Interpretive Summary

The British national cattle register was used to analyse 21.2 million births and 21.6 million deaths registered between 2011-2018. A significant proportion of on-farm mortality occurred before 3 months of age, and both dairy and male calves had higher mortality rates than beef and female calves respectively. Month of birth and environmental temperature had a strong influence on mortality rate, and it appears that providing optimal environmental conditions would greatly reduce mortality rate. National cattle registers have great potential in monitoring mortality rates and further research is needed to explore environmental factors likely to reduce calf mortality rates.

Quantitative analysis of calf mortality in Great Britain

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ABSTRACT

National bodies in Great Britain (GB) have expressed concern over young stock health and welfare and identified calf survival as a priority, however no national data have been available to quantify mortality rates. The aim of this study was to quantify the temporal incidence rate, distributional features and factors affecting variation in mortality rates in calves in GB since 2011. The purpose was to provide information to national stakeholder groups to inform resource allocation both for knowledge exchange and future research. Cattle birth and death registrations from the national British Cattle Movement Service were analysed to determine rates of both slaughter and on-farm mortality. The number of births and deaths registered between 2011-2018 within GB were 21.2 and 21.6 million respectively. Of the 3.3 million on-farm deaths, 1.8 million occurred before 24 months of age (54%), and 818,845 (25%) happened within the first 3 months of age. The on-farm mortality rate was 3.87% by 3 months of age, has remained relatively stable over time, and is higher for male calves (4.32%) than female calves (3.45%). Dairy calves experience higher on farm mortality rates than non-dairy (beef) calves in the first 3 months of life, with 6.00% and 2.86% mortality rates respectively. The 0-3 month death rate at slaughterhouse for male dairy calves has increased from 17.40% in 2011 to 26.16% in 2018, and has remained low (<0.5%) for both female dairy calves, and beef calves of both sexes. Multivariate adaptive regression spline (MARS) models were able to explain a large degree of the variation in mortality rates (R^2 = 96%). Mean monthly environmental temperature and month of birth appeared to play an important role in neonatal on-farm mortality rates, with increased temperatures significantly reducing mortality rates. Taking the optimal month of birth and environmental temperature as indicators of the best possible environmental conditions, maintaining these conditions throughout the year would be expected to result in a reduction in annual 0-3 month mortality of 37,571 deaths per year, with an estimated economic saving of around £11.6 million per annum. National cattle registers have great potential for monitoring trends in calf mortality and can provide valuable insights to the cattle industry. Environmental conditions play a significant role in calf mortality rates and further research is needed to explore how to optimize conditions to reduce calf mortality rates in GB.

Key words:

Calf mortality; monitoring; national data

INTRODUCTION

Neonatal mortality (defined as 1d of age – weaning, Compton *et al.*, 2017) represents a significant loss to the British cattle industry. Calf management is critical in rearing productive dairy cows (Hultgren and Svensson, 2009), and represents a significant economic outlay, accounting for around 20% of total dairy farm expenditure (Gabler *et al*., 2000) with costs in Great Britain estimated at around £1819 per animal (Boulton *et al*., 2017). A study following 1097 calves from 19 farms in England suggest 15% of liveborn dairy heifers die before reaching their first lactation (Brickell *et al.*, 2009), with the cost of heifer mortality representing around £139 per animal when spread across surviving animals (Boulton *et al*., 2017). Effective calf management is also crucial for efficient beef production (Mõtus *et al.*, 2017), a significant industry for the UK, being the third largest producer of beef in Europe (DEFRA, 2018).

Neonatal mortality not only represents an economic loss, but also delays genetic progress by providing fewer replacements for voluntary culling (Raboisson *et al.*, 2013). Mortality has also been explored as a marker for farm welfare surveillance, and has been suggested as an indicator of overall health on cattle farms (Ortiz-Pelaez *et al.*, 2008; von Keyserlingk *et al.*, 2009). The effective management of neonatal calves is essential for survival, welfare and productivity (Renaud *et al.*, 2018), and whilst mortality in calves is unlikely to be entirely eradicated, it should be a goal to reduce it by as much as possible (Santman-Berends *et al.*, 2014).

