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On-farm mortality, causes and risk factors in Estonian beef cow-calf herds

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Abstract

High on-farm mortality is associated with lower financial return of production and poor animal health and welfare. Understanding the reasons for on-farm mortality and related risk factors allows focus on specific prevention measures. This retrospective cohort study used cattle registry data from the years 2013 and 2014, collected from cattle from all Estonian cow-calf beef herds. The dataset contained 78,605 animal records from 1,321 farms in total. Including unassisted deaths and euthanasia (2,199 in total) the on-farm mortality rate was 2.14 per 100 animal-years. Across all age groups of both sexes the mortality rate (MR) was highest for bull calves up to three months old (MR = 7.78 per 100 animal-years, 95% CI 6.97; 8.68) followed by that for heifer calves (MR = 6.21 per 100 animal-years, 95% CI 5.49; 7.02). For female cattle the mortality risk declined after three months of age but increased again among animals over 18 months.

The reason for death stated by the farmers was analysed for cattle under animal performance testing. Other/unknown reasons, trauma and accidents, as well as metabolic and digestive disorders, formed the three most commonly reported reasons for death in cattle of all age groups.

Weibull proportional hazard models with farm frailty effects were applied in three age categories (calves up to three months, youngstock from three to 18 months and cattle aged over 18 months) to identify factors associated with the risk of mortality. Male sex was associated with increased risk of mortality in cattle up to 18 months of age. No difference between breeds was found for cattle up to 18 months of age. Beef cattle breeds rarely represented or dairy breeds (breed category ’Other’) had the highest mortality hazard (HR = 1.41, 95% CI 1.11; 1.78) compared to Hereford. The hazard of mortality generally increased with herd size for calves, young stock and older bulls. In female cattle over 18 months of age there was no difference in mortality hazard over herd size categories. Herd location was controlled in the models and regional differences in mortality hazard were found. Common to all age groups, calving season was associated with increased risk of mortality.

Keywords: beef cattle, mortality, unassisted death, euthanasia, survival analysis

1. Introduction

Cattle on-farm mortality (assisted or unassisted) is the involuntary loss of an animal. High on-farm mortality is one of several indicators of suboptimal animal health and welfare (Ortiz-Pelaez et al., 2008; de Vries et al., 2011; OIE, 2012) induced by errors in management practices, animal environment and nutrition. Premature loss of animals is a cause of economic loss; the value of the dead animals, loss of production, extra labour, loss of income from the sale of carcasses and cost of the waste management of the cadaver, in addition to increased costs of herd replacement due to higher herd turnover rate (Thomsen et al., 2004; Thomsen and Houe, 2006). Due to the poor health status of animals in herds with high on-farm mortality, expenditure for animal treatments and veterinary expenses, as well as reduced quality and safety of animal products, decrease the profitability of livestock production.

Studies covering beef cattle mortality vary for production type and age group involved. Numerous studies have focussed on mortality in intensive production systems, e.g. white veal production for different breeds (Sargeant et al., 1994; Bähler et al., 2012; Pardon et al., 2012) or fattening units (Lonegaran et al., 2001; Rumor et al., 2015). In extensive cow-calf herds calf mortality has been reported in a range of 1.4 to 9.5% (Bunter et al., 2013; Elghafghuf et al., 2014; Murray et al., 2016). Registry data has been used in Germany (Pannwitz, 2015) and France (Perrin et al., 2012) to evaluate mortality in the national herd. According to these studies, the mortality rate showed a reverse J-shaped curve with increasing age (Perrin et al., 2012; Pannwitz, 2015).

Several risk factors associated with on-farm mortality have been identified for beef calves. Sex (Bähler et al., 2012; Elghafghuf et al., 2014; Pannwitz, 2015), dystocia (Azzam et al., 1993; Tarrés et al., 2005), calf birth-weight (Azzam et al., 1993; Tarrés et al., 2005), age of the dam (Azzam et al., 1993; Tarrés et al., 2005; Elghafghuf et al., 2014), calving intervention, colostrum management, castration method (Murray et al., 2016), incidence of bovine repiratory disease (Cusack et al., 2007; Murray et al., 2016), calving season (Tarrés et al., 2005; Perrin et al., 2012; Murray et al., 2016) and the length of the calving season (Rogers et al., 1985; Elghafghuf et al., 2014; Murray et al., 2016), average ambient temperature and precipitation during calving (Azzam et al., 1993; Elghafghuf et al., 2014; Pannwitz, 2015), use of prophylactic antibiotics and injectable vitamins ADE (Rogers et al., 1985) and herd size (Rogers et al., 1985; Murray et al., 2016) is an incomplete list of factors that have been identified. Fewer studies have evaluated risk factors for older cattle in beef herds (Waldner et al., 2009) whereas most of those have been conducted in feedlots (Cusack et al., 2007; Rumor et al., 2015) or in the farmework of a national population study (Perrin et al., 2012; Pannwitz, 2015; Struchen et al., 2015). Factors relating to age, gender, season, incidence of bovine respiratory disease, floor type, nutrition and feeding management have contributed to mortality in older cattle (Cusack et al., 2007; Waldner et al., 2009; Perrin et al., 2012; Rumor et al., 2015; Struchen et al., 2015).

Most Estonian beef cattle herds have extensive herd type, according to the OIE classification (OIE, 2012). The herds can be divided into breeding herds, with pure-breed animals, and production farms. Common to both herd types beef production is mostly managed as extensive cow-calf operations with mainly late winter or early spring calving and summer grazing. Cows and breeding heifers are usually naturally mated by a bull at pasture. Calves are most commonly weaned from their dams in the autumn when 6 to 8 months old. Bull calves are sold for slaughter at a weight of 300 kg or 500-550 kg dependent on the market demands. During the winter period cattle are mostly kept inside on deep litter bedding with access to outside walking and feeding areas. The feed is mainly forage-based, and grain-feeding is used for growing youngstock (Alar Onoper, personal communication, April 18, 2016).

Despite the availability of registry databases and commitment of the farmers to register data about births, movements and exits of animals on a routine basis (Riigi Teataja, 1999), representative overviews over mortality rates within the cattle population of a country are rare (Pannwitz, 2015). So far, no studies have been conducted to determine the mortality rates and risk factors in the Estonian beef cattle population. Understanding risk factors for increased mortality would help to improve herd health by applying preventative measures. A prerequisite for planning detailed risk factor studies is to understand the population in respect of mortality epidemiology to identify animal groups with exceptional mortality. As typical beef cattle herds are extensive cow-calf herds, using national data would provide a representative overview of the mortality of the animals in these herds. Therefore, the objective of this study was to describe on-farm mortality in Estonian beef cattle and characterize this by animal cohorts. An additional purpose was to characterize the causes of on-farm mortality according to farmers´ opinions.

