Evaluating distributions for the timing of respiratory disease in feedlot cattle and determining risk factors associated with mid- and late-feeding stage bovine respiratory disease

by

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Abstract

Understanding the epidemiology of bovine respiratory disease (BRD) in feedyard cattle is an important part of improving the efficiency, economics, and animal husbandry of the cattle industry. Recent concern has developed over a suspected increase in BRD occurring later in the feeding period than previously noticed. Three studies were conducted using retrospective industry data to evaluate any relevant risk factors associated with the timing of BRD morbidity and mortality. The first study identified temporal distributions of first treatment for BRD morbidity, days from feedlot arrival to first pull for an animal that subsequently died, and days on feed (DOF) from first pull for BRD until death attributed to BRD. These were visually compared for steers and heifers that arrived in the 700 to 800 lb weight category across the quarters of the year. In general, heifers had a later DOF for all three outcomes compared to steers, and the quarter of arrival that most often was later for all three categories was Q2 (April-June). The second study utilized cluster analysis to group cohorts into the most similar disease pattern based on number of BRD pulls by DOF. Clusters were analyzed as early-, mid-, or late-feeding stage cohorts and evaluated for risk factors associated with the timing of disease. The only factor significantly ($P<0.05$) associated with cohort-level BRD morbidity timing was quarter of arrival. Cattle that arrived in Q2 were more probable to be mid- or late-feeding phase (5.5%, 10.2% respectively) morbidity at the cohort level. The third study evaluated the timing of BRD morbidity and mortality for individual animal records. Cattle demographic factors were used to evaluate associations with the probability of an individual animal first treatment BRD or mortality being early-, mid-, or late-feeding stage. 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. Further understanding of typical patterns of disease could lead to the ability to modify prevention or intervention techniques to improve cattle health.

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Introduction

Bovine respiratory disease (BRD) continues to be a major frustration in the feedyard industry that leads to morbidity and mortality. It is often frequently referenced for being the most economically detrimental disease in feedyards as well as the most common cause of mortality in finisher cattle. Most research has focused on risk factors attributable to BRD, but rarely has research been conducted on the timing of BRD throughout the feeding-phase, primary focus has been shortly after arrival to the feedyard. Chapter 1 descriptively discusses the distributions of when this disease occurs for morbidity and mortality. Chapter 2 focuses on timing of BRD at the cohort level and risk factors associated with onset of disease. Finally, chapter 3 dives into individual animal treatments and what risk factors are associated with timing of disease morbidity and mortality.

Research has previously focused on BRD early in the feeding phase, however, due to an increased concern about late-feeding phase BRD within industry personnel, using big data to evaluate the distribution of disease was deemed necessary to overview the problem at hand. The main objectives of this study were to review literature on late day BRD in the feedlot and to determine the distribution of timing of initial treatment, the distribution of time of death after initial treatment as well as days to fatal disease onset using a subset of data by known risk factors.

In United States finishing operations, cattle are often housed in various sized groups on dirt floor pens, an ongoing discussion has been if BRD is an issue primarily within these groups (cohorts), or for each individual animal. The second chapter used cluster analysis to evaluate cohorts based on days on feed (DOF) of when most of their BRD occurred. The study objective was to determine risk factors on the cohort level associated with the timing of BRD morbidity and to define a case definition for the timing of cohort-level BRD.

Disease timing has economic implications, cattle that have been in the feedyard longer have had more resources allotted to them compared with cattle that just arrived in the feedyard. Chapter three focuses on the timing of BRD based on an individual animals treatment records. Both morbidity and mortality were evaluated for associations of risk factors with mid- and late-feeding stage BRD.

Chapter 1 - Review of late feeding stage bovine respiratory disease literature and evaluation of bovine respiratory morbidity and mortality first treatment timing, fatal disease onset, and days from first treatment to death in feedlot cattle

Abstract

Limited research has evaluated the risk factors influencing the timing of bovine respiratory disease (BRD); most BRD research has focused on environmental and demographic factors influencing disease frequency. The study objectives were to descriptively evaluate BRD temporal patterns for cattle in U.S. feedyard systems. Individual animal records for first BRD treatment (n = 301,721) or BRD mortality (n = 19,332) were received from 25 feedyards. Data were split into subsets by known risk modifiers to account for multiple biological interactions based on demographic factors. The temporal distributions of first treatment for BRD morbidity (Tx1), days from feedlot arrival to first treatment for an animal that subsequently died (FDO), and DOF from first treatment for BRD until death attributed to BRD (DTD) were visually compared for steers and heifers that arrived in the 700 to 800 lb weight category across the quarters of the year. Results indicated the pattern of disease varied by quarter of arrival with cattle arriving in Q3 and Q4 having more BRD cases early compared to cattle arriving in Q2. In general, heifers had a later DOF for all three outcomes compared to steers. In groups that showed later DOF at death, the DTD were similar, but there were differences in the FDO. Overall results illustrate the temporal pattern of disease varies by animal demographics and understanding these differences allows animal health managers to better evaluate new events.

Further understanding of typical patterns could lead to the ability to modify prevention or intervention techniques to improve cattle health.

Introduction

Bovine respiratory disease is a multifactorial disease which makes it complex to research and prevent. Previous research has focused on risk factors, weather patterns, diagnostics, disease prediction and cattle demographics associated with disease frequency, thus limited research on the timing of bovine respiratory disease (BRD) throughout the feeding phase has been conducted.(Abutarbush et al., n.d.; Cernicchiaro et al., 2012; Theurer et al., 2014; White & Renter, 2009) As research has advanced and risk factors associated with BRD morbidity and mortality have been determined, management practices have been employed to decrease BRD incidence have been employed, including utilization of metaphylaxis and preconditioning prior to feedlot arrival. One study stated that part of the challenge with researching late-feeding stage BRD is due to the lack of a definition.(Engler et al., 2014) This can be seen from one article referring to “Early” being processing to d 35 and “Late” as d 35 to slaughter, while another used more categories with “first 30 days, mid-feeding period, 60 to 31 days before harvest, or last 30 days” as their feeding periods.(Thompson et al., 2006; Vogel, Bokenkroger, & Rutten-Ramos, 2015) The stated objective of one study was to identify risk factors associated with the probability of animals being treated for BRD and subsequently dying by evaluating the probability of being a treatment failure based on DOF at first treatment.(Avra et al., 2017) These authors reported that cattle treated in the first 20 DOF were more likely to be treatment failures than cattle treated after the first 40 DOF, however this study only evaluated cattle treated up until day 60. Another study reported that mortality rates have been trending upward between 2001 to 2013, and they identified lower than historical morbidity rate but higher case fatality rate during this time span.(Engler et al., 2014) A study from 2017 reported 69.3% of morbidity occurred in cattle during the first 15 days on feed, however, mortality risk due to BRD was approximately uniform throughout the remainder of the feeding period.(Baptista et al., 2017)

A similar disease pattern was noted almost a decade earlier where 74% of BRD occurred within the first 42 days on feed and mortality risk was uniformly distributed from treatment to slaughter.(Babcock et al., 2009) The DOF was variable in this study as cattle from all different weight classes on arrival were evaluated. Within the same year, a different study noted that 75% of treated cattle had been treated by day 55 and the average day of first treatment was day 40 in the feedlot.(Schneider et al., 2009) Similarly, another study reported that morbidity risk was greatest within the first 3 weeks of entering the feedlot and decreased through the end of a 12-week feeding period.(Sanderson et al., 2008) In contrast, a temporal analysis of BRD in feedlot cattle was utilized in a 2010 study to evaluate timing patterns across 7,553 cohorts of cattle. This analysis clustered the cohorts to 7 patterns of disease timing as a cumulative percent of the disease events that occurred across the first 100 DOF. One of the clusters did not have the first disease case until day-60 on feed.(Babcock et al., 2010) More recent literature that evaluated timing of BRD indicated that there may be differences in disease patterns across different classes of cattle.(Theurer et al., 2021a) The authors hypothesized that high-performing cattle had different patterns of disease than high-risk cattle. Based on the studies identified in the literature search, more research is needed to better understand these temporal disease patterns.

The first objective of this study was to determine differences in the distribution of timing of initial treatment (Tx1), the second objective was to determine differences in the distribution of time of death after initial treatment (DTD), and the third objective was to determine differences in the distribution of days to fatal disease onset (FDO) using a subset of data by known risk factors.

Materials and methods

Data Source

Data were collected from 25 U.S. commercial feedyards under data use and confidentiality agreements. Feedyards were located primarily in the Great Plains and Midwestern United States. Event records for 567,989 cattle are included in these data representing a total 4,381,336 cattle on feed. Institutional Animal Care and Use Committee approval was not required as historical operational data were utilized for the analysis. Data from 11 feedyards was provided for 2015-2019, while data from the other 14 was provided for 2018-2021. Feedyards ranged in one-time capacity from approximately 8,000 head to over 100,000 head.

BRD Morbidity Timing

Data were filtered to include only animals in cohorts with 40 to 400 head at arrival, sex was limited to steer or heifer, and arrival weights from 500 to 1,000 lbs (Figure 1). These filters were applied to remove any extreme outliers and potential data typos as this is production data. An animal was classified as a BRD treatment if the animal was diagnosed by the feedyard personnel with BRD and received antimicrobial therapy for BRD. First treatment BRD included only the initial BRD therapy and did not include cattle diagnosed with acute interstitial pneumonia (AIP). Cohorts with a minimum of 150 days on feed (DOF) were included to avoid cohorts with very short time at risk. Only treatment or death events occurring before 150 DOF were considered; therefore, time at risk for disease or death was the same among all cohorts. After filtering, the working dataset consisted of 301,721 records of cattle BRD first treatments.

All cattle were given a unique animal identifier (UID) that consisted of yard identifier number, cohort identifier, and individual tag number. The data consisted of typical variables recorded by the feedyard (arrival date, tag identifier, lot size at arrival, cohort average arrival weight, DOF at treatment, body weight at the time of BRD treatment, rectal temperature at the time of BRD treatment, diagnosis, sex, and total number of treatments in that cohort). Variables were calculated from the given information including days from treatment to death and quarter of arrival (QOA).

Known risk factors were combined into categories of weight class at arrival (500 to 600, 600 to 700, 700 to 800, 800 to 900, 900 to 1000 lbs), quarter of arrival (Q1, Jan to March; Q2, April to June; Q3, July to Sept; Q4, Oct to Dec), and cohort sex (steer, heifer). No well-defined case definition for late-feeding stage BRD has been reported, therefore disease timing was evaluated descriptively through a visual analysis of DOF at first treatment for BRD. Graphical analysis was used to more thoroughly evaluate the pattern of disease occurrence distributed throughout DOF instead of using a central tendency from a model estimate to identify, this provides an indication of normal patterns over the studied years. Within a subset, to maximize the amount of data evaluated, the weight class 700 to 800 lbs was chosen and evaluated for steers and heifers with all combinations of QOA.

BRD Mortality Timing

The same constraints for cohort size, DOF, sex, and arrival weight were applied to the mortality dataset. There were 63,075 death records from the same raw data set, which yields a 1.4% overall death risk for these yards. Only animals that died with a diagnosis BRD at death were retained, which resulted in 18,323 records within the final dataset. These data were used to calculate DOF from first treatment date for BRD to death date with a diagnosis of BRD (DTD) and days from arrival to first treatment for BRD (FDO) which subsequently died from BRD.

Subsets

Data subsets were created to account for known risk factors, including sex (steer or heifer), average cohort arrival weight category (700 to 800 lbs), and quarter of arrival (Q1, Jan to March; Q2, April to June; Q3, July to Sept; Q4, Oct to Dec). Subsets were used to evaluate all three study objectives: determining the timing of animals treated for BRD at least once (n = 102,811), the second evaluating differences in days to death with BRD diagnosis after being treated for BRD (n = 4, 663), and the third investigating differences in days from arrival to first treatment for BRD in animals that subsequently died of BRD, which we will refer to as fatal disease onset (n = 4,969). The difference in number of cattle involved in first treatment to death and fatal disease onset is due to the inclusion criteria of cohort DOF being equal or greater than 150 days, and events (treatment or death) only evaluated for the first 150 DOF.

Data analysis

Descriptive graphical analysis and Wasserstein distance (WD) were used to describe, visually evaluate, and calculate the differences in distributions of morbidity and mortality throughout the feeding phase for all three outcomes. This study was intended to characterize regular temporal patterns of BRD in a population of commercial feedlot cattle. Subsets of data were created based on previously identified risk factors for BRD morbidity and mortality. Wasserstein distance (WD) is a metric equal to the average distance between two corresponding distributions.(Panaretos & Zemel, 2019) In this type of analysis, the unit of analysis is the full distribution.(Rustamov & Majumdar, 2021),(Hallin et al., 2021; Kolouri et al., 2017) This metric is equal to 0 when two distributions perfectly overlap, and is dependent on the unit of measure of the variable. Wasserstein distance was calculated with the transport package in R Studio, for each subset of data WD comparisons were calculated for every possible comparison of quarter of arrival, as well as with each sex compared for every quarter of arrival. (Schuhmacher et al., 2020)

Results

Objective 1: BRD morbidity at first treatment

The data subset used in the analysis included both steers and heifers arriving in cohorts with average arrival weight between 700 to 800 lbs (318 to 364 kg). Yard variability was taken into account and evaluated descriptively across yards and no major discrepancies were found. Steers had 75% of their treatments in Q4 by day 45 while heifers arriving in Q4 did not reach 75% of treatments until day 53 (Table 3). However, when we look at Q3 both steers and heifers reached 75% of their treatments by DOF 50 and 52 (respectively). There was a visual difference between heifers and steers, showing that heifers had a later DOF at first treatment for BRD compared to steers (Figure 2). A greater difference between steers in Q2 and Q4 was identified compared to any other quarter-comparison with a WD 11.29, but for heifers it was greatest between Q2 and Q3 with a WD of 11.42 (Table 4). Both steers and heifers had Tx1 later when they arrived in Q2 compared to the Q1, Q3, or Q4. Across all QOA, heifers had a later first treatment for BRD than steers.

Objective 2: Mortality days to death

The analyzed data subset included mortalities from both steers and heifers, but not mixed-sex cohorts, that arrived between 700 to 800 lbs (318 to 364 kg) from all QOA. All combinations of sex and QOA were evaluated visually as well as with the WD. The greatest difference between distributions was observed between Q2 and Q4 for both steers and heifers

(Table 4) where steers arriving in Q2 had slightly later DOF from first treatment to death compared to steers during other QOA (Figure 3). No difference was observed for heifers when looking at the QOA; however, using the WD there was a greater difference between Q2 to Q3 and Q2 to Q4 than the Q1 to Q2 or Q3 to Q4 (Table 4). Across all categories, if an animal was going to die from BRD post treatment for BRD, 75% of the time it occurred within the first 38 days from treatment, except for in steers arriving in the Q2 where 75% occurred at DOF 43 (Table 5).

Objective 3: Mortality fatal disease onset

The analyzed data subset included animals that were treated and died for BRD, both steers and heifers, but not mixed-sex cohorts, that arrived between 700 to 800 lbs (318 to 364 kg) from all QOA. All combinations of sex and QOA were evaluated visually and with the Wasserstein distance. Steers had 75% of their FDO treatments by DOF 66 when they arrived Q2, comparably, heifers did not reach 75% until DOF 80 for that same QOA (Table 6). Most notably the greatest WD was between Q2 and Q4 for both steers and heifers (17.20; 17.18, respectively). The smallest variation between distributions was seen between Q1 and Q2 for both steers and heifers (Table 4). Visually there was a difference in cattle that arrived in Q2 having a later DOF at first treatment for steers and heifers that arrived in Q2 (Figure 4). More animals arrived in Q1, Q3, and Q4 than in Q2 which is typical of the industry. In all QOA, heifers had a later DOF at first treatment and wider spread in the distribution between the 25th and 75th percentiles. There was a greater variation in FDO visually than DTD, which did vary by QOA but was consistent across sex. However, for FDO there was also a noticeable variation between steer and heifer, with heifers being later.

Discussion

As is evidenced by the literature review, minimal research has been conducted with the objective of evaluating the epidemiology for timing of BRD. Future research should be conducted to further investigate differences in the timing of BRD onset for morbidity and mortality. From the literature that is available it is evident that most BRD does occur early in the feeding period, but incidence of disease is not confined to this period and raises the question of if there are different risk factors involved in BRD later in the feeding period.

Descriptive analysis was used to visualize differences in timing of disease onset. Due to the complexity of biology, traditional statistical models are challenging to interpret with greater than two-way interactions. Central tendency as a metric also has benefits but does not adequately explain trends in the data when evaluating large data sets with a wide range. The objective was to investigate interactions between multiple known risk factors to assess the timing of BRD morbidity and mortality, which is why data was partitioned by arrival weight and sex. Bar charts with standard error are typically used for visualization of model estimations, but these visualizations do not convey information about the overall distribution of the population. Therefore, raincloud plots, which consist of a box and whisker plot, violin plot, and scatter plot, were used to convey more information about the data.

Feedyards first treatments by DOF were evaluated and considered similar by distributions for timing, there are differences on a feedyard-to-feedyard basis between management, environment, and nutrition. However, due to the nature of our data, 11 yards were grouped into 2 categories and there was no way to separate out which yards were which. On a clinical and industry level, there was no evaluation of what is causing feedyard to feedyard variation and it does not add clinical meaningfulness to the objectives of this analysis. We are aware that there are differences between feedyards, but not knowing the driver of those differences makes it lack usefulness in decision making for this analysis.

One recent study found an association between timing of disease onset and sex being modified by QOA with the greatest probability for late-feeding stage morbidity being in heifers that arrived in Q2.(K. Smith et al., 2022) Those are the same risk factors commonly associated with AIP and one study noted that heifers had a 3.1 times greater odds of developing AIP than steers.(Loneragan, Gould, et al., 2001) The current study evaluated the timing of BRD morbidity and mortality, retrospective production data was utilized and diagnoses were based on information entered by the operation. Postmortem examination is a common practice, but it likely did not occur in all animals that died in this dataset, thus the potential for misclassification exists.

An interesting observation from this study is that although differences were evident in the timing of Tx1, there was no remarkable difference in the distribution of DOF from DTD; if an animal was treated for BRD and died, 25% of the time it occurred 4 days after first treatment (Table 5). One hypothesis from this observation is not a drug failure problem, but a failure of early disease detection.

