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Risk factors for mid- and late-feeding-stage bovine respiratory morbidity and mortality based on individual animal treatments of beef feedlot cattle

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ABSTRACT

Objective: Previously published research on bovine respiratory disease (BRD) has emphasized the initial portion of the feeding phase; yet, little work has investigated risk factors associated with BRD incidence later in the feeding period. Our study objective was to identify risk factors associated with BRD morbidity and mortality timing within the feeding phase.

Materials and Methods: Individual animal records for first BRD treatment (n = 188,437) or BRD mortality (n = 13,991) were classified as early stage, middle stage, or late stage based on the percentage of their cohorts' feeding phase that was complete at day of event (event days on feed/cohort total days on feed).

Results and Discussion: There were 141,097 early stage, 33,871 middle stage, and 13,469 late stage at first treatments for BRD and 7,821 early stage, 3,625 middle stage, and 2,545 late stage at death. Two ordinal logistic regression models (morbidity, mortality) were used to evaluate the association of cattle demographic factors (arrival weight, arrival lot size, sex, metaphylaxis, quarter of arrival) and the probability of an individual animal first treatment for BRD or mortality from BRD being early, middle, or late stage. All 2-way interactions of cattle demographics for morbidity were significant ($P < 0.05$), whereas for mortality, main effects of arrival weight and metaphylaxis were significant ($P < 0.05$) and only the 2-way interactions of sex by quarter of arrival and sex by lot size were significant ($P < 0.05$).

Implications and Applications: In general, heifers, heavier animals at arrival, and cattle that arrived at the yard in the first and second quarter were the most likely demographic categories to have an initial diagnosis of BRD in the mid or late stage of the feeding phase.

Key words: bovine respiratory disease, late-feeding stage, morbidity, mortality, timing

INTRODUCTION

Bovine respiratory disease (**BRD**) continues to be the most researched and common disease among feedlot cattle (Edwards, 1996; Smith, 1998; Woolums et al., 2013). Feedlots with ≥1,000 head capacity report 16.2% of cattle are affected by respiratory disease (NAHMS, 2011). Bovine respiratory disease is a multifaceted disease that has a significant economic impact on the beef industry as a whole (Chirase et al., 2001). Most literature that evaluates BRD incidence timing is from a decade ago (Babcock et al., 2009; Schneider et al., 2009) and illustrates about 75% of morbidity has occurred by 55 days on feed (**DOF**; Schneider et al., 2009); another article from the same year stated that 74% of BRD occurs by 42 DOF (Babcock et al., 2009). A more recent investigation found differences in the timing of BRD between high-risk and high-performing cattle (Theurer et al., 2021). Little work has been done evaluating risk factors potentially associated with disease at different DOF in the feedlot. Disease timing has important economic implications as cattle that have been on feed longer have incurred more costs compared with cattle early in the feeding phase. Timing of BRD onset is important as the probability of treatment failure following first treatment for BRD decreased as cattle were at the feedlot longer at the time of initial treatment (Avra et al., 2017).

The objective of the study was to identify risk factors associated with morbidity and mortality timing within the feeding phase. Data were used from 25 commercial feedlots, representing multiple feedlots throughout the Great Plains and southern regions of the United States.

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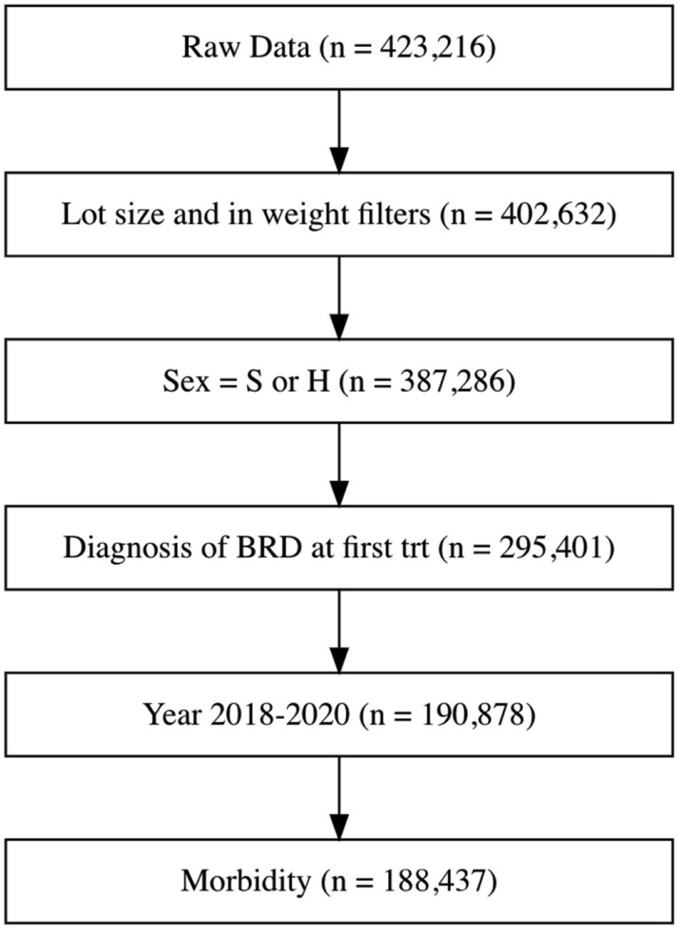

Figure 1. Flowchart of data filtering process for the number of animals filtered out to create the working data set for the morbidity analysis. S = steer; H = heifer; BRD = bovine respiratory disease; trt = treatment.