2. Materials and methods

2.1. Study population

The study included data from the Estonian cattle population between 1st of January 2013 to 31st of December 2014. The data from all cattle present in the population at the beginning of the study, imports and births of cattle during the study period, together with animal exits, were collected from the Estonian Agricultural Registers and Information Board (EARIB). For all animals, birth date, breed and sex, and the individual number of the farm and its location, were collected. The date and type of exit were also obtained for all animals during the study period. Type of exit was registered by the EARIB into seven categories: unassisted death, slaughter, euthanasia, export, animal lost, slaughter for diagnostic purposes and slaughter to impede the spread of infection. The definition of a beef cattle herd was based on the criterion that at least 75% of animals present in a herd were of a beef breed. The event of interest for the statistical analyses was on-farm unassisted death and euthanasia occurring during the study period.

The farmer´s stated reason for exit, together with the date of exit, is registered by Estonian Livestock Performance Recording Ltd (ELPR) in Estonia. In order to ascertain reasons for mortality events the corresponding data for the same two years time period was requested for all animals under animal performance testing programme. The latter is a voluntary participation electronic data collection system facilitating beef cattle farmers to monitor and analyse the animal and herd level production data of their farm. The study population included animals that were under performance testing and belonged to beef cattle herds by the definition of this study. Approximately 56% of suckler cows and 47% of youngstock present in the Estonian beef cattle population belonged to the study population in 2013 and 2014 (ELPR, 2014; ELPR, 2015).

2.2. Editing of data

Seven pre-defined age categories were created: <3 months, 3-6 months, 6-12 months, 12-18 months, 18-24 months, 24-36 months and ≥36 months. Six main breeds with substantial numbers of recordings were included as separate breed categories: Aberdeen Angus, Charolaise, Scottish Highland, Hereford, Limousin and Simmental. Animals that belonged to breeds infrequently represented (Estonian Holstein, Estonian Red, Brown Swiss, Aubrac, Blonde d'Aquitaine, Belgian Blue, Dexter, Estonian Native, Galloway, Jersey, Piedmontese and German Shorthorn) were compiled into one breed category called ”Other”. In EARIB register the breed of an animal is defined according to the breed of the sire. Cross-breed animals were not identified in this data. A variable ’herd size’ was created based on the number of animal-years on a farm per calendar year, and quartiles were used to create approximately equal groups: <40, 40-99, 100-199 and ≥200 animal-years. A variable ’region’ was created from variable ’county’ reflecting the location of the herds, and Estonia was divided into four regions: Northeast, Southeast, Southwest and Northwest Estonia. Location of one farm was not possible to identify thus creating missing values for the variable ‘region’ in the 84 animals from this herd.

In order to unite the death events registered by the EARIB, and reason for death recorded by ELPR, the two datasets were combined. In the ELPR database farmers were allowed to record only one reason for each exit event. However, one animal may have several exit events and therefore more than one reason for exit – e.g. the animal may be moved to a production herd (applicable to heifers) and/or sold in addition to the reason for the death or slaughter. Therefore dates of exit events in the EARIB and ELPR datasets were compared in order to define the reason for the mortality event. A difference of up to seven days was allowed between the dates of the two datasets to occur in attributing a reason for each mortality event. This was done to account for Estonian farmers obligation to report to the EARIB all events related to animal movements, deaths and slaughters within seven days (Riigi Teataja, 1999). For ELPR the deadline for notifications is longer and not strictly specified whereas majority of the farmers insert the data electronically directly to the database. Farmers’ stated reasons for mortality were analysed separately in four animal groups: cows, heifers (from birth to calving), young bulls (from birth to breeding) and breeding bulls. Reasons for cattle exit were categorised into larger categories consisting of reasons with similar meaning. In cows, the category ’Claw/leg disorders’ included farmers´ stated reasons of: ’leg conformation flaws’, ’leg traumas’, ’leg disorders’. The category ’Infectious diseases’ included the stated reasons: ’respiratory diseases’ and ’infectious diseases’. The category ’Metabolic and digestive disorders’ included the stated reasons: ’metabolic disorders’, ’puerperal paresis’ and ’digestive disorders’. The category ’Fertility problems’ consisted of the stated reasons: ’fertility problems’, ’gynaecological diseases’ and ’abortion’; the category ’Dystocia’ comprised the reason ’dystocia’. The category ’Trauma and accident’ included the stated reasons: ’accident’, ’traumas of udder and teats’, ’other traumas’. Reasons given that occurred in low numbers (e.g. mastitis) and were not reasonably associated with mortality events (e.g. animal sold, animal lost, moving to production herd) were categorised as “unknown reason”. This last category was combined with the reason ’other’ that could be registered by the farmers. Although the number of reasons available in the ELPR list was smaller for youngstock the classification principles in this study were the same as given above for other ages.

2.3. Statistical analysis

To analyse risk factors associated with on-farm mortality events Weibull proportional hazards models, with herd as a gamma distributed shared frailty effect, were used. A parametric model was preferred over semi-parametric Cox proportional hazard model due to the large sample size, which is not well managed in Cox regression model. Distribution of the data for the parametric model was chosen based on AIC and BIC values of the models with different distributions. Weibull distribution was chosen for the parametric survival models due smaller AIC and BIC values compared to other distributions and a good fit of the Weibull distribution for the data. Models with gamma distributed frailty were compared with models including inverse Gaussian frailty according to their AIC and BIC values and the former was preferred due to smaller values of the information criteria.’County’ as a random effect, was not significant and therefore a more parsimonious model with ’herd’ as a random effect was preferred. In order to account for left truncation in the analyses the option ’origin’ was defined as the birth date of an animal and ’enter’ specified the date the animal entered the study, when declaring data to be survival-time data (*stset* command in Stata®) (Cain et al., 2011). The ’enter’ date was (i) the 1st of January 2013 for animals that were present in a population on that date, (ii) birth date for animals born during the study period and (iii) date of purchase for imported animals. Contribution of animal-risk time was accounted from the start of the study period until failure, censoring or the end of the study period. Animals that were exported or slaughtered during the study period were regarded as censored in survival analysis. In order to retain observations starting and ending on the same day (27 observations) in the analyses one day was added to exit dates for all observations.

The analyses were stratified according to age groups into young calves (<3 months), youngstock (3-18) and adults (>18 months), because initial analyses indicated that the risks for on-farm mortality were vastly different in these age groups, and were difficult to accommodate in one model. The youngstock and adult analyses included several age categories, and age category was therefore included in the model as a time-dependent covariate by using the *stsplit* command in Stata®. The animal accumulated time at risk on its age stratum until failure, censoring, or moving into the next age category.

Due to the low number of predictor variables all variables were included into the multivariable model. Biologically significant interactions were tested by adding an interaction term between variables. When significant interactions were detected, a separate variable with all combinations of involved variables was created. To build a multivariable model a manual backward elimination technique was used. When excluding variables with the Wald test p-value >0.05 from the final model, the change of regression coefficients was observed in order to detect confounding effects of a variable. A change in regression coefficients of more than 20% and the confounding nature of the variable identified in a causal diagram were criteria for confounders, giving a reason to retain the variable in the final model. Likelihood ratio test for nested models and AIC values for non-nested models were used to compare the models (Dohoo et al., 2009). The proportional hazard assumption was evaluated by visually inspecting log-cumulative hazard plots, and the fit of the models by visual examination of the plots of the cumulative hazard versus Cox–Snell residuals (Dohoo et al., 2009).