The intention of this analysis was not to test differences in central tendency, but to compare distributions among variables known to be associated with timing of disease onset in the feedyard. Comparison of central tendency when the distribution is very wide do not provide meaningful insight on the differences in the population. The objective of this research was to evaluate population level differences which was analyzed through WD.

Limitations

This was a retrospective study utilizing production data which increases the external validity but results in some limitations including misclassification of diagnosis at first treatment or death. Multiple feedyards of different size, regions within the U.S., weather, protocols and management were represented but these feeding operations may not be representative of the entire U.S. cattle feeding industry which limits the appropriateness of wider extrapolation from these data. There was also data from many years and multiple yards that supplied different years of data, the authors acknowledge that there is year to year variation in disease. We chose to only evaluate one weight-category subset of the data. Although we could have evaluated every possible combination of variables, there would be too many graphs to adequately evaluate in this paper, and thus we chose to evaluate the weight class that was most populous in our data. Only first treatments were evaluated, therefore, further research should be done to evaluate the occurrence of multiple BRD treatments as well as complex disease treatment (animals being treated for different diagnoses).

Figures

Figure 1.1. Flowchart of data filtering process for the number of individual animals filtered out to create the working dataset for the first treatment bovine respiratory disease, fatal disease onset, days to death objectives.

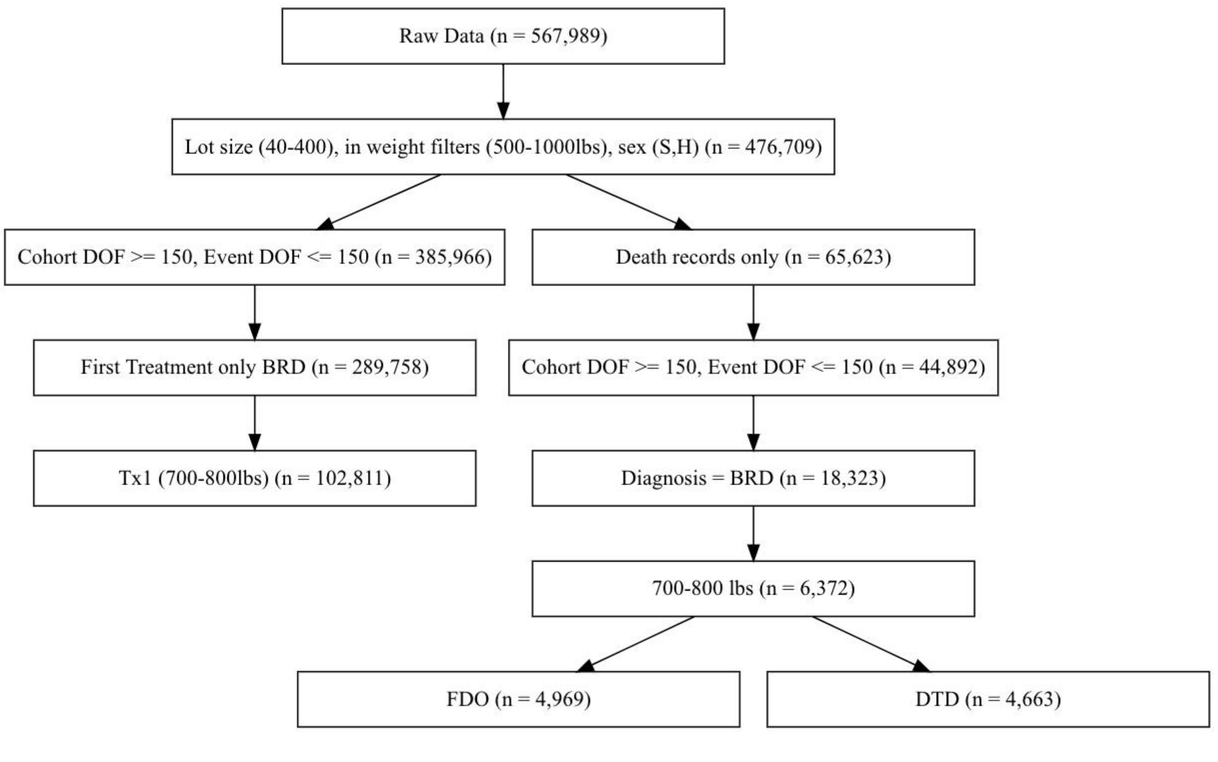
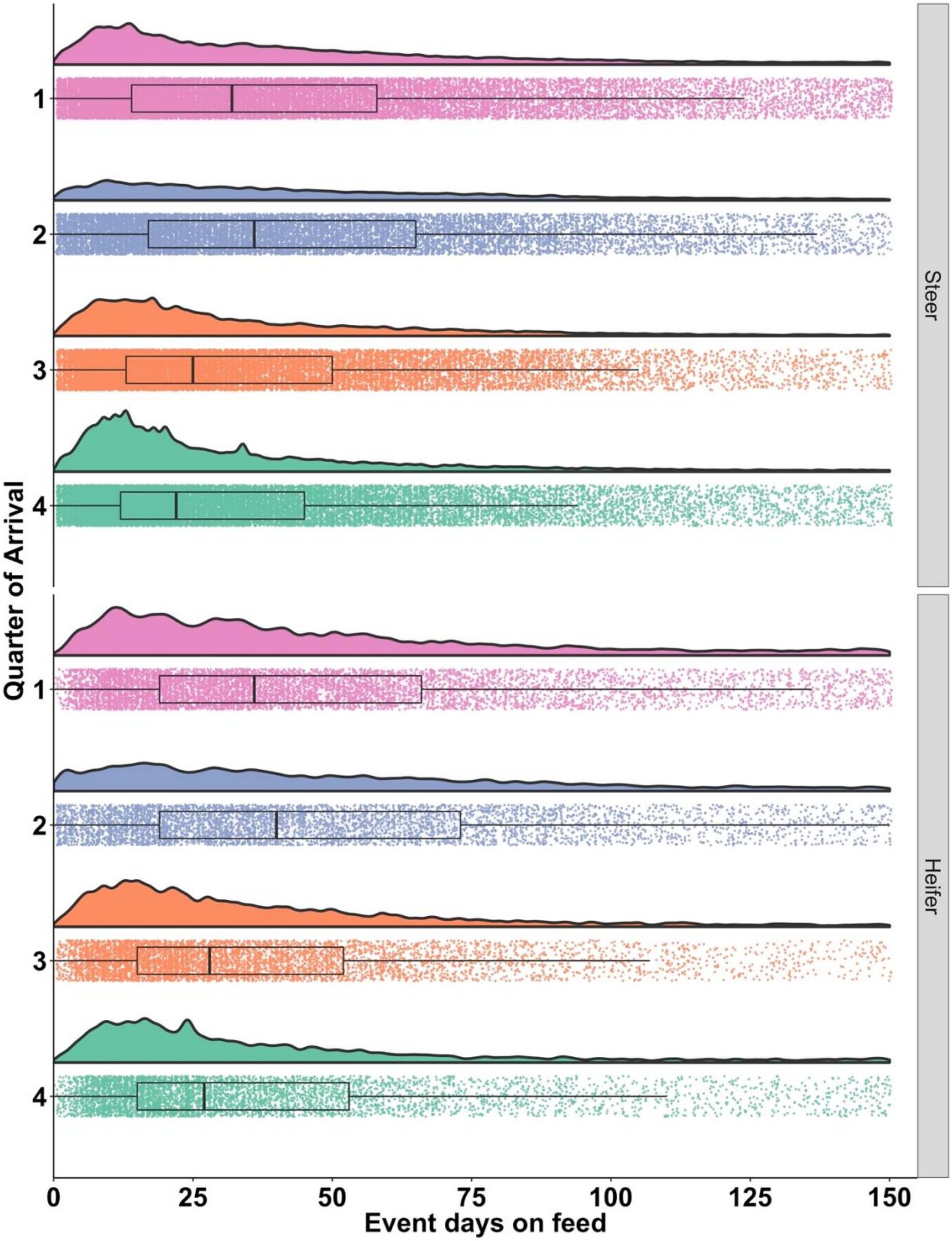
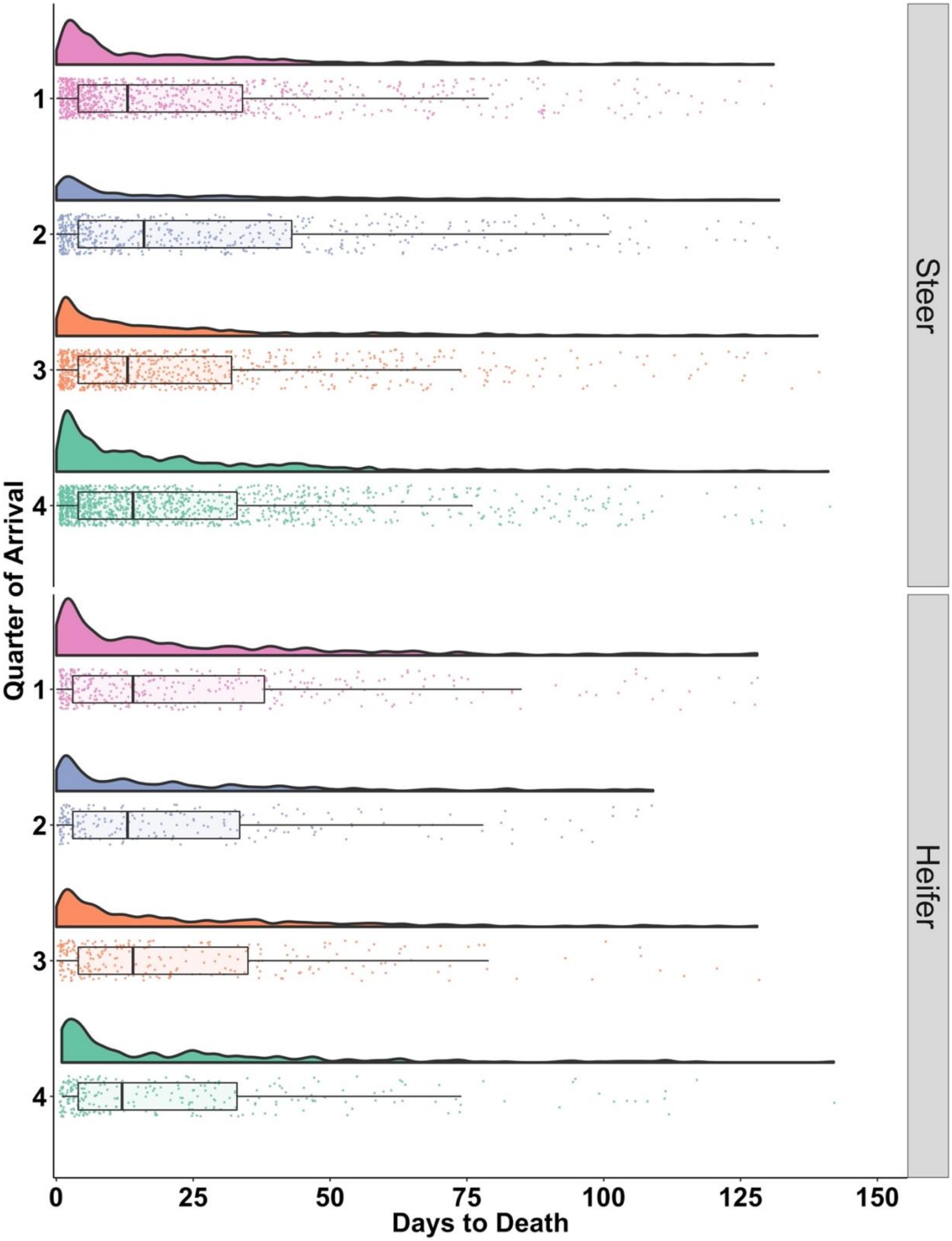


Figure 1.2. Days on feed from arrival to first treatment for bovine respiratory disease (Event days on feed), by quarter of arrival on the left vertical axis and sex faceted on the right vertical axis. The vertical axis is scaled to account for the difference in number of observations in each category. Each dot represents one observation. Box and whisker plot box represents the upper and lower quartile with the heavy line inside the box being the median.



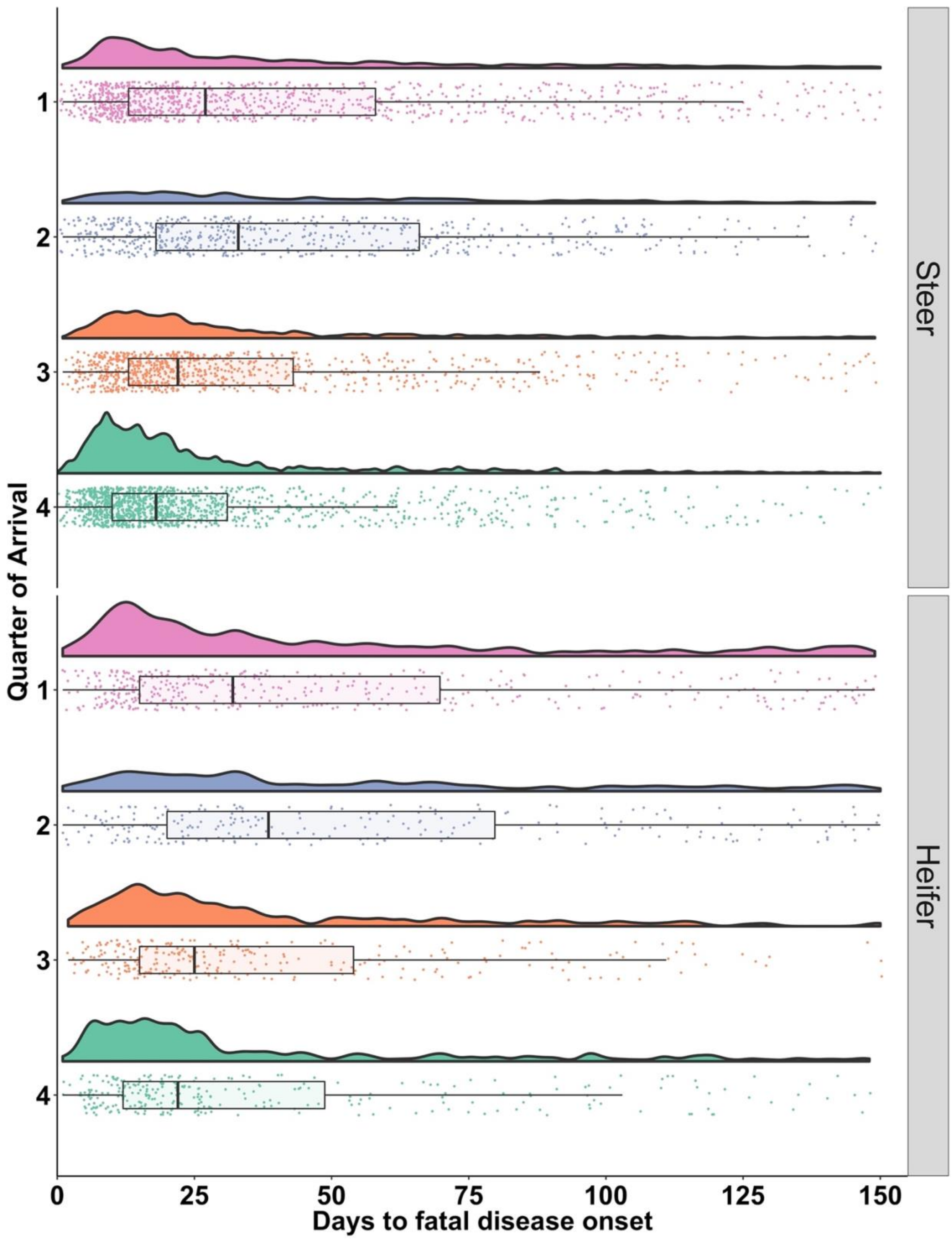
Quarter of Arrival
1
2
3
4
1
2
3
4
Steer
Heifer
0
25
50
75
100
125
150
Event days on feed

Figure 1.3. Days on feed days to death, by quarter of arrival on the left vertical axis and sex faceted on the right vertical axis. Box and whisker plot box represents the upper and lower quartile with the heavy line inside the box being the median. Day 0 here refers to the day of first treatment for bovine respiratory disease.



Steer
Heifer
Quarter of Arrival
1
2
3
4
1
2
3
4
0
25
50
75
100
125
150
Days to Death

Figure 1.4. Days on feed from arrival to first treatment for bovine respiratory disease (BRD) for animals that eventually died from BRD, by quarter of arrival on the left vertical axis and sex faceted on the right vertical axis. Box and whisker plot box represents the upper and lower quartile with the heavy line inside the box being the median.



Steer
Heifer
Quarter of Arrival
1
2
3
4
1
2
3
4
0
25
50
75
100
125
150
Days to fatal disease onset

Tables

Table 1.1. The descriptive statistics of the final working dataset n= individual animals treated for disease.

Characteristic		
	Percent of total	Total = 289,758
Quarter of arrival		
1	27.3%	79,121
2	19.2%	55,635
3	23.9%	69,152
4	29.6%	85,850
Metaphylaxis		
Yes	17.3%	50,038
No	82.7%	239,720
Sex		
S	75.5%	218,860
H	24.5%	70,898
Cohort Size		
40 – 200	68.5%	198,467
201 – 400	31.5%	91,196
Average Weight at Arrival (lb)		
500 – 600	5.1%	14,735
600 – 700	30.9%	89,425
700 – 800	35.5%	102,811
800 – 900	23.1%	66,792
900 – 1000	5.5%	15,971

Table 1.2. Descriptive statistics of the final working dataset n= individual cattle died from bovine respiratory disease.

Characteristic	Percent of total	Total = 18,323
Quarter of arrival		
1	24.8%	4,543
2	17.4%	3,192
3	24.2%	4,426
4	33.6%	6,162
Metaphylaxis		
Yes	16.1%	2,955
No	83.9%	15,368
Sex		
S	71.5%	13,109
H	28.5%	5,214
Cohort Size		
40 – 200	54.7%	10,016
201 – 400	45.3%	8,307
Average Weight at Arrival (lb)		
500 – 600	6.8%	1,243
600 – 700	31.5%	5,770
700 – 800	34.8%	6,372
800 – 900	21.6%	3,963
900 – 1000	5.3%	973

Table 1.3. Once data were filtered into subsets this table shows how many individual animals were present in each of the categories. For the first objective this includes animals within the filtering criteria that were treated at least once for bovine respiratory disease.

