Risk factors associated with animal mortality in pasture-based, seasonal-calving dairy and beef herds[1]

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ABSTRACT: Animal mortality is indicative of animal health and welfare standards, which are of growing concern to the agricultural industry. The objective of the present study was to ascertain risk factors associated with mortality at multiple life stages in pasture-based, seasonal-calving dairy and beef herds. Males and females were stratified into seven life stages based on age (0 to 2 d, 3 to 7 d, 8 to 30 d, 31 to 182 d, 183 to 365 d, 366 to 730 d, and 731 to 1,095 d) whereas females with ≥1 calving event were further stratified into five life stages based on cow parity number (1, 2, 3, 4, and 5). Mortality was defined as whether an animal died during each life stage; only animals that either survived the entire duration or died during a life stage were considered. The data, following edits, consisted of 4,404,122 records from 1,358,712 animals. Multivariable logistic regression was used to estimate the logit of the probability of mortality in each life stage separately. The odds of a young animal (i.e., aged ≤ 1,095 d) dying was generally greater if veterinary assistance was required at their birth relative to no assistance (odds ratio [OR]: 3.10 to 31.85), if the animal was a twin relative to a singleton (OR: 1.46 to 2.31) or if the animal was male relative to female (OR: 1.14 to 6.15). Moreover, the odds of a cow (i.e., females with ≥1 calving event) dying were greater when she required veterinary assistance at calving (OR: 2.69 to 7.55) compared with a cow that did not require any assistance, if she produced twin relative to singleton progeny (OR: 1.59 to 2.03) or male relative to female progeny (OR: 1.09 to 1.20). Additionally, the odds of a first or second parity cow dying when she herself had received veterinary assistance at birth were only 0.63 to 0.66 times that of a cow that was provided no assistance at birth. For both young animals and cows, the odds of dying generally increased with herd size, whereas animals residing in expanding herds had lower odds of dying. Results from the present study indicate that the risk factors associated with mortality in pasture-based, seasonal-calving herds are similar to those reported in literature in confinement, non-seasonal-calving herds. Moreover, the present study identifies that these risk factors are similar in both dairy and beef herds, yet the magnitude of the association often differs and also changes with life stage.

Key words: calf, cow, death, health, longevity, welfare

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INTRODUCTION

Animal health and welfare in the dairy and beef industry is of global concern, influencing the profitability of producers, the regulations set by policy-makers, and the purchasing decisions of consumers. Animal mortality is a trait that is

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reflective of both animal health and welfare, as sub-optimal health is associated with greater mortality risk in cattle (McConnel et al., 2008; Gulliksen et al., 2009).

Risk factors associated with animal mortality have been reported (Miller et al., 2008; Raboisson et al., 2011; Alvåsen et al., 2012). However, risk factors vary across management systems (Dechow et al., 2012) and with regions (Thomsen et al., 2004). Many countries manage seasonal-calving systems to maximize utilization of grazed grass. Nevertheless, few studies have identified the risk factors associated with mortality in pasture-based production or seasonal-calving systems (Mee et al., 2008; Burow et al., 2011; Alvåsen et al., 2012). Moreover, risk factors associated with mortality vary across periods of an animal's lifetime. Where the risk factors associated with mortality across periods of an animal's lifetime were quantified (Svensson et al., 2006; Gulliksen et al., 2009; Bleul, 2011), they were restricted to short periods or few risk factors.

The objective of the present study was to identify risk factors associated with mortality in pasture-based, seasonal-calving dairy and beef herds across periods of an animal's lifetime. Results can be used to educate the wider agricultural-food industry of the risk factors associated with a greater risk of mortality and how such associations differ with life stage. Results may also be used to instigate change in management decisions at the producer level and among policy-makers. In addition, researchers may use outcomes to investigate and develop novel solutions to reduce mortality.

MATERIALS AND METHODS

Cattle births, interlocation movements, and mortality data, together with a range of performance measures, were available from the Irish Cattle Breeding Federation (**ICBF**) database on 22,544,272 animals born in 107,565 unique herds in the Republic of Ireland between the year 2005 and 2015, inclusive. Animal birth, movement and mortality data consisted of a unique national animal identification number, the herd (or location) in which the event occurred, the date of the event, and the type of the event (i.e., birth, interlocation movement, death, export, or slaughter). The proportion of final movement events that were a birth or an interlocation movement, a death, an export, and a slaughter were 25, 9, 10, and 56%, respectively. In accordance with Statutory Instrument No. 655/2003, cattle producers in the Republic of Ireland are legally required to notify the Department of Agriculture, Food and the Marine of each event. The extent of calving assistance provided at an animal's birth, together with dates of artificial insemination(s) and natural service event(s), was also available for some animals; producers are not legally obliged to provide this information.

Definition of Mortality

The lifetime of each animal was stratified into categories based on age for both males and females aged ≤1,095 d and based on cow parity number for females with ≥1 calving event. Age categories (*j*) included 0 to 2 d, 3 to 7 d, 8 to 30 d, 31 to 182 d, 183 to 365 d, 366 to 730 d, and 731 to 1,095 d. Females with ≥1 calving event were stratified into categories based on their parity number (*i*; i.e., parity number the day after calving); these parity categories were limited to parities 1, 2, 3, 4, and 5. Animals were defined as dead for age group *j* if they died during that period. Otherwise, animals were defined as alive for age group *j* provided they survived the entire duration of that period. Animals that were not considered for age group *j* included animals that were defined as dead in an earlier age category, animals that were exported or slaughtered, and animals that were younger than the required age for age category *j*. Cows that reached parity $i + 1$ were assumed to have survived parity *i*, whereas cows that reached parity *i* but died prior to reaching parity $i + 1$ were assumed to have died during parity *i*; all other cows (e.g., exported and slaughtered cows) were not considered for parity category *i*.

Data Management

To remove obvious data errors, mortality records for animals that calved ≤545 d of age ($n = 21{,}891$; events not biologically possible) were discarded from the present study as were animals born in calving events resulting in more than two calves (i.e., rare occurrences) as well as cow parity records for cows that produced more than two calves in a calving event ($n = 38{,}447$; rare occurrences). Furthermore, to eliminate rare events and events not biologically possible, animals born to dams that were either ≤545 d of age, ≥4,380 d of age, or ≥10th parity were discarded. Herd-type was classified as either a dairy or a beef herd based on the average breed composition of calved cows. Where the known breed composition of calved cows in a herd-year (of calving) was at least 85% of a dairy breed (i.e., Ayrshire, Brown Swiss, Friesian, Holstein, Jersey, Montbéliarde, Norwegian Red, and Normandé), the herd-type was defined as dairy (n = 29,299 herds). Where the known breed composition of calved cows in a herd-year (of calving) was less than 55% of a dairy breed, the herd-type was defined as beef (n = 85,869 herds). Herds that did not have at least one calving event, as well as herds that did not conform to either a dairy or a beef herd-type, were not considered further in the study (n = 19,845 herds).

Of the remaining 20,209,208 animals (of which, 11,256,112 animals resided in a dairy herd at least once in their lifetime and 9,839,949 animals resided in a beef herd at least once in their lifetime), annual mortality incidence risk for each age group was plotted for dairy and beef herds separately for the year of death 2008 to 2015, inclusive. Annual mortality incidence risk per age group was calculated as: [number of animals that died during age group j per calendar year]/[number of animals that died during age group j per calendar year + number of animals that survived age group j per calendar year], where calendar year was considered as the year an animal would have reached its maximum possible age in the respective age group. In addition, annual mortality incidence risk per cow parity was plotted for dairy and beef herds separately for the year of calving 2011 to 2014, inclusive. Annual mortality incidence risk per cow parity was calculated as: [number of cows that died during parity i per calendar year]/[number of cows that died during parity i per calendar year + number of cows that survived parity i per calendar year], where calendar year was considered as the year the cow calved. The distribution of monthly calving events and total mortality (i.e., the sum of all animal deaths irrespective of age group or cow parity) per calendar month of the year was plotted for dairy and beef herds, separately.

Risk Factors

Variables considered as potential risk factors for mortality were either considered directly from the ICBF database or were established from the available data. A description of each variable considered directly from the ICBF database is detailed in Table 1; variables established as potential risk factors for mortality included gestation length, heterosis and recombination loss coefficients of the animal and its dam, herd size, rate of herd expansion, the calving period in which an animal was born or calved, length of the calving period (in weeks) in which an animal was born or calved, and the percentage of total herd calvings occurring within 7 d of either the animal's birth or calving.

Gestation length per animal was calculated as the number of days between the last available service date and the subsequent calving date, provided the sire recorded for the resulting progeny was also the recorded service sire; only gestation lengths between 274 and 300 d (Burris and Blunn, 1952; Norman et al., 2009) were retained. Heterosis and recombination loss coefficients for each animal and its dam were calculated as: $1-\sum_{i=1}^{n} sire_i \cdot dam_i$ and $1-\sum_{i=1}^{n} \frac{sire_i^2 + dam_i^2}{2}$, respectively, where $sire_i$ and dam_i are the proportion of breed i in the sire and dam, respectively (VanRaden and Sanders, 2003).

Herd size was calculated as the total number of calving events occurring in a herd-year; herd size was classified into one of five categories depending on the herd-type. If the herd was defined as a beef herd, then the herd size categories were 1 to 9, 10 to 16, 17 to 22, 23 to 30, and >30 cows. If the herd was defined as a dairy herd, then the herd size categories were defined as 1 to 29, 30 to 50, 51 to 65, 66 to 90, and >90 cows. The rate of herd expansion was defined using methods described by Jago and Berry (2011); using PROC ROBUSTREG in SAS, 9.3 (SAS Institute Inc., Cary, NC), linear robust regression was fitted to the annual herd size of each herd for the year 2007 to 2015, inclusive. Where the resulting linear regression coefficient was either not different from zero ($P > 0.05$) or the linear regression coefficient was negative, herds were classified as not expanding. Expanding herds was defined as those with a positive linear regression coefficient different from zero ($P < 0.05$). Expanding herds were further stratified based on the average number of additional cows per annum as slow (linear regression coefficient of less than four in dairy herds and less than three in beef herds) or rapid (linear regression coefficient of at least four in dairy herds and at least three in beef herds) expansion.

