the duration that calves were present in the herd. The preweaned mortality rate (15 to 55 d) was 0.1% per day and 4.5% per quarter and year. The mortality rate of weaned calves (56 d to 1 yr) was 0.01% per day, 0.9% per quarter, and 3.1% per year. The latter mortality rate differed between quarter and year level, as a result of a period at risk (between 56 d and 1 yr: 310 d) that was longer than the duration of a quarter. When the period at risk was equal to or less than the length in days of a quarter, the results on the quarterly level were similar to those on the annual level (Table 1).

Perinatal Calf Mortality Risk

Perinatal calf mortality risk was on average 8.5% during the analyzed period. This percentage was independent of the evaluated time period (i.e., day, quarter, or year), but was influenced by seasonal fluctuations with higher mortality in winter months and lowest mortality risk in summer months (Figure 5). Due to possible variation in mortality associated with the variation in age of ear-tagging, an alternative definition was created in which perinatal and postnatal calf mortality ≤14 d were combined in one parameter (number 10). With this definition, the mean mortality was 11.5% per quarter or year during the analyzed period. The interpretation of the difference between the mortality risk based on parameter 9 and parameter 10 would be that approximately 3% of calves (11.5–8.5%) were reported to die between the time of ear-tagging and d 14 of life.

Qualitative Evaluation of the Mortality Parameters

Each of the parameters was graded by the expert group and classified based on scientific soundness, comprehensibility by farmers and veterinarians, and usefulness for monitoring. For monitoring purposes, the preferred analytic period was also evaluated. Daily, quarterly, or yearly mortality figures showed a slightly increasing trend over the 5-yr period, but differed in seasonal fluctuations and the exact value of the mortality rate (see Appendix Figure A2 for an example). For monitoring purpose, mortality figures on quarterly level were deemed most optimal as these were comprehensible by farmers and both practical and useful for monitoring purposes.

Just one mortality parameter, namely perinatal calf mortality (parameter 9), received the optimal score (+) from the experts on each of the graded aspects (Table 1). Four of the evaluated parameters scored as unacceptable (−) on at least one aspect.

DISCUSSION

In this study, many different definitions for calf mortality were evaluated. It was concluded that each of the defined mortality parameters had its advantages and disadvantages (Table 2) and that there was no easy and perfect way to evaluate calf mortality on an ongoing basis.

Even though the formally used definition of calf mortality rate (calf mortality rate <1 yr) was scientifically sound, farmers and veterinarians thought it overestimated the true mortality. The presented calf mortality rate was highly influenced by the mortality of calves up to 2 or 3 wk of age, which explained why the level of mortality and the definition was not understood by farmers. Nevertheless, the definition of calf mortality that was generally used by the farmers themselves, mortality of calves (<1 yr relative to number of ear-tagged calves, parameter 2), was scientifically incorrect because it did not correct for cattle entering and leaving the herd such as bull calves leaving the herd to a veal herd at 2 wk of age. Additionally, parameter 2 could only be calculated on an annual level. Using this parameter on a quarterly level resulted in an overestimation of calf mortality (<1 yr) because deceased calves were at risk to be included in the numerator during 1 of 4 quarters, whereas they would exclusively be included in the denominator in the quarter in which they were tagged. This resulted in the challenge to find a definition of calf mortality that could be used to monitor trends, but that was also comprehensible by farmers and veterinarians. When evaluating the literature, it was observed that calf mortality figures between studies are difficult to compare because of different farming systems, differences in definitions, different numbers of days at risk included, and different calculation methods (Compton et al., 2017). For example, in a French study of Raboisson et al. (2014), calf mortality was stratified into 2 age categories (i.e., 0 to 2 d old and 3 to 30 d old). In the study of Seppä-Lassila et al. (2016), 2 different age groups were distinguished to evaluate calf mortality <7 d and 7 to 180 d old, and in the paper of Santman-Berends et al. (2014), calf mortality was assessed for calves between 3 d and 1 yr old. These differences among studies is not a new finding and already resulted in recommendations to align definitions of calf mortality and registration of underlying causes of death such as unassisted death or euthanasia (Radke, 2000; Fetrow et al., 2006). However, differences in definitions and age categories often appeared to result from data