Characteristic			
Total			n = 102,811
Quarter of arrival	n	Quartiles (DOF)	
Steers		25%	75%
1	22,678	14	58
2	13,946	17	65
3	19,342	13	50
4	23,567	12	45
Heifers			
1	7,223	19	66
2	5,224	19	73
3	5,627	15	52
4	5,204	15	53

Table 1.4. Wasserstein Distance used to compare distances between distributions for days on feed by sex and quarter of arrival for first treatments, days to death, and days to fatal disease onset. Greater differences between quarters of comparison are seen by greater values of Wasserstein Distance.

Quarter of comparison	Wasserstein Distance		
Steers	First treatment	Days to death	Days to fatal disease onset
1-2	3.63	6.96	4.99
1-3	6.06	6.41	6.46
1-4	7.78	12.00	12.88
2-3	9.56	13.21	10.73
2-4	11.29	18.90	17.20
3-4	9.56	5.70	6.56
Heifers			
1-2	3.10	6.38	6.90
1-3	8.72	9.41	9.30
1-4	7.39	12.05	10.40
2-3	11.42	14.93	15.94
2-4	10.13	17.74	17.18
3-4	1.78	4.53	4.10
Combined			
1-2	3.57	6.67	5.29
1-3	6.75	7.52	7.40
1-4	8.05	13.00	13.19
2-3	10.21	13.88	12.30
2-4	11.51	19.45	18.15
3-4	2.15	5.58	5.91

Table 1.5. Once data were filtered into subsets this table shows how many individual animals were present in each of the categories. For the second objective this required animals to have both a first treatment record and death record with diagnosis bovine respiratory disease. Days on feed is from days to death.

Characteristic			
Total		n = 4,663	
Quarter of arrival	n	Quartiles (DOF)	
Steers		25%	75%
1	927	4	34
2	557	4	43
3	806	4	32
4	1,257	4	33
Heifers			
1	370	3	38
2	215	3	34
3	261	4	35
4	270	4	33

Table 1.6. Once data were filtered into subsets this table shows how many individual animals were present in each of the categories for the third objective. This required animals to have both a first treatment record and death record with a diagnosis of BRD. Fatal disease onset refers to the days from arrival to first treatment for an animal that eventually died.

Characteristic			
Total		n = 4,969	
Quarter of arrival	n	Quartiles (DOF)	
Steers		25%	75%
1	1,009	13	58
2	605	18	66
3	857	13	43
4	1,309	10	31
Heifers			
1	398	15	70
2	232	20	80
3	275	15	54
4	284	12	49

Chapter 2 - Determining relevant risk factors associated with mid- and late-feeding stage bovine respiratory disease morbidity in cohorts of cattle

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Abstract

Previous bovine respiratory disease (BRD) research has focused early in the feeding phase, but the objective of this study was to determine characteristics and risk factors associated with cohort-level BRD morbidity in the middle and late portions of the feeding phase. The analysis was performed on records from 13 commercial feedlots in the U.S. from 2017 through 2020. Cohorts were analyzed over their first 100 days on feed (DOF). Two methods of classification were utilized. Veterinarian classification method: hierarchical clustering created 20 temporal patterns which were categorized by veterinary consultants as early-feeding stage, mid-feeding stage, or late-feeding stage morbidity curves. Days classification method: cohorts categorized based on which portion of the feeding period (0 to 42 d, 43 to 71 d, or 72 to 100) had the greatest percentage of treatments for BRD. An events/trials model was used to determine morbidity and mortality across different stages of the feeding phase. Ordinal regression was utilized to determine associations between cohort characteristics and BRD timing. Year and feedlot were included as random effects to account for the hierarchical structure of the data. Combined classification yielded 2429 early-feeding stage cohorts, 108 mid-feeding stage cohorts, and 61

late-feeding stage cohorts. The only factor significantly ($P<0.05$) associated with cohort-level BRD morbidity timing was quarter of arrival. Cattle arriving in the second quarter were more likely to be mid-feeding stage or late-feeding stage (5.5%, 10.2%, respectively) compared to cattle arriving in the other quarters of the calendar year (Q1: 2.7%, 4.5%; Q3 1.4%, 2.2%, or Q4 1.4%, 2.3%). This study evaluated risk factor relationships with cohort-level BRD timing. No cattle characteristics were significantly associated with BRD timing; however, cattle arriving in Q2 were at higher risk for cohort-level mid- or late-feeding stage BRD.

Introduction

Bovine respiratory disease (BRD) has persisted as the leading cause of morbidity and mortality in North American feedyards which also makes it known as the most economically impactful. Estimates have shown that 67 to 82% of total feedyard morbidity is due to BRD (R. A. Smith, 1998). Previous research has focused on BRD soon after arrival to the feedyard (Babcock et al., 2010; Vogel, Bokenkroger, Rutten-Ramos, et al., 2015). Research between 1986 and 1994 indicates that approximately 65 to 80% of morbidity occurred before 45 days on feed (DOF), 13 to 22% from 45 to 90 (DOF), and 6 to 15% after 90 DOF (Edwards, 1996). There is a gap in the literature about the timing of BRD at the cohort or individual level, and the existing literature is over a decade old. Recent literature suggests a possible shift from the previously reported epidemiological pattern (Theurer et al., 2021b). An attempt was made recently to determine differences in timing of BRD morbidity between high risk and high performing cattle cohorts throughout the feeding phase, however, no potential causes of BRD later in the feeding period were evaluated (Theurer et al., 2021b). Due to a possible increase in incidence later in the feeding period, more research focused throughout the entirety of the feeding period is necessary.

From an economic perspective, loses later in the feeding period are more detrimental as the cumulative resources expended are greater than a loss at the beginning of feeding.

A major deficiency in the literature to date has been no definition for “late” feeding mortality, (Engler et al., 2014) and late-feeding stage morbidity suffers from similar issues. Without a clear case definition, determining potential influence of risk factors is challenging. The objective of this work was to determine cohort-level associations with the timing of BRD morbidity and to define a case definition for the timing of cohort-level BRD. A secondary object was to determine differences in amount of morbidity and mortality across different stages of the feeding phase.

Materials and Methods

Data source

Lot level data from 13 feedyards were collected under confidentiality agreement with the individual feedlots. Institutional Animal Care and Use Committee (IACUC) approval was not required as historical operational data were utilized for the analysis. The Institutional Review Board (IRB) at Kansas State University, application #10348 was deemed exempt from in depth review and granted permission for use of a survey. All veterinarians that participated in the survey did so anonymously.

A cohort was defined to be a group of animals that arrived at the feedyard together; they did not have to finish out the entire time on feed in the same pen. Data were imported into RStudio (9) for analysis; there were 8,764 cohorts, each cohort contained at least one record for an animal treated for BRD. Records were from May 25, 2017 through June 17, 2020. Our case-definition for BRD was any animal identified by feedlot personnel with clinical signs consistent with BRD for the first time in the feeding period and subsequently treated with an antimicrobial by feedyard personnel. Animals were not excluded due to multiple treatments, however, only the first pull was considered for this analysis. Cohorts were limited to 30 and 500 animals at arrival, greater than 7% total BRD morbidity, single sex cohorts, and an average arrival weight between 181 kg (400 lbs) and 454 kg (1000 lbs). There were 3,550 cohorts that met these initial criteria (Figure 2.1).

Data were transformed into a format so that every cohort had an observation for each individual d from 0 to 100 creating a data set for number of animals treated for BRD each day. This was done to create equal weight in the temporal patterns for each cohort as animals were fed to many different final days. Variables were calculated for the cumulative treatments out of the total treatments per cohort and of the treatments in a lot out of the total animals in that lot. Continuous variables were categorized based on biological cutoffs or quarters to avoid violating the linearity assumption (Table 2.1).

There is no previously published case definition of early-feeding stage, mid-feeding stage, and late-feeding stage timing for cohort BRD morbidity, therefore we decided to combine two categorization methods to classify the timing of BRD; the first of which utilized hierarchical clustering based on cumulative BRD morbidity to create daily incidence curves and asking consultant veterinarians to classify each curve as having a pattern consistent with early-feeding stage, mid-feeding stage, or late-feeding stage BRD. The second approach was to categorize cohorts based on which feeding period (early-feeding stage, mid-feeding stage, or late-feeding stage) had the greatest percentage of BRD morbidity. Combining two classification methods was done to increase specificity of our case definition so that any cohort classified as having late-feeding stage BRD would likely receive that classification by a strong majority of feedlot veterinarians.

Veterinary consultant survey classification

In the first classification, clusters of BRD incidence curves were created using Ward's method, which is an agglomerative clustering technique that minimizes sum-of-squares (Ward, 1963). Agglomerative clustering is a type of clustering that starts with each individual observation and works forwards grouping them to a specified cut point. Twenty clusters were formed using a process where a cut point was chosen when an adequate number of cohorts remained in each cluster and merging groups one more time showed an evident loss of information. Each cluster represented at least 46 cohorts and clusters were graphed as percent of treatments per day for visualization. The percent of treatments per day curves for each of the twenty clusters were built into a survey on Qualtrics (*Qualtrics*, 2005), which was sent out as a convenience sample of consulting veterinarians. The survey asked each veterinarian to classify each plot as depicting early-feeding stage, mid-feeding stage, or late-feeding stage cohort-level BRD morbidity timing (Figure 2.2 & 2.3).

Days classification

In the second classification, method cohorts were categorized based on which feeding period had the greatest percentage of BRD cases. Feeding intervals were set as d 0 to 42, 43 to 71, and 72 to 100. Previous literature has stated that 75% of BRD morbidity occurs by d 42 on feed (Babcock et al., 2010), for our purposes this was defined as early-feeding stage, the mid-feeding stage and late-feeding stage categories were decided upon by allotting half the remaining DOF to each category. Percent of overall BRD morbidity within cohort was calculated for each interval, and whichever interval had the greatest number of treatments was assigned the classification. Agreement of classification methods was used to create a data set of cohorts that met our final case definition for the timing of cohort-level BRD morbidity.

Statistical analysis

An events-over-trials regression mixed-effects model was fit using the 'glmer' function from the 'lme4' package in RStudio (RStudio Team, n.d.). The outcome variable was the number of treatments/population-at-risk within cohort. Population at risk was defined by number of cattle in the cohort at arrival less number treated per day as defined previously (Cernicchiaro et al., 2012). The independent variable for this analysis was the ordinal variable 'time' which had categories for early-feeding stage , mid-feeding stage, or late-feeding stage. Feedyard and year were included as random effects to account for the hierarchical nature of the data. A similar model was fit to identify differences in mortality for the independent variable 'time' with random effects for feedyard and year. This model used outcome variable deaths(events)/population at risk (trials), with population at risk defined as number of cattle in the cohort at arrival less the number dead by day. The logistic regression model was fit to evaluate differences in morbidity and mortality across cohorts that were classified as early-feeding stage, mid-feeding stage, or late-feeding stage.

An ordinal regression mixed-effects model was fit using the 'clmm' function from the 'ordinal' package in RStudio (RStudio Team, n.d.) in order to analyze which cohort-level risk factors were associated with the outcome of interest (early-feeding stage, mid-feeding stage or late-feeding stage cohort BRD timing). Covariates evaluated for the model were sex, arrival quarter, in-weight category, lot size category at arrival and all possible interactions. Random effects of feedlot and year were included to account for lack of independence of the feedlots and years. All potential interactions were evaluated using forward manual selection. Main effects variables were screened by backward elimination until only statistically significant ($P<0.05$) variables remained for the final model. Probabilities were used to evaluate the predictor variable.

Results and Discussion

Previous literature evaluated factors related to BRD at arrival and within the early weeks in the feedyard. BRD morbidity is most predominant within the first 30 days for feedyard cattle in Brazil (Baptista et al., 2017), and a US study found that 74% of BRD cases occurred within the first 42 DOF (Babcock et al., 2009). Although a study recently investigated BRD at ≥45 DOF (Theurer et al., 2021b), the current study helps fill in the gap of research specifically addressing factors associated with timing of disease through the first 100 DOF. Previously there was no case definition of late-day cohort-level morbidity and no previous methodology to assign cohorts to a timing of disease category. Our case definition for cohort-level BRD timing was created based on agreement between a classification method that surveyed consultants to classify clusters of BRD incidence curves and classification based on which of three feeding periods had the greatest percentage of BRD cases for each cohort.

Classifying cohorts based on the timing of BRD morbidity

Thirteen surveys were returned and evaluated. Using the survey answers, the BRD timing classifications for individual cohorts were defined based on the classification of each cluster by a majority of the consultants. Using this method, there were 2,581 early-feeding stage, 892 mid-feeding stage and 120 late-feeding stage cohorts. Agreement among the consultants' cohort-level classification was at minimum 61.5% for each of the twenty clusters. There was at least one cluster from early-feeding stage, mid-feeding stage, and late-feeding stage that had 100% agreement among consultants, but more often than not at least one consultant disagreed with the rest. Some possible explanations for disagreement among consultants would be that different consultants work with different populations of cattle and are accustomed to different disease patterns. Another explanation could be that some cluster graphs were not a clean-cut distribution of disease, in that some curves had two peaks and consultants were not provided a bimodal option. Based on the method of percent BRD morbidity by interval, 3,280 cohorts were defined as early-feeding stage, 239 as mid-feeding stage, 74 were defined as late-feeding stage.

Combination of both BRD timing classification systems

Creating a data set of cohorts with perfect agreement when both classification methods were combined (n=2,598) increased specificity of our case definition and resulted in 1,121 cohorts being removed due to disagreement among classification methods. The final, combined method data set contained 2,429 early-feeding stage, 108 mid-feeding stage, and 61 late-feeding stage cohorts (Table 2.2). Of the cohorts removed, the greatest loss was where the Days classification method classified the cohort as being early-feeding stage, but the Consultant Survey method classified them as mid-feeding stage.

Results from the logistic regression events-over-trials morbidity model showed a greater incidence of morbidity in the early-feeding stage category (16.08%) compared to mid-feeding stage (14.31%) or late-feeding stage (12.23%). The logistic regression events-over-trials mortality model, identified the greatest mortality in early-feeding stage cohorts (2.97%) compared to mid-feeding stage (2.48%) or late-feeding stage (2.55%).

No interactions were found significant at the ($P<0.05$) level and therefore all were excluded from the model. The only variable significantly ($P<0.01$) associated with timing of BRD at the pen level in this study was quarter of arrival into the feedyard. The percent of cohorts that arrived in the first, second, third, or fourth quarter that were classified as having early-feeding stage BRD were 92.9% , 84.3%, 96.4%, and 96.2% respectively. Cohorts arriving in the second quarter had a 5.5% probability being classified as having mid-feeding stage BRD which was significantly different compared to 2.7%, 1.4%, and 1.4% for cohorts arriving in the first, third, or fourth quarters (respectively). Cohorts arriving in the second quarter had a 10.2% probability of being classified as having late-feeding stage BRD, which was significantly different compared to 4.5%, 2.2%, and 2.3% for the cohorts arriving in the first, third, and fourth quarters (respectively). Cattle cohorts were most likely to be either mid-feeding stage or late-feeding stage when BRD morbidity occurred if they arrived in the second quarter (April to June) (Table 2.3). Out of all the quarters, the second quarter represented the lowest percentage (14%) of animals arriving at the feedyard. Possible explanations for quarter of arrival being associated with BRD morbidity is that the type of cattle arriving in the second quarter may have some differences than those arriving the rest of the year. Some of these differences could be that the cattle market and production cycle dictates a large influx of predominantly high risk animals arrive in the feedlot in the fall, while heavier cattle generally arrive in the spring months (Babcock et al., 2013; Ribble et al., 1995; J. D. Taylor et al., 2010). Commonly, cattle are spring-born and either shipped to the feedyard in the fall immediately after weaning or retained and backgrounded for a short 30 to 60 d program or longer 90 to 120 d program (10).

This analysis was performed on cohort level data to identify factors associated with timing. It is not surprising to the authors that factors known to be associated with the incidence of BRD in the feedlot were not significantly associated with the timing of BRD. Further research is necessary to identify risk factors associated with mid-feeding stage and late-feeding stage BRD morbidity and mortality at the individual animal level. We recognize that the BRD morbidity reported in this study is inflated above reality due to the inclusion criteria of >7% BRD morbidity per cohort. Across the US in 2011 NAHMS stated that 13.4% of cattle placed in feedlot were treated with an antimicrobial for BRD, so the cut point used here is still well below the average morbidity across feedlots (NAHMS, 2011). Additionally, there was an imbalance of cohorts in the timing categories, with the fewest cohorts being considered late. Due to the total number of cohorts involved in this study and statistical tests used, this is not of major concern, but should be noted as potential associations could have been missed because of the smaller number of cohorts. In addition, interpretation of observational studies of feedlot data must recognize that different personnel are identifying sick calves with different diagnostic protocols in place at each feedlot. Potential confounding factors need to be considered when interpreting the results of this study, some examples of this would-be differences in management between feedlots, biological differences between animals, background and previous management of animals. Our analysis was done to account for sources of variability that we know have an impact on our outcome by including feedlot, and year as random effects in the model.

Applications

Evaluating the timing of BRD morbidity in the feedyard illustrated a significance of the quarter of arrival, with the greatest amount of late-feeding stage BRD occurring in cattle that arrived between April and June. Further investigation into why animals arriving in the second of the quarter year having greater risk for late-feeding stage BRD morbidity needs to be done. Our data were representing 13 feedyards from the central U.S., so caution needs to be taken when interpreting these results to feedyards in other geographic locations and with other management practices.

Figures

Figure 2.1. Flowchart describing the inclusion criteria for 13 feedyards into the working data set, all numbers are representative of number of cohorts.