In order to prevent disease and reduce mortality, it is essential to understand the incidence, prevalence, distribution and key factors that influence disease variability; this is the basis of epidemiology and is recognized as a first step in disease control (Dohoo, Martin and Stryhn, 2009). National bodies in Great Britain (GB) have expressed concern over youngstock health and welfare, identifying calf survival as a priority (CHAWG, 2017, 2018b). However, there are currently no national data being published and therefore the extent of the problem remains largely unknown. A clear understanding of patterns of calf mortality on a national scale would inform stakeholders of whether and where to allocate resources both for knowledge exchange and further research.

Furthermore, quantification of risk between groups (for example, beef or dairy calves, male or female calves and specific times of year) would allow targeting of resources towards high risk populations and time periods.

The use of national level data for epidemiological studies has been called for to help develop methods of reducing morbidity and mortality (Santman-Berends *et al.*, 2014; Veldhuis *et al.*, 2016) but rates of calf mortality in GB have not been evaluated nationally since 2007 (Gates, 2013). Whilst keepers of bovine animals in GB must register births, deaths and movements of their animals through the Cattle Tracing System, the data are not used to routinely report national incidence rates of calf mortality.

The aim of this study was to quantify the temporal incidence rate, distributional features and factors affecting variation in mortality rates in calves in Great Britain since 2011. The purpose was to provide information to national stakeholder groups to inform resource allocation for both for knowledge exchange and future research.

MATERIALS AND METHODS

Birth and death data from 2010-2019 were requested from British Cattle Movement Services (BCMS). Data were only available at county level, and included the number of births for each county, country, breed, sex, month and year as an aggregated figure. Death data were provided in a similar format, however excluded county level information, and contained the number of deaths for each age at death (months), premises of death (i.e. "on farm" or "slaughterhouse"), country, sex, breed, month and year. "On farm" deaths included animals that died on farm, and "slaughterhouse" deaths included any animals that were transported to a slaughterhouse for slaughter. These datasets were combined to allow calculation of estimated mortality rates for defined groups.

Births and deaths (of any age) were filtered to be after 2010 and before 2019. The premises of death comprised five categories; slaughterhouse, farm, market, hunt/knackers (colloquial terms for fallen stock removal enterprises) and other. The vast majority of deaths (99.97%) were reported on-farm or at a slaughterhouse. Given that less than 0.03% of deaths were categorized as market, hunt/knackers or other it was decided to exclude these from the dataset. Breeds were categorized as either "Dairy" or "Non-dairy" (i.e. beef, including beef cross dairy) according to BCMS categories. A small proportion (<0.05%) of animals were non-cattle (i.e. Bison, Yak and Water buffalo) and were removed from the dataset.

Cumulative mortality rates were calculated as a percentage of animals born in a specific month subsequently dying within a defined time period. For example, of 100 calves born in January, two calves dying in January at 0-1 months of age, two dying in February at 1-2 months of age, and one dying in March at 2-3 months of age would result in a 0-3 month mortality rate of 5%. Country and county were excluded from analysis to avoid the potentially erroneous assumption of zero cross border transport between birth and death (e.g. the assumption that calves that die in Scotland were also born in Scotland).

British cattle must be dual tagged within 20d of birth, and all births and deaths must legally be registered through BCMS. There is a requirement that deaths that occur prior to tagging also be recorded within the holding register, and inspectors visit a proportion of UK farms (at least 3% of holdings annually) to validate identification and record keeping protocols (UK Government, 2014). Whilst it is unlikely that many stillborn (0-24hour mortality) calves will be included within registered deaths, there remains uncertainty as to the current stillborn rate in GB.

Descriptive and statistical analyses were conducted in R (R Core Team, 2017). On farm mortality was treated separately to slaughterhouse deaths, and descriptive graphical analysis was conducted by breed, sex, age and month. Linear regression methods were employed to provide insight into potentially influential factors associated with calf mortality at 0-3 months of age. These factors included the breed, sex, month of birth and Met Office meteorological data (mean, minimum and maximum monthly temperatures across the UK). To explore interactions between variables and non-linearities within the data, multivariate adaptive regression spline models (Friedman, 1991) were employed using the *earth* (Milborrow, 2019) and *caret* (Kuhn. *et al.*, 2018) *R* packages. Interactions up to order 3 were tested and the maximum number of terms available to the model was explored and optimized using a dense grid of values between 2 and 25 in increments of 1. Ten -fold cross-validation repeated 10 times was used to identify the optimal value of these tuning parameters; optimization was based on minimizing model mean absolute error (MAE). Final model covariates were therefore selected based on minimizing the cross-validation model MAE; covariate selection is an integral part of the MARS procedure (Friedman, 1991). An evaluation of model fit and the extent of over-fitting was assessed by a comparison of MAE and R^2 computed from the final model based on the full dataset ('internal fit') and computed from 10-fold cross validation ('cv-fit'). Residuals were examined to ensure model fit, by examining fitted values against residuals to ensure the model was not over-, or under-predicting mortality rates, particularly at the extremities of fitted values.