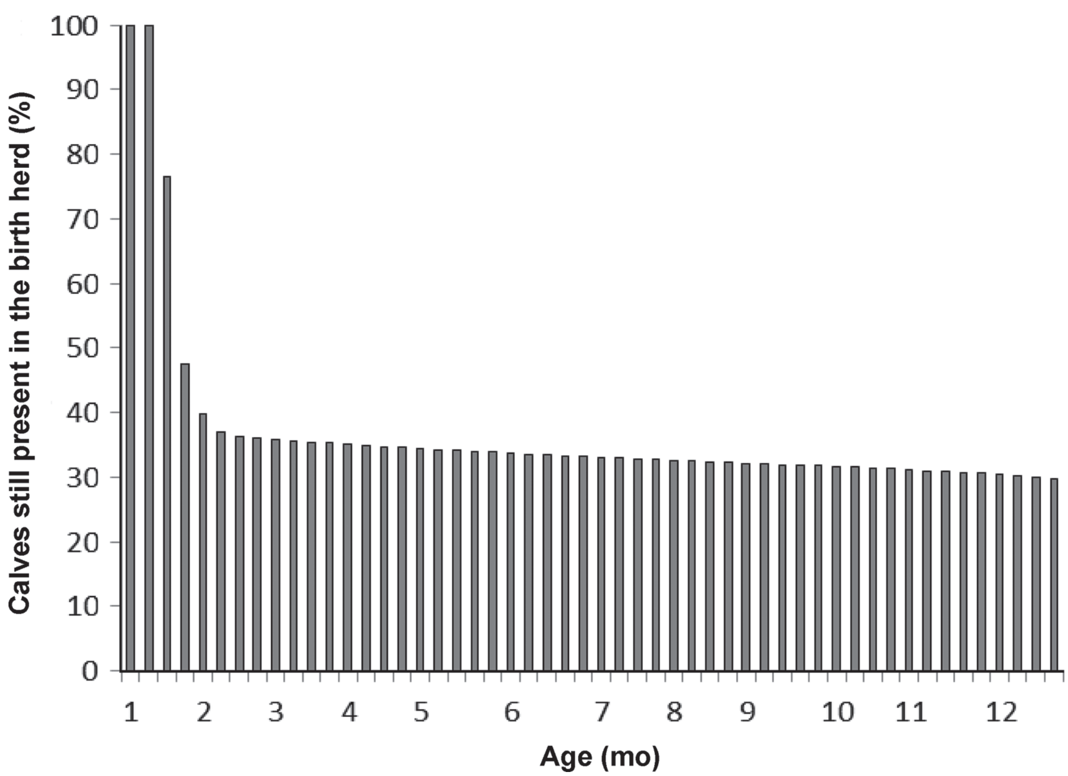

Figure 3. The percentage of calves born in an average Dutch dairy herd that stay in the herd during their first year of life. The age in months represents the percentage of calves present up to this age. This means that the first 4 bars represent the percentage of calves present from birth up to 1 mo of age.