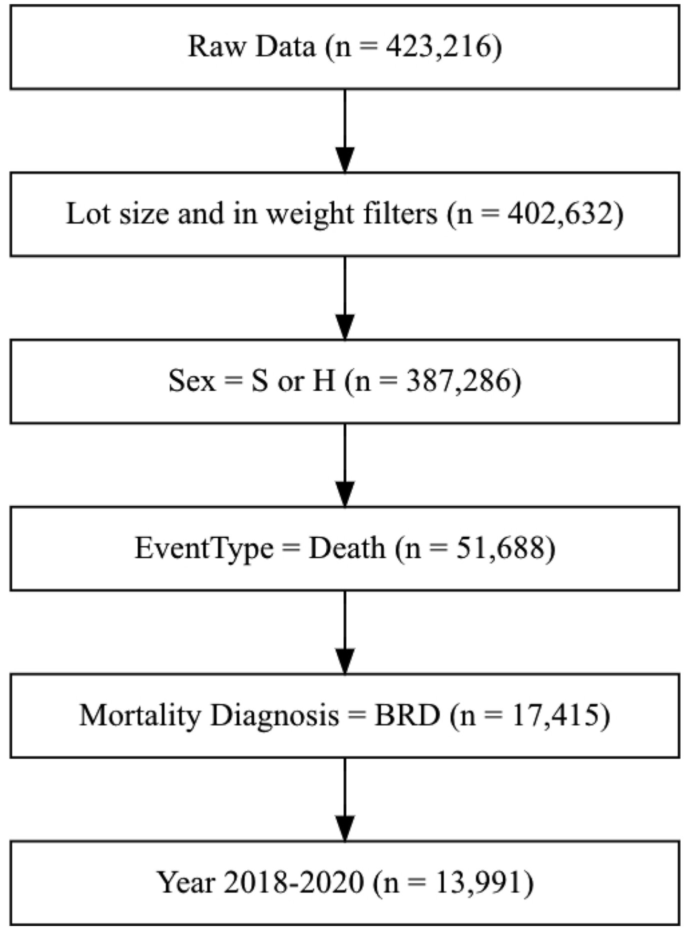

Figure 2. Flowchart of data filtering process for the number of animals filtered out to create the working data set for the mortality analysis. S = steer; H = heifer; BRD = bovine respiratory disease.

MATERIALS AND METHODS

Data Source

Individual animal treatment records from 25 US feedlots were collected under confidentiality agreements with individual yards. Institutional Animal Care and Use Committee (IACUC) approval was not required as historical operational data were used for the analysis. All individual animal records were assigned a unique identifier based on animal tag, yard identifier, and cohort identifier. Using the unique identifier, data were filtered to one row per treatment date per animal.

Morbidity Timing

Treatment records for a total of 423,216 individual animals were initially collected from collaborating feedlots. For this analysis, only cattle with first treatment records of BRD were included. Data were filtered to include only records where the cohort size at arrival was between 20 and 400 cattle. Arrival weight was averaged over cohorts, and criterion for inclusion was 227.3 to 454.5 kg. Total cohort DOF was limited to 250 d or fewer. Data were filtered to include only records from January 4, 2018, to December 28, 2020, as only 2 feedlots provided data generated before 2018. Data were filtered to include only first pull records for treatment of BRD for each individual animal (Figure 1).

A cohort was considered to have received metaphylaxis if over half the cohort received an antimicrobial labeled for control of BRD during arrival processing into the feedlot. Continuous explanatory variables were categorized to avoid violating the linearity assumption. A variable was created for quarter of arrival based on cohort arrival date (quarter 1, January to March; quarter 2, April to June; quarter 3, July to September; quarter 4, October to December). A variable was created by calculating the percentage of total feeding days that had passed when the animal had their first pull [(DOF at treatment/cohort total DOF) × 100]. Cattle were categorized as early-stage, middle-stage, or late-stage morbidity based on the percentage of the feeding phase they were in when they had their first treatment for BRD. Early stage (**EARLY**) was considered 0 to 33.3% of the feeding phase, middle stage (**MID**) was 33.3 to 66.6%, and late stage (**LATE**) was

Table 1. Characteristics of cohorts from which individual treatments were obtained for morbidity[1]

Characteristic	EARLY	MID	LATE
Total (no.)	141,097	33,871	13,469
Days on feed at first pull			
Median	22	82	148
Mean	26	85	149
Quarter of arrival			
1	36,054 (19.1)	10,469 (5.6)	4,851 (2.6)
2	26,129 (13.9)	9,583 (5.1)	3,196 (1.7)
3	38,605 (20.5)	7,528 (4.0)	2,425 (1.3)
4	40,309 (21.4)	6,291 (3.3)	2,997 (1.6)
Metaphylaxis			
Yes	11,670 (6.2)	3,084 (1.6)	1,235 (0.7)
No	129,427 (68.7)	30,787 (16.3)	12,234 (6.5)
Sex			
Steer	103,995 (55.2)	23,544 (12.5)	8,838 (4.7)
Heifer	37,102 (19.7)	10,327 (5.5)	4,631 (2.5)
Cohort size			
20–100	17,437 (9.3)	3,391 (1.8)	1,298 (0.7)
101–200	61,086 (32.4)	13,315 (7.1)	5,318 (2.8)
201–300	36,819 (19.5)	9,493 (5.0)	3,846 (2.0)
301–400	25,748 (13.7)	7,670 (4.1)	3,007 (1.6)
Average weight at arrival (kg)			
227–272	4,961 (2.6)	1,252 (0.7)	345 (0.2)
273–318	36,148 (19.2)	7,238 (3.8)	2,651 (1.4)
319–363	47,697 (25.3)	10,424 (5.5)	4,431 (2.4)
364–409	38,035 (20.2)	10,244 (5.4)	4,080 (2.2)
410–455	14,256 (7.6)	4,713 (2.5)	1,962 (1.0)

[1]Descriptive of the final working data set. Data are presented as no. (% of total), where no. = individual animals treated for disease. Percentages within characteristic across all timing categories add to 100% with respect for rounding. Early stage (EARLY) was considered 0 to 33.3% of the feeding phase, middle stage (MID) was 33.3 to 66.6%, and late stage (LATE) was 66.6 to 100% of the feeding phase completed at the time of treatment.

66.6 to 100% of the feeding phase completed at the time of treatment.

Mortality Timing

After applying the same constraints for cohort size, DOF, date, and arrival weight as listed previously, there were 51,688 death records in the data (Figure 2). These data are from the same data set as the treatment records, and an animal did not have to be treated for BRD before dying with a diagnosis of BRD to be included. Diagnosis was determined by feedlot personnel. A variable was created with categories for the percentage of the feeding period when the death occurred as [(DOF at death/cohort total DOF) × 100]. Cattle were categorized as EARLY for 0 to 33.3%, MID for 33.3 to 66.6%, or LATE for 66.6 to 100% of the feeding phase completed at the time of death.