To estimate the effect of optimizing environmental conditions on calf mortality, covariates in the final model were used to predict how mortality might change with different environmental temperatures or different months of birth.

RESULTS

The cattle population in the UK is around 9.6 million (UK Government, 2018). The number of births and deaths registered between 2011-2018 across GB were 21.2 and 21.6 million respectively, of which 18.3 million and 3.3 million deaths were at slaughterhouse and farm respectively. Of the total on-farm deaths 1.8 million occurred before 24 months of age (54%, Figure 1), and 819,703 (25%) happened within the first 3 months of age. Of the 818,845 dairy cattle that died on farm before 24 months of age, 409,612 (50%) died within the first 3 months of age, and of the 956,293 non-dairy cattle that died on farm before 24 months of age, 410,091 (43%) died within 3 months of age. Of the 18.3 million deaths that were recorded at slaughterhouses, 644,848 (3.5%) were before 3 months of age. The 0-3 month death rate at slaughterhouses (and excluding any on farm mortality) was 0.49%, 0.21% and 0.34% for dairy females, non-dairy females and non-dairy males respectively, and was 19.94% for dairy males.

The on-farm (excluding any slaughterhouse deaths) mortality rate was 3.87% by 3 months of age, and was higher for male than female calves, with male calves experiencing a mortality rate of 4.32%, compared with 3.45% for female calves. Dairy calves experienced higher mortality rates than non-dairy calves within 3 months of age, with 6.00% and 2.86% mortality rates respectively. Male dairy calves had the highest on farm mortality rate within 3 months of 7.37% compared with a mortality rate of 4.96% for female dairy calves. Female non-dairy calves had the lowest mortality rate within 3 months of 2.61% compared with a mortality rate of 3.10% for male non-dairy calves.

On-farm mortality rates remained relatively stable over time (Figure 2). Male dairy calves appeared to be the only category of animal being routinely sent for slaughter at 0-3 months of age, and this appeared to show an upward trend over time, from 17.40% in 2011 to 26.16% in 2018 (Figure 3). There appeared to be a strong seasonal component to 0-3 month on farm mortality rates across both breed types and sexes (Figure 4), with dairy calves having a lower 0-3 month mortality rate during summer, with a rate of 6.61%, 6.11%, 4.79% and 6.74% for dairy calves born during winter, spring, summer and autumn respectively. Similarly, non-dairy calves had a lower mortality rate when born during summer, and also had a lower rate during spring, with the highest rate being autumn (winter: 2.88%, spring; 2.56%, summer: 2.56% and autumn: 3.98%).

Results of the final MARS model are provided in Table 1. Both sex and breed type were associated with differences in mortality rate, with an increased rate for male calves, and decreased rate for beef calves respectively. Month of birth had an effect on mortality rate, and the mortality rate in the first 3 months of life increased for calves born in December by +1.1%. Whilst mortality rate was reduced for calves born during February (-1.4%), there was an interaction between breed type and month of birth (Feb*Non-dairy) of +1.0%, resulting in a predicted mortality rate change of -0.4% for Non-dairy calves born in February (as opposed to dairy calves born in February which had a predicted rate of – 1.4%). Similarly, dairy calves born in November had a mortality rate change of +0.3%, compared to +0.9% for Non-dairy calves (the interaction effect of Nov*Non-dairy = +0.6%). There were interactions between month and breed type for February, March, October and November, and interactions between month and sex for January and August indicating that these subsets of animals at these specific times had different predicted risks of mortality.

MARS models identified a hinge point within the mean monthly temperature variable at 4.8℃, and at 9.6℃ where an interaction effect with Non-dairy (beef) calves was included. This indicated that reduced mean monthly temperatures were associated with increased calf mortality regardless of month, and this association was slightly stronger below 4.8℃. An interaction term for non-dairy breed type and temperature was present; Non-dairy*h(Mean temperature – 9.6). This interaction term coefficient indicated a change in mortality rate for non-dairy calves (as denoted by *non-dairy*h*) for each 1℃ above 9.6℃ (as denoted by *(mean temperature – 9.6)*) of -0.2%, effectively neutralizing the 0.2% decrease in mortality above 4.8% suggested by the term h(4.8 – Mean temperature). In short, this indicated that the mortality of non-dairy calves increased by 0.2% for every 1℃ decrease in temperature, but that this effect was limited to below 9.6℃ only, and there was minimal effect of temperature on the mortality rate of non-dairy calves above this point.