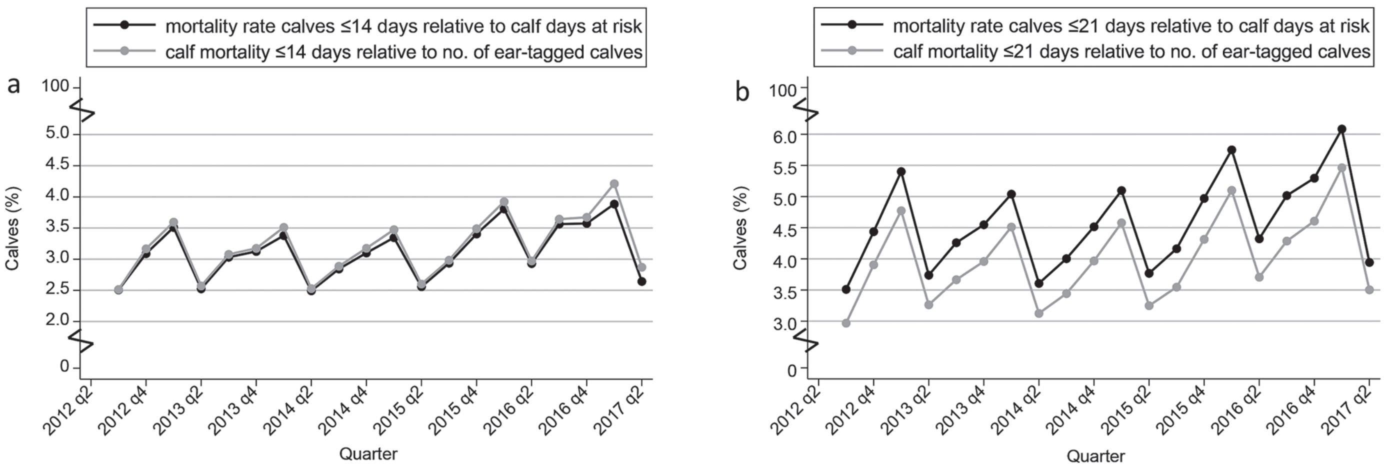

Figure 4. Postnatal calf mortality (a) ≤14 d and (b) ≤21 d in Dutch dairy herds per quarter of the year from July 1, 2012, to June 30, 2017, according to 2 different denominators for calculation of calf mortality.

limitations (only access to group level data) or differences in the overall aim of the study. When the aim of the study is to monitor trends, it is logical to analyze large amounts of data on a quarterly level, as it is not necessary to conduct such analysis on a daily basis. Additionally, the results should be interpretable by veterinary experts and stakeholders. When the aim of calculating calf mortality is early detection of deviations, mortality on a weekly or daily level should be assessed and other calculation methods or for example sentinel herds instead of census data may be more feasible. Finally, when calf mortality is evaluated to inform the farmer about his rearing performance, again other factors influence the choice of age categories and definitions. Currently, data in which causes of death are registered for Dutch dairy cattle are not available for the cattle health monitoring and surveillance system, even though such data are known to be very relevant for monitoring purposes (Radke, 2000; Fetrow et al., 2006). Recently a new data source became available in the Netherlands in which medicine supplies by the veterinarian are registered (MediRund). These data might in the future be used to distinguish assisted from unassisted deaths, which may subsequently improve the added value for the national cattle health monitoring and surveillance system.

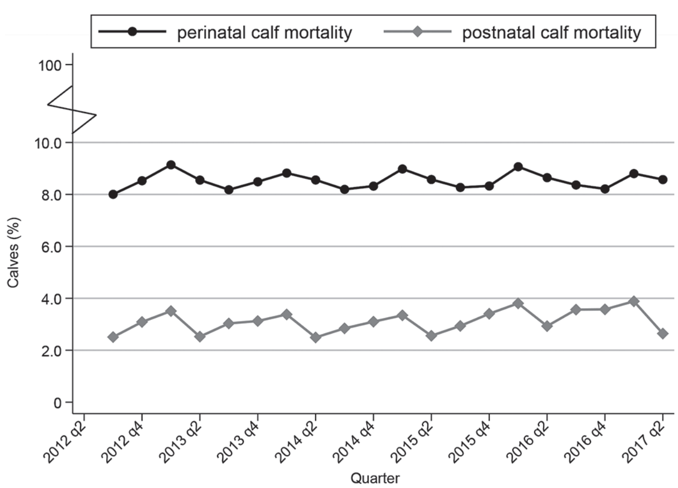

Figure 5. Perinatal (before the moment of ear-tagging) and postnatal calf mortality (≤14 d) in Dutch dairy herds per quarter in the period from July 1, 2012, to June 30, 2017.

Our study focused on monitoring trends in cattle health in which calf mortality was one of the key indicators in quarterly census data. Based on the evaluation of the formerly used parameter for calf mortality (<1 yr) and the discussions with the stakeholders, it was decided to (1) stratify mortality of calves into multiple age periods that align with specific events such as calves sold to veal herds at 14 to 21 d old and weaning calves at approximately 8 wk old (56 d), and (2) to evaluate the possibility to simplify the definition of the denominator. Additionally, the mortality parameters were first calculated at the individual herd level and subsequently aggregated to averages on a national level to assess the trends in time. We preferred this method over calculating the mortality parameters directly on a national level because in the latter case the mortality parameters are more strongly influenced by large dairy herds and deviations in smaller herds may not be detected.