Statistical Analysis

Two ordinal regression mixed-effects models were fit using the ‘clmm’ function from the ‘ordinal’ package in R (https://CRAN.R-project.org/package=ordinal) to analyze individual animal risk factors associated with the timing of BRD morbidity and BRD mortality. The dependent

Table 2. Covariate *P*-value for the final ordinal morbidity model for bovine respiratory disease timing in the feedlot

Covariate	*P*-value
Sex	<0.01
Quarter of arrival	<0.01
Lot size category	<0.01
Arrival weight category	<0.01
Metaphylaxis	0.14
Sex × quarter of arrival	0.01
Sex × arrival weight category	0.01
Quarter of arrival × lot size category	0.01
Quarter of arrival × arrival weight category	<0.01
Quarter of arrival × metaphylaxis	<0.01
Lot size category × arrival weight category	<0.01

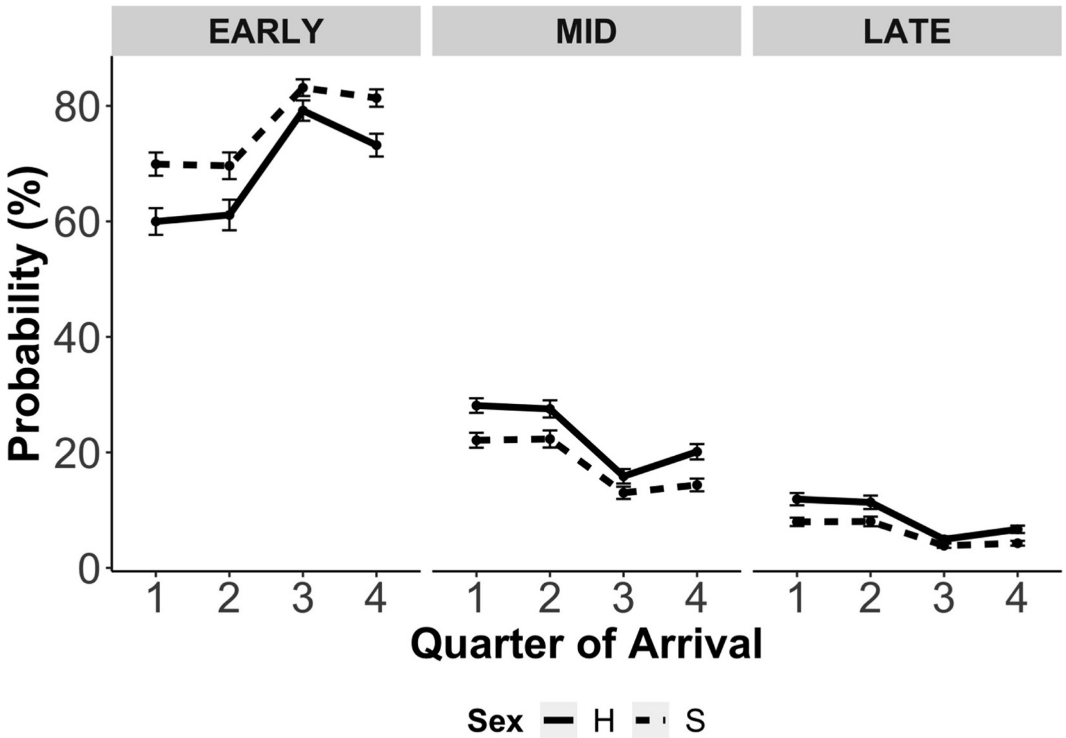

Figure 3. Model-predicted probability for timing of first treatment for bovine respiratory disease based on quarter of arrival into the feedlot (1 = January–March, 2 = April–June, 3 = July–September, 4 = October–December) modified by sex (solid line = heifers, dashed = steers). Early stage (EARLY) was considered 0 to 33.3% of the feeding phase, middle stage (MID) was 33.3 to 66.6%, and late stage (LATE) was 66.6 to 100% of the feeding phase completed at the time of treatment. Probabilities were from an ordinal logistic mixed model, and error bars represent 1 SE.

variable was time of morbidity or mortality as categorized by the percentage of feeding phase complete. Independent variables evaluated in the model were cohort sex, quarter of arrival to the feedlot, cohort size at arrival, average in weight of the cohort at arrival, metaphylaxis, and any 2-way interactions between these variables. Continuous variables, such as weight at arrival, and cohort size at arrival were categorized into bins to avoid violating the linearity assumption. Backward elimination was used to select the variables to remain in the final model for the 2-way interactions. Values of $P < 0.05$ were considered significant. Random effects were included in the model for cohort nested within yard, and year, to account for the hierarchical structure of the data as well as cohort total DOF to account for differing days at risk among groups.

RESULTS AND DISCUSSION

The study objective was to identify risk factors associated with BRD morbidity and mortality timing within the feeding phase. Understanding risk factors associated with the timing of onset of BRD may lead to management practices to reduce late-feeding-phase morbidity and mortality. The structure of our data allowed us to perform analysis on multiple risk factors theorized to effect morbidity and mortality timing in cattle. Most previous BRD research focused on severity of disease and demographic risk factors that may increase BRD risk; however, this analysis evaluated risk factors potentially influencing BRD timing. Disease later in the feeding phase is important to producers as it costs more to treat heavier animals and a death late in the feeding phase is more costly due to greater resources allocated. Babcock found 7 temporal patterns of disease at the cohort level; in this analysis we only looked at 3 timings, which were at the individual animal level (Babcock et al., 2010). Both analyses found that most cattle that are treated at the feedlot are treated early in their feeding phase, but that is modified by multiple other factors. Although the Babcock article identified different timing curves, the analysis was not intended to identify different risk factors, in contrast to this article.

Morbidity

The final sample for morbidity consisted of 188,437 records for individual first pull treatment of BRD (Table 1). Using these case definitions for the timing of BRD morbidity in feedlot cattle, 74.9% (n = 141,097) of individual treatments classified as EARLY, 18.0% (n = 33,871) classified as MID, and 7.1% (13,469) classified as LATE.

The final ordinal multivariable model included significant 2-way interactions of sex by quarter of arrival, sex by arrival weight category, metaphylaxis by quarter of arrival, quarter of arrival by cohort size category, arrival quarter by arrival weight category, and cohort size cat-

Table 3. Final model[1] results from significant ($P < 0.05$) interactions demonstrating estimated probabilities of an individual animal's first treatment for bovine respiratory disease (BRD) being early, mid, or late[2]