Analysis of model fit showed an R^2 value of 95.77%, RMSE of 0.44 and mean absolute error (MAE) of 0.34 when using 10-fold cross validation, and an R^2 value of 96.24%, RMSE of 0.40 and (MAE) of 0.31 when using internal fit, indicating there were no signs of model overfitting. Optimal model parameters were a degree of 2 interactions, and the number of terms for inclusion (*nprune*) set at 16.

To examine the effect of environmental conditions on calf mortality the final model was used to predict mortality given optimal month and environmental temperature. Calves born in February were shown to have the lowest mortality rate independent of temperature, and increased mean monthly environmental temperature was shown to decrease mortality rates at 0-3months of age independent of month (the maximum monthly mean temperature recorded was 17.3℃).

Predictions of mortality were made by assuming all calves were born in February and with the environmental temperature set constantly at 17.3℃. This resulted in an estimated total reduction of 300,570 deaths at 0-3 months of age over the period 2011-2018, equating to a mean reduction of 37,571 fewer deaths per year.

Variable	Coefficient
Intercept	6.0
Breed type (Non-Dairy)	-2.7
Sex (Male)	2.4
h(Mean temperature -4.8)	-0.2
h(4.8- Mean temperature)	0.2
Sex (Male) * Breed type (Non Dairy)	-1.9
Month (Mar) * Breed type (Non Dairy)	-1.2
Month (Feb)	-1.4
Breed type (Non Dairy) * h(Mean temperature-9.6)	0.2
Month (Dec)	1.1
Month (Nov)	0.3
Month (Feb) * Breed type (Non Dairy)	1.0
Month (Oct) * Breed type (Non Dairy)	0.7
Month (Jan) * Sex (Male)	0.6
Month (Nov) * Breed type (Non Dairy)	0.6
Month (Aug) * Sex (Male)	-0.4

Table 1. Results from multivariate adaptive regression splines (MARS) model; “h” denotes hinge point.

DISCUSSION

This research represents one of the largest calf mortality datasets ever reported and suggests minimal change in GB calf mortality rates between 2011 and 2018. The results indicate that environmental temperature, time of year, sex, and breed type are strong predictors of mortality rate, and account for around 96% of the total variation in on-farm mortality. Importantly, it appears that relatively low mortality rates are achievable at specific times of year, in certain groups of animals and in relatively warm temperatures. For example, in the lowest risk groups for both dairy and non-dairy breed types (female calves born in February) a mortality rate of <2% would be expected at temperatures of 17.3^{0}C (the maximum monthly temperature recorded). If the environmental conditions provided for these groups of animals could be identified and replicated through improvements in housing management, a reasonable national target for the British cattle industry could be to reduce overall 0-3 month calf mortality to <2%. To achieve this, further research into and understanding of these specific environmental conditions is required; these areas are discussed below.

The effect of environmental temperature and month of birth appear to play a significant role in neonatal mortality rates. Reductions in mortality during summer has been previously reported in both dairy (Lombard *et al.*, 2007; Raboisson *et al.*, 2013) and beef calves (Mõtus *et al.*, 2017), and colder temperatures have been suggested as an important factor in mortality rates, with temperatures of ≥10 °C being associated with lower mortality (Pannwitz, 2015). Colder weather may also have a negative effect on calf vigour, which may subsequently affect the transfer of passive immunity (Olson *et al*., 1980; Robison *et al*., 1988); an essential component in reducing morbidity and mortality (Godden, 2008; Cuttance *et al.*, 2018). There may also be an effect of increased infection pressure during housing through winter, which might subsequently increase the risk of morbidity and mortality (Raboisson *et al.*, 2013). The large effects of month and temperature suggest a substantial environmental component to the risk of mortality; if calf housing was able to replicate optimal environmental conditions all year round, major reductions in mortality could result. The potential mean annual reduction in mortality of 37,571 fewer deaths identified in this study as attributable to sub-optimal environmental conditions, represents a potential economic saving of around £11.6 million per year when using an estimate of £310 per calf death (Kossaibati and Esslemont, 1997) as well as having obvious welfare implications. The impact of environmental conditions on calf mortality rates in GB should certainly be the subject of future research.

