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A multivariable assessment quantifying effects of cohort-level factors associated with combined mortality and culling risk in cohorts of U.S. commercial feedlot cattle

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Abstract

Economic losses due to cattle mortality and culling have a substantial impact on the feedlot industry. Since criteria for culling may vary and may affect measures of cumulative mortality within cattle cohorts, it is important to assess both mortality and culling when evaluating cattle losses over time and among feedlots. To date, there are no published multivariable assessments of factors associated with combined mortality and culling risk. Our objective was to evaluate combined mortality and culling losses in feedlot cattle cohorts and quantify effects of commonly measured cohort-level risk factors (weight at feedlot arrival, gender, and month of feedlot arrival) using data routinely collected by commercial feedlots. We used retrospective data representing 8,904,965 animals in 54,416 cohorts from 16 U.S. feedlots from 2000 to 2007. The sum of mortality and culling counts for each cohort (given the number of cattle at risk) was used to generate the outcome of interest, the cumulative incidence of combined mortality and culling. Associations between this outcome variable and cohort-level risk factors were evaluated using a mixed effects multivariable negative binomial regression model with random effects for feedlot, year, month and week of arrival. Mean arrival weight of the cohort, gender, and arrival month and a three-way interaction (and corresponding two-way interactions) between arrival weight, gender and month were significantly ($P < 0.05$) associated with the outcome. Results showed that as the mean arrival weight of the cohort increased, mortality and culling risk decreased, but effects of arrival weight were modified both by the gender of the cohort and the month of feedlot arrival. There was a seasonal pattern in combined mortality and culling risk for light and middle-weight male and female cohorts, with a significantly ($P < 0.05$) higher risk for cattle arriving at the feedlot in spring and summer (March through September) than in cattle arriving during fall, and winter months (November through February). Our results quantified effects of covariate patterns that have been heretofore difficult to fully evaluate in smaller scale studies; in addition, they illustrated the importance of utilizing multivariable approaches when quantifying risk factors in heterogeneous feedlot populations. Estimated effects from our model could be useful for managing financial risks associated with adverse health events based on data that are routinely available.

Keywords: cattle, culling, mortality, negative binomial regression, risk factors

1. Introduction

Losses due to cattle mortality and culling have tremendous economic impacts on North American feedlot production systems (Smith et al., 2001). These economic impacts reflect costs associated with feed consumption, personnel labor, pharmaceutical products, carcass disposal, price paid for the animal, and loss of interest on invested money. Despite continued advances in health management programs and pharmaceutical products, recent research indicates that U.S. feedlot mortality risk has increased over time (Loneragan et al., 2001; Loneragan, 2004; Babcock et al., 2006). However, the apparent increased risk over time may be due to true increases in mortality across feedlot populations, changes in cattle demographics and corresponding risk factors, or an increasing reluctance of feedlots to cull cattle. Culling is defined as removal of animals from their cohort prior to harvest. Feedlots may have different criteria on culling chronically ill or poor performing animals prior to harvest, and may cull animals in an attempt to decrease overall mortality. If feedlot personnel cull animals quickly and aggressively, the mortality risk for the population may appear low relative to similar populations of cattle in feedlots with more conservative culling practices. Some researchers have suggested that a more comprehensive approach to assessing cattle losses across multiple feedlots and years would require that data on mortality and culling are combined and assessed simultaneously using multivariable models accounting for differences in cattle populations (Loneragan, 2004).

Multivariable approaches assessing risk factors for mortality and culling are important because cattle demographics changing over time, within and across feedlots, can confound the observed relationship between seasonal patterns and health risks (Ribble et al., 1995). Literature quantifying effects of risk factors of feedlot mortality are limited, and there are no published data on factors affecting culling of feedlot cattle. Animal weight at feedlot arrival, gender, arrival month, weather, and commingling of cattle have been found to be associated with feedlot mortality risk (Martin et al., 1982; MacVean et al., 1986; Ribble et al., 1998; Loneragan, 2004). However, most studies of mortality risks have used data from only a limited number of feedlots, or used data aggregated by month at the feedlot level; when cohort should be the unit of interest as feedlots tend to purchase, manage and market cattle as cohorts (often called "lots" of cattle). There are no published data demonstrating the effects of multiple risk factors and their interactions on combined mortality and culling risk in cohorts of commercial feedlot cattle. Quantifying the effects of potential risk factors will allow managers of feedlot finances and cattle health to make more informed production decisions about cattle cohorts they typically purchase, and also provide data on atypical cohorts where the effects of risk factors are often difficult to quantify due to a lack of data. The objective of our study was to quantify the effects of commonly measured cohort-level risk factors on combined cumulative mortality and culling risk within cattle cohorts using operational data routinely collected by commercial feedlots.

2. Materials and Methods

2.1. Data

We collected cohort-level data from commercial feedlots in four U.S. states (Colorado, Kansas, Nebraska, and Texas). Cohorts were considered as "lots" of animals that may or may not have been housed in the same physical location (pen) for the duration of the feeding period; however, all animals in a lot were purchased, managed and marketed similarly. Cohort-level variables regularly collected across feedlots were: mean weight on arrival at the feedlot (recorded on an interval scale), days on feed (recorded on a continuous scale), gender and arrival date (recorded on a nominal scale). Cattle were designated as male or female in our analysis, rather than steer or heifer, as data on the castration or pregnancy status on arrival to the feedlot were not consistently available. Data on several other potential risk factors were either not existent or were not collected consistently across feedlots; therefore, additional variables (e.g., shipping distance, source location, preconditioning) were not incorporated in the analysis. Study inclusion criteria included: feedlots that reported cohort-level data on both mortality and culling, cohorts classified as male or female (not mixed) that arrived to the feedlot between 2000 and 2007, and cohorts containing between 40 and 340 animals upon arrival with a mean arrival weight between 91 and 470 kg. The sum of mortality and culling counts for each cohort (given the number of cattle at risk) was used to generate the outcome of interest, hereafter referred as the combined mortality and culling risk, representing the cumulative incidence over each cohort's feeding period.