One of the most important requests of the stakeholders was to include a fixed number of calves in the denominator such as number of births or number of ear-tagged calves. In general, a fixed number of calves as the denominator instead of calf-days-at-risk does not

Table 2. Ten definitions to describe calf mortality in Dutch dairy herds with their advantages and disadvantages

Parameter [numerator; denominator]	Advantage (A)/disadvantage (D)
1. Calf mortality rate (<1 yr) [no. of deaths (<1 yr); no. of calf-days-at-risk (<1 yr)]	A: Epidemiologically sound D: Difficult to comprehend by farmers/stakeholders D: Highly influenced by the skewed distribution in mortality during first year of life D: Highly influenced by the skewed age distribution of dairy calves present in the herd
2. Calf mortality risk (<1 yr) [no. of deaths (<1 yr); no. of ear-tagged calves (<1 yr)]	A: Easy to calculate A: Comprehensible for farmers/stakeholders D: Epidemiologically incorrect D: Does not correct for calf-days-at-risk during the first year of life D: Can only be calculated after the end of the first year of life, and can therefore not be calculated per day or per quarter (unsuitable for monitoring)
3. Postnatal calf mortality risk (≤14 d) [no. of deaths (≤14 d); no. of ear-tagged calves (≤14 d)]	A: Comprehensible for farmers/stakeholders A: Not influenced by the skewed age distribution A: Useful for policymakers A: Result is approximately the same as parameter 5 D: Sporadic mismatch where calves are included in the denominator in period 1 and in the numerator in period 2 D: No correction for calf-days-at-risk D: Can only be calculated after the end of the 14-d period, and can therefore not be calculated per day D: Quarterly and annual results seem lower compared with mortality in older calves (parameters 7 and 8)
4. Postnatal calf mortality risk (≤21 d) [no. of deaths (≤21 d); no. of ear-tagged calves (≤21 d)]	A: Comprehensible for farmers/stakeholders A: Total period at risk of bull calves is included D: Sporadic mismatch where calves are included in the denominator in period 1 and in the numerator in period 2 D: No correction for calf-days-at-risk D: Underestimation of calf mortality because veal calves are removed before 21 d old D: Can only be calculated after the end of the 21-d period, and can therefore not be calculated per day D: Results differ substantially from parameter 6
5. Postnatal calf mortality rate (≤14 d) [no. of deaths (≤14 d); no. of calf-days-at-risk (≤14 d)]	A: Epidemiologically sound A: Not influenced by the skewed age distribution of present calves A: Useful for policymakers D: Difficult to comprehend by farmers/stakeholders D: Quarterly and annual results seem lower compared with mortality in older calves (parameters 7 and 8)
6. Postnatal calf mortality rate (≤21 d) [no. of deaths (≤21 d); no. of calf-days-at-risk (≤21 d)]	A: Epidemiologically sound D: Difficult to comprehend for farmers/stakeholders D: Results differ substantially from parameter 4
7. Preweaned calf mortality rate (15 to 55 d) [no. of deaths (15 to 55 d); no. of calf-days-at-risk (15 to 55 d]	A: Epidemiologically sound A: Age period consists of the total preweaned period of Dutch dairy calves at which they are in general still present in the dairy herd A: Useful for policymakers D: Difficult to comprehend for farmers/stakeholders D: Mortality rate on quarterly and annual level seems higher than postnatal calf mortality (parameters 3 and 5)
8. Weaned calf mortality rate (56 d to 1 yr) [no. of deaths (56 d to 1 yr); no. of calf-days-at-risk (56 d to 1 yr)]	A: Epidemiologically sound A: Age period consists of the period in which calves that are moved off-farm to a rearing facility are not included A: Useful for policymakers D: Difficult to comprehend for farmers/stakeholders
9. Perinatal calf mortality risk [no. of deaths (non-ear-tagged); no. of calves delivered]	A: Epidemiologically sound A: Useful for policymakers D: Difficult to interpret by farmers/stakeholders because all calvings resulting in deceased perinatal calves are included (abortions >100 d in gestation, stillbirths, and deceased newborn calves) D: Difficult to evaluate exact cause of fluctuations (but is more specific than parameter 10) D: Influenced by time of ear-tagging
10. Peri- and postnatal calf mortality risk (≤14 d) [no. of deaths (non-ear-tagged and ear-tagged ≤14 d); no. of calves delivered]	A: Epidemiologically sound A: Not influenced by time of ear-tagging D: Difficult to interpret by farmers/stakeholders D: Difficult to evaluate the exact cause of fluctuations (are there fluctuations in perinatal or postnatal calf mortality?) D: Can only be calculated after the end of the 14-d period and therefore cannot be calculated per day