Higher neonatal mortality rates in males compared with females has been previously reported (Raboisson *et al.*, 2013; Pannwitz, 2015; Cuttance *et al.*, 2017), potentially related to the higher mortality associated with concomitant dystocia (Johanson *et al.*, 2011), particularly for breeds with heavier birth weights (Gundelach *et al.*, 2009; Linden *et al.*, 2009). Male dairy calves are also often regarded as less economically valuable as heifer calves, and thus may not receive the same standard of care (Renaud *et al.*, 2017), potentially resulting in higher morbidity and mortality rates. Variations in neonatal mortality rates between breed types has previously been reported and is possibly due to management of the breeds rather than the breed themselves (Raboisson *et al.*, 2013). Whilst mortality risk might be hypothesised to be higher in beef crossed calves due to increased dystocia (Raboisson *et al.*, 2013), this study suggests that dairy animals are at increased risk of mortality. This has been previously reported in a study of 1.3 million Slovenian calves reporting a 2-30d mortality rate of 2.68%, and indicating calves from Holstein Friesian dams having higher mortality rates than calves from other breeds, with herd size and calving season also being important factors influencing mortality rate (Voljč *et al.*, 2017). Results from the current study suggest there is an urgent need for additional research to identify strategies to reduce mortality rates in male dairy calves in particular.

The increasing trend of calves being sent for slaughter by 3 months of age has not been previously reported in GB, and whilst it is not possible to identify reasons for this increase in this study, it is likely that there are a range of social and economic factors involved. An increase in the number of male dairy calves entering the beef chain rose by 59% from 2006 to 2015, and recent estimates indicate 81% of all male dairy calves in 2015 were reared for beef in GB (CHAWG, 2018a). The fate of male dairy calves is an important issue for the industry (Renaud *et al.*, 2018), and the increase in male dairy calves entering the beef chain may, in part, be due to this increased rate of early slaughter. There is a slight reduction in on farm mortality of male dairy calves at 0-3 months of age, however this may also be due to the increased rate of early slaughter of male dairy calves.

Previous on farm mortality estimates for GB calves are relatively sparse, with previous estimates from national CTS data suggesting an on-farm 0-6 month mortality rate of 2.47% for beef and 7.42% for dairy calves born in 2007 (Gates, 2013), compared with 4.15% and 8.31% 0-6 month mortality rates found in the current study for beef and dairy respectively. Research from 11 farms in the south-east of England in 2011-2012 estimated 24hr-2mo dairy calf mortality at 4.5% (Johnson *et al.*, 2017), similar to the current studies' finding of a 4.87% mortality rate between 0-2 months. Mortality rates have been reported to be highly variable between herds (Brickell *et al.*, 2009), with a recent study reporting a 2-56d mortality rate of 12.7% for one dairy herd (Mahendran *et al.*, 2017). Mortality rates in GB do not appear to have altered dramatically over time, with historic mortality rates up to six months, estimated at around 5.2% in 1952 (Withers, 1952), extremely similar to the current study reporting 5.5%.

Previous research suggests a significant portion of on farm mortality occurs within early life, with the majority of calves dying within the first month (Gates, 2013; Santman-Berends *et al.*, 2014), and around two thirds of cattle mortality being within the first 4 months (Struchen *et al.*, 2015). There are a number of factors that affect calf mortality rates up to 3 months of age (Windeyer *et al.*, 2014), which are largely beyond the scope of this article, however neonatal diarrhea and pneumonia are likely to play a significant role (Compton *et al.*, 2017).

Whilst calf mortality is a commonly reported metric in many countries, there are a wide variety of metrics being reported, and recent research has evaluated and assessed 10 definitions for calf mortality (Santman-Berends *et al*., 2019). Age classes for mortality studies also differ considerably between studies (Raboisson *et al.*, 2013), making comparisons challenging. A systematic review and meta-analysis, however, found the rate of perinatal (defined as 0-2d of age) mortality ranged from 3-9%, and was increasing over time, with neonatal (defined as 1d-weaning) mortality ranging from 5-11%, which was not found to have changed over time (Compton *et al.*, 2017).