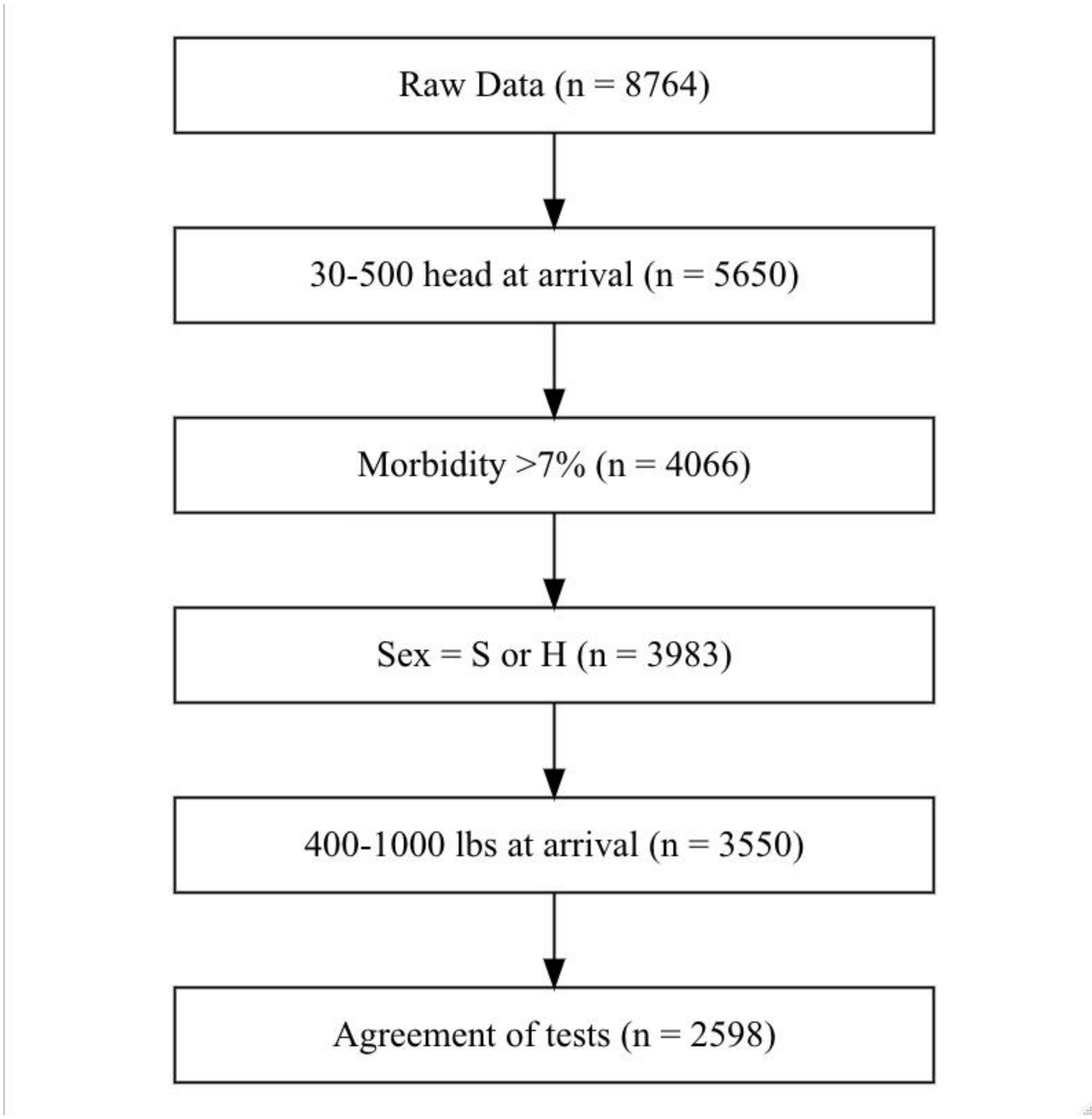


Figure 2.2. Example of one of the twenty clusters of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represent 46 different cohorts and was determined to be late-feeding stage morbidity by all veterinarians consulted.

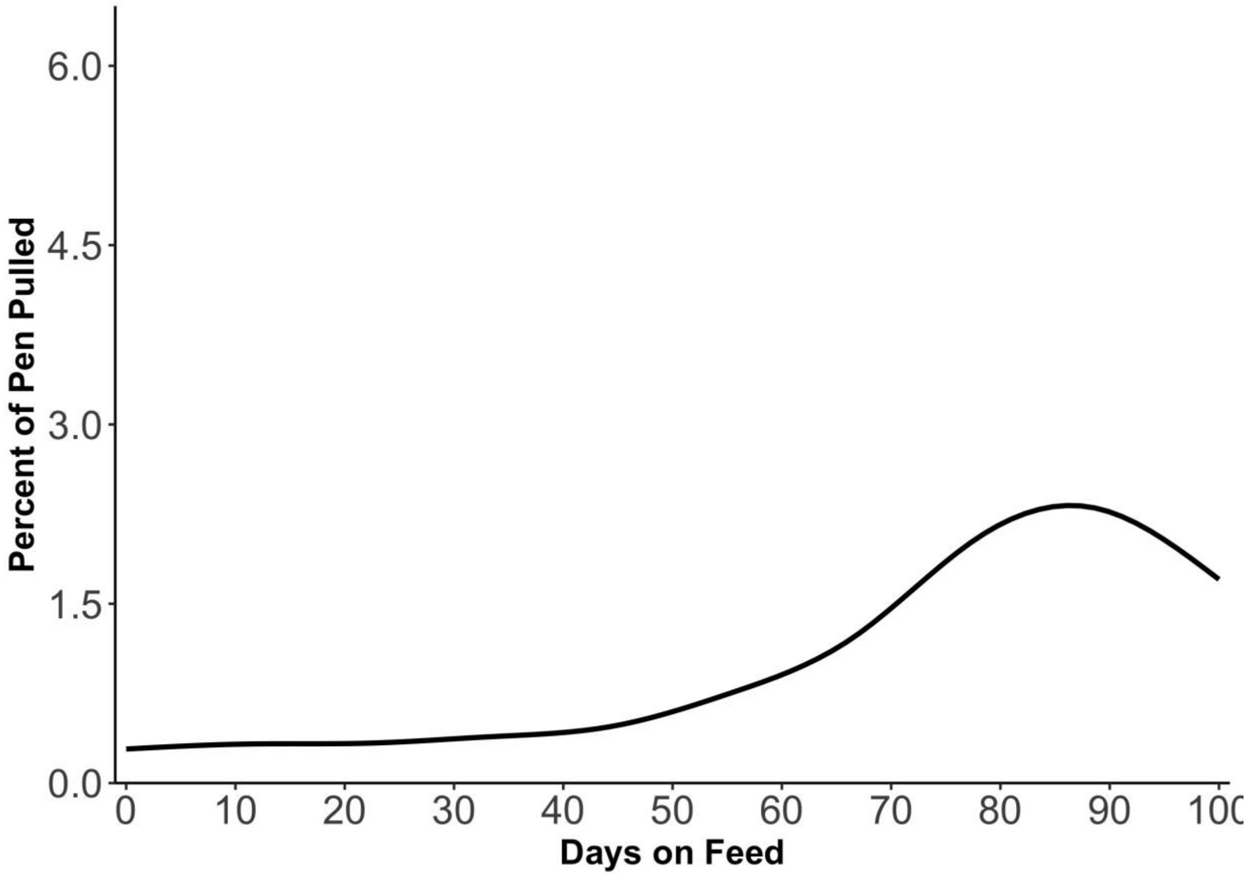


Figure 2.3. Example of one of the twenty clusters of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 209 different cohorts and was determined to be mid-feeding stage morbidity by all veterinarians consulted.

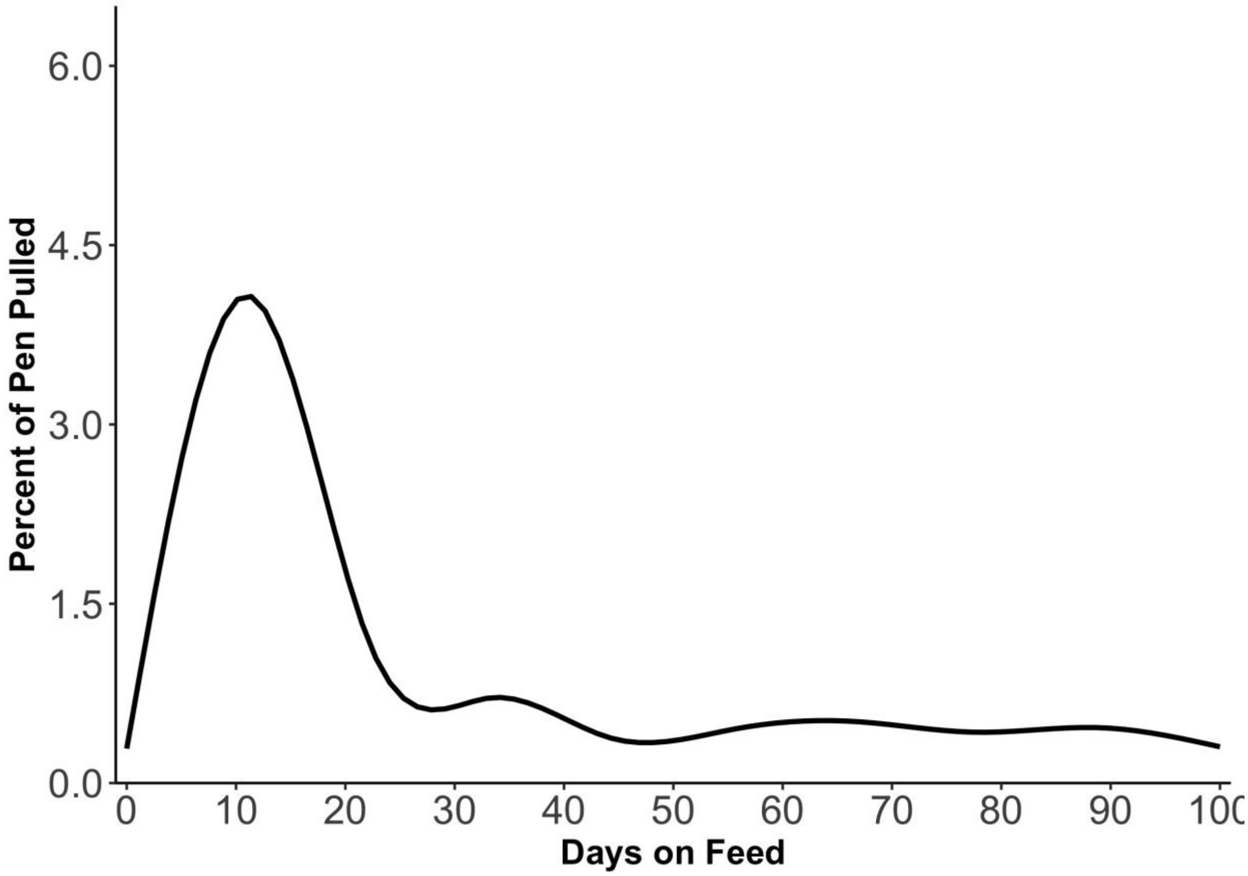
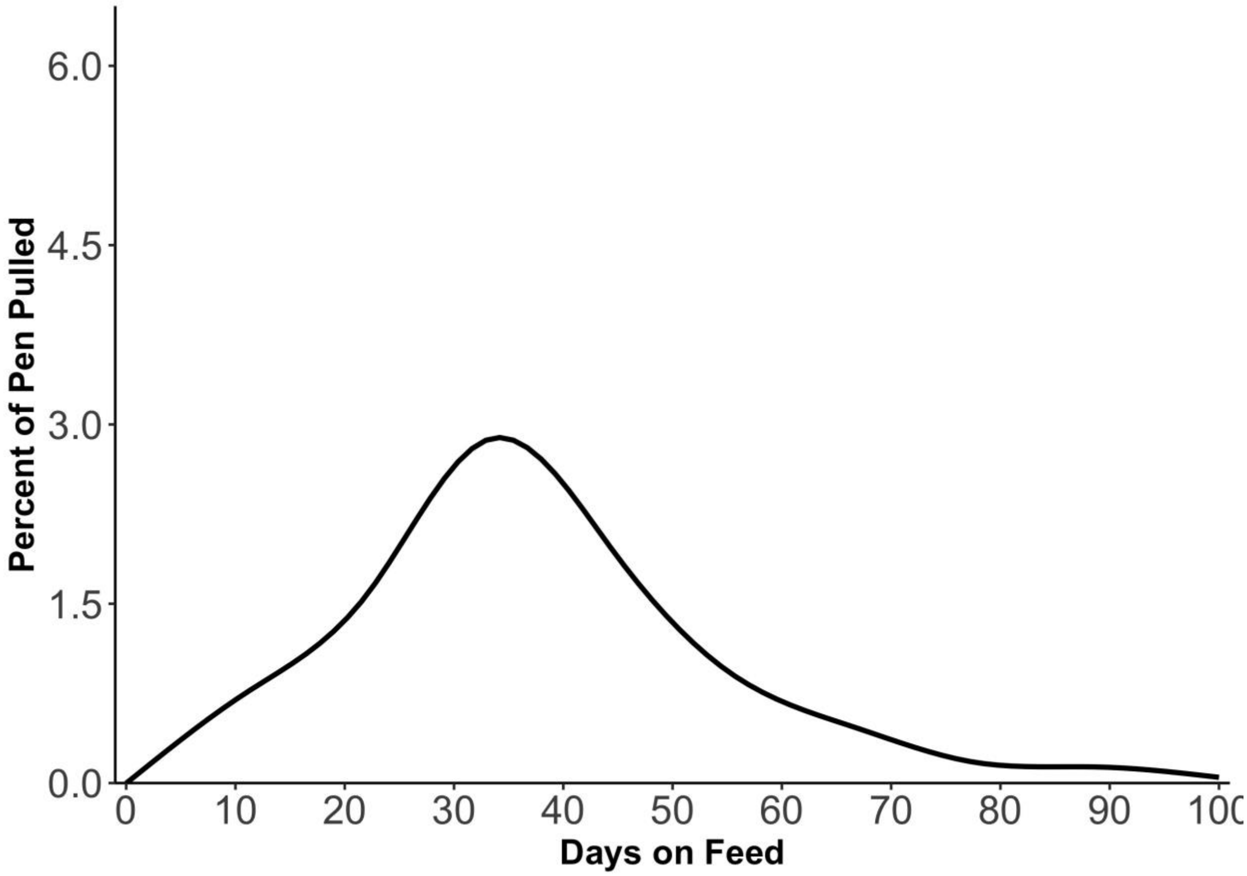


Figure 2.4. Example of a one of the twenty clusters of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 158 different cohorts and was determined to be mid-feeding stage morbidity by all veterinarians consulted.



Tables

Table 2.1. Variables used in the working dataset.

Variable	Description
Headin	Number of animals in the cohort at arrival
Sex	Steer or Heifer
QuarterArrival	Quarter of arrival at the feedyard (1: January-March, 2: April-June, 3: July-September, 4: October-December)
Time	BRD incidence curve category (early-feeding stage, mid-feeding stage, late-feeding stage)
NumberTrt	Total number treated from day 0-100 per cohort
DOF	Count of days on feed from day 0-100 per cohort
NumberTrtPerDay	Count of number treated per day 0-100 per cohort
Total100dTrt	Total treatments in the cohort from day 0-100
CumsumPercent	Cumulative number treated by day / total treated
CumsumCohort	Cumulative number treated by day / total animals in the cohort at arrival
Yardlot	Unique identifier for each cohort

Table 2.2. Descriptive demographics of cohorts by timing category for 13 feedlots from 2017-2020.

Variable	Time		
	Early	Mid	Late
Quarter of arrival			
1	620	34	19
2	292	33	19
3	567	17	6
4	950	24	17
Sex			
S	1794	67	38
H	635	41	23
Cohort Size			
30 – 100	529	42	18
100 – 150	583	21	20
151 – 200	596	20	9
201 – 300	526	20	12
301 – 500	194	5	2
Average Weight at Arrival (kg)			
181 – 226	53	3	2
227 – 272	196	11	7
272 – 318	638	30	16
318 – 363	753	30	18
364 – 409	560	24	13
410 – 455	229	10	5

Table 2.3. Model estimated probabilities and standard error of BRD morbidity by quarter of arrival.

Time Quarter of Arrival	Probability, %	SE
Early-feeding stage		
1	92.5[a]	.019
2	84.2[b]	.039
3	96.4[a]	.011
4	96.3[a]	.011
Mid-feeding stage		
1	2.8[a]	.007
2	5.5[b]	.014
3	1.4[a]	.004
4	1.4[a]	.004
Late-feeding stage		
1	4.7[a]	.013
2	10.3[b]	.028
3	2.2[a]	.007
4	2.3[a]	.007

Different letter superscripts within a category indicate statistically significant differences ($P<0.05$).

Chapter 3 - Mid- and late-feeding stage bovine respiratory morbidity and mortality risk factors based on individual animal treatments

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Abstract

Previously published bovine respiratory disease (BRD) research 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. The study objective was to identify risk factors associated with BRD morbidity and mortality timing within the feeding phase. Individual animal records (n = 188, 437) for first BRD treatment 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). There were 141,097 early-stage, 33,871 middle-stage, and 13,469 late-stage 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 two-way interactions of cattle demographics for morbidity were significant (P<0.05), while for

mortality main effects of arrival weight and metaphylaxis were significant ($P<0.05$) and only the two-way interactions of sex by quarter of arrival and sex by lot size were significant ($P<0.05$). 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.

Introduction

Bovine respiratory disease (BRD) continues to be the most researched and common disease among feedlot cattle (Edwards, 1996; R. A. Smith, 1998; Woolums et al., 2013). Feedlots with ≥ 1000 head capacity report 16.2% of cattle are affected by respiratory disease (NAHMS, 2011). BRD is a multifaceted disease that causes significant economic impact on the beef industry as a whole (Chirase and Greene, 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 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., 2021a). Little work has been done evaluating risk factors potentially associated with disease at different days on feed in the feedlot. Disease timing has important economic implications as cattle that have been on feed longer have incurred more costs compared to 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 utilized from 25 commercial feedlots, representing multiple feedlots throughout the great plains and southern regions of the United States.