2.2. Regression model

Associations between cohort-level demographic factors with the incidence risk of the combined mortality and culling were modeled using a generalized linear mixed model (Proc GLIMMIX) built in SAS 9.2 (SAS Institute Inc., Cary, NC, USA), with a negative binomial distribution, log link function, and maximum likelihood estimation based on Laplace approximation of the marginal log likelihood. The count of combined mortality and culling within each cohort was the outcome of interest and the natural logarithm of the total number of cattle within each cohort upon feedlot arrival (considered our population at risk) was specified as the offset variable of the model. To account for the hierarchical structure of the data, a cross-classification of feedlot-years (11 feedlots in 2000, 13 in 2001-2002, 14 in 2003, and 16 in 2004-2007) was included as a random intercept to model the overdispersion arising from the lack of independence of cohorts nested within feedlots, and of feedlots nested within arrival years. In addition, arrival month (n = 12) was modeled as a random intercept using a first-order autoregressive covariance structure to account for the repeated measures of cohorts, within feedlot-years, over months with decay in correlation with increasing distance between observations (Dohoo et al., 2009). Lastly, arrival week (n = 5) within a month was modeled as a random intercept to control for the correlation of weeks within arrival months.

Independent variables tested in our regression models, which were also the main predictors of interest based on our causal models, included: mean arrival weight of the cohort, gender of the cohort, and arrival month. The linearity assumption between the log of the expected value of the incidence risk of the outcome and mean cohort arrival weight, originally recorded on a continuous scale, was not met. Thus, this variable was categorized into 22.7 kg (approximately 50 lbs, cutoff commonly used in the feedlot industry) categories using Walter's hierarchical methods to categorize ordinal independent variables (Walter et al., 1987). A backward elimination procedure (with $P < 0.05$) was used to collapse arrival weight categories inward toward the initially centered referent category (i.e., 295 to 317 kg, category that represented the most frequent cohort arrival weight). This process resulted in the following nine weight categories: <182, 182 to 204, 205 to 227, 228 to 249, 250 to 271, 272 to 317, 318 to 340, 341 to 362 and >362 kg. Gender of the cohort (male vs. female) and arrival month (January through December) were analyzed on a nominal scale as initially recorded by the feedlots. Variables pertaining to the length of the feeding period or days on feed and cohort size were considered intervening variables in our causal model, as they may intervene in the causal pathway between arrival weight class, arrival month, gender and the predicted outcome, respectively. Thus, these variables were not included in the final model as they would prevent us from correctly estimating the true effects of the main predictors of interest (Dohoo et al., 2009).

A pair-wise correlation analysis was performed using the Spearman's rank correlation statistic to identify possible collinearity among independent variables. If the value of the correlation statistic was |0.8| or higher, one of the variables was selected to be included into the multivariable model based upon completeness and quality of the available data (Dohoo et al., 2009).

After conducting bivariable analyses assessing the association between the combined mortality and culling risk with each independent variable, a mixed-effects multivariable main effects model was built by including variables significantly associated to the outcome at the 5% significance level ($P < 0.05$), using a manual backward elimination procedure.

A three-way interaction (and its corresponding two-way interactions) among arrival weight, gender, and arrival month, was tested ($P < 0.05$) using a backward elimination procedure. Significance testing for all stages of model building was performed using likelihood-ratio tests comparing the full to the reduced model for the categorical predictors included in our model (Dohoo et al., 2009).

Diagnostic assessment of residuals from the final multivariable model included the evaluation of the predicted values of the random variables in the model or best linear unbiased predictors (BLUPs) for the feedlot by year combinations. Predicted relative risk (RR) of combined mortality and culling risks based on analysis of 54,410 cohorts of commercial feedlot cattle were computed. The BLUPs are of the form of a feedlot by year combination mean minus the overall mean, as: $\bar{y}_{\bullet\bullet\bullet mn\bullet\bullet} - \bar{y}_{\bullet\bullet\bullet\bullet\bullet\bullet}$ where $\bar{y}_{\bullet\bullet\bullet mn\bullet\bullet}$ denotes the mean of the m^{th} arrival year at the nth feedlot and $\bar{y}_{......}$ denotes the overall mean all on the log base e or link function scale.

The inverse link of these predictors provides the following:

$$e^{y_{mn}-y} = e^{y_{mn}} - e^{y} = \frac{e^{y_{mn}}}{e^{y}} = \frac{\text{P (mortality and culling for mth year and nth feedlot)}}{\text{P(mortality and culling overall)}}$$

$$= \text{Relative Risk (RR) at nth feedlot in the mth year as compared to the overall average.}$$

Normal probability plots, Kolmogorov-Smirnov, Cramer-von Mises, and Anderson-Darling tests for normality were examined to assess the normality assumption of the BLUPs and general model fit. Graphical indication of departures from normality or statistically significant normality statistics ($P < 0.05$) were used as criteria to indicate lack of fit. To assess the pattern of combined mortality and culling risk over time across feedlots, estimates of the BLUPs were plotted across feedlots and arrival years based on the results of the final multivariable model. Residuals plots at the lowest level (i.e., cohort) were also visually examined to assess overall model fit and to identify potential outliers and influential observations. After verifying that no recording errors were made, observations from cohorts with a probability of combined mortality and culling risk equal or higher than 85% (n = 10) were censored given their removal improved model fit and convergence. Least square means and differences in model-adjusted means were estimated for variables included in significant interactions in the final multivariable model.

When building the mixed effects multivariable model, different distributions for count data (e.g., negative binomial, Poisson (Figure 1), binomial), random effects and covariance pattern models were attempted, including the use of days within a week as random intercept, and of sine and cosine functions to model arrival day, week and month. The best fitting model for dealing with the hierarchical structure of the data was chosen based on information criteria

(Akaike and Bayesian information criteria), the results of the generalized Chi-square statistic divided by its degrees of freedom, and appropriate model convergence.