As previously reported, there are several limitations to using BCMS databases for research purposes (Gates, 2013), particularly the potential exclusion of stillborn calves and early mortality prior to tagging. Previous estimates suggest around 7.9% of dairy calves die before 24 hours of age (Brickell *et al.*, 2009), and therefore the current studies estimates of mortality are likely to exclude perinatal mortality. Despite the legal requirement to register all deaths, including those before the registration and tagging of calves, there is a small risk that not all deaths/euthanasias that occur prior to tagging and registration are recorded. The absence of individual farm and calf level information available for this study meant some assumptions had to be made in order to calculate mortality figures, particularly that births and deaths were evenly distributed throughout months. Whilst this is important to recognize, the effects of these potential errors are likely to be small due to the large scale of the data and are unlikely to have significant bearing on the interpretation of the data. Data quality of CTS data has been reported to have improved over time (Green and Kao, 2007) and whilst it is unlikely to be completely free of error (Gates, 2014), the large scale of data being collected means extremely useful insights can be made.

CONCLUSIONS

The GB national cattle register provides an important resource in identifying neonatal mortality trends in the GB herd and will provide invaluable insights to the cattle industry if reported on a regular basis. Environmental conditions appear to play a significant role in calf mortality rates, and further research is needed to explore precise environmental factors likely to reduce calf mortality rates in GB.

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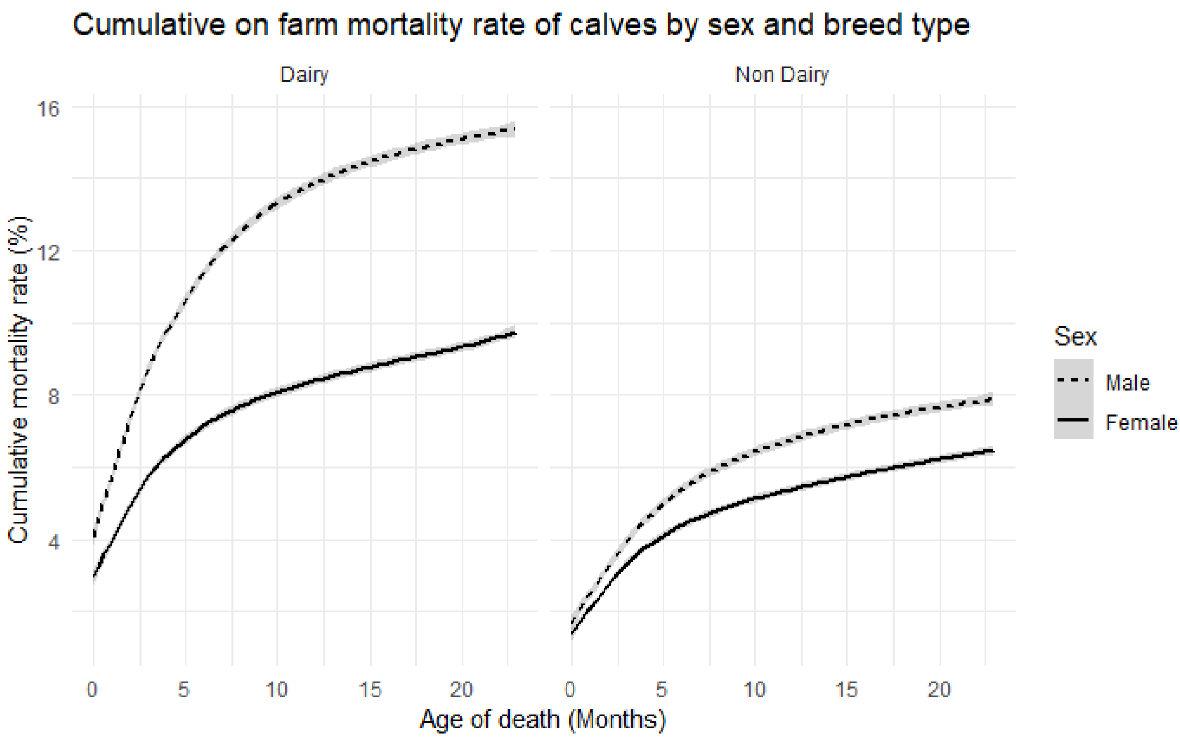

Figure 1: Cumulative on-farm mortality rates by age, sex and breed type. 95% confidence interval as grey shading.