In order to identify seasonal effects the data was further split at the first day of each month. For each month the mortality rate was calculated by using *strate* command in Stata®. In order to detect significant changes in the risk of on-farm mortality between adjacent months a univariable Weibull proportional hazard model was run with month as a hierarchical predictor and farm as a shared frailty effect.

All statistical analyses were performed with Stata MP 14 (StataCorp, College Station, Texas, USA).

3. Results

3.1. Descriptive statistics of the study population

The dataset contained 78,605 animal records from 1,321 farms for the two years of the study period including 102,978 animal-years. In total 1,870 (2.38%) animals died unassisted, 329 animals were euthanized (0.42%), 13,521 (17.20%) were slaughtered, 8,462 (10.77%) were exported, 658 (0.84%) were lost, one was slaughtered for diagnostic purposes and one was slaughtered to impede the spread of infection. The remaining 53,763 (68.40%) animals survived until the end of the study period and were right censored. Including unassisted deaths and euthanasia's (2,199 in total), the on-farm mortality rate per 100 animal-years was 2.14 (95% confidence interval (CI) 2.05; 2.23). Crude mortality rates together with number of animals in each animal group according to breed, sex, herd size and region are provided in Supplementary table 1.

Crude mortality rate estimates in female and male cattle by age group are shown in Figure 1. The highest mortality rate (MR) was found for calves up to three months old, and it was higher for male calves compared to females (MR = 7.78, 95% CI 6.97; 8.68 and MR = 6.21, 95% CI 5.49; 7.02 per 100 animal-years, respectively). Among female animals the mortality rate was lowest during the age period from three to six months (MR = 1.09, 95% CI 0.81; 1.46). In general, the mortality rate remained below 1.5 per 100 animal-years between three to 18 months of age. A significantly higher mortality hazard was confirmed for cows older than five years compared to four to five year old cows (hazard rate ratio; HR = 1.56, 95% CI 1.26; 1.93, $p<0.001$). In males the mortality rate dropped after three months of age and was 1.24 (95% CI 0.94; 1.64) among animals from three to six months. In bulls six to 12 months of age MR increased to 1.95 (95% CI 1.64; 2.31) (Figure 1).

3.2. Risk factors for on-farm mortality

Results of the multivariable Weibull proportional hazard model in the young calves are presented in Table 1. Male calves had a higher risk of on-farm death compared to female calves (HR = 1.27, 95% CI 1.08; 1.50), and calves from larger herds and from the Northeast region had a higher risk of mortality.

The interaction term between age category and herd size was significant in the youngstock model (Table 2, Figure 2). In herds with <40 and 100-199 animal-years the hazard of mortality was significantly higher for 12-18 month old cattle compared to 3-6 months old animals (HR = 1.78, 95% CI 1.02; 3.10, $p = 0.041$ and HR = 1.79, 95% CI 1.01; 3.18, $p = 0.047$, respectively). In herds with 40-99 and ≥200 animals the hazard of mortality was lower in 12-18 months old age group compared to 6-12 months old animals (HR = 0.57, 95% CI 0.36; 0.89, $p = 0.014$ and HR = 0.58, 95% CI 0.42; 0.82, $p = 0.002$, respectively). Male cattle were at a higher risk of mortality than females (HR = 1.33, 95% CI 1.11; 1.59). There were no regional differences in mortality risk, but this variable behaved as a confounder in the model and was therefore retained (Table 2).

According to the multivariable Weibull model for the beef cattle over 18 months of age, the risk of dying on-farm was significantly higher in cattle over 60 months of age compared to the animals 18-24 months of age (HR = 1.35, 95% CI 1.11; 1.65). The mortality hazard was not significantly different between Hereford as a reference group in the model and Charolaise, Scottish Highland, Aberdeen Angus, Limousine and Simmental breed cattle. Beef cattle breeds rarely represented or dairy breeds (breed category 'Other') had the highest mortality hazard (HR =1.41 95% CI 1.11; 1.78) compared to reference group Hereford. According to herd size and sex the mortality hazard was lowest in bulls from herds with less than 100 animal-years. The mortality hazard did not differ significantly between female cattle of different herd size categories (Table 3).

3.3. Seasonal distribution of mortality rate

The highest mortality rate was found between February to May in 2013 and 2014 for all three age groups. The period with lowest mortality was during the summer months, with a subsequent gradual increase during the autumn months (Figure 3).

3.4. Farmers stated reasons for on-farm mortality

The reason for on-farm mortality event was identified for 320 cows in total, including 41 for euthanasia and 279 unassisted death events, where other/unknown reasons (29.1%) were the most common reasons. The total proportion of euthanasia was 12.8%, and the highest number of euthanasia of cows were due to dystocia, trauma and accident and metabolic and digestive disorders. The median age of cows dying on-farm was 71.2 months (quartiles; Q1: 48.3; Q3:103.2) (Table 4).

The reason for on-farm mortality in heifers was identified for 501 cases (59 euthanasia and 442 unassisted deaths), and the proportion of euthanasia was 11.8%. The most commonly stated reasons were trauma and accident (30.3%). Euthanasia was most often carried out due to trauma and accident, other/unknown reasons and fertility problems (Table 4).

Metabolic and digestive disorders were the most common causes for on-farm mortality events among the 473 young bulls with identified mortality events. The proportion of euthanasia among young bulls was 8.5% and it occurred most often due to trauma and accident, metabolic and digestive disorders and other/unknown reasons (Table 4).

Reason of death could be identified for 10 adult bulls, where accident, reported in three animals, was the most common farmers´ stated reason for death. (Table 4).

3.5. Modelling

The fit of the Weibull proportional hazard random effect models was confirmed with the presence of a unit exponential distribution expressed as a straight line in the plot of Cox-Snell residuals and cumulative hazard. Parallell curves for the predictor categories were present in the log-cumulative hazard plot, confirming that the proportional hazards assumption was met (Dohoo et al., 2009).

4. Discussion

4.1. On-farm mortality

Survival analysis of mortality data stratified by age in this study revealed a pattern very similar to that recently found in both Germany (Pannwitz, 2015) and France (Perrin et al., 2012). Calves <3 months old had the highest mortality rates, which declined considerably from then until rising among older animals. In this study male cattle had a higher mortality risk than females up to 18 months of age. Nevertheless, when comparing the age-stratified mortality rates found in the Estonian cattle population with that of Germany (Pannwitz, 2015) the mortality rates were lower in Estonia among calves up to 6 months old, higher in animals from 1 to 2 years old and relatively similar in the other age groups. A common reporting bias of underreporting first week calf deaths before they are ear-tagged was reported here and elsewhere (Pannwitz, 2015), leading to an underestimation of the apparent mortality rate in the first age stratum. In this study the on-farm mortality rate was similar to that found in the French beef cattle population (Perrin et al., 2012).