3. Results

3.1. Descriptive statistics

A total of 54,406 cohorts (representing 8,904,965 individual animals) from 16 different feedlots during arrival years 2000 to 2007 were included in the final multivariable model. The participating feedlots were located in Colorado, Kansas, Nebraska, and Texas, and their capacities ranged from 22,000 to 82,000 cattle. The mean number of cattle within cohorts was 163 (SE = 0.32) with a median of 150 animals. Sixty-four percent of the cohorts were classified as male and 36% as female. Cohort-level mean cattle arrival weight ranged from 119 to 468 kg, with a median of 322 kg and mean of 316 kg (SE = 0.24). Cumulative mortality risk ranged from 0% to 31.9% with a median of 0.9% and mean of 1.5% (SE = 0.009%). Culling risk ranged from 0% to 100%, with a median of 0.9% and a mean of 0.8% (SE = 0.007%). The combined mortality and culling risk ranged from 0% to 100%, with a median of 1.4% and mean of 2.3% (SE = 0.43%). The mean ratio of mortalities to culls across feedlots (all years) ranged from 1.3 to 5.1, with a median of 2.0 and a mean of 2.3 (SE = 0.004); among different years (all feedlots) these ratios ranged from 1.2 to 3.2 with a median of 2.0 and mean of 2.1 (SE = 0.003).

3.2. Regression model

The final multivariable model for combined mortality and culling risk included the following significant ($P < 0.05$) predictors: gender of the cohort, arrival month, mean arrival weight class, and a three-way interaction (and corresponding two-way interactions) among the three main effects (parameter estimates are available upon request to the corresponding author). The effect of the cohort’s gender on combined mortality and morbidity risk depended on the weight class and the month of feedlot arrival. Figures 2 and 3, and Tables 1 and 2, depict the model-estimated probabilities of mortality and culling risk for the arrival weight groups for each arrival month by gender. Generally the lower arrival weight calves had higher probabilities of combined mortality and culling risk. Similar patterns are shown to exist for both males and females: as arrival weight increased, combined mortality and culling risk decreased. For males, light weight cattle (< 182 kg) showed a significantly ($P < 0.05$) higher risk of mortality and culling risk in March to April, June to July and October to November, with the highest peak occurring in August (Figure 2, Table 1). In middleweight classes (182 to 271 kg), the combined mortality and culling risk mainly increased in the months of May to June to then stabilize and decreased towards December. Heavier weight males (>271 kg) showed a constant lower mortality and culling risk compared to their lighter weight counterparts (Figure 2, Table 1). Females showed a similar pattern compared to males as lighter weight cattle had significantly ($P < 0.05$) higher risk of mortality and culling than heavier cattle, across the different arrival months. Light weight females (<182 kg) showed higher cumulative mortality and culling risk earlier in the months of March and May, recording the highest peak in risk from August to October (Figure 3, Table 2). Middleweight female cattle cohorts (182 to 271 kg) showed a steady increment of mortality and culling risk from March to September to then decrease in the months of November and December, whereas heavier weight females (>271 kg) showed a constant lower risk of mortality and culling than females in lighter weight categories (Figure 3, Table 2).

Visual appraisal of the plotted final model’s best linear unbiased predictors (BLUPs) over time across feedlots indicated that the combined mortality and culling risks were similar among and within years for most of the feedlots (Figure 4). However, there were a few exceptions. Two feedlots (feedlots 16 and 17) had higher combined mortality and culling risks in years 2003 and 2007, respectively, than they had in other years or than other feedlots had in 2003 and 2007 (Figure 4). In addition, feedlots 41 and 42 had lower predictions for years 2004 to 2007 than did other feedlots during those years (Figure 4).

Our initial study population consisted of 54,416 cohorts, however, based on a visual assessment of residual plots, ten cohorts were deemed to act as outliers in the outcome variable. These cohorts, originated from four feedlots, exhibited values of probability of combined mortality and culling risk that exceeded 85%. The outliers had the following characteristics in terms of covariates: cohorts arrived in years 2000 (n = 1), 2002 (n = 2), 2003 (n = 4), 2004 (n = 2) and 2006 (n = 1); two were female and eight were male cohorts; and they belonged to the following weight classes: <182 kg (n = 3), 182 to 204 (n = 1), 205 to 227 (n = 1), 228 to 249 (n = 1), 318 to 340 (n = 1), 341 to 362 (n = 1) and >362 kg (n = 2). These cohorts showed a range of combined mortality and culling risk of 94.7 to 100% which was mainly driven by high culling percentages (range: 91.2 to 100%), as mortality ranged from 0 to 6.3% on this subset of cohorts. In addition, our feedlot collaborators indicated that these extremely high levels of culling are likely indicative of cohorts removed from the feedlot for alternative management (e.g., temporary pasture rearing) rather than true culling for health reasons. The identified outliers were deleted because their removal dramatically improved the fit and convergence of the model.

4. Discussion

Although mortality risks for feedlot cattle have been discussed previously (Kelly and Janzen, 1986; Vogel and Parrott, 1994; Loneragan, 2004), ours is the first study to use multivariable methods to quantify the effects of common risk factors and to assess the combination of culling and mortality in large, commercial feedlot cattle populations. A multivariable assessment of risk factors for combined mortality and culling provides a more comprehensive approach to assess losses from heterogeneous populations of cattle, across multiple feedlots and time (Loneragan, 2004).

Previous research on mortality risks was performed using only one or a limited number of feedlots, or data aggregated by feedlot on a monthly basis (MacVean et al., 1986; Ribble et al., 1998; Loneragan et al., 2001). Using a limited number of feedlots for analysis reduces the external validity of results because feedlots may differ in terms of management, cattle demographics, environmental and pathogen-related factors. Although our study population was not chosen randomly, we did utilize several years of data from multiple feedlots that were similar to other commercial operations in the studied U.S. region. When data aggregated at the feedlot level are analyzed, important information regarding cohorts within feedlots is lost. Thus, it is not possible to quantify the effects of risk factors at the cohort-level; the level at which feedlot managers often make procurement, marketing and health management decisions. The structure of our data enabled us to perform an analysis at the cohort-level and to utilize multivariable approaches to quantify the effects of cohort-level risk factors and interactions among them that have not been previously described.