always provide a good estimate of the rate of mortality, particularly when the period of interest is large (e.g., quarter or year) and the denominator fluctuates during this period. In such cases, large deviations between the rate and the risk may occur as the fixed number of calves in the denominator of the risk does not correct for within herd dynamics during the period for which calf mortality is calculated. In the Netherlands, however, calves are not allowed to be moved off-farm until they are at least 14 d old. Thereafter, bull calves are quickly (usually in the subsequent week) moved off-farm to veal herds. Therefore, both the mortality rate (days at risk as denominator) and mortality risk (no. of ear-tagged calves as denominator) were evaluated and compared for the first 14 and first 21 d of life. The slight difference in mortality rate and mortality risk up to the age of 14 d was due to deceased calves that were weighted differently between both parameters. When calculating the mortality rate, we corrected for the fact that the weight of a deceased calf in the denominator (included as 1 multiplied with the proportion of the period in which it was still alive and at risk to die) was lower than the weight of a calf that survived (included as 1). In the calculation of the mortality risk, both deceased and survived calves were included with a similar weight in the denominator (i.e., 1). This resulted in a very small underestimation of the mortality when using the mortality risk as a parameter. Additionally, when the number of ear-tagged calves were used as denominator, it was possible that a calf was born (and included in the denominator) in one quarter and died in the next (included in the numerator). These events happening across different time periods did, however, only have a negligible effect on the results. For the parameter evaluating calf mortality up to 21 d old, the difference between the mortality risk and mortality rate became substantial and resulted in a clear underestimation of the mortality risk. Thus it was decided to evaluate the mortality of postnatal calves up to an age of 14 d relative to the number of ear-tagged calves and to evaluate mortality of older calves relative to calf-days-at-risk.

For this study, in which we evaluated several definitions of calf mortality to monitor trends, bull calf and heifer calf mortality were not separated. For national monitoring purposes, stratifying mortality to sex is not so relevant given that incursion of diseases will affect mortality in bull and heifer calves in the same way. From a previous study (Santman-Berends et al., 2018), we know that the mortality rates of bull and heifer calves can be somewhat different, which is relevant management information for individual farmers and their veterinarians. For such cases, the formulas that are presented in this paper can easily be used for both sexes, with the only difference that the number of deaths in the numerator and the number of calf days-at-risk in the denominator will be sex specific.

It has to be noted that the sum of postnatal calf mortality (≤14 d), preweaned calf mortality (15 to 55 d), and mortality of weaned calves (56 d to 1 yr) per year does not add up to the calf mortality rate (<1 yr). This is due to the conditional nature of the mortality parameter that is stratified into 3 age categories; for example, the mortality rate of preweaned calves is conditional on the fact that the calves in this age category have survived the postnatal period. Thus, when presenting calf mortality figures for multiple age categories separately, the sum will result in an underestimation of the total calf mortality (<1 yr) and it has to be communicated that these number cannot be simply added to obtain an overall calf mortality. This phenomenon is illustrated with an example that is described in Appendix Figure A1.

The only parameter for calf mortality that received a favorable advisement on all 3 indicators according to the expert group (i.e., scientific soundness, comprehensibility, and usefulness for monitoring) was perinatal calf mortality up to the time of ear-tagging. Nevertheless, this parameter also had some disadvantages (Table 2). Although the definition of this parameter was comprehensible for stakeholders and farmers, the mortality percentages between farmers may not be comparable because of the variation in time until registration and ear-tagging of the calves. In the Netherlands, farmers are obliged to register and ear-tag their calves within 3 working days after birth. Some of the farmers ear-tag their calves as soon they are born, and others wait for 2 or 3 d. This influences the herd-specific perinatal calf mortality and introduces variation among herds. This variation could be avoided by combining perinatal and postnatal calf mortality into one parameter (number 10). Nevertheless, for monitoring purposes, this is not a preferred definition because when a deviating trend occurs, it remains unclear in which group (perinatal or postnatal calves) the mortality changed. This is important to know because an increase in perinatal calf mortality may be associated with a different cause than an increase in postnatal calf mortality. Still, the parameter "perinatal calf mortality" was a combined parameter in which both late abortions, stillbirths, and deaths before the moment of ear-tagging were included. This is not optimal given that these different subcategories of mortality might be associated with other causes. Nevertheless, we depend on the available data from the rendering plant that does not specify causes of deaths of perinatal calf mortality nor distinguish between heifer and bull calves. The advantage of calculating perinatal calf mortality on rendering data was that these data contained complete records (both bull and heifer calves) on all deaths of perinatal calves in the Netherlands.