Materials and Methods

Data Source

Individual animal treatment records from 25 U.S. feedyards were collected under confidentiality agreements with individual yards. Institutional Animal Care and Use Committee (IACUC) approval was not required as historical operational data were utilized for the analysis. All individual animal records were assigned a unique identifier (UID) based on animal tag, yard identifier, and cohort identifier. Using the UID, 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 kg to 454.5 kg. Total cohort days on feed (DOF) was limited to 250 d or fewer. Data were filtered to include only records from 4 January 2018 to 28 December 2020 as only two feedlots provided data generated prior to 2018. Data were filtered to include only first pull records for treatment of BRD for each individual animal (Fig 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, Jan to March;

quarter2, April to June; quarter 3, July to Sept; quarter 4, Oct to Dec). 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 percent 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 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 above, there were 51,688 death records in the data (Fig 2). These data are from the same dataset as the treatment records, and an animal did not have to be treated for BRD prior to dying with a diagnosis of BRD in order 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-stage (EARLY) for 0 to 33.3%, middle-stage (MID) for 33.3 to 66.6%, or late-stage (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 (Christensen RHB, 2019)in order to analyze individual animal risk factors associated with the timing of BRD morbidity and BRD mortality. The dependent variable was time of morbidity or mortality as categorized by the percent of feeding phase complete. Independent variables evaluated in the model were cohort sex, quarter of arrival to the feedyard, cohort size at arrival, average in weight of the cohort at arrival, metaphylaxis, and any two-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. Backwards elimination was used to select the variables to remain in the final model for the two-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 amongst 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 evaluates 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 seven temporal patterns of disease at the cohort level, in this analysis we only looked at three 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. While the Babcock paper identified different timing curves the analysis was not intended to identify different risk factors, in contrast to this paper.

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) were LATE.

The final ordinal multivariable model included significant two-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 category by arrival weight category (Table 2). Sex was modified by quarter of arrival and indicated that steers were more likely to be EARLY across all quarters of arrival while 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 to heavyweight steers (66.8%). The same effect was seen in heifers, but not as big of an impact, lightweight heifers were more likely to be EARLY (75.6%) compared to 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, this analysis 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 reveals different information than previous analysis that only looked at cohort-level risk factors associated with timing of BRD (Smith et al., 2021). 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 & 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 while 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 and 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 two weight categories (363 kg or more) had a lower probability (quarter 1 x 363 to 409 kg; 61.0%, quarter 1 x 409 to 454 kg; 52.5%, quarter 2 x 363 to 409 kg; 60.9%, quarter 2 x 409 to 454 kg; 52.1%) of being EARLY for BRD morbidity compared to cattle that arrived in the same quarters that were lighter in weight (<364 kg) (which ranged from 67 to 75%) (Fig 4). Overall cattle that arrived in the third and fourth quarter were more likely to be EARLY but when cattle arrived in the first and second quarter of the year their risk was modified by other factors; steers were more likely to be EARLY and 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 quarter 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 system has 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 & Berg, 1995). In this study, we found that when cattle are typically at lower risk for disease, as seen in the first two 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 quarter 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 definitions 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% (2,545) were 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 four 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 two-way interactions for sex by quarter of arrival and sex by lot size at arrival (Supplementary Table B.1.). 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 to heifers in the same arrival lot size categories (Fig 5). The two-way interaction for sex by quarter of arrival showed that steers were always more likely to be EARLY than heifers but there was no difference between steers and heifers to be middle feeding phase 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 quarter of the year, which is historically the most problematic part of the year for BRD (Supplementary Table B.2.). 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., 2001).

The data presented here shows 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, 3rd and 4th (July to Sept, Oct to Dec, 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 November through January (Loneragan, et al., 2001). Contrast to that, 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 only pertains directly to feedlots in the region of those 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 different personnel performing the necropsies and classifying disease diagnosis. Across the feedlot industry, nation-wide surveys have been utilized 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 possibility of misdiagnosis which expands to more diseases than just AIP, also digestive, and heart failure. As the third and fourth quarter 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 are 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 higher probability of BRD mortality early in the feeding phase for steers (L. Taylor et al., 1997). This is 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 time greater risk of suffering AIP than steers (Loneragan, Gould, et al., 2001). 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, etc). 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 to 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 based on multiple different risk factors 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 to 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 probable to experience EARLY morbidity than those that did not receive metaphylaxis during the third quarter for arrival.

Figures

Figure 3.1. Flowchart of data filtering process for the number of animals filtered out to create the working dataset for the morbidity analysis.

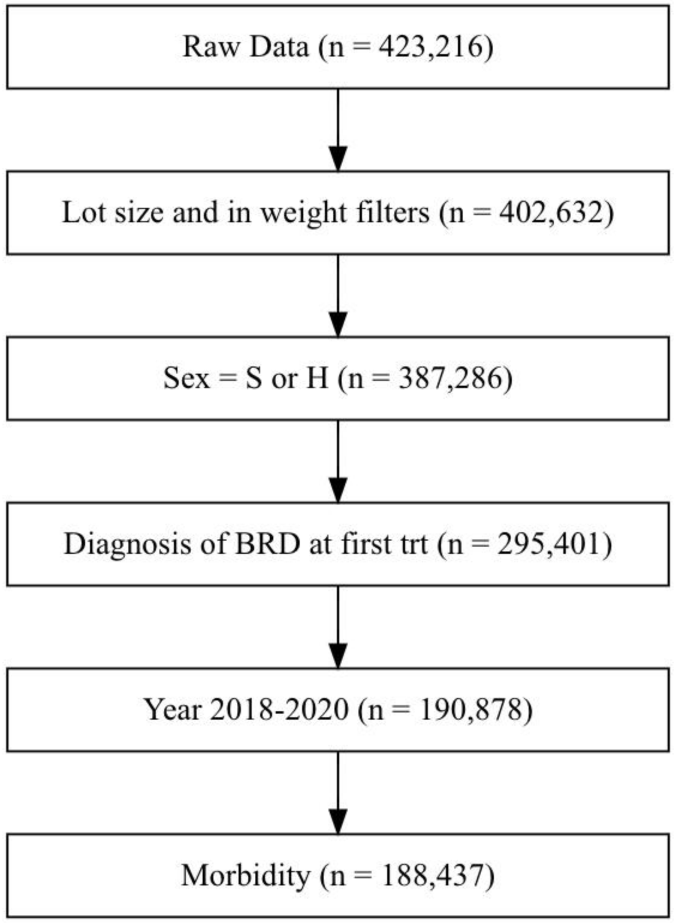


Figure 3.2. Flowchart of data filtering process for the number of animals filtered out to create the working dataset for the mortality analysis.

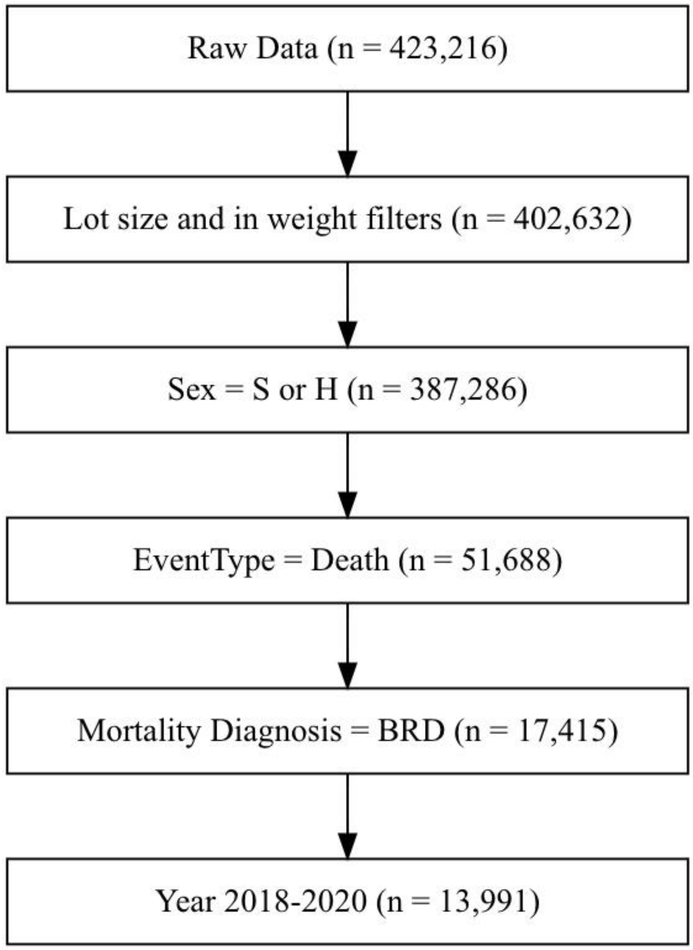


Figure 3.3. Model predicted probability for timing of first treatment for BRD based on quarter of arrival into the feedlot (1 = Jan-March, 2 = April-June, 3 = July-Sep, 4 = Oct-Dec) modified by sex (solid line = heifers, dashed = steers). Probabilities were from an ordinal logistic mixed model and error bars represent one standard error.

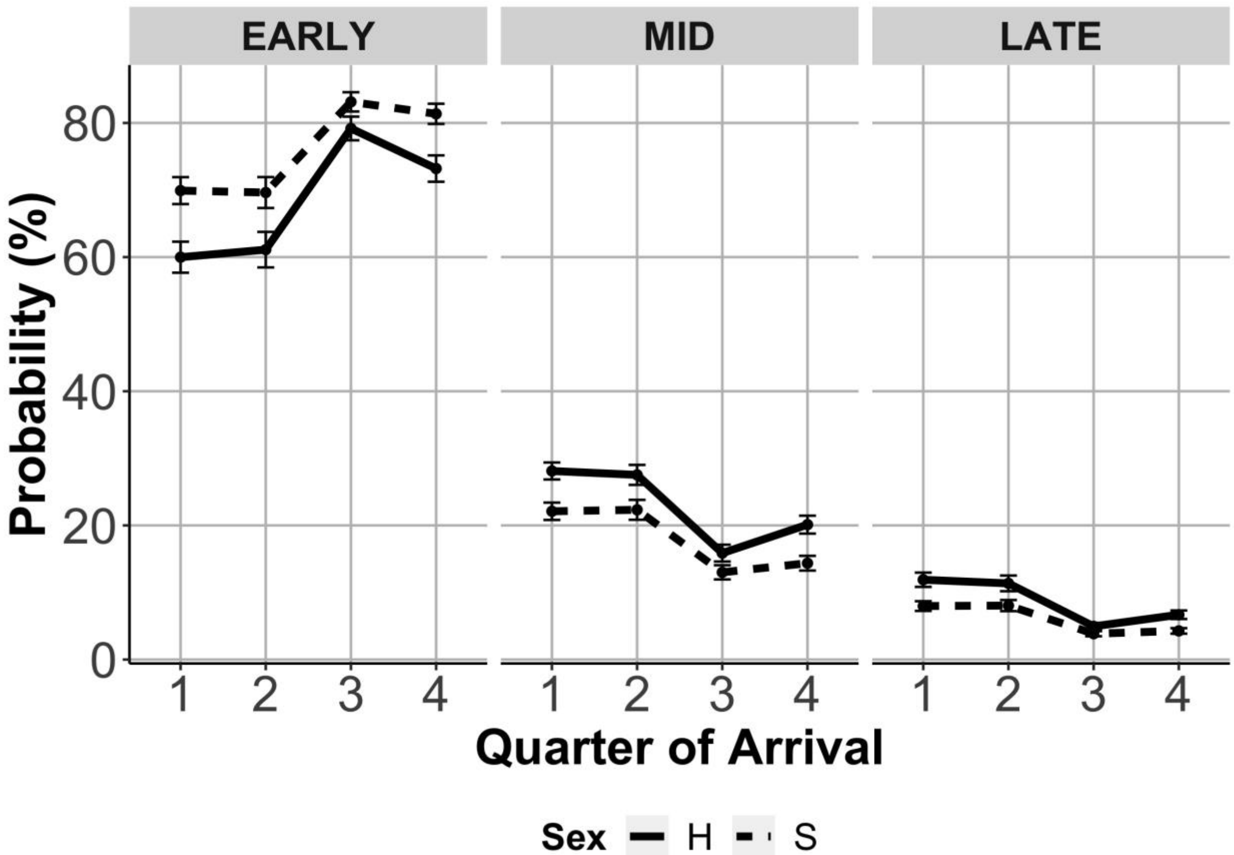


Figure 3.4. Model predicted probability for timing of first treatment for BRD based on quarter of arrival into the feedlot (1 = Jan-March, 2 = April-June, 3 = July-Sep, 4 = Oct-Dec) modified by arrival weight category (solid line = 227-272 kg, dashed narrow = 272-318 kg, dashed narrow gap = 318-363 kg, dashed wide gap = 363-409 kg, dotted = 409-454 kg). Probabilities were from an ordinal logistic mixed model and error bars represent one standard error.

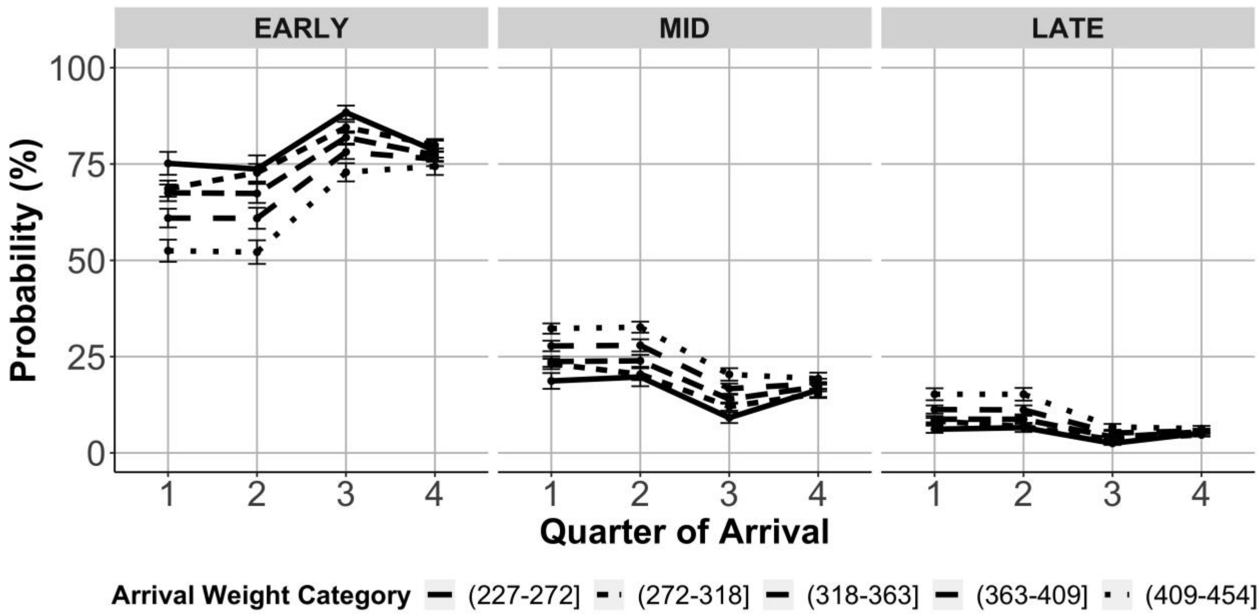
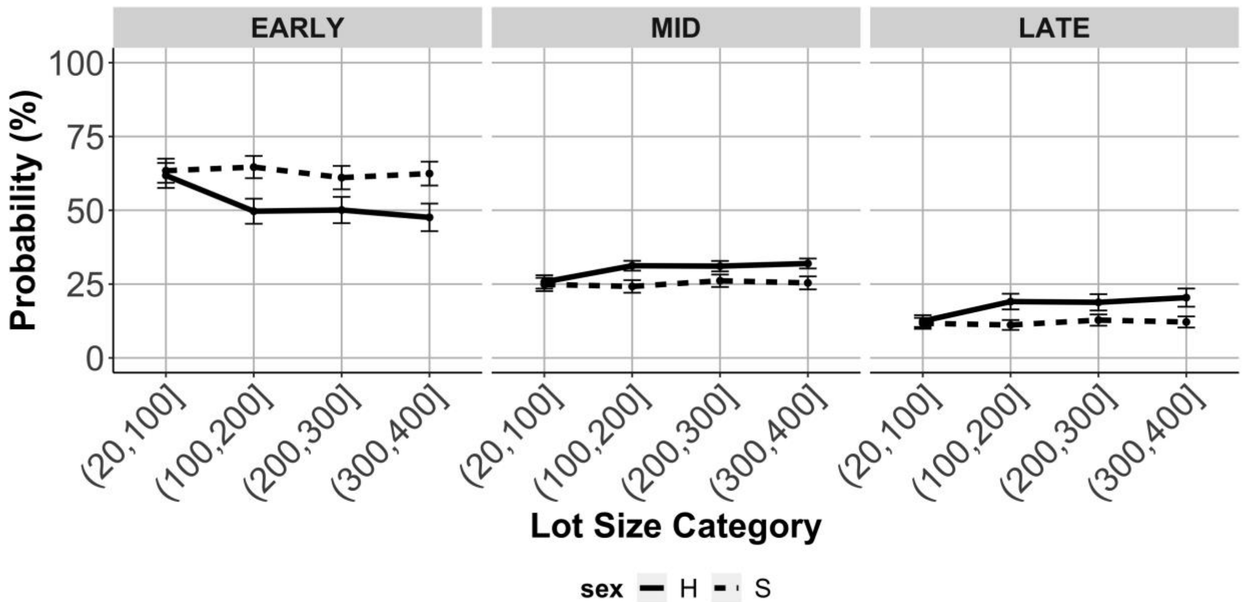


Figure 3.5

. Model predicted probability for timing of death from BRD based on lot size at arrival into the feedlot modified by sex (solid line = heifers, dashed = steers). Probabilities were from an ordinal logistic mixed model and error bars represent one standard error.



Tables

Table 3.1. Characteristics of cohorts from which individual treatments were obtained for morbidity. Descriptive of the final working dataset where n= individual animals treated for disease.

Characteristic			
	EARLY, n	MID, n	LATE, n
Total	141,097	33,871	13,469
DOF at first pull			
Median	22	82	148
Mean	26	85	149
Quarter of arrival			
1	36,054	10,469	4,851
2	26,129	9,583	3,196
3	38,605	7,528	2,425
4	40,309	6,291	2,997
Metaphylaxis			
Yes	11,670	3,084	1,235
No	129,427	30,787	12,234
Sex			
S	103,995	23,544	8,838
H	37,102	10,327	4,631
Cohort Size			
20 – 100	17,437	3,391	1,298
101 – 200	61,086	13,315	5,318
201 – 300	36,819	9,493	3,846
301 – 400	25,748	7,670	3,007
Average Weight at Arrival (kg)			
227 – 272	4,961	1,252	345
272 – 318	36,148	7,238	2,651
318 – 363	47,697	10,424	4,431
364 – 409	38,035	10,244	4,080
410 – 455	14,256	4,713	1,962

Table 3.2. Covariate p-value for the final ordinal morbidity model for BRD 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 x quarter of arrival	0.01
Sex x arrival weight category	0.01
Quarter of arrival x lot size category	0.01
Quarter of arrival x arrival weight category	<0.01
Quarter of arrival x metaphylaxis	<0.01
Lot size category x arrival weight category	<0.01

Table 3.3. Characteristics of cohorts from which individual animal records were obtained for mortality.