The mean mortality (1.5%) and (0.8%) culling risks in our data were similar to earlier reports that utilized feedlot data from the United States Department of Agriculture's National Animal Health Monitoring System (USDA, NAHMS), where mean mortality risk was reported at 1.26% and mean culling risk ranged from 0.07% to 0.42% (Frank et al., 1988; Loneragan et al., 2001). Others have stated that mortality risk can reach as high as five percent when freshly weaned animals six to eight months of age enter the feedlot (Smith et al., 2001). Our data indicate that cumulative mortality and culling are occasionally higher than five percent: 6.2% (n = 3,390 cohorts) and 2.4% (n = 1,301) of cohorts in our study population had mortality and culling risks (respectively) equal or higher than 5%.

Utilizing a large dataset containing cumulative cohort data was useful for estimating cumulative measures of adverse health outcomes and assessing corresponding cohort-level risk factors. However, there are also limitations to analyzing this type of data. In our study, we were not able to assess the timing at which death or culling occurred. Previously, Babcock and colleagues demonstrated that the timing of adverse health events affects cattle performance and subsequent health measures (Babcock et al., 2009). The timing of losses due to mortality and culling may have a large impact on feed and production costs; thus, temporal effects should be assessed in future research. Other limitations of utilizing operational retrospective data from multiple feedlot production systems pertain to the lack of consistent, standardized reporting of data across feedlots (Corbin and Griffin, 2006) and to the restriction on the inferences that can be made. We found only five cohort-level variables (gender, arrival weight, date of arrival, days on feed and cohort size) were collected across all 16 feedlots. Therefore, we could not evaluate other factors that have been assessed in smaller-scale studies, such as the origin of animals or the feedlots' feed rations (Martin et al., 1982; Ribble et al., 1995). Furthermore, we did not have data available on management practices related to cattle handling and commingling during transportation, which are factors that have been associated with increased risk of morbidity and mortality in beef calves (Grandin, 1997; Ribble et al., 1998; Swanson and Morrow-Tesch, 2001; Fike and Spire, 2006; White et al., 2009). Moreover, the distance cattle were shipped has been found to be positively associated with BRD morbidity (Sanderson et al., 2008). Similarly, distance traveled was found to be a significant predictor of BRD morbidity and overall mortality risks in another study; however, effects depended on specific characteristics of the cohort (region the cattle originated from, cohort gender, cohort mean arrival weight and the season cattle arrived at the feedlot) (Cernicchiaro et al., 2012). Unfortunately, data on the distance traveled and the source of origin of these cohorts were not available in our database. These and other factors could act as confounders of some of the associations reported here, and could elucidate some of the unexplained variance of the presented model, as these factors can be associated with demographic factors and the risk of morbidity and mortality in commercial feedlots. Lastly, the retrospective, observational cross-sectional nature of the data analyzed, prevented us from drawing direct causal inferences between the cohort-level demographic factors and combined mortality and culling risk. Nevertheless, these data reflect the type of operational information available in most feedlot operations.

Researchers have previously reported that feedlot mortality risks increased over time during the late 1990's and early 2000's (Loneragan et al., 2001; Loneragan, 2004; Babcock et al., 2006). The 2006 study by Babcock and colleagues showed an increasing trend in mortality risk from 1992 through 2006. The results of our current study indicate that despite differences in few individual feedlots, the combined mortality and culling risks for the majority of feedlots were similar within and across years and feedlots after adjusting for cohort demographic variables. Our results may have differed because their earlier study used data aggregated across feedlots and arrival months. In addition, their data arose from a relatively small subpopulation of feedlots (n = 9) located in a single geographic location in Kansas (Babcock et al., 2006).

Feedlot mortality has been assessed in several studies, but both mortality and culling within cohorts have yet to be incorporated into a single outcome. In our dataset, the ratios of mortality and culling within cohorts illustrate the variability in these measures among different feedlots over multiple years. Combining culling and mortality data in a single outcome can result in a more precise estimate of animal losses in feedlots when comparing health performance across feedlots over time (Loneragan, 2004), as well as it may provide results that are more robust to differential and non-static culling criteria. However, we were unable to determine whether certain risk factors have different effects across culling and mortality as separate outcomes. Thus, a competing risk analysis could be used to further assess how factors affect mortality and culling as two competing risks (Chiang, 1991). However, the complexity of our dataset precludes standard approaches to competing risks analysis and there are very practical reasons to assess effects associated with combined mortality and culling risks.

Our data indicated that the gender of the cohort, the mean arrival weight class and the month of arrival at the feedlot were significantly associated with the combined mortality and culling risk and that the effect of each predictor depended on one another. Previous research determined that female cohorts have higher mortality risk than male cohorts (Loneragan et al., 2001). We observed similar results in bivariable models, however, after accounting for other covariates in the model, we found that the effect of gender on the combined mortality and culling risk depended on weight and month at feedlot arrival, as depicted by a significant ($P < 0.05$) three-way interaction. The data indicated there was a seasonal pattern to the combined mortality and culling risk for light and middleweight male and female cohorts, with a significantly higher risk in spring and summer arrivals compared to that of cattle arriving in autumn and winter months. The specific reasons for this effect modification cannot be determined in our study, but there are several feedlot management practices that differ between genders, weight categories and time of the year. Some factors that may explain the differences in risks between genders are related to differential hormonal status and biological processes (e.g., riding behavior of females, parturition or induced abortion upon feedlot arrival), differences in steroid growth promoters and rations, or differences in how female and male cattle are marketed from the cow-calf herd to the feedlot (Lechtenberg et al., 1998; Smith et al., 2001).