For monitoring, mortality figures need to be produced frequently to detect deviations as soon as possible (Perrin et al., 2012; Torres et al., 2015). This may result in different preferred definitions for parameters to monitor calf mortality than for communication purposes. Annual mortality figures are preferred for communication because they are more intuitive for the general public, are easy to understand by stakeholders, and are not influenced by seasonal fluctuations (Appendix Figure A2). The mean calf mortality per quarter is less suitable for communication purposes but does provide additional insight in seasonal fluctuations and enables earlier detection of deviations. A disadvantage of monitoring on quarterly level is that mortality in older calves might appear higher than in younger calves due to the different periods at risk (i.e., 14 d for postnatal calf mortality, 41 d for preweaned calf mortality, and 310 d when calculating weaned calf mortality). This issue is tackled when the mortality rates are calculated per day, but result in very low values that are not intuitive. Based on expert consultations it was eventually agreed to evaluate quarterly figures for monitoring calf mortality. Additionally, annual numbers will be calculated specifically for communication purposes and presented to the stakeholders once a year.

In this study, the means of the mortality rates are presented, which are known to be highly influenced by extreme values in the data. Nevertheless, presenting and using the median instead of the mean resulted in difficulties when comparing the results because the median was often zero, especially for the mortality parameters that were calculated on a daily level. Given the aim of this study, which was to evaluate different definitions of calf mortality based on national census data, we believe that the mean could be used for comparison purposes because the results of all evaluated parameters were influenced by the same herds with extreme mortality rates.

CONCLUSIONS

Calf mortality can be calculated in many different ways with varying results. The optimal definition of a calf mortality parameter will depend on the purpose of the calf mortality parameter (e.g., early detection, monitoring trends, or assessing mortality figures for individual farmers). Nevertheless, it is very important to thoroughly discuss the purpose, the definition (numerator and denominator), and the age categories for the calculation of calf mortality. Many aspects have to be taken into account on both epidemiological and practical levels. The definition of the parameters should be comprehensible by farmers to maximize their understanding of the presented numbers and to increase compliance when subsequent actions to reduce calf mortality have to be taken. Based on this evaluation, 4 different mortality parameters were selected and were implemented to analyze and monitor calf mortality in Dutch dairy beginning in 2018: (1) perinatal calf mortality risk relative to the number of calves delivered (parameter 10), (2) postnatal calf mortality risk relative to the number of ear-tagged calves (parameter 3), (3) preweaned calf mortality rate relative to the number of calf-days-at-risk (parameter 7), and (4) weaned calf mortality rate relative to the number of calf-days-at-risk (parameter 8). Our evaluation resulted in understanding of the definitions of the selected mortality parameter and agreement by the stakeholders to use these parameters to monitor calf mortality. Strong stakeholder involvement is important when defining indicators for monitoring purposes.

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APPENDIX

No.	Description	formula	Periods in days since birth			Total
			0-14	15-55	56-365	
1	Duration time period at risk	t	14	41	310	365
2	N calves at start	N	14	13	11	14
3	N calves decreased in period	n	1	2	1	4
4	Total days at risk	(N-n) × t + n × (t × .5) [a]	189	492	3255	3936
5	Avg N calves present per day	*No 4*/365	0.5	1.3	8.9	10.8
6	True rate (incidence rate)	n / *No 4*	0.0053	0.0041	0.0003	0.0010
7	True risk (cumulative incidence)	n / N	0.07	0.15	0.09	0.29 [b]
8	True risk calculated from rates	1-exp(-*No 6* × t)	0.07	0.15	0.09	0.29 [c]
9	Avg time in period at risk per calf	*No 4* / N	13.5	37.8	295.9	281.1
10	% death calves per avg calf period at risk	*No 6* × *No 9* × 100	7.1	15.4	9.1	28.6 [d]
11	% death calves per total period at risk	*No 6* × *No 1* × 100	7.4	16.7	9.5	37.1

Figure A1. Example calculation of overall mortality rate of Dutch dairy calves (<1 yr) in total and stratified into 3 age groups under the assumption that no calves are sold off-farm. [a]For the purpose of this example, we assume that animals that are deceased were on average half the time at risk; in the paper the actual number of animals that were present in the herd were included. [b]Note that the annual risk is not the sum of the period risks at linear scale (0.07 + 0.15 + 0.09 = 0.31). [c]Note that the annual risk is the sum of the period risks at exponential scale $(1 - \text{EXP}\{-1 \times [(0.0053 \times 14) + (0.0041 \times 41) + (0.0003 \times 310)]\} = 0.29)$. [d]Equal to the cumulative incidence.