Characteristic			
	EARLY, n	MID, n	LATE, n
Total	7,821	3,625	2,545
DOF at death			
Median	29 days	90 days	155 days
Mean	32 days	91 days	157 days
Quarter of arrival			
1	1,661	915	763
2	1,029	857	621
3	2,195	935	555
4	2,936	918	606
Metaphylaxis			
Yes	592	183	129
No	7,229	3,442	2,416
Sex			
S	5,458	2,358	1,592
H	2,363	1,267	952
Cohort Size			
20 – 100	1,498	550	345
101 – 200	2,957	1,293	939
201 – 300	2,074	1,065	709
301 – 400	1,292	717	552
Average Weight at Arrival (kg)			
(227 – 272)	404	140	70
(272 – 318)	2,234	914	562
(318 – 363)	2,712	1,276	868
(363 – 409)	1,866	956	779
(409 – 454)	605	338	266

Table 3.4. Covariate p-value for the final ordinal mortality model for BRD 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 x sex	0.03
Sex x lot size category	<0.01

Conclusions

BRD in feedyards continues to be a major contributor of morbidity and mortality, even with years of research and management changes focused on it. Many risk factors have been found to be associated with this disease; however, research focusing on the timing of the feeding phase when disease occurs has been limited. The purpose of this thesis was to evaluate mid- and late- feeding phase BRD morbidity and mortality in feedyards, both at the cohort level as well as the individual animal level. Late-feeding phase BRD is a complex problem, and no simple solution has been found, but these analyses have laid a foundation for future work and begun to explore aspects of the issue for the industry.

BRD has previously been considered an early- feeding phase issue, but our data showed that it continues to burden feedyards throughout the total DOF. There were risk factors that visually had an impact on DOF at first pull for BRD as well as fatal disease onset, in both cases heifers and cattle arriving in the second quarter appeared to have later disease onset. Additionally, using the Wasserstein distance the greatest difference in timing of treatments between quarters of the year was between the 2nd and 4th quarter in steers and the 2nd and 3rd quarters of arrival in heifers. The same was true for fatal disease onset except the greatest distance for both steers and heifers was in the 2nd to 4th quarters.

When the timing of BRD morbidity was evaluated at the cohort level, quarter of arrival was found to be a risk factor associated with animals having late- feeding phase BRD. The fewest animals arrive in the feedlot during the second quarter of the year, cohorts that did had a 15% probability of being classified as mid- or late- feeding morbidity. Cattle that arrive in feedyards in the second quarter of the year are at the heaviest and closest to finishing during the peak heat of summer, which could be a factor in BRD timing.

Interestingly, the analysis of individual animal treatments also showed that quarter of arrival played a significant role in the timing of BRD. Cattle that arrived in the second quarter of the year were more likely to be mid- or late-feeding phase morbidity and mortality than those that arrived in any other quarter of the year. Another interesting finding was that heifers were more likely to be mid- or late- than steers were when accounting for quarter of arrival or arrival weight. Late- feeding phase BRD is a complex issue within the industry, and this is only the beginning of investigating the problem.

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Appendix A - Supplementary Chapter 2 Material.

Figure A.1

Cluster 1 of incidence for the percent of a pen pulled from day 0 to 100 DOF, this is what was surveyed to the consulting veterinarians. This cluster represents 85 different cohorts and was determined to be mid-feeding stage morbidity by majority of veterinarians consulted.

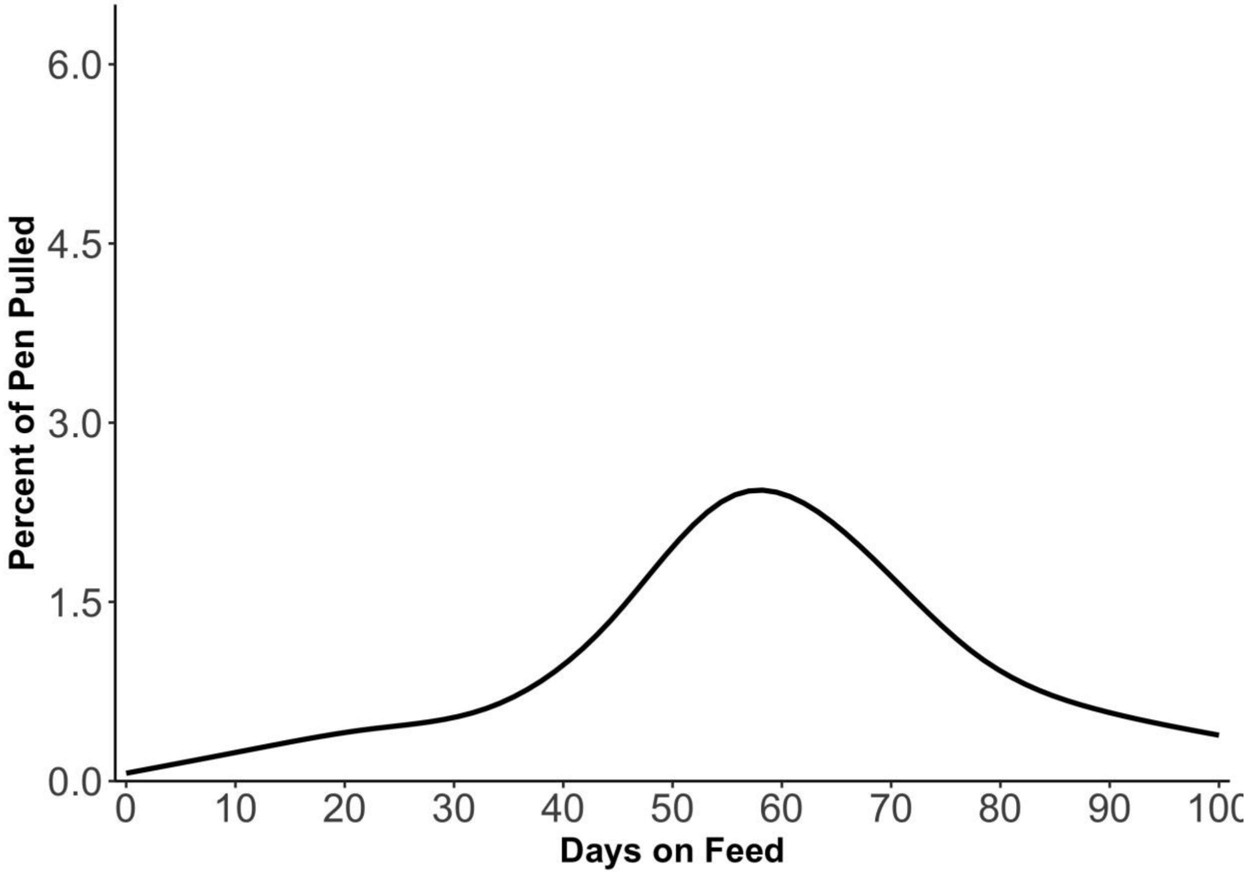


Figure A.2

Cluster 2 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 206 different cohorts and was determined to be early-feeding stage morbidity by majority of veterinarians consulted.

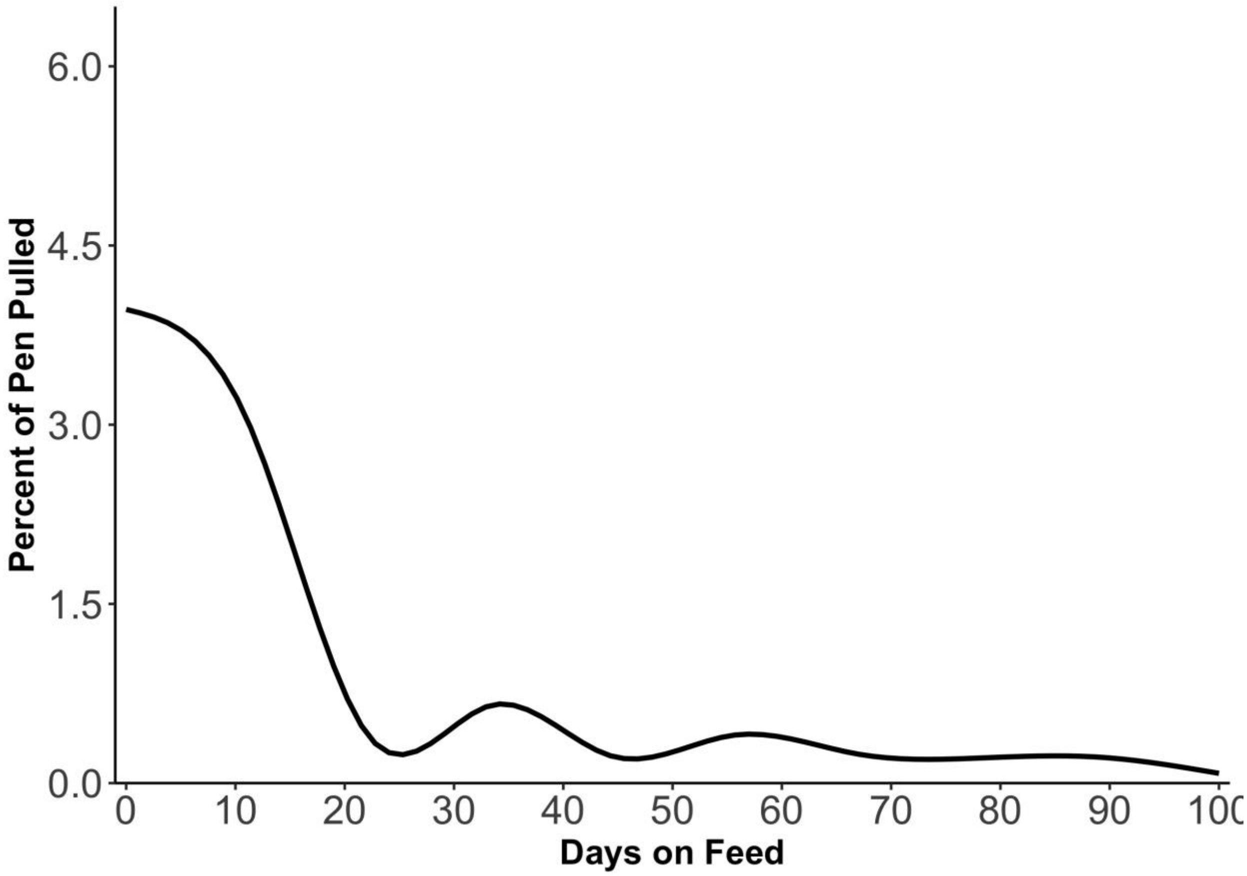


Figure A.3

Cluster 3 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 370 different cohorts and was determined to be early-feeding stage morbidity by majority of veterinarians consulted.

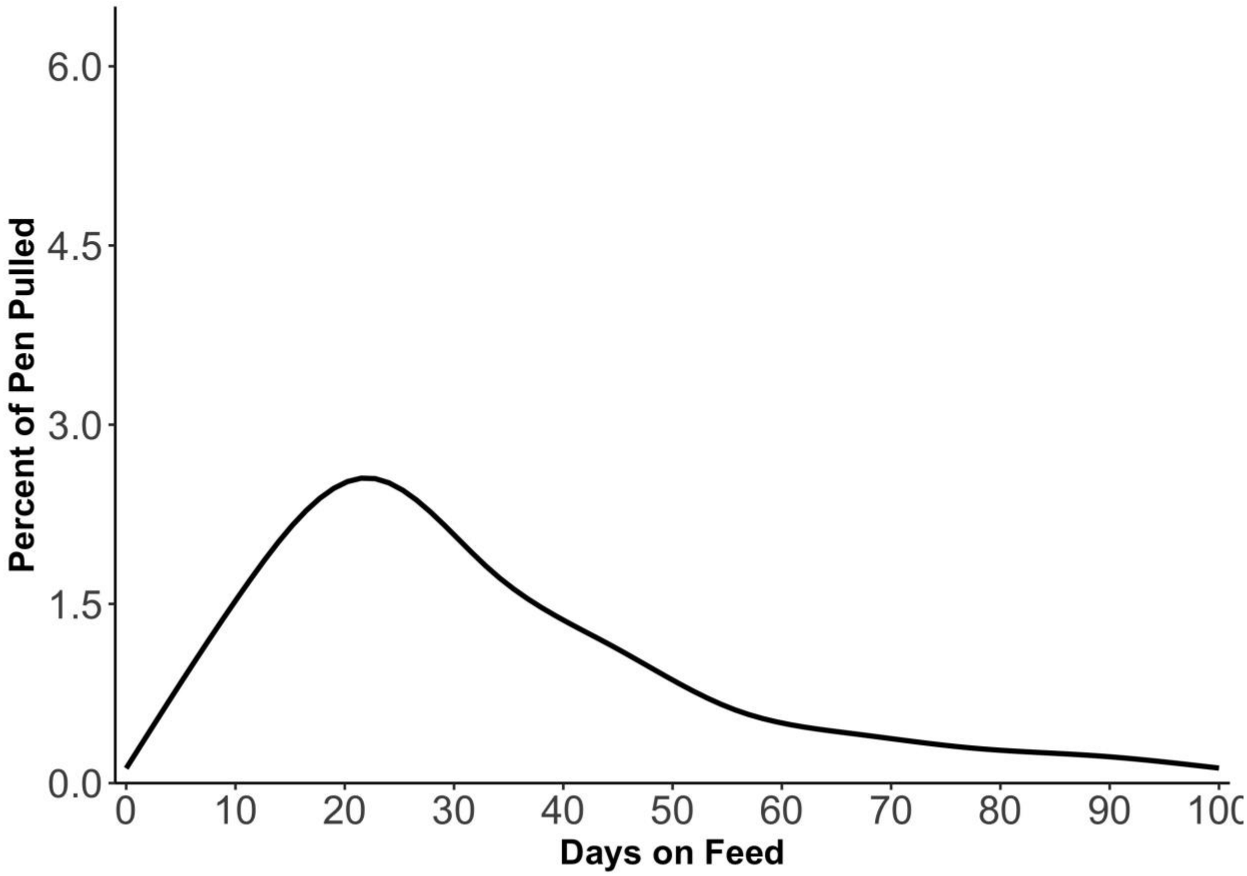


Figure A.4

Cluster 4 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 292 different cohorts and was determined to be early-feeding stage morbidity by majority of veterinarians consulted.

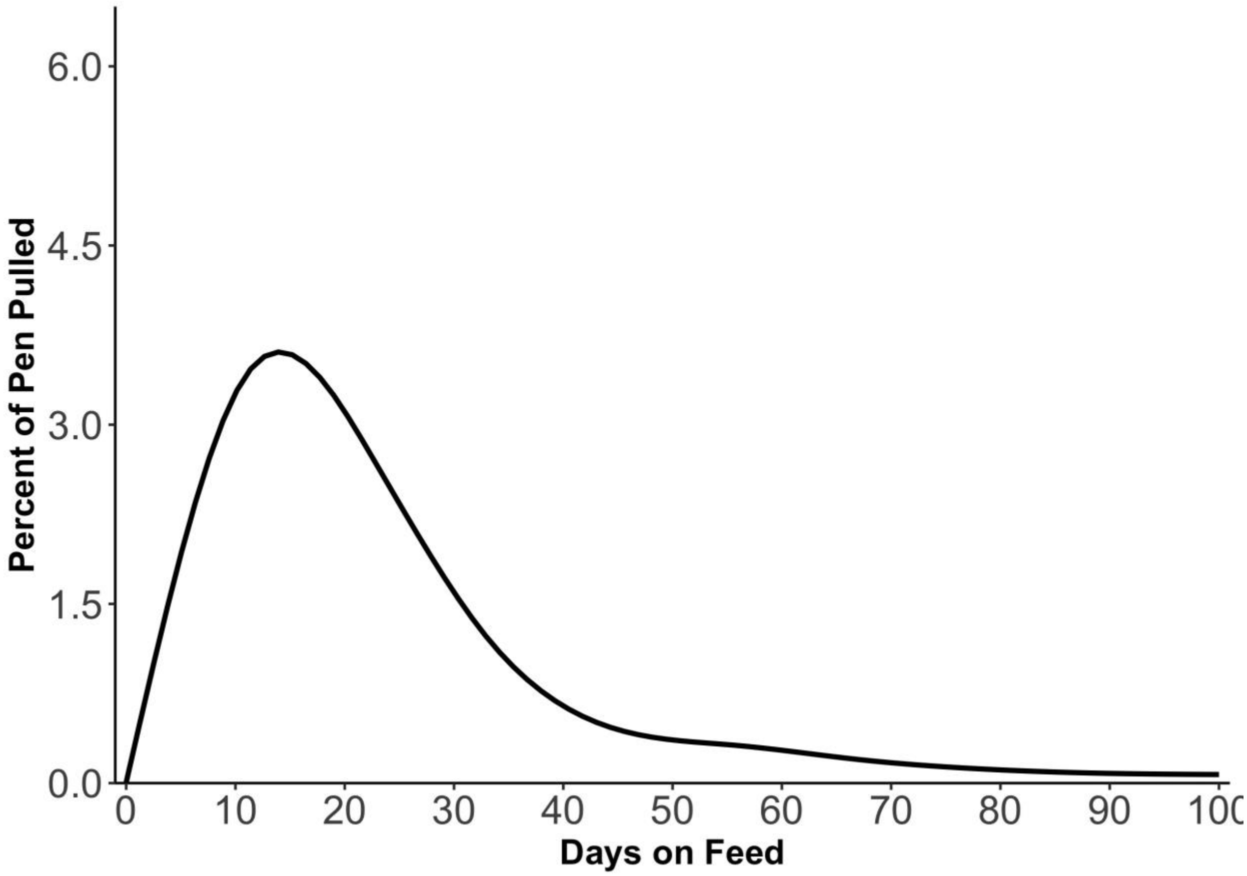


Figure A.5

Cluster 5 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 209 different cohorts and was determined to be early-feeding stage morbidity by majority of veterinarians consulted.