The mortality rate increased after 18 months of age in female cattle and was stable up to four years of age. The mortality hazard declined among cows aged four to five years and increased after that (Figure 1). The lowest incidence of mortality in four year old beef cattle and increasing mortality risk thereafter was also found in a study of Waldner et al. (2009). A typical reverse J-shaped pattern of mortality rate over animals´ age as outlined in previous studies (Perrin et al., 2012; Pannwitz, 2015), was found also here. In this study the mortality of male cattle formed a roughly L-shaped distribution, with a small increase in the mortality rate in the age category of 6-12 months. Due to spring-time seasonal calving of beef cattle in Estonia the 6-12 month age group are those that experience adverse climatic conditions, by experiencing the first winter period at that age. This group of young bulls are mostly kept in a separate group, or are castrated if separation is not possible, and the feed ration may also be different containing concentrate feeds (Alar Onoper, personal communication, April 18, 2016). A significantly higher mortality hazard was found for bulls over two years of age compared to the 18-24 months age group. Older male cattle are mostly used for breeding and the higher hazard of mortality could arise from increased risk of injuries and other disorders associated with mating.

Comparing mortality estimates from different studies is complicated due to several reasons. First, studies of calf mortality in cow-calf herds have mostly used mortality risk to express death incidence (Bunter et al., 2013; Elghafghuf et al., 2014; Murray et al., 2016). Secondly, most of the studies reported calf mortality in the preweaning period, which may differ in duration, and some stratify into shorter age bands. Studies are also difficult to compare directly due to the fact that some of these included losses that occured during the first 24 hours after birth (Elghafghuf et al., 2014), whereas the studies using registry data may miss the true mortality cases occurring during the first week of life (Pannwitz, 2015). We identified a very small number of death events occurring during the first week of life meaning that the true mortality rate for calves is probably considerably higher. Also, population studies (Perrin et al., 2012; Pannwitz, 2015) have not discriminated between extensive and intensive beef production systems making comparison with our study more difficult.

4.2. Risk factors

A higher mortality for male calves and young bulls compared with females is in accordance with previous studies conducted on dairy and beef cattle populations, and is explained by the higher biological risk of mortality for males (e.g higher birth weight and concomitant risk of dystocia), as well as the lower market value of male cattle (Bleul, 2011; Bähler et al., 2012; Raboisson et al., 2013; Pannwitz, 2015). According to Cusack et al. (2007) steers raised in feedlots in Australia were slightly more likely to die during the feeding period than heifers. Young bulls are often kept in a separate group in Estonian beef herds, and different housing management and feeding could contribute to their higher mortality incidence compared to heifers. The factors influencing the mortality of young bulls should be addressed in future studies. In the present study the effect of sex was dependent on herd size among cattle over 18 months of age. Bulls from herds with less than 100 animal-years had significantly smaller hazard of mortality compared to female cattle and bulls from larger herds (borderline insignificant association). According to farmer´s stated reasons of mortality older males most commonly died due to leg/claw disorders. It should be studied further whether and how the incidence of claw diseases is influenced by herd size and discover the predisposing risk factors.

The mortality hazard in calves and youngstock was not different across breeds, while significant differences in mortality hazard over breed occured in cattle over 18 months of age. There was no significant difference in mortality hazard between Charolaise, Scottish Highland, Aberdeen Angus, Limousine and Simmental breed cattle compared to the reference group Hereford. Cattle of infrequently represented beef breeds and dairy breeds emerged as having considerably higher hazard of mortality. A significantly higher mortality risk in milk breeds compared to beef breeds has also been reported in Germany (Pannwitz, 2015). Rarely represented beef breeds are relatively new in Estonia and farmers may not have been able to adapt their farm environment and management in compliance with the demands of those breeds. It is also possible that those herds have recently started with farming which could be a risk factor for higher incidence of diseases. Breed is strongly clustered in herds meaning that herd chracteristics may have substantial influence on mortality level of specific breed. Therefore further studies should include more herd level variables in order to provide explanation for the findings. A nondifferential misclassification error might be present due to impossibility to discriminate between purebreed animals and cross-breeds in EARIB data diminishing the associations with ‘breed’. The associations with breed should be validated with the ELPR data in which the breed definition is more precise and well controlled.

According to previous studies (Rogers et al., 1985; Pannwitz, 2015) larger herd size was on average associated with increased mortality rate. Contrasting results were found by Murray et al. (2016), where greater herd size was associated with reduced calf mortality, however the authors recognized that reporting bias might have occurred in the study towards large herds, underestimating calf losses in this questionnaire survey. Herd size had no effect on perinatal calf mortality in a study by Bleul (2011). We confirmed a higher mortality hazard in larger herds for young calves but in older young stock the association between herd size and mortality hazard was dependent on age category and *vice versa*. Among 6-12 months old animals the hazard of mortality was highest in largest herds. The explanation may be that in larger herds individual attention given to animals is reduced. Significant differences in mortality hazard were found for different young stock age groups in herds of different size. As herd size is a proxy for several management-related factors this should be studied further in order to provide clear explanation for the findings. For female cattle over 18 months of age the mortality risk was not different in herds of different size. Most possibly the housing and feeding of pregnant heifers and cows is relatively homogenous over herds of different size and animal level factors become decisive in determining the mortality hazard.

Region acted as a confounder in our models, and the effect of the main predictors was adjusted for this. In addition, regional differences were significant in calves and over 18 month old cattle models, indicating that animals in the Southeast region had the lowest mortality hazard. Earlier studies have found some regional differences in mortality level (Rogers et al., 1985; Pannwitz, 2015). The climatic conditions are relatively similar in all regions of Estonia, however animal husbandry and management may differ regionally influencing the hazard of failure.

According to the variance parameters of the models, and the significant frailty term, a clustering of mortality at the herd level was evident, which was also found previously (Rogers et al., 1985; Tarrés et al., 2005; Elghafghuf et al., 2014). However, in this study, small herds were included, meaning that high herd level clustering may in some part arise from the fact that extreme herd level mortality could occur in very small herds, increasing the between-herd variance. Raboisson et al. (2013) found high standard deviations for dairy calf and heifer mortality rate estimates, and demonstrated that some farmers were able to achieve relatively low calf mortality, even in cohorts of animals known to have a high biological risk of mortality. Herd level clustering of mortality was highest in the calf model, which is explained by the infectious aetiology that could be attributed to calf deaths according to the farmer's opinions. High between-herd variance and low regional variance was also reported in a Canadian calf mortality study (Elghafghuf et al., 2014).