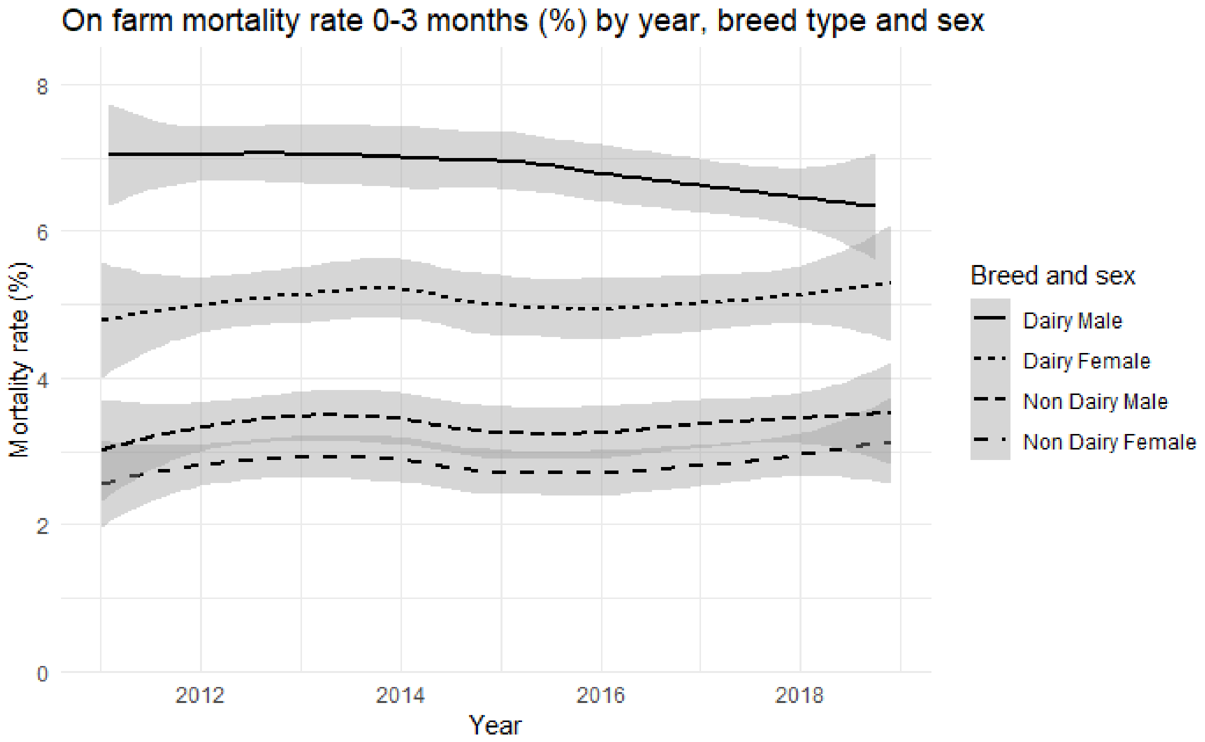

Figure 2: On-farm mortality rate 0-3months of age (%) by year breed type and sex from 2011-2018. 95% confidence interval as grey shading.