Arrival weight and month are two common risk factors that are often difficult to separate due to the seasonal marketing patterns of feeder cattle in North America (Ribble et al., 1995). Often light weight cattle (frequently newly weaned animals) arrive at the feedlot in the autumn while heavier weight (yearling animals) cattle arrive during the spring months. Differential mortality and culling risk among cattle in different weight categories across different months may be the result of differences in cattle types, weather characteristics, management practices in different seasons, pathogen factors, or inherent physiologic and immunologic differences of cattle in different weight classes. Likewise, the age of the animals on arrival may explain some of those differences. Weight is often used as a proxy for age; however, animals arriving at similar weights throughout the year may not always be the same age. External factors such as drought or feed costs may impact the age at which cow-calf operations market and send calves to feedlots (Neville and McCormick, 1981). This may also explain the high variability in risk that we observed across arrival months for lighter weight cohorts.

Several weather factors (e.g., wind speed, wind chill temperature, and temperature change) have been associated with increased daily incidence of respiratory disease, and their effects depended on cattle demographic factors including the weight class of the cohort (Cernicchiaro et al., 2011). Thus, weather effects on morbidity could have contributed the subsequent higher mortality and culling risk during spring and summer months among light and middleweight arriving cohorts in our study. Literature on the effects of weather on morbidity and mortality, particularly related to respiratory disease in feedlot cattle, is limited, yet seems to indicate colder months are associated with adverse health outcomes. However, we cannot dismiss the effects of hot weather adversely affecting health and performance of vulnerable cattle during prolonged extreme heat (Hahn and Mader, 1997; Hahn, 1999). Further, it is plausible that both colder weather in northern parts of North America and warmer weather in more southern parts of the continent adversely affect cattle reared in feedlot settings. There is a need for more research on the effects of management or environment conditions that impact adverse feedlot cattle health. Understanding these relationships may lead to the development of better management or purchasing practices for different types of cattle throughout the year.

Several modeling strategies were explored in an attempt to account for the distribution and structure of the data. Initially, an examination of different functional forms of count models (i.e., Poisson, negative binomial) was made (Figure 1) and compared with binomial models. The negative binomial regression model was deemed to better fit these data. Although feedlots and arrival years were not randomly selected in our study, they were included as random intercepts, because we were interested in making inferences to wider populations of feedlots across time. Smaller time units also were included as random effects (i.e., months and weeks within months) to obtain a further decomposition of the variance. Moreover, a first order autoregressive structure was included to model the existing autocorrelation among months. Continuing with efforts directed towards improvement of the model, ten cohorts identified as outliers were removed before fitting the final model. Although we recognize this approach can decrease the validity of the model to predict future observations (Dohoo et al., 2009), we opted for removing these observations favoring a more stable model. A future evaluation of similar datasets using

Bayesian techniques or another statistical framework for complex random effects and covariance structures may be appropriate.

5. Conclusion

Cohort-level factors associated with combined mortality and culling risk in feedlot cattle can be quantified utilizing mixed models and cumulative data commonly available in the feedlot industry. Interactions among effects, such as arrival month and arrival weight, have been discussed anecdotally in the literature, but have never been quantified for multiple cattle types and production settings. The observed effect modification and potential for confounding in these data illustrate the importance of multivariable approaches when evaluating data from diverse feedlot cattle populations**.** By demonstrating effects of factors that have not been appropriately quantified in previous literature, we provide information that may be used in monitoring adverse cattle health outcomes over time and among production systems, and may allow risk managers to better predict potential losses for heterogeneous cattle populations by utilizing available data.

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Table captions

Table 1.

Arrival Month	Arrival Weight in categories <182 kg	182-204 kg	205-227 kg	228-249 kg	250-271kg	272-317 kg	318-340 kg	341-362 kg	>362 kg
Jan	3.4 (2.3 - 5.1)	2.9 (1.9 - 4.2)	2.2 (1.6 - 2.9)	2.2 (1.8 - 2.8)	2.6 (2.1 - 3.1)	2.1 (1.9 - 2.3)	1.8 (1.6 - 1.9)	1.4 (1.3 - 1.6)	1.1 (0.9 - 1.2)
Feb	1.9 (0.8 - 4.7)	3.9 (2.8 - 5.5)	2.7 (1.9 - 3.9)	2.2 (1.7 - 2.9)	3.1 (2.6 - 3.8)	1.8 (1.6 - 2.0)	1.5 (1.4 - 1.7)	1.2 (1.1 - 1.4)	0.9 (0.8 - 1.0)
Mar	3.7 (2.2 - 6.1)	3.5 (1.9 - 6.2)	3.5 (2.4 - 5.1)	2.4 (1.7 - 3.3)	2.2 (1.7 - 2.9)	1.7 (1.5 - 1.9)	1.4 (1.2 - 1.6)	1.1 (1.0 - 1.3)	0.9 (0.8 - 1.0)
Apr	7.0 (5.2 - 9.6)	2.7 (1.9 - 3.8)	2.9 (2.3 - 3.8)	2.8 (2.2 - 3.4)	2.3 (1.8 - 2.8)	1.7 (1.4 - 1.9)	1.3 (1.1 - 1.6)	1.1 (1.0 - 1.3)	0.9 (0.8 - 1.0)
May	5.3 (4.5 - 6.3)	5.3 (4.6 - 6.2)	3.7 (3.2 - 4.2)	2.8 (2.4 - 3.3)	2.7 (2.3 - 3.1)	1.6 (1.4 - 1.8)	1.3 (1.2 - 1.5)	1.1 (0.9 - 1.2)	0.9 (0.8 - 1.0)
Jun	7.9 (6.8 - 9.2)	6.4 (5.6 - 7.2)	5.6 (4.9 - 6.3)	4.7 (4.1 - 5.3)	3.4 (2.9 - 4.0)	2.1 (1.8 - 2.4)	1.6 (1.4 - 1.8)	1.1 (1.0 - 1.3)	1.0 (0.9 - 1.2)
Jul	7.6 (6.6 - 8.8)	5.8 (5.1 - 6.7)	5.8 (5.2 - 6.4)	4.4 (3.8 - 4.9)	4.0 (3.6 - 4.6)	2.5 (2.3 - 2.8)	1.6 (1.4 - 1.8)	1.3 (1.1 - 1.4)	0.9 (0.8 - 1.0)
Aug	9.9 (8.4 - 11.6)	4.9 (4.1 - 5.9)	4.9 (4.4 - 5.6)	4.9 (4.3 - 5.5)	3.9 (3.6 - 4.5)	2.2 (2.0 - 2.4)	1.5 (1.4 - 1.7)	1.2 (1.1 - 1.4)	0.9 (0.9 - 1.1)
Sep	5.0 (4.1 - 6.1)	5.4 (4.5 - 6.5)	4.8 (4.2 - 5.4)	4.4 (3.9 - 4.9)	3.8 (3.4 - 4.2)	2.7 (2.4 - 2.9)	1.7 (1.6 - 1.9)	1.4 (1.2 - 1.5)	1.0 (0.9 - 1.2)
Oct	6.5 (5.5 - 7.7)	3.6 (3.0 - 4.3)	3.9 (3.4 - 4.4)	3.6 (3.2 - 4.1)	4.1 (3.7 - 4.5)	2.8 (2.6 - 3.0)	2.2 (1.9 - 2.4)	1.6 (1.4 - 1.8)	1.2 (1.1 - 1.4)
Nov	6.9 (5.8 - 8.1)	3.9 (3.2 - 4.6)	4.1 (3.6 - 4.8)	3.9 (3.4 - 4.4)	2.9 (2.6- 3.3)	2.7 (2.5 - 2.9)	2.2 (1.9 - 2.4)	1.6 (1.4 - 1.8)	1.5 (1.3 - 1.7)
Dec	4.9 (3.9 - 5.9)	3.0 (3.2 - 4.7)	3.1 (2.7 - 3.6)	2.8 (2.4 - 3.3)	2.5 (2.2 - 2.9)	2.7 (2.4 - 2.9)	2.4 (2.1 - 2.7)	1.6 (1.4 - 1.9)	1.1 (0.9 - 1.3)