Risk factors pertinent to each herd's calving period were considered only for spring calving dairy and beef herds; spring calving herds are described herein. A herd's calving period (i.e., the time period between the start and finish of a calving season within a herd-year) was defined for primiparous and multiparous cows together, based on methods outlined by Berry et al. (2013); within a herd, a calving period began when five consecutive calving events occurred within a 14-d period. The calving period

Table 1. Description of risk factors tested for association with mortality per age group and per cow parity

Risk factors	Age group	Cow parity	Description
Stage of lactation	–	Stage of lactation cow died	Expressed in weeks (up to 20 wk) postcalving
Seasonal factors	–	Wk-d, mo, and yr of cow calving	Expressed in wk-d, calendar mo, and calendar yr, respectively
Breed	Breed proportion of the animal and the animal's dam	Breed proportion of the cow	Aberdeen Angus, Belgian Blue, Charolais, Hereford, Limousin, Simmental, Friesian, Jersey, Montbéliarde, Norwegian Red, Holstein, other beef breeds and other dairy breeds. To avoid linear dependencies, Holstein and Charolais were not considered in dairy and beef herds, respectively
Heterosis and recombination	Heterosis and recombination loss coefficients of the animal and the animal's dam	Heterosis and recombination loss coefficients of the cow	0.00 to 0.09, 0.10 to 0.29, 0.30 to 0.49, 0.50 to 0.69 and 0.70 to 1.00
Calving assistance	Extent of assistance provided to the animal at birth	Extent of assistance provided to the cow at birth and at calving	(1) No assistance, (2) assistance provided with some calving difficulty, (3) assistance provided with considerable calving difficulty but without veterinary intervention, and (4) assistance provided with considerable calving difficulty resulting in veterinary intervention
Twin births	Whether animal was a single or a twin birth	Whether cow was a single or a twin birth and whether cow's progeny was single or twin births	Single or twin birth
Gender	Animal gender	Gender of cow's progeny	Animal gender: male or female. Progeny gender: male singleton or female singleton
Gestation length	Gestation length of the animal	Gestation length of the cow's progeny	Expressed in days
Dam parity	Parity number of the animal's dam at the animal's birth	Parity number of the cow's dam at the cow's birth	1, 2, 3, 4, 5, ≥6
Age at first calving	–	Cow age at first calving	Expressed in mo
Stillbirths	Whether the animal's dam had a stillborn calf in any lactation prior to the animal's birth	Whether the cow's progeny was stillborn	Dead or alive 48 h after birth
Calving period factors	Number of herd-mates born ± 7 d of the animal's birth	Number of herd-mates calved ± 7 d of the cow's calving	Expressed as a percentage of total herd-yr calvings
	Timing of the calving period that the animal was born	Timing of the calving period that the cow calved	Born or calved in the first quarter (very early), second quarter (early), third quarter (late), or fourth quarter (very late) of the herds calving period
	Length of the calving period that the animal was born	Length of the calving period that the cow calved	Expressed in weeks
Herd factors	Herd size in the herd the animal resided	Herd size in the herd the cow resided	Beef: 10 to 16, 17 to 22, 23 to 30, and >30 calvings Dairy: 30 to 50, 51 to 65, 66 to 90, and >90 calvings
	Rate of expansion in the herd the animal resided	Rate of expansion in the herd the cow resided	Beef: Increasing at an average rate of 0 cows/yr (not expanding), 1 to 2 cows/yr (slow), or ≥3 cows/yr (rapid) Dairy: Increasing at an average rate of 0 cows/yr (not expanding), 1 to 3 cows/yr (slow), or ≥4 cows/yr (rapid)

terminated with a registered calving event that was not subsequently followed by a calving event in the next 21 d. Only calving periods between 35 and 200 d in length were considered. Each calving period per herd-year was partitioned into four time periods (very early, early, late, and very late) with an equal number of days per time period.

Contemporary groups were assigned to animals for each mortality category separately using the algorithm adapted from Berry et al. (2013). Within a herd, the algorithm clusters animals together that consecutively either calve or are born in very close proximity (≤10 d) of each other; where less than 10 animals are initially clustered together, the group is amalgamated with an adjacent group. This process is reiterated until the contemporary group contains at least 10 animals, provided the number of days between the initial and final event (i.e., calving or birth) does not exceed 180 d. With the exception of animals aged 0 to 2 d, animals with a mortality record for age group *j* were allocated a contemporary group based on their birthdate and the herd they resided in for age group $j - 1$; animals aged between 0 and 2 d were assigned a contemporary group based on their birthdate and the herd they were born in. Animals with a mortality record for parity i were allocated a contemporary group based on their calving date and the herd they resided in for parity i.

Data Edits

Prior to statistical analyses, the size of the dataset was reduced for computational reasons using SAS, 9.3 (SAS Institute Inc., Cary, NC). Only animals born between 2010 and 2012, inclusive were considered when mortality per age group was of interest, whereas only cows that calved for the first time between the year 2007 and 2011, inclusive were considered where mortality per cow parity was of interest. A total of 26,182,264 records from 5,547,498 animals in 88,048 herds were considered for the age group categories while 4,716,312 records from 1,392,173 cows in 83,314 herds were considered for the cow parity categories. To ensure historical management effects were properly accounted for in the models (discussed herein), mortality records in age group j were discarded where an animal moved herds between mortality categories $j - 1$ and j (525,115 records from 507,471 animals in 49,393 herds were discarded); similarly, and for the same reason, cow parity mortality records in parity i were discarded where a cow did not calve in the same herd for parity i and $i + 1$ (67,065 records from 66,425 cows in 24,023 herds were discarded). To represent spring calving herds, only herds with ≥70% of herd-year calving events occurring between the months January to May, inclusive, were retained (8,782,693 age records from 1,941,987 animals in 41,590 herds were discarded as were 1,385,667 cow parity records from 464,948 cows in 39,851 herds). Furthermore, to represent herds of the national population, herds that did not maintain a herd size ≥ 10 (i.e., beef herd) or ≥ 30 (i.e., dairy herd) calvings per annum for each of the year between 2007 and 2015, inclusive were discarded. In addition, to ensure maximum likelihood of mortality recording within herd, herds that did not document at least one animal death in a mortality category between the year 2007 and 2015, inclusive were not considered in the respective mortality category (278,697 animals from 66,763 animals in 1,939 herds were discarded). Following edits, and a random selection of, where possible, approximately 250,000 records per mortality category, the final (analyzed) dataset consisted of 4,404,122 records from 1,358,712 animals (i.e., 6% of the animals that were available in the original dataset); the number of records as well as the mortality incidence risk per category is given in Table 2. The number of records available per risk factor for each age group and cow parity is provided in Supplementary Tables 1 and 2, respectively.

Statistical Analyses

The logit of the probability of mortality in each age group and separately in each cow parity was estimated using multivariable logistic regression in ASReml 3.0 (Gilmour et al., 2009). Risk factors considered for inclusion in all models are given in Table 1. Contemporary group was fitted as a random effect in all models. Stepwise forward–backward regression was used to test the significance of potential risk factors as well as interactions considered biologically relevant. Statistically significant risk factors for mortality, declared at $P < 0.001$,

Table 2. Following edits, the number of records (n) and mortality incidence risk (%) per age or parity category in dairy and beef herds

	Dairy herds		Beef herds	
Age or parity category	n	%	n	%
0 to 2, d	240,658	2.35	277,399	1.50
3 to 7, d	233,201	1.28	266,411	0.62
8 to 30, d	231,181	2.23	266,317	0.96
31 to 182, d	230,821	3.02	276,979	1.67
183 to 365, d	233,936	1.12	261,933	1.04
366 to 730, d	140,283	1.38	140,385	1.81
731 to 1095, d	150,252	2.05	60,971	1.90
Cow parity 1	203,843	2.77	114,858	2.36
Cow parity 2	168,750	2.57	105,533	1.83
Cow parity 3	186,391	3.03	93,641	1.80
Cow parity 4	182,734	3.57	81,132	1.89
Cow parity 5	195,025	4.38	61,488	2.30

were retained in the final multivariable models (Supplementary Tables 3 and 4). Dairy and beef herds were initially analyzed together as were each age group category and each cow parity category; however, the presence of significant interactions for mortality between both herd-type and age group as well as between herd-type and cow parity resulted in the analysis of mortality per age group and mortality per cow parity being undertaken for dairy and beef herds separately.

RESULTS AND DISCUSSION

The *P*-values for each risk factor considered per age group and per cow parity are available in Supplementary Tables 3 and 4, respectively. Risk factors declared associated ($P < 0.001$) with mortality in at least one age group or cow parity are discussed herein. Direct effect estimates are presented.

National Mortality Trends

The overall mortality trend per month for both dairy and beef herds (Fig. 1) closely followed the seasonal-calving pattern in Irish herds and other pasture-based systems. Previous studies (Fuerst-Waltl and Fuerst, 2010; Fuerst-Waltl and Sørensen, 2010; Murray et al., 2016) have also reported that the highest mortality incidence risk occurs immediately after calving/birth.

In both dairy and beef herds, the annual trend in mortality incidence risk per age group (Supplementary Fig. 1) was generally stagnant over the year 2008 to 2015, inclusive. The annual trend in mortality incidence risk for multiparous cows (Supplementary Fig. 2) generally increased, plateaued and then decreased, whereas for primiparous cows, mortality incidence risk increased, plateaued and then increased again from 2011 to 2014, inclusive. The mean mortality incidence risk differed per age group by herd-type. For example, the greatest mortality incidence risk in young animals (i.e., animals aged ≤ 1,095 d; Supplementary Fig. 1) in dairy herds occurred between 31 and 182 d of age (mortality incidence risk range per annum: 2.9 to 3.7%), which may have been prompted by the stressful period coinciding with weaning and thus, dietary and environmental changes; the absence of weaning and diet changes during the same life stage in beef herds may explain the lower mortality incidence risk observed in this period in beef herds (mortality incidence risk range per annum: 1.4 to 2.3%).