		EARLY		MID		LATE	
Covariate	**Level**	**Probability (%)**	**95% CI**	**Probability (%)**	**95% CI**	**Probability (%)**	**95% CI**
Quarter of arrival × arrival weight category (kg)	1 × (227–272)	75.2	69.3, 81.0	18.7	14.7, 22.7	6.1	4.3, 8.0
	1 × (273–318)	68.6	64.5, 72.7	23.1	20.5, 25.7	8.3	6.8, 9.8
	1 × (319–363)	67.5	63.3, 71.8	23.7	21.1, 26.4	8.8	7.1, 10.4
	1 × (364–409)	61.0	56.2, 65.7	27.8	25.1, 30.5	11.3	9.2, 13.3
	1 × (410–455)	52.5	46.9, 58.1	32.2	29.7, 34.9	15.2	12.2, 18.3
	2 × (227–272)	73.7	66.7, 80.7	19.7	15.0, 24.5	6.6	4.3, 8.8
	2 × (273–318)	72.7	68.3, 77.2	20.4	17.4, 23.4	6.8	5.4, 8.3
	2 × (319–363)	67.4	62.5, 72.2	23.9	20.9, 27.0	8.7	6.9, 10.5
	2 × (364–409)	60.9	55.6, 66.3	27.9	24.9, 31.0	11.2	8.9, 13.5
	2 × (410–455)	52.1	46.1, 58.1	32.6	29.8, 35.5	15.2	12.0, 18.4
	3 × (227–272)	88.4	84.8, 91.9	9.1	6.4, 11.8	2.5	1.7, 3.3
	3 × (273–318)	84.5	81.7, 87.3	12.0	10.0, 14.1	3.4	2.7, 4.2
	3 × (319–363)	81.9	78.8, 85.0	14.0	11.7, 16.2	4.1	3.3, 5.0
	3 × (364–409)	78.2	74.5, 81.8	16.7	14.1, 19.3	5.2	4.1, 6.2
	3 × (410–455)	72.9	68.2, 77.5	20.4	17.2, 23.5	6.8	5.3, 8.2
	4 × (227–272)	78.4	73.3, 83.6	16.4	12.7, 20.0	5.2	3.7, 6.7
	4 × (273–318)	79.9	76.8, 83.0	15.4	13.2, 17.6	4.7	3.8, 5.6
	4 × (319–363)	77.3	74.0, 80.7	17.2	14.8, 19.5	5.5	4.5, 6.5
	4 × (364–409)	76.3	72.7, 79.9	18.0	15.4, 20.5	5.7	4.6, 6.8
	4 × (410–455)	74.4	70.0, 78.8	19.3	16.3, 22.3	6.3	4.9, 7.7
Sex × arrival weight category (kg)	Heifer × (227–272)	75.6	71.4, 79.8	18.3	15.5, 21.2	6.1	4.7, 7.5
	Heifer × (273–318)	73.5	70.0, 77.0	19.7	17.4, 22.1	6.7	5.6, 7.9
	Heifer × (319–363)	68.4	64.5, 72.3	23.1	20.7, 25.6	8.5	7.0, 9.9
	Heifer × (364–409)	65.2	61.0, 69.3	25.1	22.6, 27.5	9.8	8.1, 11.5
	Heifer × (410–455)	59.2	53.9, 64.5	28.3	25.5, 31.1	12.5	10.0, 15.1
	Steer × (227–272)	82.3	77.4, 87.1	13.6	10.1, 17.2	4.1	2.8, 5.4
	Steer × (273–318)	79.4	76.4, 82.3	15.7	13.6, 17.8	4.9	4.0, 5.8
	Steer × (319–363)	78.7	75.7, 81.6	16.3	14.2, 18.4	5.1	4.2, 6.0
	Steer × (364–409)	73.0	69.6, 76.4	20.1	17.8, 22.4	6.9	5.7, 8.0
	Steer × (410–455)	66.8	62.8, 70.7	24.0	21.6, 26.4	9.2	7.7, 10.8

Continued

Table 3 (Continued). Final model[1] results from significant ($P < 0.05$) interactions demonstrating estimated probabilities of an individual animal's first treatment for bovine respiratory disease (BRD) being early, mid, or late[2]

		EARLY		MID		LATE	
Covariate	**Level**	**Probability (%)**	**95% CI**	**Probability (%)**	**95% CI**	**Probability (%)**	**95% CI**
Quarter of arrival × lot size category	1 × (20–100)	68.7	64.4, 73.0	22.7	20.0, 25.4	8.6	6.9, 10.2
	1 × (101–200)	64.2	59.8, 68.6	25.6	23.1, 28.2	10.2	8.4, 12.0
	1 × (201–300)	64.2	59.5, 68.9	25.7	22.9, 28.5	10.1	8.2, 12.0
	1 × (301–400)	62.7	58.1, 67.3	26.4	23.7, 29.0	10.9	8.9, 13.0
	2 × (20–100)	68.8	63.9, 73.7	22.7	19.6, 25.8	8.5	6.6, 10.3
	2 × (101–200)	65.0	60.1, 69.8	25.2	22.3, 28.1	9.8	7.8, 11.8
	2 × (201–300)	63.2	57.8, 68.6	26.4	23.1, 29.6	10.4	8.2, 12.6
	2 × (301–400)	64.4	59.1, 69.7	25.4	22.3, 28.6	10.1	8.0, 12.3
	3 × (20–100)	83.9	81.0, 86.8	12.4	10.3, 14.5	3.7	2.9, 4.4
	3 × (101–200)	81.3	78.2, 84.4	14.4	12.1, 16.6	4.3	3.5, 5.2
	3 × (201–300)	80.6	77.1, 84.0	14.9	12.4, 17.4	4.5	3.6, 5.5
	3 × (301–400)	78.9	75.2, 82.6	16.0	13.4, 18.7	5.1	4.0, 6.2
	4 × (20–100)	82.5	79.5, 85.5	13.5	11.3, 15.7	4.0	3.2, 4.8
	4 × (101–200)	75.6	72.0, 79.2	18.4	16.0, 20.9	6.0	4.8, 7.1
	4 × (201–300)	72.9	68.7, 77.1	20.3	17.5, 23.1	6.8	5.4, 8.1
	4 × (301–400)	78.1	74.2, 82.0	16.7	13.9, 19.5	5.2	4.1, 6.3
Quarter of arrival × sex	1 × heifer	60.0	55.5, 64.5	28.1	25.6, 30.6	12.0	9.8, 14.0
	1 × steer	70.0	66.0, 73.8	22.1	19.6, 24.6	8.0	6.6, 9.4
	2 × heifer	61.1	55.9, 66.3	27.5	24.6, 30.4	11.4	9.1, 13.7
	2 × steer	69.9	65.1, 74.1	22.3	19.4, 25.2	8.0	6.4, 9.7
	3 × heifer	79.2	75.7, 82.6	15.9	13.4, 18.3	5.0	4.0, 6.0
	3 × steer	83.1	80.3, 86.0	13.0	10.9, 15.1	3.9	3.1, 4.6
	4 × heifer	73.2	69.3, 77.1	20.1	17.5, 22.7	6.7	5.4, 7.9
	4 × steer	81.4	78.4, 84.3	14.4	12.2, 16.5	4.3	3.5, 5.1
Quarter of arrival × metaphylaxis	1 × no metaphylaxis	69.0	65.4, 72.7	22.7	20.3, 25.0	8.3	6.9, 9.6
	1 × metaphylaxis	60.8	55.7, 66.0	27.6	24.7, 30.4	11.6	9.3, 13.9
	2 × no metaphylaxis	67.2	63.4, 71.0	23.8	21.4, 26.2	9.0	7.5, 10.4
	2 × metaphylaxis	63.5	56.7, 70.3	26.0	22.0, 30.0	10.4	7.6, 13.2
	3 × no metaphylaxis	79.2	76.3, 82.0	15.9	13.9, 17.9	5.0	4.1, 5.8
	3 × metaphylaxis	83.2	79.1, 87.2	13.0	10.0, 15.9	3.8	2.8, 4.9
	4 × no metaphylaxis	77.8	74.7, 80.8	16.9	14.7, 19.1	5.3	4.4, 6.2
	4 × metaphylaxis	76.8	72.8, 80.7	17.6	14.8, 20.3	5.6	4.4, 6.8