Table 1. Estimated probabilities (%) and corresponding 95% confidence intervals for combined mortality and culling risk by weight class and month of feedlot arrival for cattle cohorts classified as male

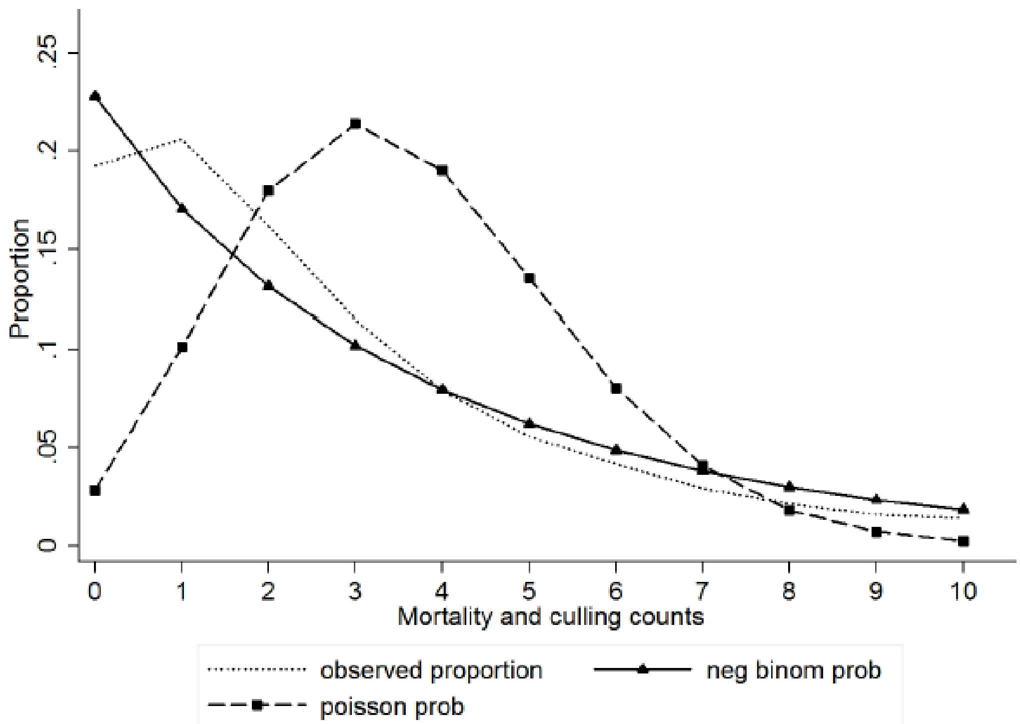
Table 2.