The lower mortality incidence risk in the present study during the first month of life (on average 1.6 and 0.9% of calves died between birth and 30 d of age in dairy and beef herds, respectively) relative to older age periods (on average 2.2 and 2.0% of calves died between 31 and 1,095 d of age in dairy and beef herds, respectively) is contrary to international reports in both dairy and beef herds (Gulliksen et al., 2009; Murray et al., 2016; Compton et al., 2017). Nevertheless, the lower mortality incidence risk observed in the present study before 30 d of age relative to other studies is in line with expectations for many reasons. Firstly, birth and death recording on Irish farms is mandatory; producers that do not comply with the legal regulations face severe penalties. Secondly, where studies have reported greater mortality incidence risk ≤ 30 d of age relative to older age periods, they have generally been derived from countries with larger herds than Ireland (e.g., United States, Canada, and New Zealand); an association between larger herd size and a higher risk of stillbirths has been documented elsewhere (Gulliksen et al., 2009; Bleul, 2011). In addition,

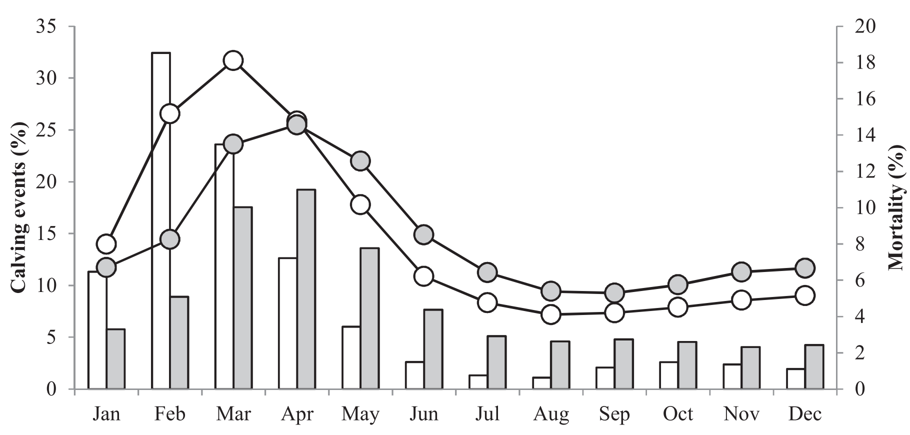

Figure 1. Distribution of calving/birth events per calendar mo of the year (primary axis, histogram) and mortality incidence risk of all animals (secondary axis, line) in dairy (no fill) and beef (filled) herds.

calf sales largely contribute to the annual income on Irish herds, but this is not a consistent trend internationally; as a result, Irish producers likely pay greater attention to calf rearing practices contributing to lower mortality.

On average, 3.3% of first and second parity cows that calved in dairy herds between 2011 and 2014 died, whereas 4.7% of fourth and fifth parity cows died during the same period (Supplementary Fig. 2). In beef herds, first parity cows had the greatest mortality incidence risk for all years (mortality incidence risk range per annum: 2.4 to 3.4%) followed by fourth and fifth parity cows (mortality incidence risk range per annum: 1.9 to 2.8%; Supplementary Fig. 2). Postparturition production diseases are often exacerbated in more mature cows (Lee and Kim, 2006), which likely contributes to the greater mortality incidence risk generally observed in older cows both in the present study and elsewhere (Thomsen et al., 2004; Miller et al., 2008; Raboisson et al., 2011); to our knowledge, no such study on cow mortality in beef herds exists.

Lactation Stage and Seasonal Risk

In both dairy and beef herds, the odds of a cow dying were greatest in the first week postparturition (Supplementary Table 5). The odds of a cow dying in a dairy herd in her first week of lactation were between 1.65 and 1.90 (95% confidence interval [**CI**] range per parity: 1.45 to 2.14) and between 1.89 and 2.80 (95% CI range per parity: 1.64 to 3.12) times greater than a cow in her second and third week of lactation, respectively; the odds decreased with every week (up to 20 wk) postparturition in dairy herds (Supplementary Table 5). The odds of a cow dying in beef herds in her first week postparturition was between 2.73 and 4.31 (95% CI range per parity: 2.09 to 5.79) and between 4.30 and 5.51 (95% CI range per parity: 3.13 to 7.22) times greater than a cow in her second and third week postparturition, respectively; the odds reduced from the first to the fourth week postparturition with no difference thereafter (Supplementary Table 5).

Greater odds of cow deaths in early lactation corroborate findings by Mulligan and Doherty (2008) who stated that the period immediately following parturition is most at risk of production diseases. Greater death rates among older cows, together with peak mortality events occurring closely after parturition, are consistent with previous findings on dairy cow mortality (Thomsen et al., 2004; Miller et al., 2008; Raboisson et al., 2011), but no such study of cow mortality in beef herds exists.

Breed

Young animals in dairy herds with greater Jersey, Montbéliarde or Norwegian Red breed proportion had, in general, greater odds of dying up to 730 d of age compared with young animals with a greater beef breed proportion (Supplementary Table 6). The odds of dying associated with greater Jersey breed proportion in young animals persisted with cows in dairy herds, although cows with more Montbéliarde or Norwegian Red breed proportion were the least likely breed to die in dairy herds.

In beef herds (Supplementary Table 7), calves with greater Charolais, Limousin or Holstein breed proportion had greater odds of dying in their first week of life relative to calves with a greater proportion of other breeds. Calves with more Charolais breed proportion persisted in their greater odds of dying up to 1,095 d of age in beef herds, while calves with greater Holstein, Hereford or Aberdeen Angus breed proportion were less likely to die between 8 and 1,095 d of age relative to animals with a greater proportion of other breeds. Cows with more Holstein, Friesian or Simmental breed proportion were, in general, the most likely breed of cow to die in beef herds, while cows with more Limousin, Charolais or Hereford breed proportion were the least likely breed of cow to die in beef herds.

In dairy herds, cows with greater Jersey breed proportion had greater odds of producing calves that died within 1,095 d of birth in contrast to cows with a greater proportion of any other breed (results not presented), while cows with more Montbéliarde breed proportion had the lowest odds of producing calves that died within 1,095 d of birth. Moreover, cows residing in beef herds with greater Holstein, Friesian or Montbéliarde breed proportion had greater odds of producing calves that died up to 1,095 d of age compared with cows with a greater proportion of any beef breed (results not presented); in beef herds, there was no obvious differential in the odds of a cow's progeny dying when that cow had a greater proportion of any of the beef breeds.

Unfavorable associations between Jersey breed proportion and the odds of calf mortality have been documented elsewhere (Withers, 1953; Pryce et al., 2006; Bleul, 2011) as have the greater mortality incidence risk in Jersey cows relative to Holsteins (Maia et al., 2014). The low monetary value of Jersey animals (particularly males), relative to Holstein or beef breed animals (McHugh et al., 2010), may contribute to suboptimal management practices, with repercussions for mortality.

Many studies have associated the risk of an animal dying with Holstein, Jersey, and Montbéliarde breeds (Miller et al., 2008; Raboisson et al., 2011; Alvåsen et al., 2012). For example, Raboisson et al. (2011) found that where the predominant breed of a French dairy herd was Montbéliarde rather than Holstein, cows had a higher mortality incidence risk. Alvåsen et al. (2012) also reported a greater mortality incidence risk in herds that had Swedish Holstein as the predominant breed compared with herds that had any other breed as the predominant breed. Nonetheless, both of these studies considered breed as the predominant herd breed, and not individual cow breed. To date, only one study (Bleul, 2011) has considered the breed association with an animal's risk of dying. The present study builds on findings by Bleul (2011) who associated a greater risk of young animal mortality when the animal was of a dairy breed compared with a beef breed animal. Moreover, to our knowledge, no study exists that considers the association between breed and the odds of a cow dying or the odds of her progeny dying; the present study fills this void.

Heterosis and Recombination

Several studies have reported the benefits of heterosis to include reduced dystocia (Heins et al., 2006a; Maltecca et al., 2006), fewer stillbirths (Heins et al., 2006a; Maltecca et al., 2006), greater longevity (Heins et al., 2006b; Kelleher et al., 2016), and improved fertility (Vance et al., 2013; Dezetter et al., 2015). In the present study, although the association between the level of heterosis and the odds of a young animal dying was only statistically significant ($P < 0.001$; Supplementary Table 3) for calves less than 3 d of age in beef herds, and animals aged between 731 and 1,095 d in dairy herds, no consistent trend across age groups was observed (results not presented). For example, in beef herds, the odds of a calf dying in its first 2 d of life when it had a heterosis coefficient of between 0.10 and 0.49 was 1.35 to 1.48 (95% CI: 1.10 to 1.87) times greater than a calf with a heterosis coefficient ≤ 0.09. In contrast, the odds of dying for an animal aged between 731 and 1,095 d in a dairy herd when it had a heterosis coefficient > 0.09 was only 0.69 to 0.82 (95% CI: 0.60 to 0.92) times that of an animal with a heterosis coefficient ≤ 0.09. A generally favorable association existed between higher heterosis coefficients and a reduced odds of cow mortality in both dairy and beef herds (Table 3; Supplementary Table 4). The observed benefit of heterosis to cow survival in the present study suggests that producers could reduce cow mortality by maintaining a herd of cross-bred lactating cows, although a similar benefit to young animals may not be experienced. The present study identified inconsistent, yet generally unfavorable associations, between recombination loss coefficients and the odds of dying as both a young animal and as a cow (Supplementary Table 8); this implies that producers should focus their management efforts on other risk factors that are likely to be more beneficial in reducing mortality.