4.3. Seasonality

Calf mortality followed a seasonal pattern in two years data, and was highest between January to May 2013 and February to April 2014. According to the available data, the number of calves born was highest between March and June, in which 63% of calves were born in 2013 and 66% in 2014 (data not shown). Several studies have confirmed that beef calf mortality risk increases as births accumulate (Tarrés et al., 2005; Raboisson et al., 2013; Elghafghuf et al., 2014), probably due to higher competition for resources and a higher risk of exposure to infectious diseases (Larson and Tyler, 2005; Tarrés et al., 2005; Elghafghuf et al., 2014). The mortality rate declined significantly in May and June and remained lower until the new calving season. It is known that the hazard of mortality among calves is highest if calving takes place in very cold weather (Azzam et al., 1993; Elghafghuf et al., 2014; Murray et al., 2016). The average monthly temperatures of 2013 and 2014 in Estonia were -5.8℃, -1.5℃, -2.1℃, 4.4℃ and 12.1℃ from January to May, respectively (Estonian Weather Service, 2016). Hahn (1981) recommends a temperature range of 10 to 26ºC for beef cattle and it has been found that a U-shaped relationship occurs between the temperature-humidity index and mortality (Morignat et al., 2015). In order to increase the calf survival rate it is recommended to protect newborn calves from unfavourable climatic conditions (Hahn, 1981; Azzam et al., 1993) or time calving to later in spring (Azzam et al., 1993; Murray et al., 2016). Further studies should concentrate on factors that affect calf losses in beef herds during the calving season in order to offer better underpinned recommendations.

From this study it appears that calving season is also a high risk period for older animals. According to a Canadian study by Waldner et al. (2009) the incidence of mortality was higher in the spring compared to that in other seasons for replacement heifers and cows. Mortality rate also peaked in the month with the highest number of calvings for cattle over two years of age in a French study (Perrin et al., 2012). In addition to adverse weather conditions in late winter and early spring, a higher number of susceptible animals, lower immunity level and stress related to calving, and crowding of animals, may favour the spread of infectious diseases which are risk factors for animals of all ages.

Although the seasonal trends were ascertained in this two years survival data, a time-series analysis covering longer time period would be needed to confirm the seasonality of mortality in Estonian beef cattle.

4.4. Reported reasons for on-farm mortality

The most frequent reported reason for on-farm mortality among cows belonged to the category 'other/unknown reasons' which is consistent with that found in dairy cattle (Thomsen and Houe, 2006; McConnel et al., 2009; Alvåsen et al., 2014). Studies have indicated that farmers´ perception in defining the cause of death based on *antemortem* histories can be incorrect in nearly half of the cases (McConnel et al., 2009; Thomsen et al., 2012) and is even higher in unassisted deaths events (Thomsen et al., 2004; McConnel et al., 2009; Thomsen et al., 2012). This may also reflect the uncertainty of the farmers in determining the cause of death and euthanasia. Euthanasias were most often carried out due to dystocia, trauma and accident among cows, reflecting that it is carried out in cases of more severe and hopeless conditions. Trauma and accident, as well as metabolic and digestive disorders, were also common reasons for cow mortality in the current study. According to Waldner et al. (2009) approximately 25% of the causes of death could be directly or indirectly attributed to feeding management in adult cows and replacement heifers. Therefore, measures to reduce the incidence of injuries and ensuring good feeding management would be important in preventing deaths among cows.

The most commonly stated causes of pre-weaned calf mortality in this study were metabolic and digestive disorders and respiratory and infectious diseases. Common causes affecting the mortality of young beef cattle have been identified previously (Loneragan et al., 2001; Waldner, 2001; Bähler et al., 2012; Pardon et al., 2012). In older youngstock, trauma and accidents dominated. Half of the deaths due to metabolic and digestive disorders occurred in the ages of 0.4 to 10 months in heifers and young bulls (Table 4) reflecting that neonatal diarrhoea as well as parasitic pasture infections may be the underlying causes for diseases and subsequent death events. That the high proportion of calf and youngstock deaths were for unknown reasons is consistent with earlier studies (Bunter et al., 2013).

There was a low number of mortality events in adult bulls, making it difficult to draw conclusions.

Of all the dead animals, 15% were euthanized, which is considerably lower than the 55.3% and 58% reported for dairy cows by McConnel et al. (2009) and Thomsen et al. (2004). Supervision and individual contacts between farmer and beef cattle is not as frequent as with dairy cows. Due to that severe disease conditions may remain unnoticed in beef herds leading to higher proportion of unassisted deaths. The main reasons for the unassisted deaths differed from those of assisted deaths which is in line with other studies of dairy cow mortality (Thomsen et al., 2004; McConnel et al., 2009; Thomsen et al., 2012).

The study population used for identifying reasons for on-farm death included farms that participated in animal performance testing. These are herds which have or aim to keep mostly purebreed cattle. Also, we may assume that participating farmers are better motivated and ambitious compared to non-participating farmers. The identified mortality causes can therefore not be extrapolated to the whole population but mainly to farms with better management.

5. Conclusions

This study found the on-farm mortality of cattle in Estonian cow-calf herds comparable to that reported in other beef cattle populations. This study highlights the need to improve beef calf health primarily during first months of life. The most critical period occurs during the calving season when the mortality risk was highest for animals of all ages. This information is relevant for farmers, who should employ more effective measures during that time in order to ensure good health and welfare of their animals. More effective measures to combat respiratory diseases and digestive tract disorders in calves could improve their health and reduce mortality. Older animals should be protected against injuries and metabolic and digestive disorders. As beef cattle farms are expanding, and a higher mortality risk was found in larger farms for several age groups, contemporary research is needed to identify factors that influence mortality and could be easily managed to improve cattle welfare.

Conflict of interest

Authors of this research paper have no financial or personal interests that could have influenced the output of this paper.

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Table 1. Risk factors for on-farm beef calf (less than 3 months) mortality as identified in a Weibull proportional hazard random effect model evaluated in 35,121 calves from 1,150 herds in Estonia

Variable	Category	n	MR[a]	Hazard rate ratio (HR)	95% Confidence interval of HR	Wald-test P-value	Likelihood ratio test P-value
Sex	Female	17,574	6.21	1			0.005
	Male	17,547	7.78	1.27	1.08; 1.50	0.005	
Herd size (animal-years)	<40	8,430	3.33	1			<0.001
	40-99	9,651	3.56	1.16	0.76; 1.79	0.487	
	100-199	8,082	8.73	2.53	1.56; 4.09	<0.001	
	≥200	8,958	12.71	3.48	1.90; 6.37	<0.001	
Region[b]	Northeast	6,908	12.00	1			0.049
	Southeast	5,902	3.41	0.49	0.27; 0.90	0.021	
	Southwest	10,732	6.38	0.67	0.41; 1.09	0.108	
	Northwest	11,584	6.45	0.53	0.32; 0.87	0.012	

[a]Mortality rate (per 100 animal-year) in each category

[b]Northeast Estonia: Ida-Viru, Lääne-Viru, Jõgeva, Järva county; Southeast Estonia: Tartu, Valga, Võru, Põlva county; Southwest Estonia: Pärnu, Viljandi, Saare county; Northwest Estonia: Harju, Rapla, Lääne, Hiiu county

Variance parameter for herd was 2.85 (95% CI 2.13; 3.82), shape parameter p = 0.62, scale parameter λ=0.00067048

Table 2. Risk factors for on-farm beef young stock (3-18 months old) mortality as identified in a Weibull proportional hazard random effect model evaluated in 47,876 cattle from 1,243 herds in Estonia