Continued

Table 3 (Continued). Final model[1] results from significant ($P < 0.05$) interactions demonstrating estimated probabilities of an individual animal's first treatment for bovine respiratory disease (BRD) being early, mid, or late[2]

Covariate	Level	EARLY		MID		LATE	
		Probability (%)	95% CI	Probability (%)	95% CI	Probability (%)	95% CI
Lot size category × arrival weight category (kg)	(20–100) × (227–272)	84.1	80.3, 87.9	12.3	9.5, 15.1	3.6	2.6, 4.6
	(101–200) × (227–272)	74.7	69.8, 79.6	18.9	15.6, 22.2	6.3	4.8, 7.9
	(201–300) × (227–272)	75.1	67.2, 83.0	18.6	13.3, 24.0	6.2	3.7, 8.7
	(301–400) × (227–272)	81.2	75.9, 87.5	14.0	9.8, 18.3	4.2	2.6, 5.8
	(20–100) × (273–318)	80.5	77.4, 83.5	14.9	12.8, 17.1	4.6	3.7, 5.5
	(101–200) × (273–318)	78.7	75.7, 81.7	16.2	14.1, 18.3	5.1	4.2, 6.0
	(201–300) × (273–318)	73.3	69.4, 77.1	19.9	17.4, 22.5	6.8	5.5, 8.0
	(301–400) × (273–318)	73.3	69.1, 77.6	19.9	17.0, 22.7	6.8	5.4, 8.2
	(20–100) × (319–363)	77.6	74.4, 81.0	16.9	14.6, 19.2	5.5	4.4, 6.5
	(101–200) × (319–363)	72.8	69.4, 76.3	20.2	17.9, 22.5	7.0	5.8, 8.2
	(201–300) × (319–363)	71.3	67.6, 75.0	21.2	18.8, 23.6	7.5	6.2, 8.8
	(301–400) × (319–363)	72.4	68.5, 76.3	20.5	17.9, 23.1	7.1	5.8, 8.5
	(20–100) × (364–409)	72.7	68.9, 76.6	20.2	17.7, 22.7	7.1	5.7, 8.4
	(101–200) × (364–409)	68.2	64.4, 72.1	23.1	20.7, 25.6	8.6	7.2, 10.1
	(201–300) × (364–409)	68.5	64.5, 72.4	23.0	20.6, 25.5	8.5	7.0, 10.0
	(301–400) × (364–409)	66.9	62.7, 71.1	23.9	21.4, 26.5	9.1	7.5, 10.8
	(20–100) × (410–455)	64.9	60.1, 69.7	25.0	22.2, 27.7	10.1	8.1, 12.2
	(101–200) × (410–455)	63.1	58.7, 67.5	26.1	23.6, 28.6	10.8	8.8, 12.7
	(201–300) × (410–455)	63.0	58.2, 67.8	26.2	23.5, 29.0	10.8	8.7, 12.9
	(301–400) × (410–455)	60.8	55.5, 66.2	27.3	24.4, 30.2	11.8	9.4, 14.3

[1]Ordinal regression mixed-effects model with random intercepts for year, cohort within yard, and group days on feed.

[2]Probabilities added directly across columns add to 100% with respect for rounding differences. Early stage (EARLY) was considered 0 to 33.3% of the feeding phase, middle stage (MID) was 33.3 to 66.6%, and late stage (LATE) was 66.6 to 100% of the feeding phase completed at the time of treatment.