Calving Assistance

The extent of assistance provided at an animal's birth was a significant risk factor for calf mortality, especially within the first 182 d of life (Supplementary Table 3). Calves that required veterinary assistance at birth had up to 19.36

Table 3. Associations between a cow's heterosis coefficient and the $\log_e$ of the odds ratio of mortality (SE in parentheses) per cow parity in dairy and beef herds

	Heterosis coefficient				
Mortality category	0.00 to 0.09	0.10 to 0.29	0.30 to 0.49	0.50 to 0.69	0.70 to 1.00
Dairy herds					
Cow parity 1	0.00 (0.00)[a]	−0.05 (0.08)[ab]	−0.18 (0.09)[ab]	−0.17 (0.08)[ab]	−0.27 (0.06)[b]
Cow parity 2	0.00 (0.00)[a]	−0.07 (0.05)[ab]	−0.26 (0.06)[bc]	−0.30 (0.06)[bc]	−0.41 (0.06)[c]
Cow parity 3	0.00 (0.00)[a]	−0.06 (0.04)[ab]	−0.14 (0.06)[abc]	−0.20 (0.05)[bc]	−0.32 (0.05)[c]
Cow parity 4	0.00 (0.00)[a]	0.07 (0.04)[a]	−0.11 (0.05)[ab]	−0.13 (0.05)[ab]	−0.27 (0.05)[b]
Cow parity 5	0.00 (0.00)[a]	0.16 (0.06)[a]	0.01 (0.07)[ab]	−0.04 (0.07)[ab]	−0.23 (0.05)[b]
Beef herds					
Cow parity 1	0.00 (0.00)[a]	−0.02 (0.17)[ab]	−0.03 (0.09)[ab]	−0.08 (0.14)[ab]	−0.23 (0.06)[b]
Cow parity 2	0.00 (0.00)[a]	−0.18 (0.20)[ab]	−0.45 (0.12)[b]	−0.15 (0.16)[ab]	−0.34 (0.06)[b]
Cow parity 3	0.00 (0.00)[a]	0.39 (0.24)[a]	−0.19 (0.19)[a]	−0.03 (0.22)[a]	−0.12 (0.14)[a]
Cow parity 4	0.00 (0.00)[a]	−0.01 (0.23)[ab]	0.00 (0.12)[ab]	−0.25 (0.19)[ab]	−0.31 (0.07)[b]
Cow parity 5	0.00 (0.00)[a]	−0.17 (0.28)[ab]	−0.25 (0.15)[ab]	−0.62 (0.25)[ab]	−0.31 (0.07)[b]

[a–c]Values within rows with different superscripts differ ($P < 0.001$).

times (95% CI: 16.36 to 22.90) and up to 31.85 times (95% CI: 28.07 to 36.14) greater odds of dying up to 182 d of age compared with their unassisted contemporaries ($P < 0.001$) in both dairy (Fig. 2a) and beef (Fig. 2b) herds, respectively. Yet as cows, these calves that required veterinary assistance at their birth had only a 0.63 to 0.66 times (95% CI: 0.41 to 0.98) the odds of dying during their first and second lactations in dairy herds ($P < 0.05$; Fig. 2c; Supplementary Table 4) relative to their unassisted contemporaries; no association existed in beef herds between assistance at birth and subsequent odds of mortality several year later as a cow ($P > 0.05$; Supplementary Table 4). Moreover, the odds of a cow dying during her lactation were up to 4.45

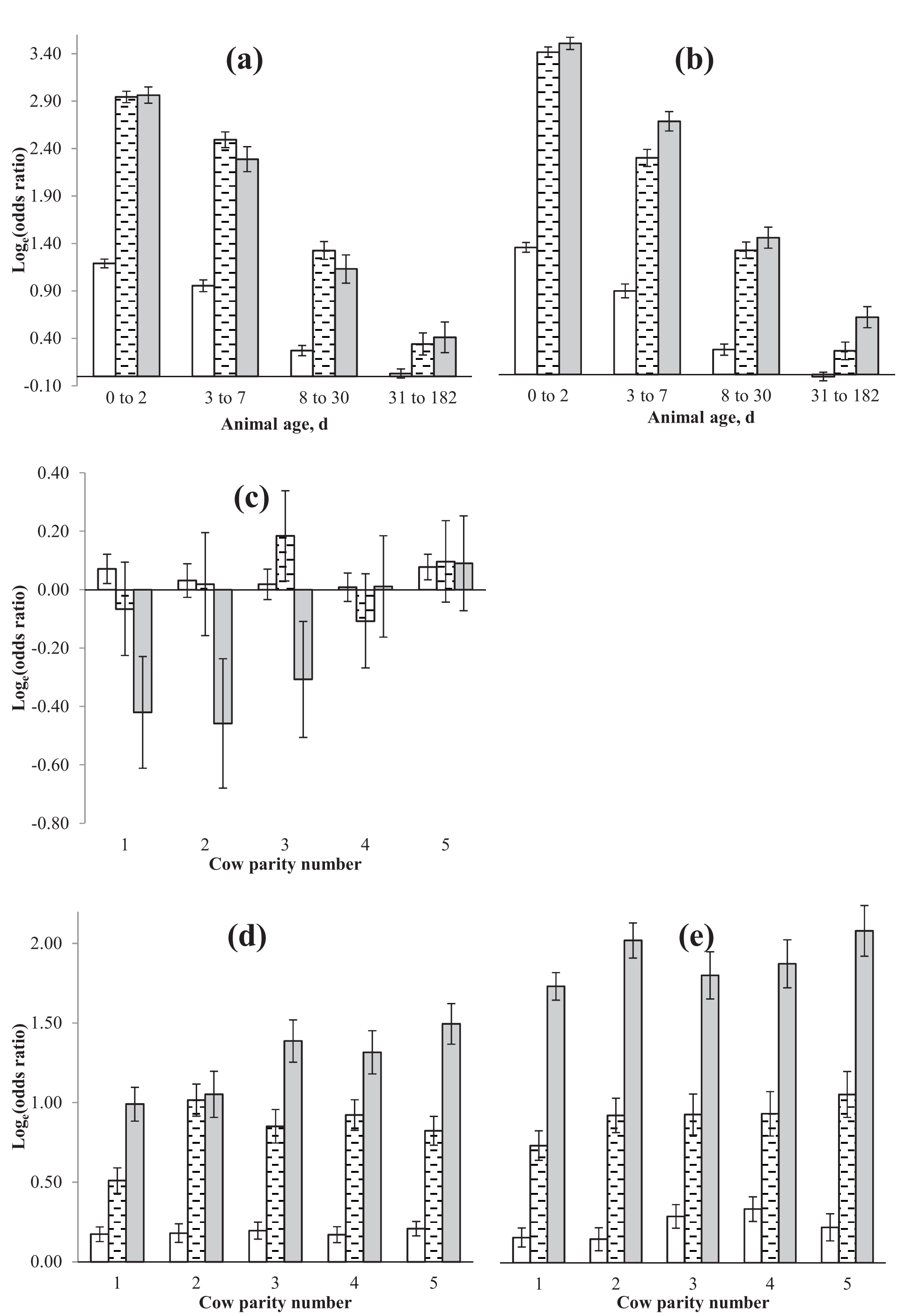

Figure 2. Associations between calving assistance at an animal's own birth and the log$_e$ of the odds ratio of mortality (and 1 SE at each side) per age group in (a) dairy and (b) beef herds as well as (c) per cow parity in dairy herds and associations between calving assistance at a cow's calving event and the log$_e$ of the odds ratio of mortality (and 1 SE at each side) per cow parity in (d) dairy and (e) beef herds. Calving assistance categories include no assistance (referent category, not shown), assistance provided with some calving difficulty (no fill), assistance provided with considerable calving difficulty but did not require veterinary intervention (dashed), and assistance provided with considerable calving difficulty resulting in veterinary intervention (filled).

(95% CI: 3.47 to 5.72) and up to 7.55 (95% CI: 5.57 to 10.23) times greater when she herself required veterinary assistance during calving relative to cows that calved unassisted (Supplementary Table 4) in both dairy (Fig. 2d) and beef (Fig. 2e) herds, respectively. In addition, the association between assistance at birth and calf mortality within 2 d of birth differed by animal gender in dairy herds ($P < 0.001$) and differed by the parity of the animal's dam in beef herds ($P < 0.001$). In dairy herds, where some assistance was required at the birth of a male calf, the odds of that male calf dying during its first 2 d of life were only 0.78 (95% CI: 0.61 to 0.92) times the odds of a female that also required some assistance at birth. In beef herds, the odds of a calf dying in its first 2 days of life were in general lower when it was born to a multiparous dam (odds ratio [**OR**]: 0.77 to 1.18, 95% CI: 0.56 to 1.51) relative to a primiparous dam, except when veterinary assistance was provided at their birth; when veterinary assistance was provided to a calf at their birth and the calf was born to a multiparous dam, its odds of dying within the first two days were 1.17 to 2.27 (95% CI: 0.77 to 3.28) times greater than a calf born to a primiparous dam that also required veterinary assistance at their birth.

The influence of dystocia on calf mortality has been well documented (Johanson and Berger, 2003; Mee et al., 2008; Gulliksen et al., 2009), as has the impact of dystocia on cow mortality (Dematawena and Berger, 1997; Shahid et al., 2015). Nevertheless, the present study is the first to elucidate the long-term consequences of dystocia at an animal's own birth on mortality both as a young animal and when that animal becomes a cow. The antagonistic relationship observed in the present study between the association of assistance at an animal's birth on the odds of mortality as a young animal relative to when that animal becomes a cow may be due to an incompatibility between body size proportions relative to pelvic area dimensions (Deutscher, 1987; Mee, 2008). For example, Johanson and Berger (2003) identified both a 1.13 times greater odds of dystocia with each additional kilogram calf birthweight but also a reduction in the odds of dystocia as pelvic area of the animal's dam increases. Therefore, calves most likely to be born without assistance at their birth (and as a result also have lower odds of dying) are those that have a low birth weight and/or are born to a dam with a large pelvic area. Nevertheless, calves born with a low birth weight likely maintain both a lower mature body weight and/or a smaller pelvic area throughout their lifetime, which may contribute to greater risk of dystocia when that animal calves and subsequently may then render her more likely to die due to dystocia. Such an antagonistic correlation between direct dystocia and maternal dystocia has been documented at a genetic level (Eaglen and Bijma, 2009). The results from the present study corroborate previous research that have found the use of "easy calving" sires both reduces dystocia on-farm and also reduces the odds of both calf and cow mortality in the short term (Mee et al., 2008; Dechow et al., 2012; McHugh et al., 2014). Nonetheless, results from the present study should raise concerns among producers that use such "easy calving" sires to breed female replacements as females born without assistance at their birth are themselves more likely to die once they enter the lactating dairy herd compared with calves that required veterinary assistance at their birth.