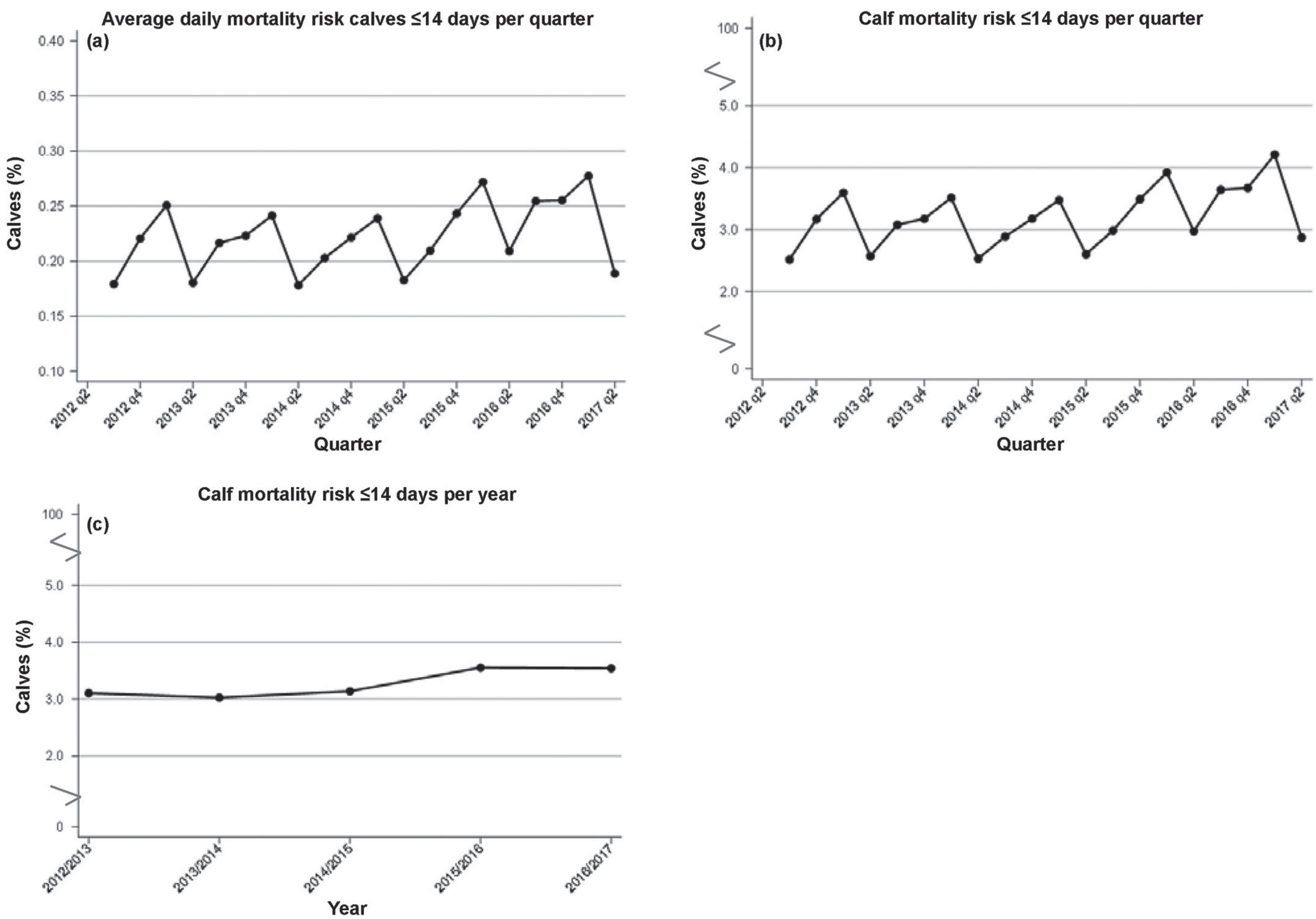

Figure A2. Calf mortality risk of calves ≤14 d in Dutch dairy herds per average day within a quarter (a), quarter (b), or year (c) from July 1, 2012, to June 30, 2017.