Arrival Month	Arrival Weight in categories								
	<182 kg	182-204 kg	205-227 kg	228-249 kg	250-271kg	272-317 kg	318-340 kg	341-362 kg	>362 kg
Jan	2.4 (1.5 - 4.0)	3.4 (2.3 - 5.1)	3.0 (2.4 - 3.8)	2.2 (1.8 - 2.6)	2.3 (1.9 - 2.6)	2.0 (1.9 - 2.3)	1.6 (1.4 - 1.8)	1.5 (1.3 - 1.8)	1.8 (1.4 - 2.3)
Feb	4.4 (2.9 - 6.7)	0.9 (0.3 - 3.1)	1.9 (1.3 - 2.9)	2.4 (1.9 - 3.0)	2.2 (1.8 - 2.6)	1.7 (1.5 - 1.9)	1.3 (1.1 - 1.5)	1.3 (1.1 - 1.6)	1.3 (1.1 - 1.7)
Mar	7.2 (5.1 - 10.2)	3.0 (1.7 - 5.5)	3.6 (2.4 - 5.4)	2.4 (1.8 - 3.2)	2.3 (1.9 - 2.7)	1.7 (1.5 - 1.9)	1.2 (1.1 - 1.4)	1.0 (0.9 - 1.2)	1.0 (0.8 - 1.2)
Apr	3.7 (2.0 - 6.8)	3.6 (1.8 - 7.5)	2.7 (1.8 - 3.9)	2.3 (1.7 - 2.9)	2.5 (2.1 - 2.9)	1.5 (1.3 - 1.7)	1.1 (0.9 - 1.3)	0.9 (0.8 - 1.1)	1.0 (0.8 - 1.2)
May	5.9 (4.2 - 8.5)	3.4 (2.5 - 4.6)	3.9 (3.0 - 4.9)	2.9 (2.3 - 3.7)	2.9 (2.6 - 3.4)	1.5 (1.3 - 1.7)	1.0 (0.9 - 1.2)	0.9 (0.8 - 1.2)	0.9 (0.8 - 1.2)
Jun	4.6 (3.3 - 6.4)	6.1 (4.9 - 7.6)	4.3 (3.7 - 5.1)	3.9 (3.3 - 4.6)	3.9 (3.4 - 4.5)	1.8 (1.6 - 2.0)	1.2 (1.0 - 1.4)	0.8 (0.7 - 1.0)	1.5 (1.2 - 1.8)
Jul	5.9 (5.0 - 7.0)	6.8 (5.8 - 7.9)	4.9 (4.4 - 5.6)	4.1 (3.5 - 4.7)	3.6 (3.2 - 4.1)	2.0 (1.8 - 2.3)	1.4 (1.2 - 1.6)	0.9 (0.8 - 1.1)	1.3 (1.1 - 1.6)
Aug	7.7 (6.6 - 8.9)	6.4 (5.6 - 7.3)	5.3 (4.7 - 5.9)	3.9 (3.5 - 4.5)	3.7 (3.3 - 4.1)	2.2 (1.9 - 2.4)	1.3 (1.1 - 1.5)	0.9 (0.7 - 1.0)	1.3 (1.1 - 1.6)
Sep	7.3 (5.8 - 9.3)	8.1 (7.1 - 9.2)	5.4 (4.8 - 5.9)	4.0 (3.6 - 4.5)	3.4 (3.0 - 3.8)	2.2 (2.0 - 2.5)	1.4 (1.2 - 1.6)	1.1 (0.9 - 1.3)	1.5 (1.2 - 1.8)
Oct	7.5 (5.8 - 9.8)	6.8 (5.9 - 7.9)	5.6 (4.9 - 6.4)	4.2 (3.7 - 4.6)	4.1 (3.7 - 4.6)	2.6 (2.4 - 2.9)	1.8 (1.5 - 2.0)	1.3 (1.1 - 1.6)	1.8 (1.5 - 2.2)
Nov	3.0 (1.8 - 4.9)	3.6 (2.8 - 4.6)	3.8 (3.1 - 4.6)	3.1 (2.6 - 3.6)	2.9 (2.6 - 3.3)	2.6 (2.3 - 2.9)	1.8 (1.6 - 2.2)	1.5 (1.2- 1.9)	2.1 (1.7 - 2.7)
Dec	2.5 (1.5 - 4.3)	2.4 (1.7 - 3.6)	2.9 (2.3 - 3.9)	2.9 (2.4 - 3.4)	2.9 (2.6 - 3.3)	2.6 (2.4 - 2.9)	1.5 (1.3 - 1.8)	1.6 (1.3 - 1.9)	2.1 (1.7 - 2.8)

Table 2. Estimated probabilities (%) and corresponding 95% confidence intervals for combined mortality and culling risk by weight class and month of feedlot arrival for cattle cohorts classified as female

Figure captions

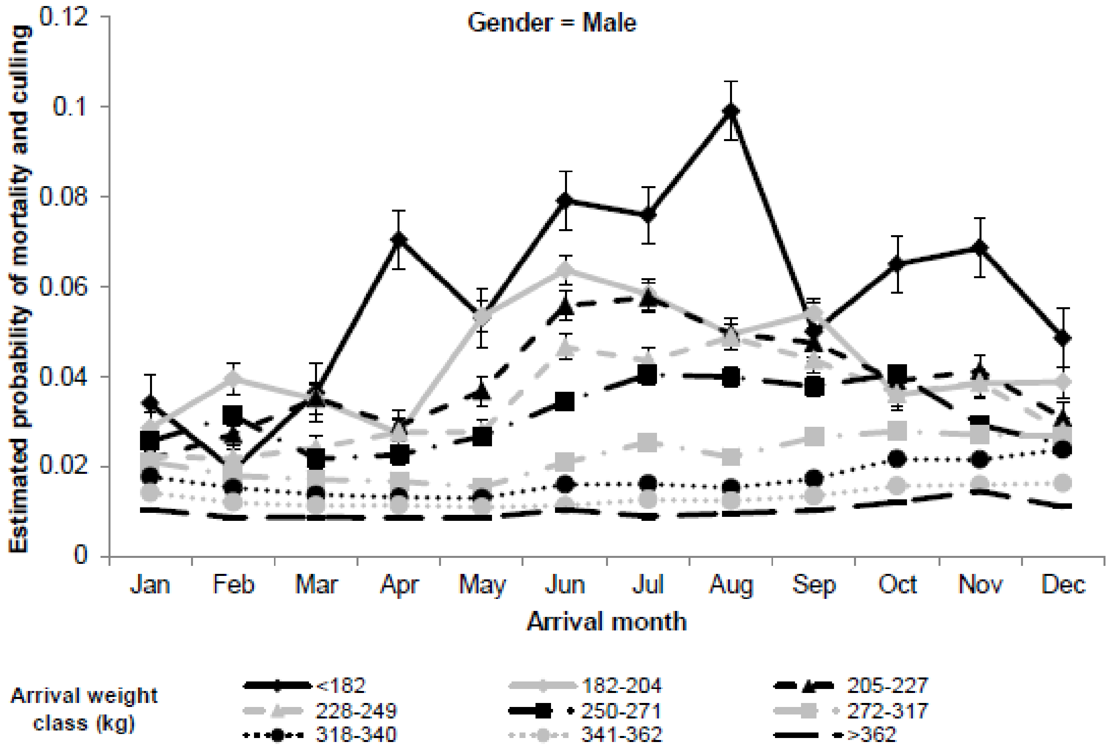
Figure 1.