Twins

The odds of a twin calf dying within 2 d of birth were up to 2.31 (95% CI: 2.03 to 2.64) times greater than singletons, and although the extent of the association declined thereafter, the greater odds of death in twins did not disappear until 182 d of age (Supplementary Table 3; Table 4). As mature animals, there was no differential in the risk of mortality between cows born as singleton or twin (Supplementary Table 4). Nonetheless, cows that produced twins had a greater odds of dying during their lactation compared with cows that produced singletons, although the difference was only statistically significant ($P < 0.001$; Supplementary Table 4) for multiparous cows in dairy herds (OR per parity ranged from: 1.59 to 2.03, 95% CI: 1.30 to 2.27).

Results from the present study corroborate findings of previously documented associations between twin births and stillbirths (Mee et al., 2008; Gulliksen et al., 2009) as well as associations between dairy cows that produce twins and cow mortality (Shahid et al., 2015). Nevertheless, our work extends this knowledge to the long-term implications of twins on mortality as the animal matures and identifies that twin animals are not at greater odds of dying once they become cows. Both dairy and beef herds should therefore allocate farm resources to both cows that produce twin calves as well as to the twin calves themselves during their first 6 mo of life.

Table 4. Associations between animal gender, twin births, and stillbirths on the odds ratio of mortality (95% CI in parentheses) per age group in dairy and beef herds[1]

Mortality category	Gender	Twin births	Stillbirths
Dairy herds			
0 to 2, d	1.02 (0.96 to 1.08)	1.96 (1.74 to 2.21)***	1.89 (1.69 to 2.11)***
3 to 7, d	1.08 (1.00 to 1.17)	1.55 (1.31 to 1.84)***	1.49 (1.27 to 1.74)***
8 to 30, d	1.62 (1.52 to 1.73)***	1.25 (1.08 to 1.45)**	1.23 (1.08 to 1.40)**
31 to 182, d	1.71 (1.63 to 1.81)***	1.16 (1.01 to 1.33)*	1.14 (1.02 to 1.28)*
183 to 365, d	1.44 (1.32 to 1.56)***	1.19 (0.97 to 1.46)	1.07 (0.88 to 1.29)
366 to 730, d	3.23 (2.89 to 3.61)***	1.08 (0.85 to 1.39)	1.07 (0.85 to 1.33)
731 to 1,095, d	6.15 (5.18 to 7.30)***	1.23 (1.00 to 1.53)	1.10 (0.93 to 1.31)
Beef herds			
0 to 2, d	1.15 (1.07 to 1.23)***	2.31 (2.03 to 2.64)***	1.84 (1.58 to 2.13)***
3 to 7, d	1.20 (1.09 to 1.33)***	1.46 (1.17 to 1.83)***	1.38 (1.07 to 1.78)*
8 to 30, d	1.07 (0.99 to 1.16)	1.52 (1.27 to 1.82)***	1.44 (1.17 to 1.76)***
31 to 182, d	1.14 (1.08 to 1.21)***	1.24 (1.07 to 1.43)**	1.25 (1.05 to 1.47)*
183 to 365, d	1.71 (1.59 to 1.85)***	0.97 (0.79 to 1.20)	1.13 (0.90 to 1.42)
366 to 730, d	2.33 (2.15 to 2.54)***	1.06 (0.86 to 1.30)	0.96 (0.74 to 1.24)
731 to 1,095, d	3.34 (2.83 to 3.94)***	1.04 (0.73 to 1.49)	0.81 (0.54 to 1.20)

[1]Odds ratio for gender, twin births, and stillbirths compare the likelihood of mortality for a male relative to a female, a twin relative to a singleton and an animal born to a dam that had a stillborn calf in any lactation prior to the animal's birth relative to an animal born to a dam that did not have a stillbirth in a lactation prior to the animal's birth, respectively.

***$P < 0.001$, **$P < 0.01$, *$P < 0.05$.

Gender

Both the animal's gender and their progeny's gender were significant risk factors for young animal mortality (Supplementary Table 3) and for cow mortality (Supplementary Table 4), respectively. Although not significant for all age groups, males had up to 6.15 (95% CI: 5.18 to 7.30) and 3.34 (95% CI: 2.83 to 3.94) times greater odds of dying compared with their female contemporaries in both dairy and beef herds, respectively (Table 4). Similarly, cows in dairy herds that produced male singleton progeny had 1.09 to 1.11 times (95% CI range: 1.04 to 1.19) greater odds of dying during their lactation than cows that produced female singleton progeny (results per parity not presented). In beef herds, cows that produced male singletons also numerically had a greater odds of dying, yet the association was only significant ($P < 0.001$; Supplementary Table 4) for fifth parity cows (OR: 1.20, 95% CI: 1.08 to 1.34).

The well-established greater risk of stillbirth among males has been attributed to their increased risk of dystocia (Mee, 2008), heavier birth weights (Meijering, 1984; McDermott et al., 1992), and fetal malposition (Holland et al., 1993). The use of a multiple regression model in the present study, however, ensured that the observed association between gender and mortality was independent of the effects of dystocia and yet, greater deaths still persisted in both the males themselves and the cows that produced them. Moreover, the present study is, to our knowledge, the first to quantity the long-term associations between the gender of the animal itself and its odds of mortality.

Fisher (1930) proposed that natural selection favors populations with an equal tertiary sex ratio. The secondary sex ratio in our study (dairy herds: 51.4:48.6; beef herds: 51.2:48.8) and elsewhere (Roche et al., 2006; Berry et al., 2011) suggest a skewed secondary sex ratio in favor of males. The bias in secondary sex ratio toward males is likely a necessity to ensure equal tertiary sex ratio given the greater odds of mortality in males. Coupled with the increased likelihood of dystocia associated with male calves, cows that produce males tend to have greater body fat reserves (Roche et al., 2009) and, independent of calf gender, obese cows also tend to experience greater dystocia (Chassagne et al., 1999). Obese cows and cows that experience dystocia are more likely to succumb to metabolic health disorders (Gillund et al., 2001; Roche et al., 2009) in their lactation which can result in death (Thomsen et al., 2004; McArt et al., 2012). To minimize the risk of both young animal mortality and cow mortality, producers could therefore consider using sexed semen where possible to generate females rather than males.

Gestation Length

Although not significant in either dairy or beef herds ($P > 0.05$; Supplementary Table 3), there was a tendency for calves aged less than 30 d to have a greater odds of dying where they were gestated ≤ 277 d (OR: 0.84 to 2.66, 95% CI: 0.18 to 7.17) or gestated ≥ 289 d (OR: 0.41 to 1.33, 95% CI: 0.19 to 2.54), compared with calves gestated for between 278 and 288 d, inclusive. Moreover, no association ($P > 0.05$; Supplementary Table 4) existed in dairy or beef herds between the odds of a cow dying in a given lactation and the length of the gestation period of her most recent calving. Nevertheless, it should be noted that in the present study, the number of gestation length records available were fewer than for any of the other risk factors considered for both young animals (Supplementary Table 1) and cows (Supplementary Table 2); the scarcity of records, particularly at the extremities (i.e., gestations ≤ 277 or ≥ 289 d), may have resulted in a lack of statistical power.

Findings from the present study, nonetheless, support earlier documented nonlinear associations between both short and long gestations being associated with a greater odds of calf mortality (Johanson and Berger, 2003; Bleul, 2011; Jenkins et al., 2016). There are no documented associations between the risk of a cow dying and the length of the gestation period of her most recent calving. Although the standard errors were large in the present study, results suggest that independent of both calving difficulty and animal gender, calves born following either short or long gestations are more likely to die in early life.

Dam Parity

Older cows had greater odds of producing calves that were more likely to survive, both as young animals (Fig. 3; Supplementary Table 3) and even subsequently as cows (Supplementary Table 4). Relative to an animal born to a primiparous dam, the odds of death for a first, second, third, fourth, and fifth parity cow born to at least a fifth parity dam in both dairy and beef herds ranged from 0.72 to 0.86 (95% CI: 0.62 to 0.95), 0.74 to 0.88 (95% CI: 0.62 to 0.99), 0.81 to 0.96 (95% CI: 0.70 to 1.15), 0.68 to 0.88 (95% CI: 0.58 to 0.97), and 0.80 to 0.99 (95% CI: 0.70 to 1.20), respectively. The present study corroborates earlier studies (Johanson and Berger, 2003; Riley et al., 2004; Yao et al., 2014) that indicate a greater frequency of preweaning mortality in the progeny of younger cows. This outcome may be due to differences in mothering ability or colostrum quality between older and younger cows. Passive absorption of immunoglobulins from colostrum is essential for the development and longevity of healthy calves (Faber et al., 2005; Godden, 2008) and the benefits of colostrum ingestion as a calf have even been reported to translate into greater milk production yields in Brown Swiss first and second parity cows (Faber et al., 2005). Older cows produce superior quality colostrum (Gulliksen et al., 2008; Kehoe et al., 2011; Conneely et al., 2013) and the progeny of multiparous dams achieve greater passive transfer of immunity than the progeny of primiparous dams (Waldner and Rosengren, 2009). The present study further builds on existing knowledge by identifying that older cows (i.e., survived longer in the herd) had greater odds of producing progeny that themselves survived for longer.