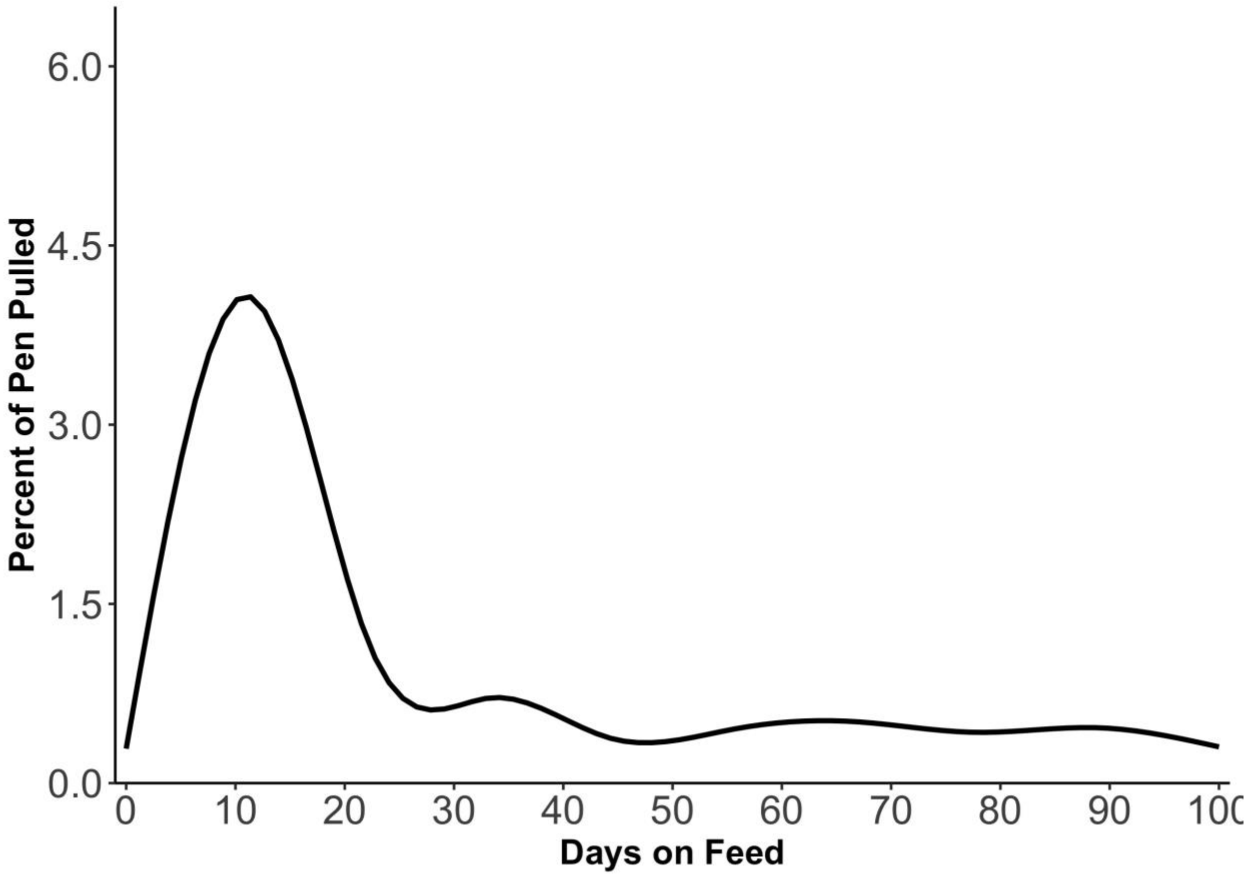


Figure A.6

Cluster 6 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 46 different cohorts and was determined to be late-feeding stage morbidity by majority of veterinarians consulted.

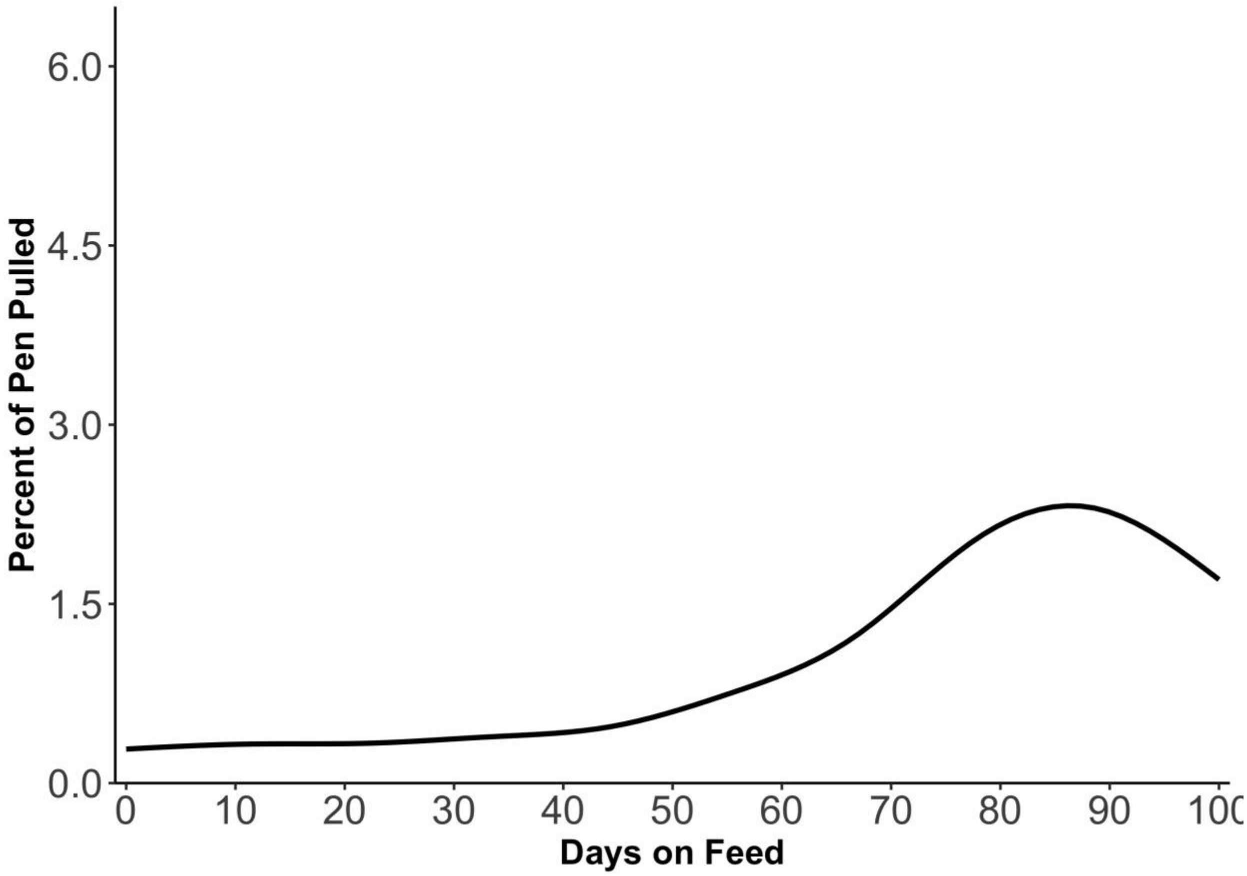


Figure A.7

Cluster 7 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 104 different cohorts and was determined to be early-feeding stage morbidity by majority of veterinarians consulted.

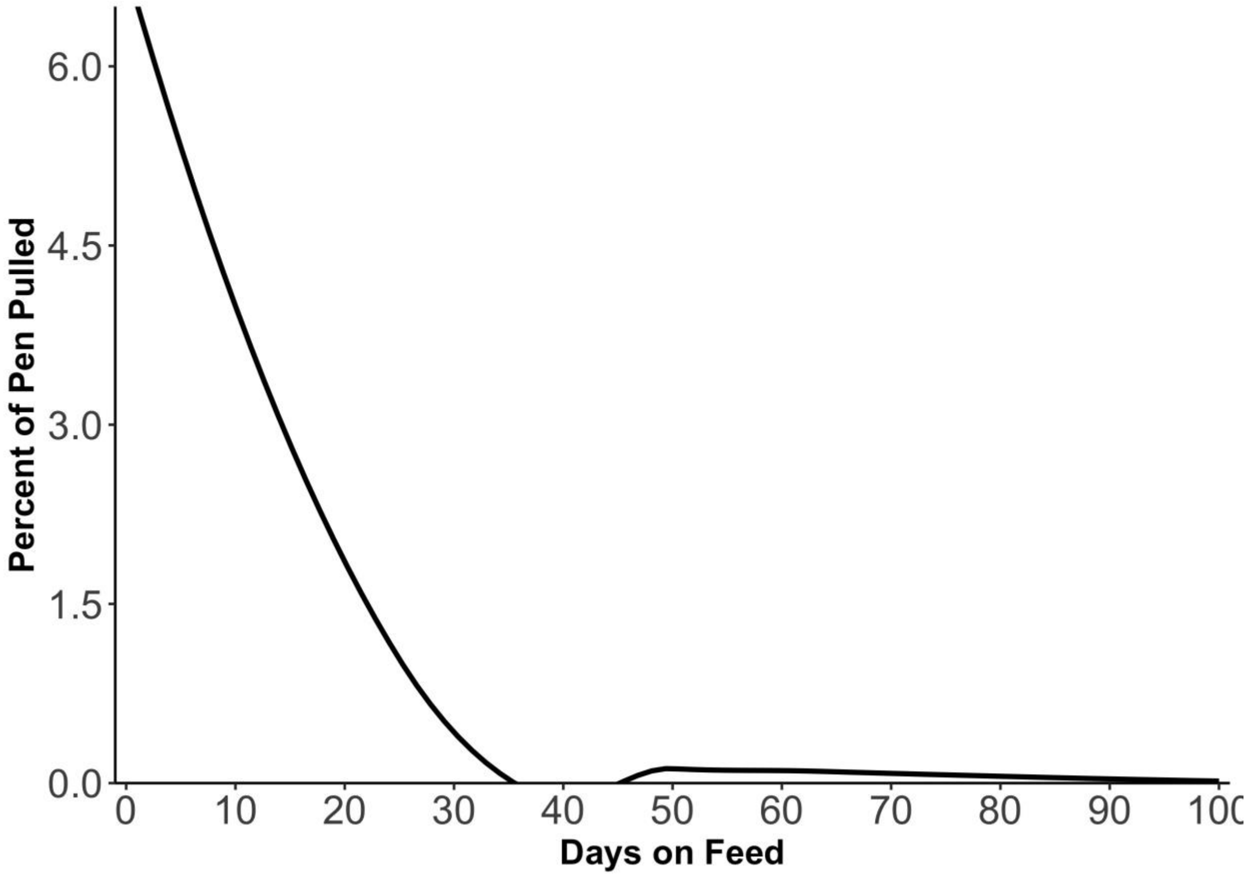


Figure A.8

Cluster 8 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 158 different cohorts and was determined to be mid-feeding stage morbidity by majority of veterinarians consulted.

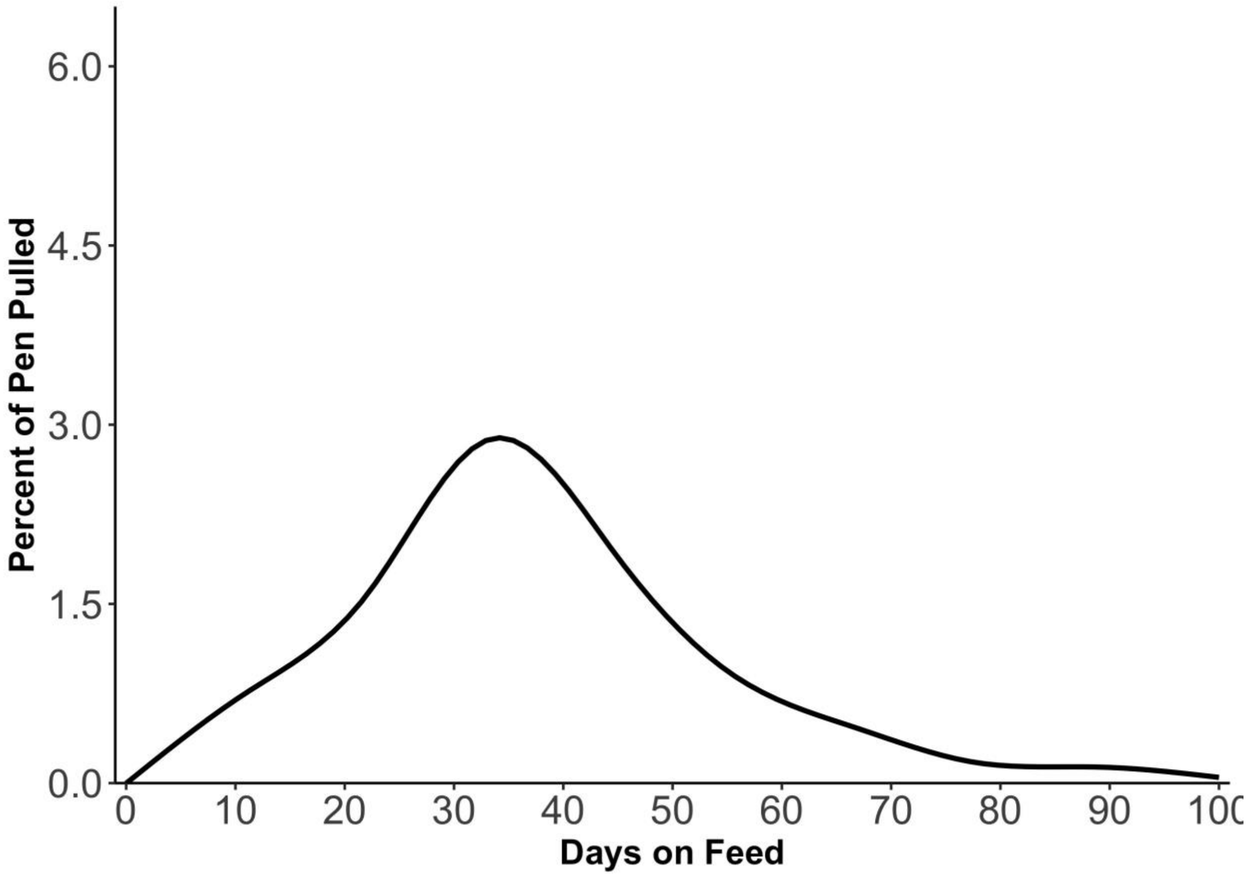


Figure A.9

Cluster 9 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 155 different cohorts and was determined to be early-feeding stage morbidity by majority of veterinarians consulted.

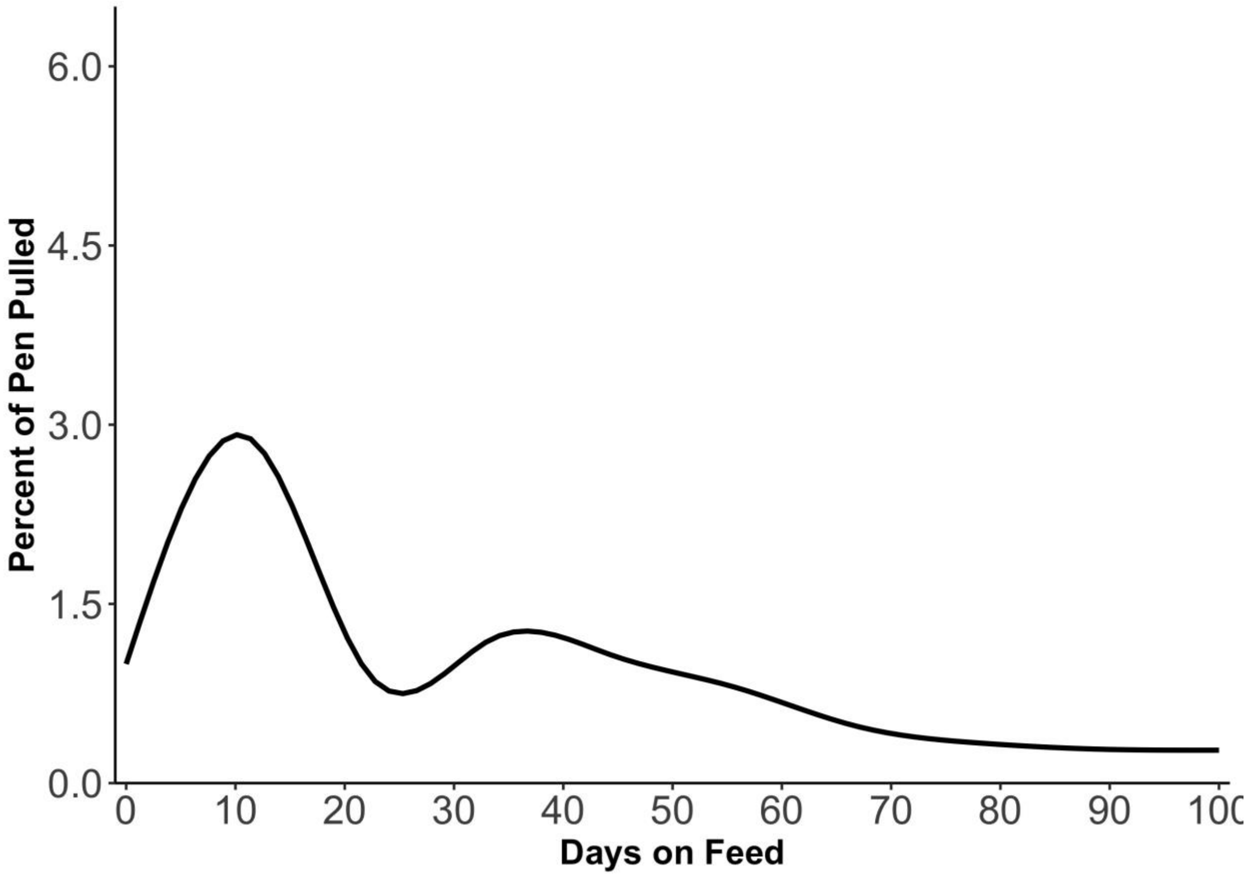


Figure A.10

Cluster 10 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 282 different cohorts and was determined to be mid-feeding stage morbidity by majority of veterinarians consulted.