This figure graphs the distribution of the variable pertaining to combined mortality and culling counts against a Poisson (modeled with the same mean (3.53)) and negative binomial distributions (modeled with the same mean and variance (3.53 and 1.04, respectively). This graph was constructed using the “nbvargr” command in STATA/MP 11.2 (StataCorp LP, College Station, TX, USA)

Figure 1. Probabilities for within-cohort combined mortality and culling counts based on observed data, Poisson and negative binomial distributions (mean observed count = 3.53; overdispersion parameter = 1.04)

Figure 2.

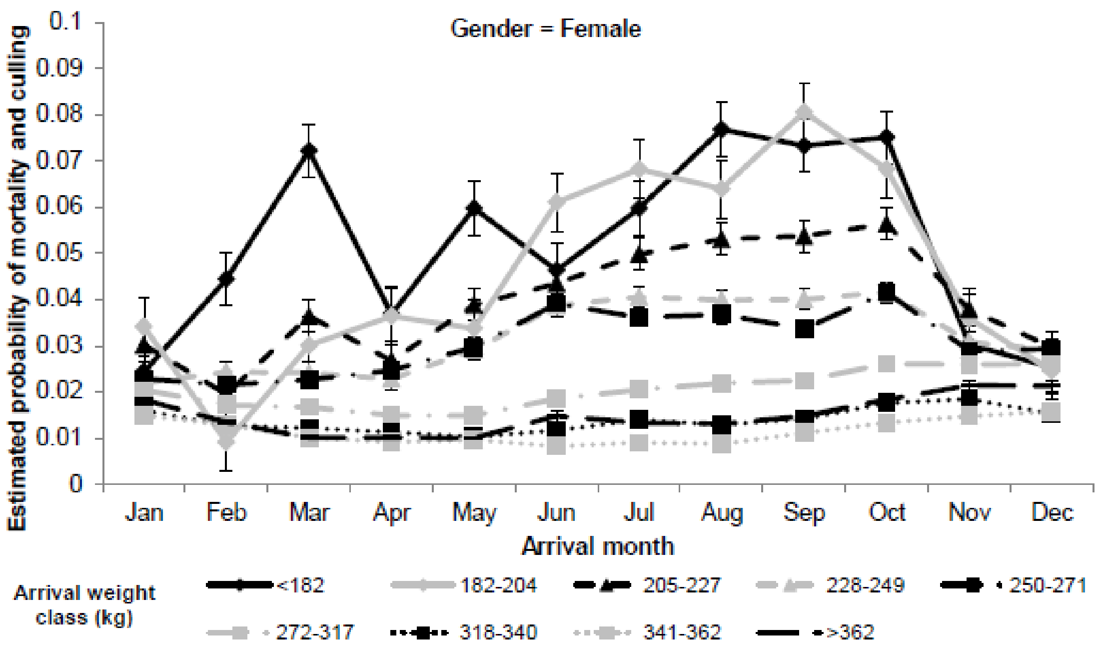


[1]Estimated probabilities from a generalized linear mixed model that accounted for the hierarchical and temporal structure of the data

Error bars indicate standard errors of least square means

Figure 2. Estimated probability[1] for combined mortality and culling risk by gender, weight class and month of feedlot arrival for cattle cohorts classified as male

Figure 3.

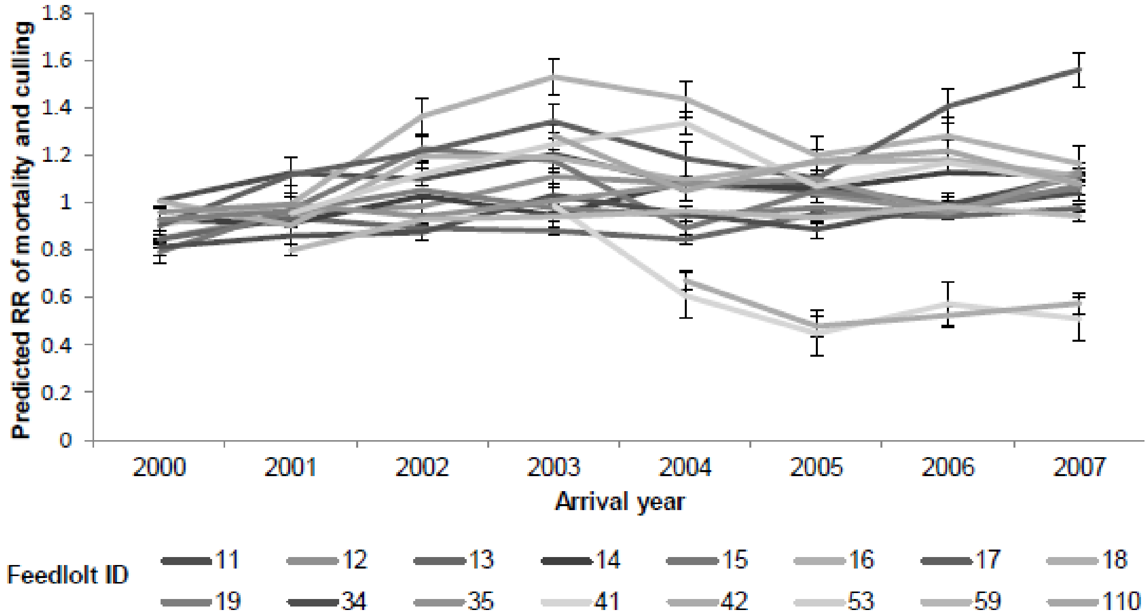


[1]Estimated probabilities from a generalized mixed linear model that accounted for the hierarchical and temporal structure of the data

Error bars indicate standard errors of least square means

Figure 3. Estimated probability[1] for mortality and culling risk by gender, weight class and month of feedlot arrival for cattle cohorts classified as female

Figure 4.



Error bars indicate standard errors of least square means
Data from feedlot IDs 41 and 42 were not available for years preceding 2003 and 2004, respectively

Figure 4. Predicted relative risk (RR) for combined mortality and culling risks for each year and feedlot based on analysis of 54,406 cohorts of commercial feedlot cattle.