Age at First Calving

Although the difference was only statistically significant in beef herds ($P < 0.001$; Supplementary Table 4), cows that calved for the first time at 18 mo of age, or older than 38 mo of age, had a greater odds of dying as primiparous cows compared with primiparous cows that calved for the first time at any other age. Relative to calving at 18 mo of age, a primiparous cow that calved for the first time between 23 and 25 mo of age, inclusive had an odds of dying of only 0.42 to 0.43 times (95% CI: 0.17 to 1.09) and 0.32 to 0.36 times (95% CI: 0.19 to 0.53) in dairy and beef herds, respectively. Once a cow survived her first lactation, her odds of dying in subsequent lactations was not associated with her age at first calving in either dairy or beef herds thereafter (Supplementary Table 4).

These findings are supported by Berry and Cromie (2009) who reported that Holstein heifers that calved for the first time at 24 mo of age were more likely to survive to older parities compared with heifers that calved for the first time at 36 mo of age. Ettema and Santos (2004) also documented compromised milk production and reproductive performance in Holstein primiparous cows that calved for the first time less than 700 d of age (approx. <23 mo), compared with cows that calved between 701 and 750 d of age (approx. 23 to 25 mo). These findings, together with results from the present study, indicate that producers could aim to optimize age at first calving to both minimize cow mortality and maximize economic returns (Ettema and Santos, 2004), by targeting an age at first calving of between 23 and 25 mo of age in both dairy and beef herds.

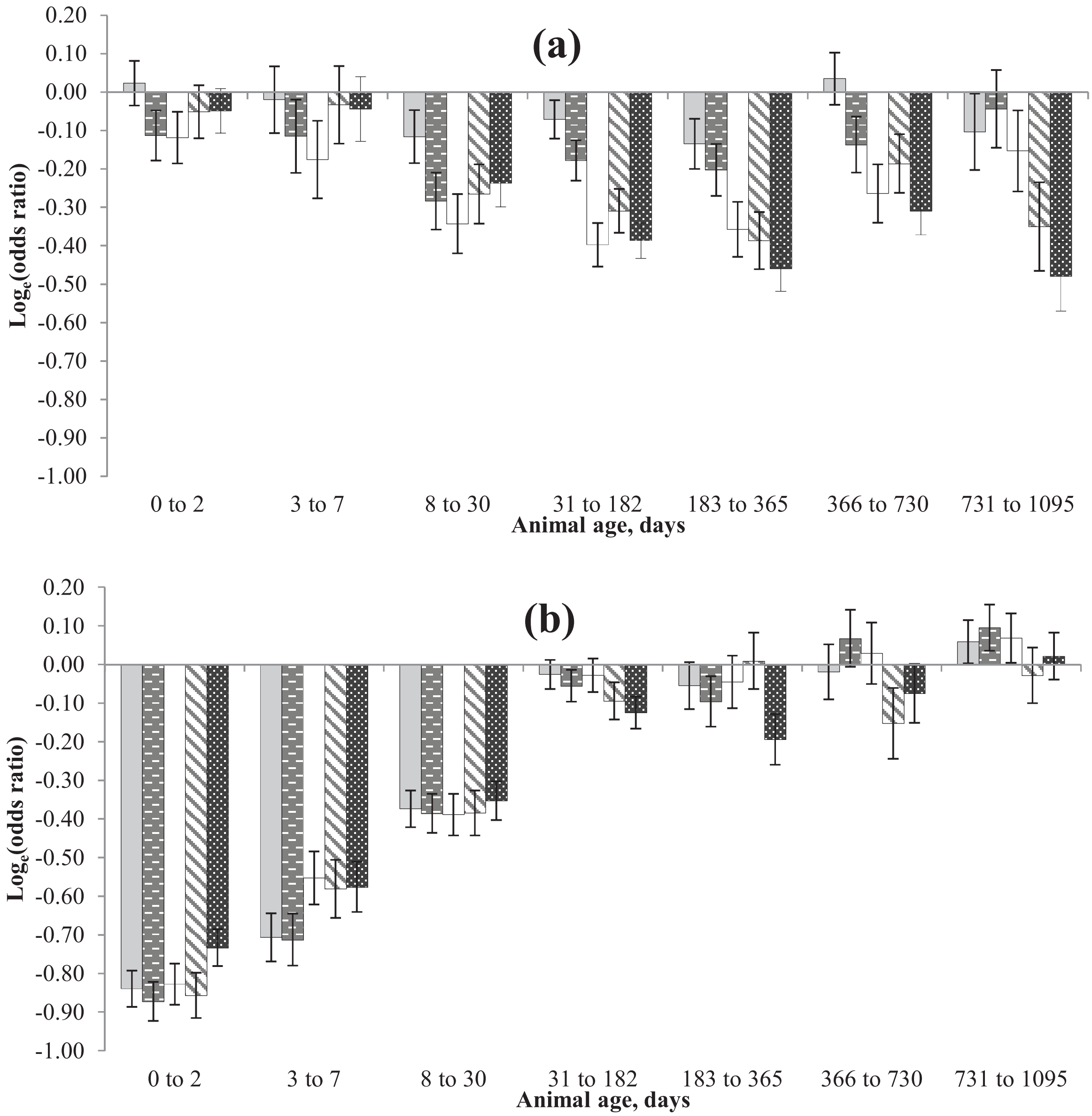

Figure 3. Associations between the age of the animal's dam (i.e., parity number) and the $\log_e$ of the odds ratio of mortality (and 1 SE at each side) per age group in (a) dairy and (b) beef herds; parities include second (solid gray filled), third (speckled-gray filled), fourth (no fill), fifth (diagonal-gray striped filled), and sixth or greater (speckled-black filled). First parity cows are the referent parity (not shown).

Stillbirths

Being born to a dam that previously had a stillbirth (i.e., a calf that died within 2 d of birth) or having a stillbirth were significant risk factors for young animal mortality (Supplementary Table 3) and for cow mortality (Supplementary Table 4), respectively. A calf born to a dam that had a stillbirth in any previous lactation had nearly twice the odds of dying (95% CI: 1.07 to 2.13) in the first 30 d of life, relative to a calf born to a dam that did not previously have a stillborn calf (Table 4). Additionally, a cow that had a stillborn calf also had greater odds of dying during that lactation than a cow that did not have a stillborn calf in both dairy (OR per parity ranged from: 1.99 to 2.58, 95% CI: 1.69 to 3.01) and beef (OR per parity ranged from: 3.07 to 5.29, 95% CI: 2.63 to 7.00) herds. In dairy herds, the odds of a primiparous cow dying when she had a stillborn calf in that lactation was also dependent on the extent of calving assistance provided ($P < 0.001$). Relative to a primiparous cow that did not have a stillborn calf in that lactation, the odds of a primiparous cow dying in a dairy herd when she had a stillborn calf in that lactation were 1.84 (95% CI: 1.42 to 2.37), 1.52 (95% CI: 1.13 to 2.06), 2.03 (95% CI: 1.50 to 2.76), and 2.63 (95% CI: 1.72 to 4.02) times greater when provided with no assistance, some assistance, extensive assistance without veterinary intervention, and extensive assistance resulting in veterinary intervention, respectively.

Mee et al. (2008) reported that dairy cows that produced a stillborn calf were 4.21 times more likely to produce a stillborn calf in their following lactation, whereas Thompson and Rege (1984) reported a low repeatability (0.02) for mortality within 48 h of life between first and second parity dairy cows. Earlier studies have also identified that cows that produce a stillborn calf are more likely to die in that lactation (Bicalho et al., 2007; Shahid et al., 2015) as well as being at greater risk of being culled in that lactation (Bicalho et al., 2007). Results from the present study, coupled with previous research, indicate that animal mortality may be under genetic control (Hansen et al., 2003; Fuerst-Waltl and Sørensen, 2010) and genetic selection for reduced mortality throughout an animal's lifetime may be possible. Nevertheless, research to date has solely focused on the association between stillbirths and mortality in dairy herds, whereas the present study is the first to document such associations in beef herds. Results indicate that producers should either consider culling or allocating greater resources to cows that produce stillborn calves as these cows are more likely to die themselves in that lactation but also their future progeny have greater odds of mortality.

Calving Period Factors

Although the length of a herd's calving season was not associated with the odds of mortality, the timing of birth during the calving season was associated with the odds of mortality in both young animals (Supplementary Table 3) and their dams (Supplementary Table 4). The concentration of births surrounding an animal's own birth was also associated with the odds of a calf dying in the first 182 d of life in both dairy and beef herds (Supplementary Table 3); the odds of a calf dying reduced as the concentration of herd-year births occurring within 7 d of the animal's own birth increased (Fig. 4). Although only significant for second parity cows in dairy herds ($P < 0.001$; Supplementary Table 4), the odds of a cow dying typically reduced as the concentration of herd-year calving events occurring within 7 d of the cow's own calving increased (results not presented).

In dairy herds, the odds of calves dying within 2 d of birth when born late or very late in the calving season were only 0.78 (95% CI: 0.75 to 0.92) and 0.83 (95% CI: 0.69 to 0.88) times that, respectively, of calves born very early in the calving season. In contrast, relative to calves born very early in a dairy herd, the odds of a young animal dying between 7 and 730 d of age were 1.21 to 1.71 (95% CI range: 1.11 to 1.91) and 1.40 to 1.96 (95% CI range: 1.26 to 2.30) times greater when the animal was born late or very late in the calving season, respectively. Moreover, relative to cows in dairy herds that calved very early in the calving season, the odds of cows dying during their lactation when they calved very late were 1.31 to 1.47 (95% CI range: 1.17 to 1.62) times higher, although the difference was not significant for second parity cows ($P > 0.05$; Supplementary Table 4).