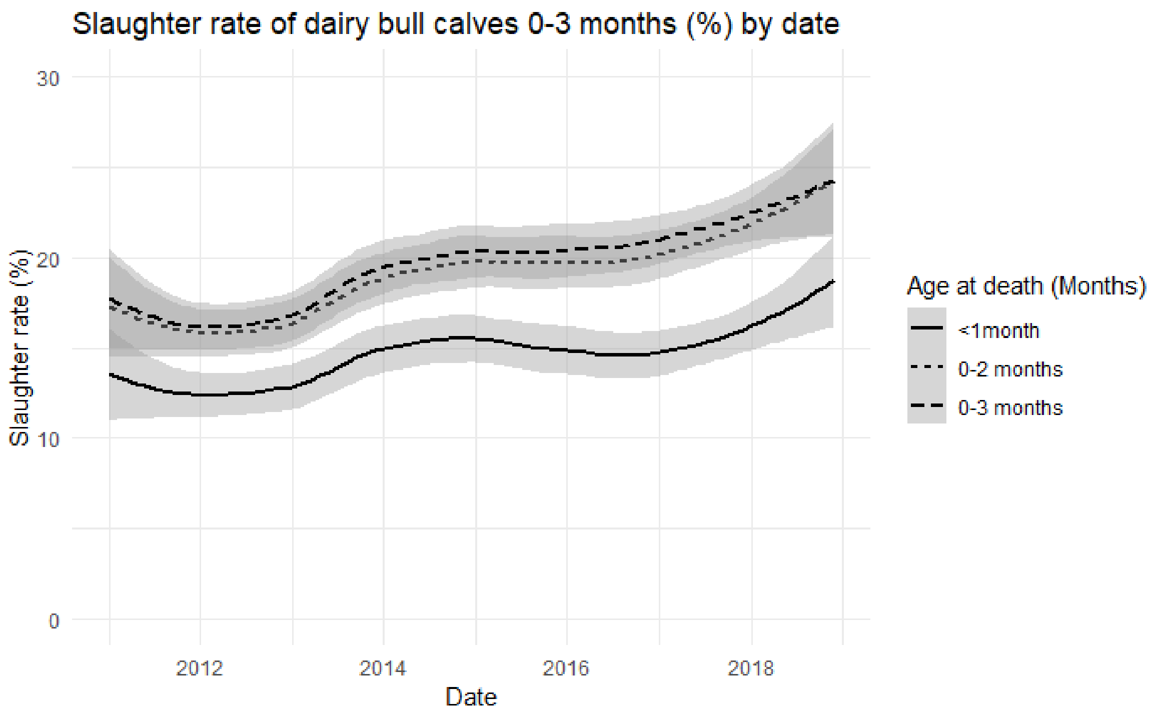

Figure 3: Slaughter rate over time within 1 month, 0-2 months and 0-3 months of age. 95% confidence interval as grey shading.

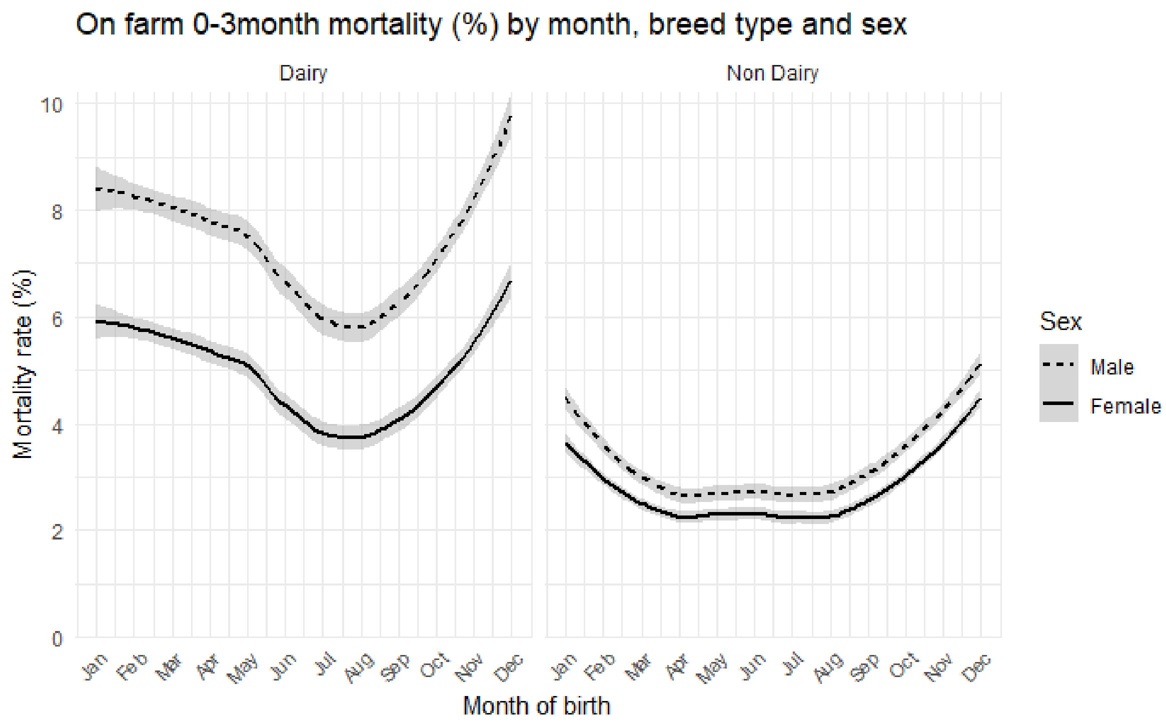

Figure 4: Seasonal patterns in on-farm 0-3 month mortality rates by breed type and sex. 95% confidence interval as grey shading.