Variable	Category	N[a,b]	MR[c]	Hazard rate ratio (HR)	95% Confidence interval of HR	Wald-test P-value	Likelihood ratio test P-value
Age category x herd size (animal-years)[b]	3-6 months, <40 animals	8,473	0.94	1			0.001
	3-6 months, 40-99 animals	9,820	1.07	1.23	0.64; 2.37	0.532	
	3-6 months, 100-199 animals	8,024	0.87	0.91	0.43; 1.93	0.809	
	3-6 months, ≥200 animals	8,707	1.75	1.63	0.79; 3.38	0.189	
	6-12 months, <40 animals	9,747	1.08	1.19	0.67; 2.11	0.541	
	6-12 months, 40-99 animals	11,601	1.45	1.65	0.93; 2.94	0.089	
	6-12 months, 100-199 animals	9,471	1.38	1.44	0.76; 2.72	0.259	
	6-12 months, ≥200 animals	10,325	2.72	2.62	1.33; 5.18	0.005	
	12-18 months, <40 animals	6,837	1.56	1.78	1.02; 3.10	0.041	
	12-18 months, 40-99 animals	8,296	0.83	0.94	0.50; 1.77	0.847	
	12-18 months, 100-199 animals	6,930	1.51	1.63	0.86; 3.09	0.133	
	12-18 months, ≥200 animals	7,468	1.62	1.53	0.76; 3.11	0.237	
Sex[a]	Female	24,900	1.27	1			0.002
	Male	22,976	1.64	1.33	1.11; 1.59	0.002	
Region[a,d]	Northeast	9,150	1.86	1			0.411
	Southeast	8,152	0.75	0.72	0.42; 1.24	0.240	
	Southwest	14,344	1.54	0.99	0.64; 1.53	0.972	
	Northwest	16,230	1.46	1.10	0.71; 1.69	0.681	

[a]Number of animals in each category

[b]Number of observations in each category after splitting the observations according to age categories

[c]Mortality rate (per 100 animal-year) in each category

[d]Northeast Estonia: Ida-Viru, Lääne-Viru, Jõgeva, Järva county; Southeast Estonia: Tartu, Valga, Võru, Põlva county; Southwest Estonia: Pärnu, Viljandi, Saare county; Northwest Estonia: Harju, Rapla, Lääne, Hiiu county

Variance parameter for herd was 2.03 (95% CI 1.49; 2.78), shape parameter $p = 0.98$, scale parameter $\lambda = 0.00002543$

Table 3. Risk factors for on-farm adult beef cattle (over 18 months) mortality in Weibull proportional hazard random effect model evaluated in 49,950 cattle from 1,214 herds in Estonia

Variable	Category	n[ab]	%[c]	HR	95% CI	Wald testi P-value	Likelihood ratio test P-value
Age category[b]	18-24 months	28,421	1.62	1			<0.001
	24-36 months	21,585	1.85	1.18	0.96; 1.45	0.113	
	36-48 months	15,074	1.90	1.18	0.94; 1.47	0.146	
	48-60 months	11,670	1.47	0.88	0.68; 1.13	0.306	
	>60 months	15,010	2.11	1.35	1.11; 1.65	0.003	
Breed[a]	Hereford	12,955	1.73	1			0.004
	Charolais	3,298	1.58	0.86	0.59; 1.23	0.400	
	Scottish Higland	3,520	1.46	0.74	0.52; 1.04	0.087	
	Aberdeen Angus	11,111	1.73	1.09	0.88; 1.36	0.430	
	Limousin	10,002	2.06	1.05	0.84; 1.31	0.669	
	Simmental	4,141	1.71	1.35	0.99; 1.85	0.057	
	Other[d]	4,923	2.74	1.41	1.11; 1.78	0.005	
Herd size (animal-years) x gender[a]	<100, male	6,286	0.92	1			0.001
	≥100, male	5,456	1.69	1.60	0.99; 2.58	0.054	
	<40, female	8,201	1.64	1.74	1.18; 2.56	0.005	
	40-99, female	10,631	1.97	2.15	1.48; 3.12	<0.001	
	100-199, female	9,552	1.90	2.20	1.44; 3.35	<0.001	
	≥200, female	9,824	2.19	1.85	1.18; 2.90	0.007	
Region[e]	Northeast	8,891	1.62	1			0.004

Southeast	7,582	1.13	0.70	0.48; 1.00	0.053
Southwest	15,717	2.18	1.14	0.85; 1.52	0.395
Northwest	17,760	2.01	1.24	0.92; 1.66	0.154

[a]Number of animals in each category

[b]Number of observations in each category after splitting the observations according to age categories

[c]Mortality rate (per 100 animal-years) in each category

[d]Other breeds: Estonian Holstein, Estonian Red, Brows Swiss, Aubrac, Blonde d'Aquitaine, Belgian Blue, Dexter, Estonian Native, Galloway, Jersey, Piemontese, German Shorthorn

[e]Northeast Estonia: Ida-Viru, Lääne-Viru, Jõgeva, Järva county; Southeast Estonia: Tartu, Valga, Võru, Põlva county; Southwest Estonia: Pärnu, Viljandi, Saare county; Northwest Estonia: Harju, Rapla, Lääne, Hiiu county

Variance parameter for herd was 0.86 (95% CI 0.66; 1.11), shape parameter $p = 0.86$, scale parameter $\lambda=0.00004125$

Table 4. Descriptive statistics of farmer´s stated reasons for on-farm mortality of Estonian beef cattle in 2013 and 2014

Reason of exit	n (total)	(%)	n (euthanasia)	n (unassisted death)	Median age in months (quartiles)
COWS					
Claw/leg disorders	10	3.1	4	6	71.0 (65.4; 120.0)
Infectious diseases	9	2.8	1	8	51.0 (37.1; 80.1)
Metabolic and digestive disorders	65	20.3	6	59	69.8 (52.0; 93.8)
Fertility problems	11	3.4	4	7	47.5 (39.0; 87.2)
Dystocia	42	13.1	11	31	49.2 (44.6; 95.5)
Trauma and accident	90	28.1	10	80	76.6 (54.7; 108.1)
Other/unknown reasons	93	29.1	5	88	78.2 (50.5; 108.5)
Total	320	100.0	41	279	71.2 (48.3; 103.2)
HEIFERS[a]					
Claw/leg disorders	12	2.4	3	9	12.0 (4.1; 16.7)
Respiratory diseases	52	10.4	1	51	1.8 (0.5; 5.0)
Metabolic and digestive disorders	142	28.3	2	140	1.6 (0.4; 10.0)
Fertility problems	13	2.6	6	7	33.3 (20.1; 36.8)
Trauma and accident	152	30.3	30	122	9.2 (1.2; 24.9)
Other/unknown reasons	130	26.0	17	113	8.5 (1.1; 26.5)
Total	501	100.0	59	442	6.1 (0.6; 22.4)
YOUNG BULLS[b]					
Claw/leg disorders	18	3.8	2	16	16.1 (1.2; 32.7)
Respiratory and infectious diseases	70	14.8	2	68	1.7 (0.6; 5.0)
Metabolic and digestive disorders	143	30.2	8	135	1.0 (0.4; 6.6)
Trauma and accident	136	28.8	19	117	3.3 (0.4; 12.6)
Other/unknown reasons	106	22.4	5	91	1.1 (0.3; 11.5)
Total	473	100.0	40	433	1.7 (0.4; 9.6)
BULLS					
Claw/leg disorders	2	20.0	2	0	27.2 (18.3; 36.2)