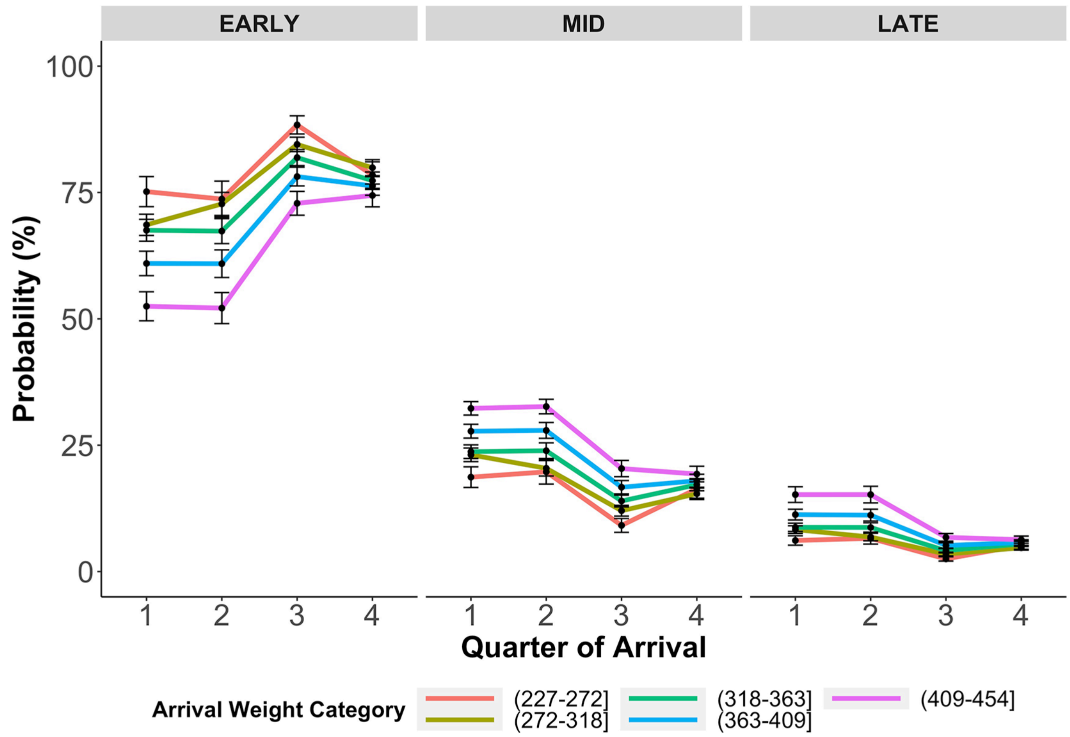

Figure 4. Model-predicted probability for timing of first treatment for bovine respiratory disease based on quarter of arrival into the feedlot (1 = January–March, 2 = April–June, 3 = July–September, 4 = October–December) modified by arrival weight category (solid line = 227–272 kg, dashed narrow = 273–318 kg, dashed narrow gap = 319–363 kg, dashed wide gap = 364–409 kg, dotted = 410–455 kg). Early stage (EARLY) was considered 0 to 33.3% of the feeding phase, middle stage (MID) was 33.3 to 66.6%, and late stage (LATE) was 66.6 to 100% of the feeding phase completed at the time of treatment. Probabilities were from an ordinal logistic mixed model, and error bars represent 1 SE.

egory by arrival weight category (Table 2). Sex was modified by quarter of arrival, and steers were more likely to be EARLY across all quarters of arrival, whereas heifers were more likely to be MID or LATE, except in the third quarter, where there are the most cattle entering the yard and there was no difference associated with sex. (Figure 3). The interaction for weight at arrival by sex indicated that lightweight steers were more likely to be EARLY (82.3%) compared with heavyweight steers (66.8%). The same effect was seen in heifers, but it was not as big of an effect. Lightweight heifers were more likely to be EARLY (75.6%) compared with heavy heifers (59.2%; Table 3). One study found that the incidence of BRD morbidity differed between steers and heifers, with steers being at higher risk than heifers. The analysis in that study did not investigate risk factors for incidence but instead looked at the risk factors associated with timing of disease, and sex was significant for both morbidity and mortality timing (Snowder et al., 2006).

This analysis was performed on individual animal treatment records, which revealed different information than previous analysis that only looked at cohort-level risk factors associated with timing of BRD (J. K. Smith, D. E. Amrine, R. L. Larson, M. E. Theurer, and B. J. White, 2021, unpublished data). In general, the lightweight cattle population is considered high risk and expected to have the greatest daily risk for BRD morbidity soon after arrival to the feedlot when stress is high (Ives and Richeson, 2015). Therefore, it is not surprising that we saw an increased probability of EARLY BRD morbidity among cattle in the lightest arrival weight category (227 to 272 kg) and that those cohorts that received metaphylaxis were often EARLY.

Metaphylaxis is given to animals during processing when they are deemed high risk as an attempt to lessen their risk of BRD. Lightweight animals are generally considered higher risk and treated with metaphylaxis more often than heavyweight animals. Quarter of arrival was modified by metaphylaxis; the only significant difference was seen during the first quarter of the year. Animals that received metaphylaxis in the first quarter had a 60.8% probability of being EARLY, whereas cattle that did not receive metaphylaxis had a 69.0% probability of being EARLY, but in the third quarter, cattle that received metaphylaxis had an 83.2% probability of being EARLY, whereas those that did not receive metaphylaxis had a 79.2% probability of being EARLY. Cattle that arrived in the first and second quarter of the year that were in the highest 2 weight categories (363 kg or more) had a lower probability (quarter 1 × 364 to 409 kg, 61.0%; quarter 1 × 410 to 455 kg, 52.5%; quarter 2 × 364 to 409 kg, 60.9%; quarter 2 × 410 to 455 kg, 52.1%) of being EARLY for BRD morbidity compared with cattle that arrived in the same quarters that were lighter in weight (<364 kg, which

Table 4. Characteristics of cohorts from which individual animal records were obtained for mortality[1]

Characteristic	EARLY	MID	LATE
Total (no.)	7,821	3,625	2,545
Days on feed at death			
Median	29	90	155
Mean	32	91	157
Quarter of arrival			
1	1,661 (11.9)	915 (6.5)	763 (5.5)
2	1,029 (7.4)	857 (6.1)	621 (4.4)
3	2,195 (15.7)	935 (6.7)	555 (4.0)
4	2,936 (21.0)	918 (6.6)	606 (4.3)
Metaphylaxis			
Yes	592 (4.2)	183 (1.3)	129 (0.9)
No	7,229 (51.7)	3,442 (24.6)	2,416 (17.3)
Sex			
Steer	5,458 (39.0)	2,358 (16.9)	1,592 (11.4)
Heifer	2,363 (16.9)	1,267 (9.1)	952 (6.8)
Cohort size			
20–100	1,498 (10.7)	550 (3.9)	345 (2.5)
101–200	2,957 (21.1)	1,293 (9.2)	939 (6.7)
201–300	2,074 (14.8)	1,065 (7.6)	709 (5.1)
301–400	1,292 (9.2)	717 (5.1)	552 (3.9)
Average weight at arrival (kg)			
(227–272)	404 (2.9)	140 (1.0)	70 (0.5)
(273–318)	2,234 (16.0)	914 (6.5)	562 (4.1)
(319–363)	2,712 (19.4)	1,276 (9.1)	868 (6.2)
(364–409)	1,866 (13.3)	956 (6.8)	779 (5.6)
(410–455)	605 (4.3)	338 (2.4)	266 (1.9)

[1]Data are presented as no. (% of total). Percentages within characteristic across all timing categories add to 100% with respect for rounding. Early stage (EARLY) was considered 0 to 33.3% of the feeding phase, middle stage (MID) was 33.3 to 66.6%, and late stage (LATE) was 66.6 to 100% of the feeding phase completed at the time of death.

ranged from 67 to 75%; Figure 4). Overall cattle that arrived in the third and fourth quarters were more likely to be EARLY, but when cattle arrived in the first and second quarters of the year, their risk was modified by other factors. Steers were more likely to be EARLY, whereas heifers were more likely to be MID and LATE, and heavy animals were more likely to be MID or LATE. This interaction may be due to less cattle getting sick or receiving metaphylaxis in the first and second quarters of arrival as the demographic of cattle that arrive in different quarters changes. These lightweight cattle are likely exposed to pathogens at a younger age, and their immune systems have not yet developed fully to be able to successfully address exposure to pathogens. Another study also found that animals placed in the fall months, particularly October in their case, were at a higher risk for BRD morbidity (Gallo and Berg, 1995). In this study, we found that when cattle are typically at lower risk for disease, as seen in the first 2 quarters of the year, the distinction of timing based on weight is important; however, when the overall risk of BRD morbidity increases, such as in the third and fourth quarters of the year, this effect dissipates, leaving fewer differences in timing.