In beef herds, the odds of a cow dying were not associated with the time period within the calving season she calved in ($P > 0.01$; Supplementary Table 4). Similar to dairy herds, the odds of calves dying within 2 d of age in beef herds were only 0.75 times (95% CI: 0.64 to 0.88) as likely to die when they were born very late in the herd's calving season compared with being born very early in the calving season. Beyond 2 d of age, calves had a greater odds of dying in beef herds when they were born early in the calving season as opposed to very early, late or very late in the calving season, although the difference in the odds of mortality was only significant (Supplementary Table 3) for calves aged 8 to 30 d of age (OR: 1.41, 95% CI: 1.21 to 1.64).

Industry goals on pasture-based systems target high reproductive performance through narrow breeding windows to maximize herd profitability (Roche et al., 2000; Verkerk, 2003). To our knowledge, this is the first study to quantify the association between a compact calving season system and subsequent odds of mortality. The favorable association observed in the present study, between increasing concentration of herd-mate births/calvings coinciding with the animals own birth/calving and the continuous decline in the odds of mortality for both calves up to 182 d of age and cows, suggests that narrow calving windows in both dairy and beef herds may be advantageous in reducing calf and cow mortality.

The differing odds of mortality associated with timing of birth across the different age groups in the present study are likely due to differing causes. For example, the greater odds of mortality during the first 2 d of life associated with calvings occurring earlier in the calving season may be caused by a lack of supervision at calving, perhaps due to unexpected or premature calvings. Nonetheless, the greater odds of mortality beyond 2 d of age associated with calvings occurring later in the calving season may be due to increased infection pressure as a result of deterioration in housing sanitary conditions as the calving period progresses.

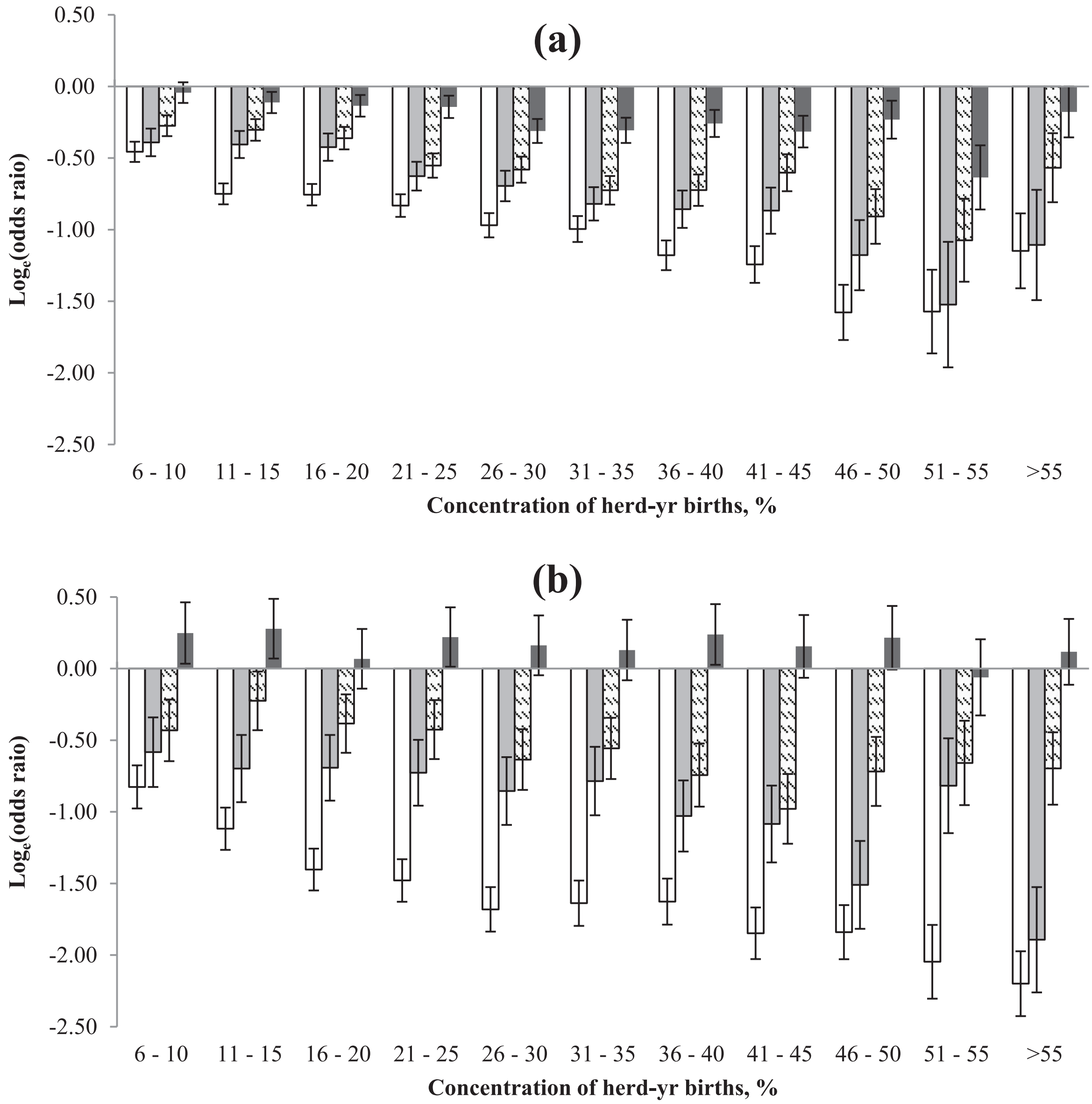

Figure 4. Associations between the concentration of herd-year births occurring ±7 d of the animal's birth and the $\log_e$ of the odds ratio of mortality (and 1 SE at each side) at 0 to 2 d (no fill), 3 to 7 d (light gray fill), 8 to 30 d (dashed) and 31 to 182 d (dark gray fill) in (a) dairy and (b) beef herds. The referent category is 0 to 5% (not shown).

In dairy herds in the present study, the greater odds of death for cows that calve later in the calving season may be due to the practice of terminating the lactation of all cows in seasonal-calving herds approximately 6 to 8 wk prior to the expected start date of the forthcoming calving season. Cows subjected to longer dry periods gain more body condition (Pezeshki et al., 2007; Watters et al., 2008), with higher BCS at calving (i.e., ≥3.5 on a 5-point scale) associated with increased risk of metabolic disorders (Gillund et al., 2001; Roche et al., 2009). Therefore, later calving cows are likely to have gained more BCS at calving that may render them more likely to die during their lactation as a result of succumbing to metabolic disorder(s) compared with cows that calve earlier in the calving season. In addition, cows genetically superior for milk yield tend to have a greater predisposition to postparturition metabolic disorders than cows genetically inferior for milk yield (Pryce et al., 1997; Appuhamy et al., 2009), which may in part explain the absence of a significant association ($P > 0.01$) between the timing of calving and the odds of dying for cows in beef herds that calve later in the calving season.

To our knowledge, no study has previously examined the association between timing of birth/calving with either young animal or cow mortality. Producers should, therefore, place a greater emphasis on having resources organized well in advance of the calving season, optimizing BCS, particularly for "late-calvers," as well as maintaining hygienic standards throughout the entire calving period to minimize consequential ill-health and possible death.

Herd Size

Although the association was not always statistically significant ($P > 0.001$), depending on age or cow parity, both young animals (Supplementary Table 3) and cows (Supplementary Table 4) that resided in larger dairy and beef herds, generally had greater odds of dying than animals that resided in smaller herds (Fig. 5). For example, in dairy herds the odds of a calf dying in its first week of life were 1.19 to 1.23 (95% CI range: 1.01 to 1.39) times greater when it resided in a herd with 66 to 90 cows, inclusive, relative to a herd with 30 to 50 cows; nonetheless, there was no differential in the odds of dying for calves aged ≤7 d when they resided in herds with >90 cows relative to 30 to 50 cows. From 8 d of age, for both young animals and cows that resided in dairy herds comprising of at least 90 cows, their odds of dying were 1.17 to 1.47 (95% CI range: 1.00 to 1.61) times greater than their contemporaries that resided in dairy herds with 30 to 50 cows, inclusive.

For young animals in beef herds, the greatest association between the odds of dying and herd size were for animals aged between 731 and 1,095 d; where an animal resided in a beef herd with 25 to 30 cows, inclusive, its odds of dying between 731 and 1,095 d of age were only 0.87 times that of an animal residing in a herd with 10 to 16 cows, inclusive. In contrast to dairy herds, where the odds of dying in larger herds were greatest for primiparous cows, there was no association ($P > 0.05$) between herd size and the odds of a primiparous cow dying in beef herds (Fig. 5; Supplementary Table 4); nevertheless, similar to dairy herds, multiparous cows in beef herds had the greatest odds of dying during