Respiratory diseases	1	10.0	0	1	24.8 (24.8; 24.8)
Metabolic and digestive disorders	2	20.0	0	2	31.8 (27.1; 36.5)
Accident	3	30.0	1	2	83.8 (52.0; 99.1)
Other/unknown reasons	2	20.0	0	2	65.7 (43.6; 87.8)
Total	10	100.0	3	7	40.0 (27.1; 87.8)

[a] Female cattle from birth to first calving

[b] Male cattle from birth to first registered breeding event

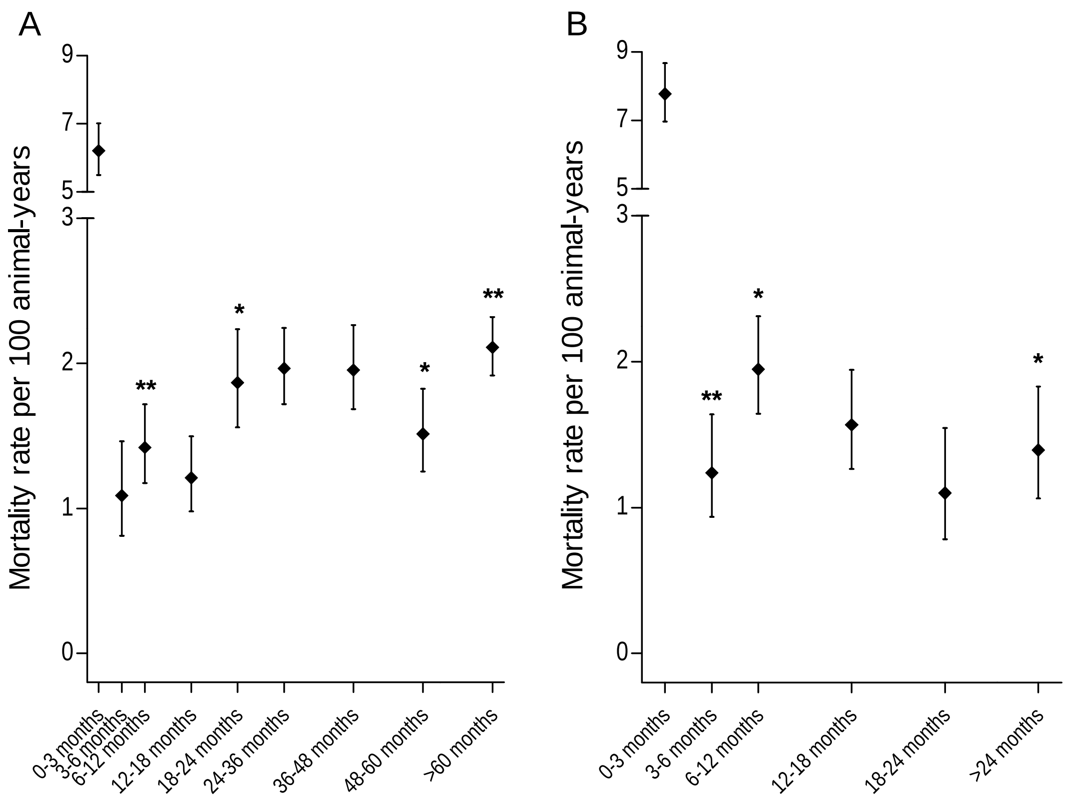

Figure 1. Crude mortality rate estimates in female and male cattle of Estonian beef herds by age group (A – females, B – males).

* $p < 0.05$ and ** $p < 0.001$ compared to preceding age category in Weibull proportional hazard model with with farm frailty effect.

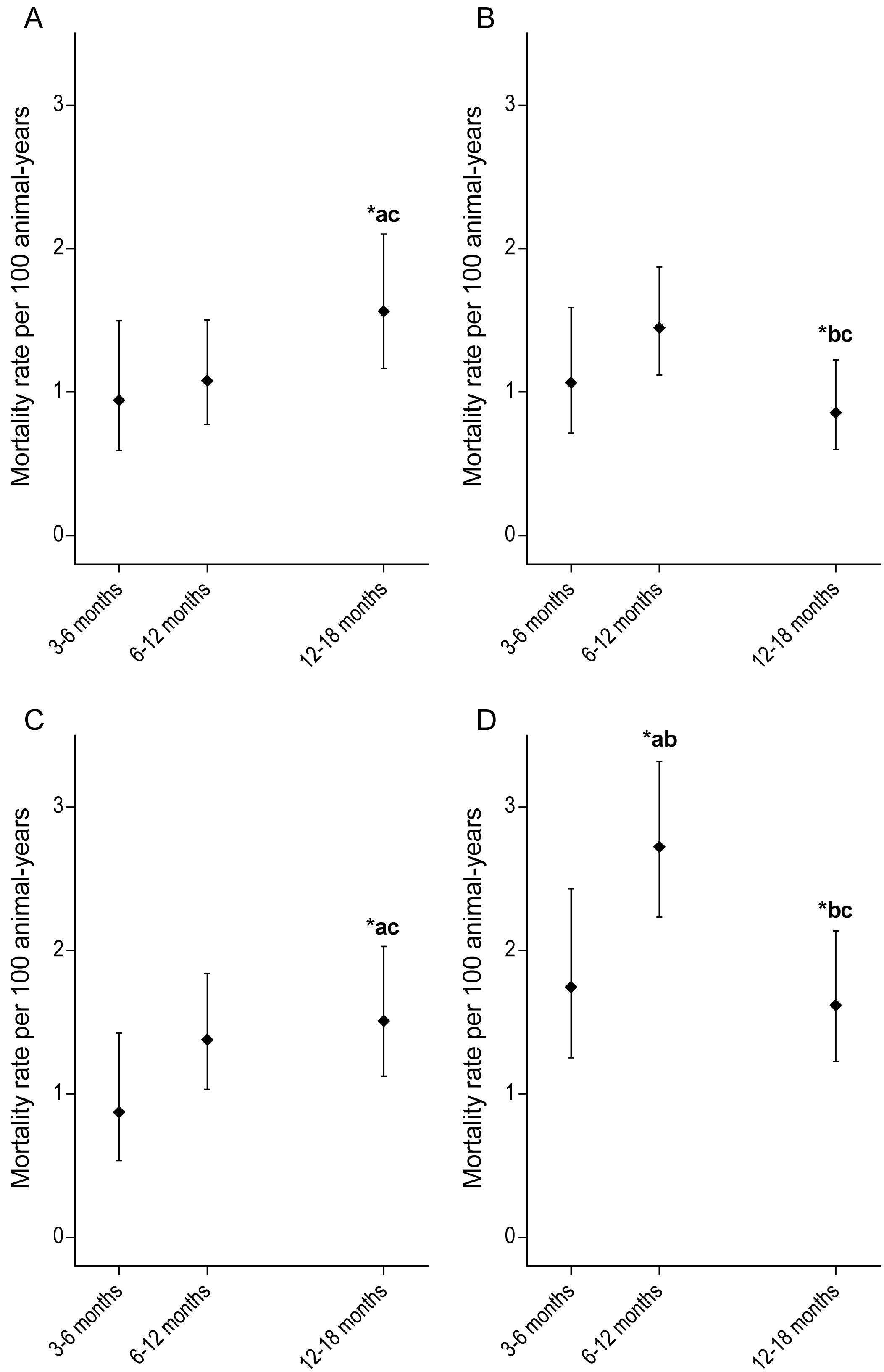
A
B
C
D
Mortality rate per 100 animal-years
0
1
2
3
3-6 months
6-12 months
12-18 months
*ac
*bc
*ac
*ab
*bc