Mortality

The final sample for mortality consisted of 13,991 records for individual death from BRD. Using these case defini-

Table 5. Covariate *P*-value for the final ordinal mortality model for bovine respiratory disease timing in the feedlot

Covariate	*P*-value
Sex	<0.01
Quarter of arrival	<0.01
Lot size category	0.01
Arrival weight category	<0.01
Metaphylaxis	<0.01
Quarter of arrival × sex	0.03
Sex × lot size category	<0.01

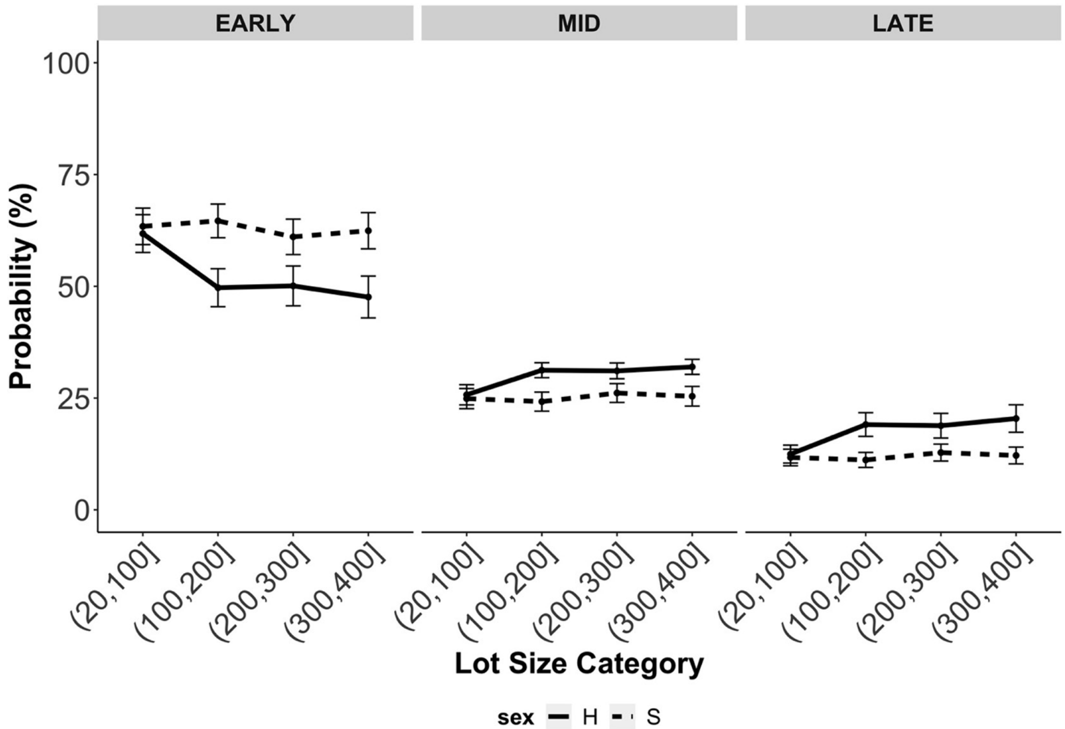

Figure 5. Model-predicted probability for timing of death from bovine respiratory disease based on lot size at arrival into the feedlot modified by sex (solid line = heifers, H; dashed = steers, S). Early stage (EARLY) was considered 0 to 33.3% of the feeding phase, middle stage (MID) was 33.3 to 66.6%, and late stage (LATE) was 66.6 to 100% of the feeding phase completed at the time of death. Probabilities were from an ordinal logistic mixed model, and error bars represent 1 SE.

tions for the timing of BRD mortality in feedlot cattle, 55.9% (n = 7,821) of individual treatments classified as EARLY, 25.9% (n = 3,625) classified as MID, and 18.2% (n = 2,545) classified as LATE. Cohorts ranged from 20 to 400 cattle at arrival with a median of 187. Descriptions of the raw data indicate that 31.9% (n = 4,460) of BRD deaths arrived in the last quarter of the year, which was the highest of the 4 quarters. Among cattle that died with a diagnosis of BRD late in the feeding phase, the greatest number arrived in the first quarter (Table 4).

The final ordinal regression model for mortality included significant ($P < 0.05$) main effects for arrival weight and metaphylaxis as well as 2-way interactions for sex by quarter of arrival and sex by lot size at arrival (Table 5). The main effects for metaphylaxis showed cattle that did get metaphylaxis were more likely (probability 63.3%, with a 95% CI of 55.0, 71.6) to die early than cattle that did not get metaphylaxis (probability 51.9%). Cattle that arrived in the lightest weight category (227 to 272 kg) were most likely to die of BRD early in their feeding phase than any other weight category. Sex was modified by lot size category as there was an increased risk for steers when they arrived in lots of more than 100 cattle to be EARLY mortality when compared with heifers in the same arrival lot size categories (Figure 5). The 2-way interaction for sex by quarter of arrival showed that steers were always more likely to be EARLY compared with heifers, but there was no difference between steers and heifers to be MID mortality when they arrived during the second quarter of the year (April to June). Both steers and heifers were more likely to be EARLY mortality when they arrived during the third or fourth quarters of the year, which is historically the most problematic part of the year for BRD (Table 6). A previous study also found that sex was a significant risk factor for beef animal mortality from BRD, with heifers having an increased risk of dying from respiratory disease (Loneragan et al., 2001b).

The data presented here show that mortality was greatest for animals that arrived during the fall and winter months, which was also seen by another study in 2020 (Broadway et al., 2020). This peak coincides with the most frequent time for cattle to arrive in the feedlot. There are times of year, third and fourth (July to September, October to December, respectively) quarters, when the other risk factors appear to have less influence on the timing of disease, which could be due to an overwhelming influx of high-risk animals into the feedlot. According to one study, relative risk of mortality from BRD was found to be at its highest during November through January (Loneragan et al., 2001a). In contrast, a different study found that the average death loss percentage from BRD was highest from April to June (Buda et al., 2021).