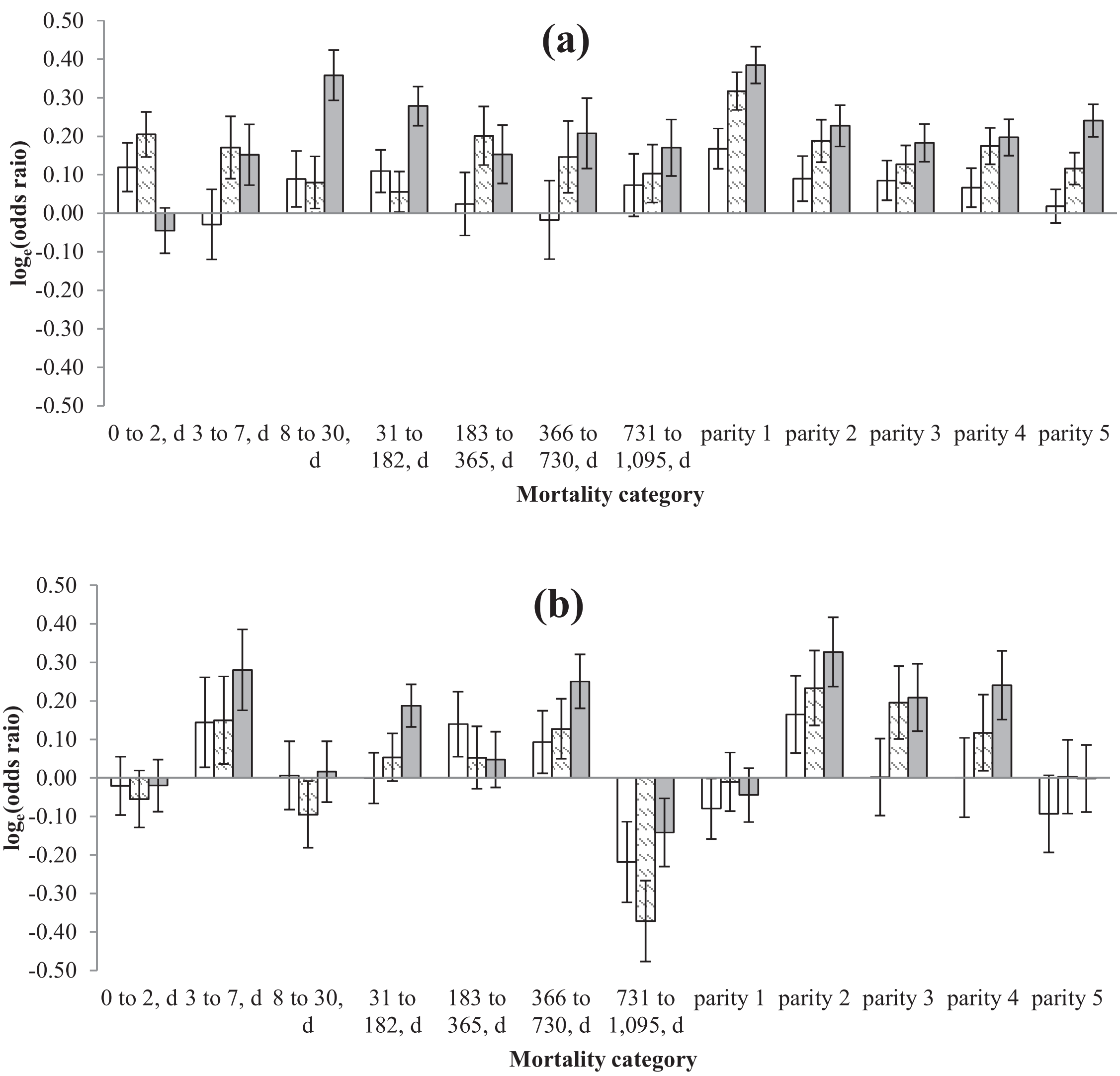

Figure 5. Associations between herd size and the log$_e$ of the odds ratio of mortality (and SE) per age or parity category in (a) dairy and (b) beef herds. Dairy herd size categories include 30 to 50 calvings (referent category, not shown), 51 to 65 calvings (no fill), 66 to 90 calvings (dashed), >90 calvings (filled). Beef herd size categories include 10 to 16 calvings (referent category, not shown), 17 to 22 calvings (no fill), 23 to 30 calvings (dashed), and >30 calvings (filled).

their lactation when they resided in the largest herd size category (>30 cows), although this was not significant for fifth parity cows in beef herds ($P > 0.05$; Supplementary Table 4).

Earlier studies in both beef and dairy herds have found inconsistent associations between herd size and the risk of mortality in both young animals (Mee et al., 2008; Gulliksen et al., 2009; Murray et al., 2016) and cows (McConnel et al., 2008; Miller et al., 2008; Alvåsen et al., 2012). The present study, however, examined the association of herd size with multiple age groups and cow parities and found a generally consistent overall trend across all age groups and cow parities of increasing odds of mortality in larger herds. To our knowledge, the present study is the first to examine the association of herd size on mortality in animals >2 d of age in pasture-based production systems. Cattle residing in larger pasture-based herds are generally required to walk longer distances to graze forage compared with cattle in smaller herds; longer walking distances are often accompanied by an increase in herd lameness prevalence, which has been associated with a greater risk of cow mortality in dairy herds (McConnel et al., 2008). Moreover, producers in larger herds may rely on hired labor or mechanization (e.g., robotic milking machines) to perform farm tasks, which may result in animals receiving less attention from the producer and a subsequent rise in herd mortality incidence risk.

Herd Expansion

The odds of mortality in both young animals and cows that resided in expanding dairy herds were lower than in nonexpanding dairy herds (Table 5; Supplementary Tables 3 and 4). Only during the first 2 d of life were the odds of dying in a dairy herd greater in expanding herds (OR: 1.11 to 1.25, 95% CI: 1.02 to 1.39) relative to nonexpanding herds. Beyond 2 d of age, young animals and cows had the lowest odds of death when they resided in dairy herds expanding at a slow rate relative to dairy herds that were not expanding or expanding at a rapid rate (Table 5). In addition, the differential in the odds of a calf dying between 8 and 30 d of age (but no other age group) due to the rate of herd expansion was dependent on herd size in dairy herds ($P > 0.001$); a calf had lower odds of dying between 8 and 30 d of age when it resided in a herd of 30 to 50 cows when that herd was expanding at a rapid (OR: 0.68, 95% CI: 0.47 to 0.97) rate relative to a nonexpanding herd, although there was no differential in the odds of dying during this period between nonexpanding herds and herds expanding at a slow rate. In contrast, a calf had lower odds of dying between 8 and 30 d of age when it resided in a dairy herd of >90 cows when that herd was expanding at a slow (OR: 0.42, 95% CI: 0.31 to 0.56) rate relative to a nonexpanding herd, although there was no differential in the odds of dying during this period between nonexpanding herds and herds expanding at a rapid rate.

Expansion in beef herds was not associated with odds of mortality in young animals ($P > 0.001$; Supplementary Table 3) but expansion was associated with a reduced odds of mortality in cows, albeit only in primiparae (Supplementary Table 4). The odds of a primiparous cow dying during her lactation when she resided in a rapidly expanding

Table 5. Associations between the rate of herd expansion (slow expansion and rapid expansion relative to not expanding) on the odds ratio of mortality (95% CI in parentheses) per age or parity category in dairy herds[1]

Age or parity category	Slow expansion	Rapid expansion
0 to 2, d	1.25 (1.14 to 1.39)	1.11 (1.02 to 1.21)
3 to 7, d	0.88 (0.76 to 1.02)	1.31 (1.19 to 1.45)
8 to 30, d	0.75 (0.67 to 0.85)	0.96 (0.88 to 1.05)
31 to 182, d	0.73 (0.66 to 0.80)	0.98 (0.91 to 1.05)
183 to 365, d	0.72 (0.63 to 0.83)	0.96 (0.87 to 1.05)
366 to 730, d	0.76 (0.64 to 0.89)	1.21 (1.09 to 1.34)
731 to 1,095, d	0.80 (0.71 to 0.90)	0.91 (0.84 to 0.99)
Cow parity 1	0.83 (0.75 to 0.91)	0.88 (0.83 to 0.94)
Cow parity 2	0.78 (0.70 to 0.86)	0.86 (0.80 to 0.92)
Cow parity 3	0.80 (0.73 to 0.87)	0.92 (0.87 to 0.99)
Cow parity 4	0.82 (0.75 to 0.88)	0.98 (0.92 to 1.04)
Cow parity 5	0.83 (0.78 to 0.89)	0.85 (0.81 to 0.90)

[1]Rate of herd expansion defined as herds increasing at an average rate of 0 cows/yr (not expanding), 1 to 3 cows/yr (slow expansion), or ≥4 cows/yr (rapid expansion) between the year 2007 to 2015, inclusive.

beef herd were only 0.71 times (95% CI: 0.59 to 0.86) that of a primiparous cow that resided in a nonexpanding beef herd.

Herd expansion in dairy herds has been associated with compromised biosecurity measures (Faust et al., 2001), increased lameness (Bewley et al., 2001), lower average herd cow age (Jago and Berry, 2011), and increased human resource challenges (Bewley et al., 2001; Hadley et al., 2002). Irrespective of these challenges, the results from the present study suggest that herd expansion in either dairy or beef herds does not increase an animal's odds of dying. The present study, however, did not examine the association between whether expansion occurred as a result of homebred or purchased stock, where it is likely that expansion due to stock purchases would have greater odds of mortality due to the biosecurity-associated risks.

CONCLUSION

Although several studies of risk factors for mortality in cattle exist, those studies have generally been limited to dairy herds and do not consider any temporal trends in the odds of mortality over an extensive period of the animal's lifetime with such a vast array of risk factors. Nevertheless, some studies (Gardner et al., 1990; Gulliksen et al., 2009) have reported mortality incidence over time and risk factors for mortality over shorter life periods. Although the size of dataset used in the present study was large, cross-sectional studies (such as the present study) are not without their limitations. For example, the dataset used was not collected for the sole purposes of the present study, which as a consequence may have led to some inaccuracies (e.g., breed composition may not be fully correct due to parentage errors or mortality incidence risk may have been underestimated due to incomplete data recording). In addition, all animals did not have a record for each risk factor (e.g., gestation length and calving assistance). Nonetheless, one could assume that such errors are not systematic and the sheer size of the dataset used in the present study should overcome the inaccuracies associated with cross-sectional studies.

Results from the present study suggest that the risk factors associated with mortality are, in general, the same in both dairy and beef herds, although the magnitude of the associations sometimes differs. In both dairy and beef herds, among the greatest risk factors for young animal mortality were the extent of calving assistance provided at birth, animal gender, being born a twin or being born from a young dam or a dam that had a stillbirth in a previous lactation. For cows, the greatest period of risk of mortality in both dairy and beef herds were in the initial weeks postpartum with the greatest risk factors for cow mortality similar to those for young animal mortality; the extent of calving assistance provided at calving, progeny gender, twin progeny, or having stillborn progeny were among the greatest risk factors for cow mortality. To minimize the odds of both young animal and cow mortality producers should focus management practices on these areas; producers could use ultrasonography services for pregnant females to determine both the predicted date of calving, expected progeny gender and if twin births are to be anticipated. Producers could use such information to prioritize attention to twin-bearing cows and cows carrying males.

SUPPLEMENTARY DATA

Supplementary data are available at *Animal Frontiers* online.

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