Figure 2. Distribution of mortality rate in age categories by different herd size in three to 18 months old youngstock (A – herds with <40, B – 40-99, C – 100-199, D – ≥200 animal-years).
Comparison between age categories within the same herd size groups: a - 3-6, b - 6-12, c - 12-18 months
* $p < 0.05$ between assigned categories in multivariable Weibull model

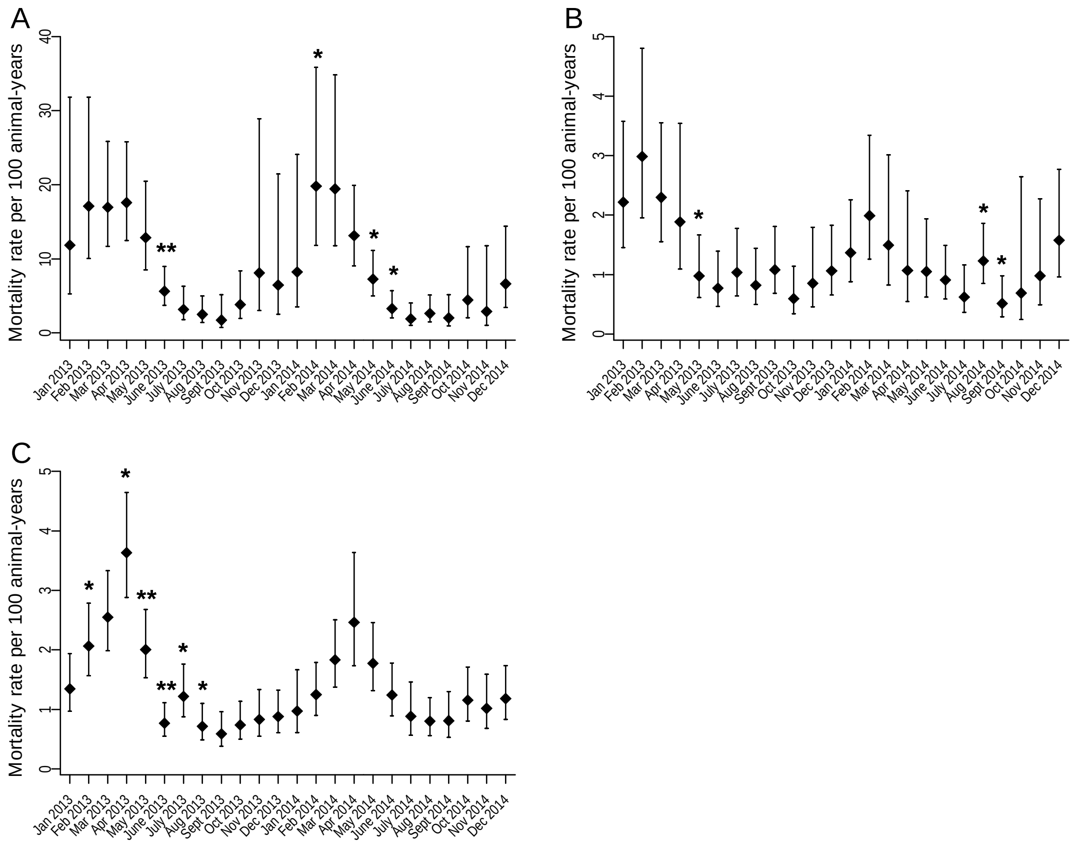

Figure 3. Seasonal distribution of mortality rate among three age groups in Estonian beef herds: A – calves younger than three months, B – youngstock from three to 18 months, C – cattle ≥18 months.
* $p < 0.05$ and ** $p < 0.001$ compared to previous month in Weibull proportional hazards model

SUPPLEMENTARY MATERIAL

Supplementary table 1. Crude on-farm mortality rates in three age groups in Estonian beef herds

Variable	Category	Calves <3 months		Youngstock 3-18 months		Cattle ≥18 months	
		n	MR[a]	n	MR	n	MR
Breed	Aberdeen Angus	7,930	7.76	10,943	1.29	11,189	1.75
	Charolais	3,115	9.59	3,993	1.75	3,298	1.58
	Scottish Higland	1,877	5.41	2,582	1.34	3,520	1.46
	Hereford	8,734	5.03	12,099	1.38	12,955	1.73
	Limousin	7,000	8.62	9,219	1.27	10,002	2.06
	Simmental	4,379	6.13	5,645	1.52	4,141	1.71
	Other[b]	2,091	6.22	3,433	2.27	4,923	2.74
Sex	Female	17,578	6.21	24,920	1.27	38,267	1.94
	Male	17,548	7.78	22,994	1.65	11,761	1.26
Herd size (animal-years)	<40	8,430	3.33	11,548	1.21	11,001	1.54
	40-99	9,656	3.56	13,440	1.15	14,195	1.86
	100-199	8,082	8.73	10,948	1.31	12,258	1.80
	≥200	8,958	12.71	11,978	2.11	12,574	2.22
Region[c]	Northeast	6,903	12.00	9,150	1.86	8,891	1.62
	Southeast	5,902	3.41	8,152	0.75	7,582	1.13
	Southwest	10,732	6.38	14,344	1.54	15,717	2.18
	Northwest	11,584	6.45	16,230	1.46	17,760	2.01

[a]Mortality rate (per 100 animal-year) in each category

[b]Other breeds: Estonian Holstein, Estonian Red, Brows Swiss, Aubrac, Blonde d'Aquitaine, Belgian Blue, Dexter, Estonian Native, Galloway, Jersey, Piemontese, German Shorthorn

[c]Northeast Estonia: Ida-Viru, Lääne-Viru, Jõgeva, Järva county; Southeast Estonia: Tartu, Valga, Võru, Põlva county; Southwest Estonia: Pärnu, Viljandi, Saare county; Northwest Estonia: Harju, Rapla, Lääne, Hiiu county