Limitations and Conclusions

Limitations from the study include that this information only pertains directly to feedlots in the region of those

Table 6. Final model[1] results from significant ($P < 0.05$) interactions demonstrating estimated probabilities of an individual animal's death due to bovine respiratory disease (BRD) being early, mid, or late[2]

Covariate	Level	EARLY Probability (%)	EARLY 95% CI	MID Probability (%)	MID 95% CI	LATE Probability (%)	LATE 95% CI
Arrival weight category	(227–272)	66.7	58.5, 75.0	22.9	18.2, 27.7	10.3	6.8, 13.9
	(273–318)	59.9	52.3, 67.6	26.6	22.7, 30.5	13.4	9.6, 17.3
	(319–363)	57.3	49.5, 65.1	27.9	24.1, 31.7	14.8	10.7, 18.9
	(364–409)	53.0	44.9, 61.0	29.8	26.3, 33.3	17.2	12.5, 21.9
	(410–455)	51.0	42.5, 59.5	30.6	27.2, 34.0	18.4	13.2, 23.6
Metaphylaxis	No metaphylaxis	51.9	44.3, 59.5	30.3	27.1, 33.5	17.8	13.3, 22.4
	Metaphylaxis	63.3	55.0, 71.6	24.9	20.4, 29.4	11.8	8.0, 15.7
Quarter of arrival × sex	1 × heifer	44.8	36.2, 53.4	33.0	30.2, 35.8	22.2	16.2, 28.3
	2 × heifer	46.5	37.7, 55.3	32.5	29.4, 35.5	21.0	15.1, 26.9
	3 × heifer	58.1	49.7, 66.5	27.7	23.5, 31.9	14.2	9.9, 18.5
	4 × heifer	59.8	51.5, 68.0	26.9	22.6, 31.2	13.4	9.3, 17.4
	1 × steer	60.9	52.9, 69.0	26.4	22.1, 30.7	12.7	8.9, 16.4
	2 × steer	53.7	45.3, 62.2	29.9	26.0, 33.8	16.4	11.7, 21.0
	3 × steer	67.6	60.3, 74.9	22.7	18.3, 27.0	9.7	6.8, 12.7
	4 × steer	69.3	62.2, 76.3	21.7	17.3, 26.0	9.1	6.3, 11.9
Sex × lot size category	Heifer × (20–100)	61.8	53.5, 70.1	25.7	21.3, 30.2	12.5	8.5, 16.4
	Heifer × (101–200)	49.7	41.4, 58.0	31.2	28.0, 34.5	19.1	13.9, 24.3
	Heifer × (201–300)	50.1	41.4, 58.8	31.1	27.6, 34.6	18.8	13.4, 24.2
	Heifer × (301–400)	47.6	38.4, 56.8	32.0	28.7, 35.3	20.4	14.4, 26.5
	Steer × (20–100)	63.4	55.4, 71.4	24.9	20.5, 29.3	11.7	8.1, 15.4
	Steer × (101–200)	64.6	57.2, 72.0	24.2	20.0, 28.4	11.2	7.9, 14.4
	Steer × (201–300)	61.1	53.3, 68.8	26.1	22.0, 30.3	12.8	9.1, 16.5
	Steer × (301–400)	62.4	54.5, 70.4	25.4	21.1, 29.7	12.2	8.5, 15.8

[1]Ordinal regression mixed-effects model with random intercepts for year, cohort within yard, and group days on feed.

[2]Probabilities added directly across columns add to 100% with respect for rounding differences. Early stage (EARLY) was considered 0 to 33.3% of the feeding phase, middle stage (MID) was 33.3 to 66.6%, and late stage (LATE) was 66.6 to 100% of the feeding phase completed at the time of death.

analyzed and from similar management styles. Many feedlots in the United States face similar problems overall, but there are regional differences such as weather, climate, processing protocols, and management that limit the appropriateness of extrapolation. Retrospective observational studies have some limitations, especially when combining data from multiple locations; each feedlot has differences in management as well as different personnel identifying disease in animals and performing the necropsies and classifying disease diagnosis. Across the feedlot industry, nationwide surveys have been used to estimate the number of animals that undergo postmortem examination; in 2011 this number was approximately 48.7% (SE, 2.6%; NAHMS, 2011). When necropsy was not performed, there is the possibility of misdiagnosis, which expands to more diseases than just acute interstitial pneumonia (**AIP**), also digestive, and heart failure. As the third and fourth quarters of the year are historically the worst for disease, personnel at feedlots are likely more attentive and apt to treat animals in an attempt to stop disease early. This leads to some potential confounding due to human nature. Some confounding factors were accounted for as covariates in the model; however, some known risk factors for BRD such as cattle source, weather, and distance traveled were not available for this analysis. This was an exploratory study, and the findings should be considered as hypotheses for further research.

Steers were more likely to be EARLY for morbidity than heifers across all quarters of arrival, and they were also more likely to die from BRD early than heifers across most quarters of arrival. There was not a significant difference during the second quarter of arrival for mortality between heifers and steers. Taylor et al. found an association between buller steers in their first 30 DOF and BRD mortality, which could explain some of why there is a greater probability of BRD mortality early in the feeding phase for steers (Taylor et al., 1997). This was a retrospective analysis, and there is the possibility that some BRD mortalities were misdiagnosed and actually were AIP deaths. A study identifying risk factors for AIP found that heifers were at a 4.9-times greater risk of suffering AIP than steers (Loneragan et al., 2001b). Loneragan noted in the same study that summer months and heavier animals had an increased risk of AIP.

Timing of disease was modified by lot size at arrival as animals that arrived in smaller cohorts were more likely to be EARLY when modified by quarter of arrival or arrival weight. Lot size at arrival could be a proxy for other risk factors that were not evaluated in this study (distance traveled, management structure within the feedlot, cattle source, and so on). A previous study had discovered an increased BRD incidence in medium and large lot sizes; our study did not look at the overall incidence but the timing of disease onset (Cernicchiaro et al., 2012). In this present study there was an increased probability of mortality from BRD EARLY among heifers of small lot sizes compared with heifers of lot sizes with more than 100 animals at arrival, but there was no difference among steers of any lot size at arrival across timing.

APPLICATIONS

Evaluating risk factors for individual animals to be EARLY, MID, or LATE for BRD based on their DOF at treatment or death could help direct future research on the timing of respiratory disease. In the current study, heifers had an increased probability to be MID or LATE compared with steers when quarter of arrival and arrival weight were accounted for in the statistical model. Heifers arriving in small lot sizes were more likely to have mortality EARLY in the feedlot; however, lot size effects were not observed for steers. Cattle that received metaphylaxis were more likely to experience EARLY mortality than those that did not receive metaphylaxis. Cattle receiving metaphylaxis in the first quarter were less likely to experience EARLY morbidity than cattle that did not receive metaphylaxis in the first quarter. However, cattle arriving in the third quarter were more likely to experience EARLY morbidity, regardless of metaphylaxis, than any other quarter of arrival. Cattle receiving metaphylaxis were 4% more likely to experience EARLY morbidity than those that did not receive metaphylaxis during the third quarter for arrival.

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