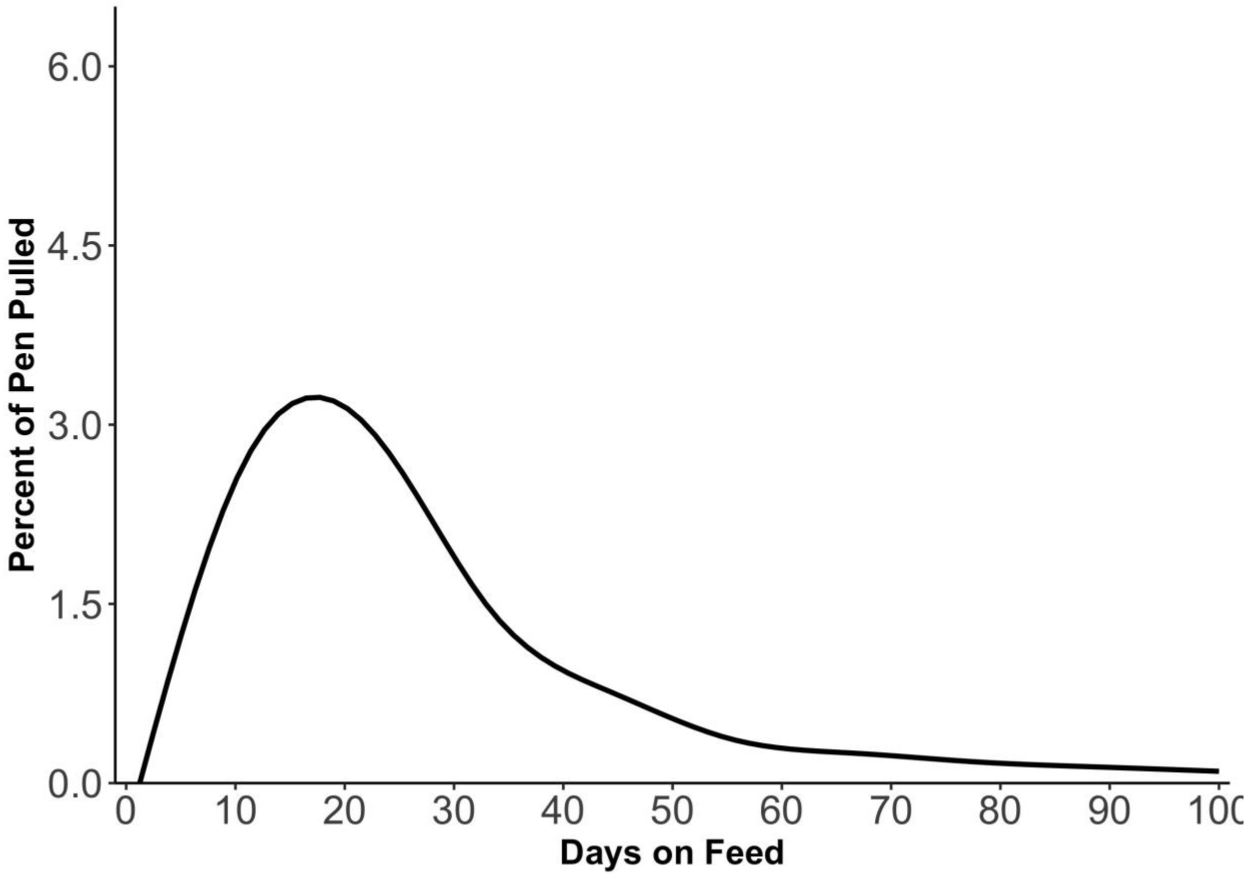


Figure A.11

Cluster 11 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 202 different cohorts and was determined to be early-feeding stage morbidity by majority of veterinarians consulted.

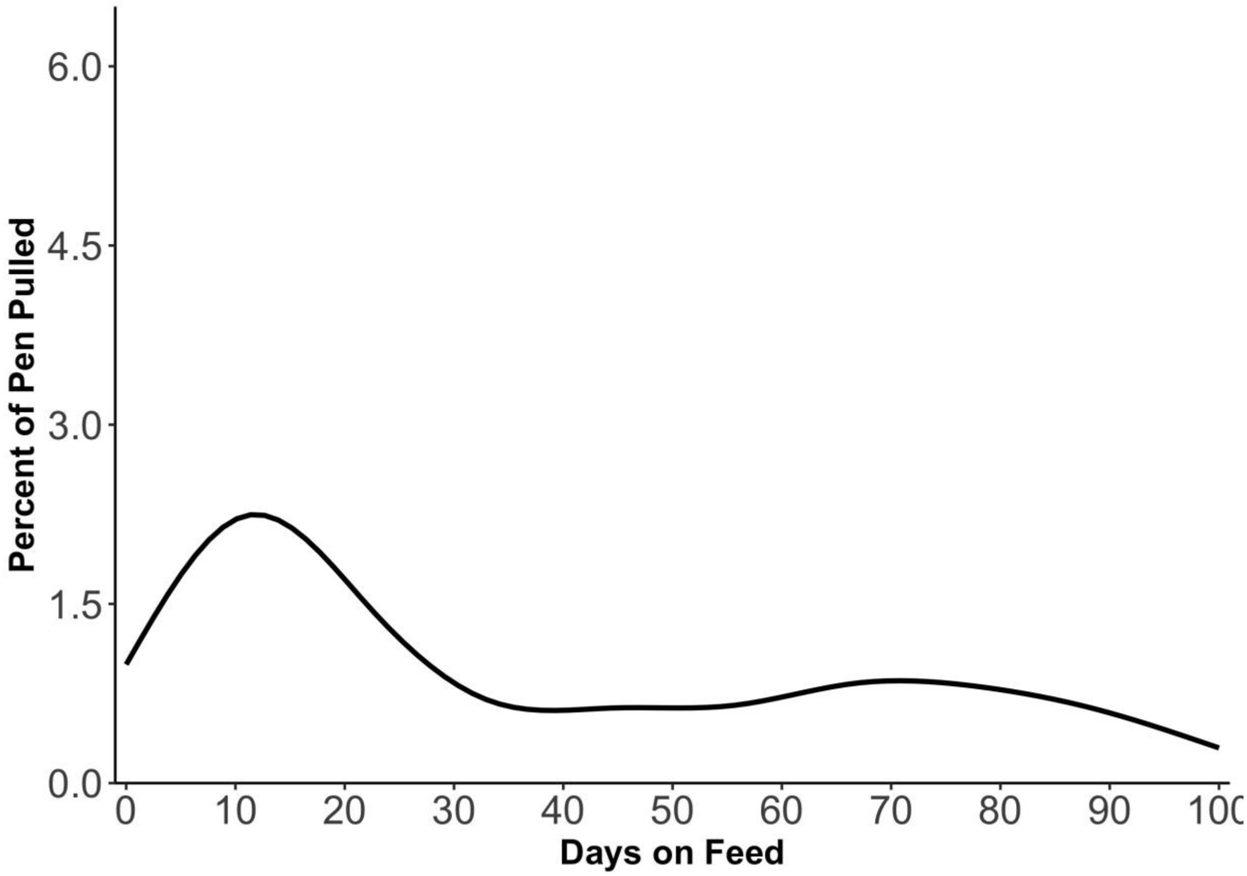


Figure A.12

Cluster 12 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 99 different cohorts and was determined to be late-feeding stage morbidity by majority of veterinarians consulted.

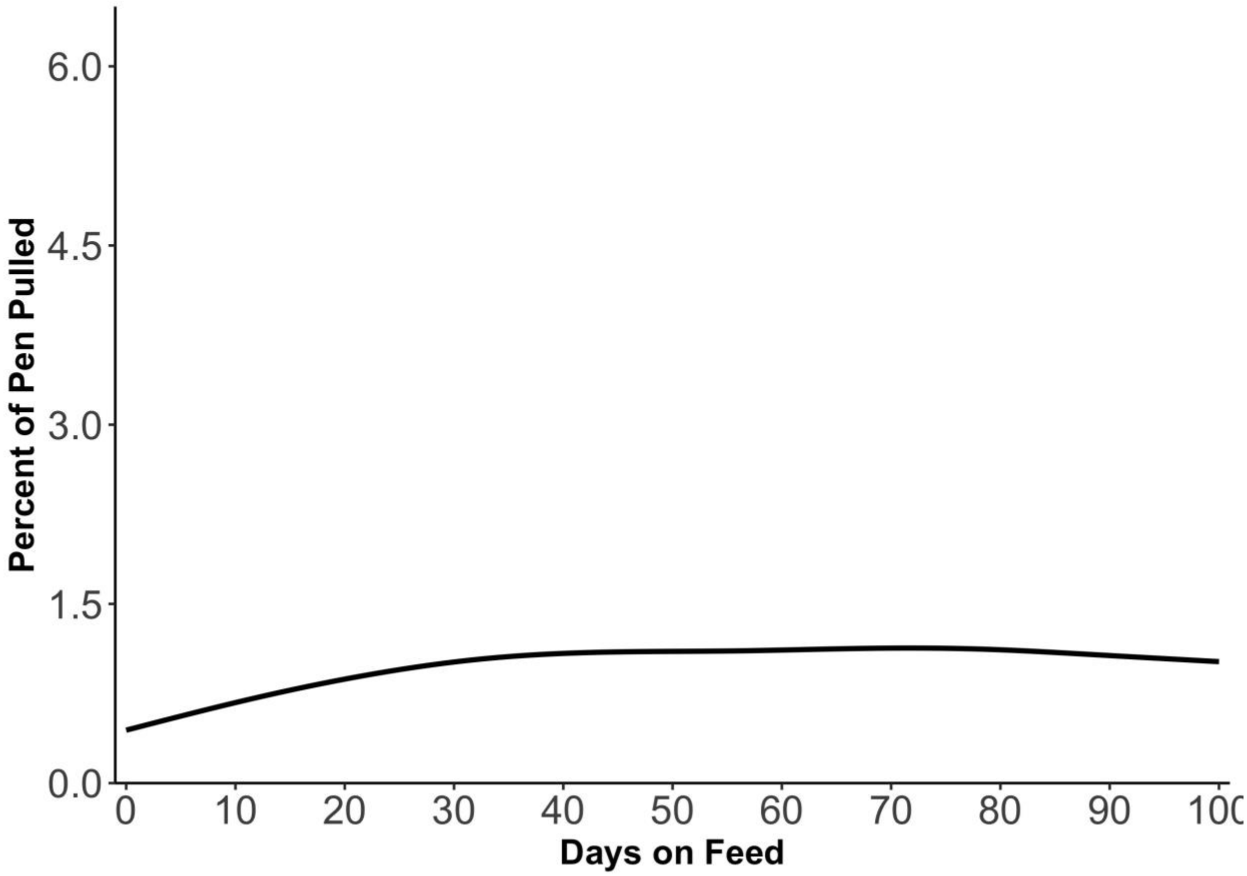


Figure A.13

Cluster 13 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 178 different cohorts and was determined to be early-feeding stage morbidity by majority of veterinarians consulted.

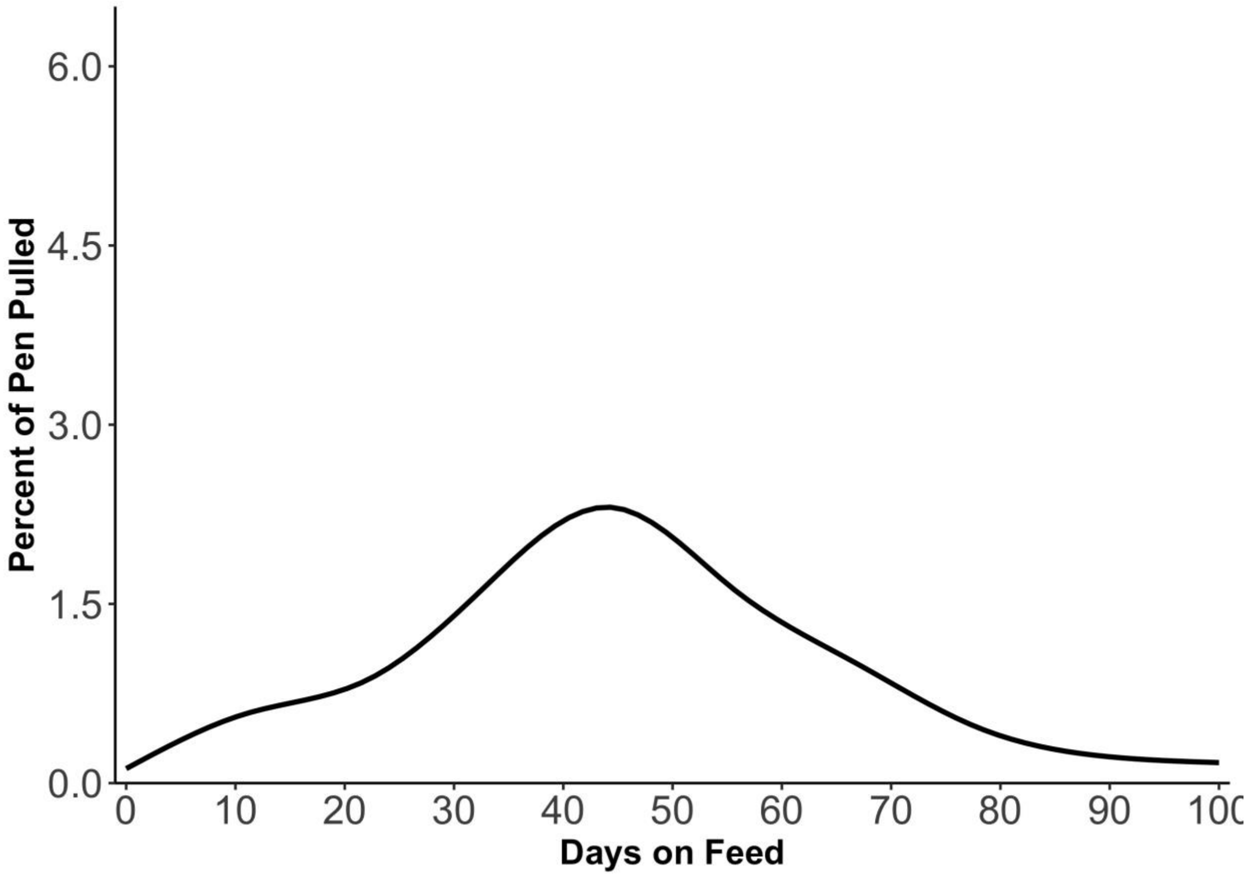


Figure A.14

Cluster 14 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 127 different cohorts and was determined to be mid-feeding stage morbidity by majority of veterinarians consulted.

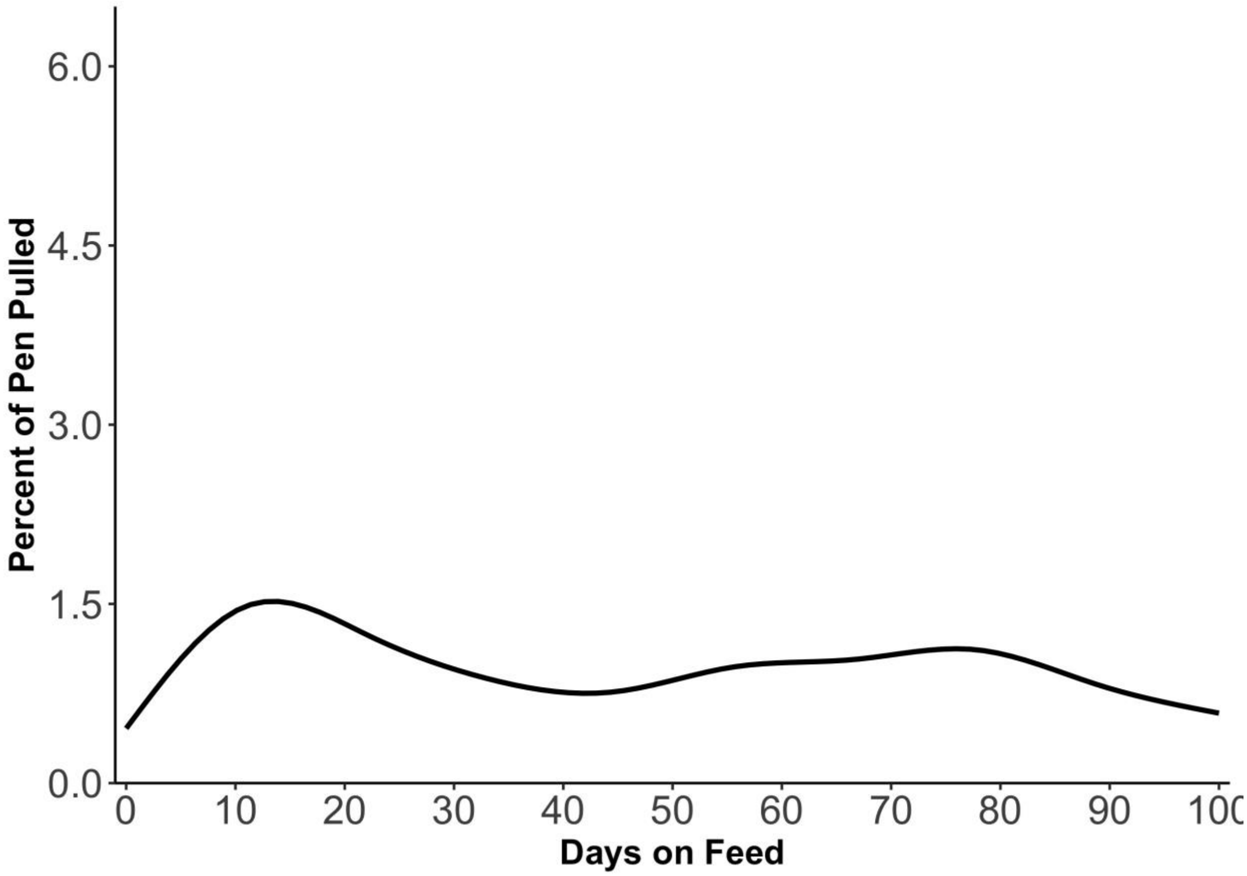


Figure A.15

Cluster 15 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 280 different cohorts and was determined to be mid-feeding stage morbidity by majority of veterinarians consulted.

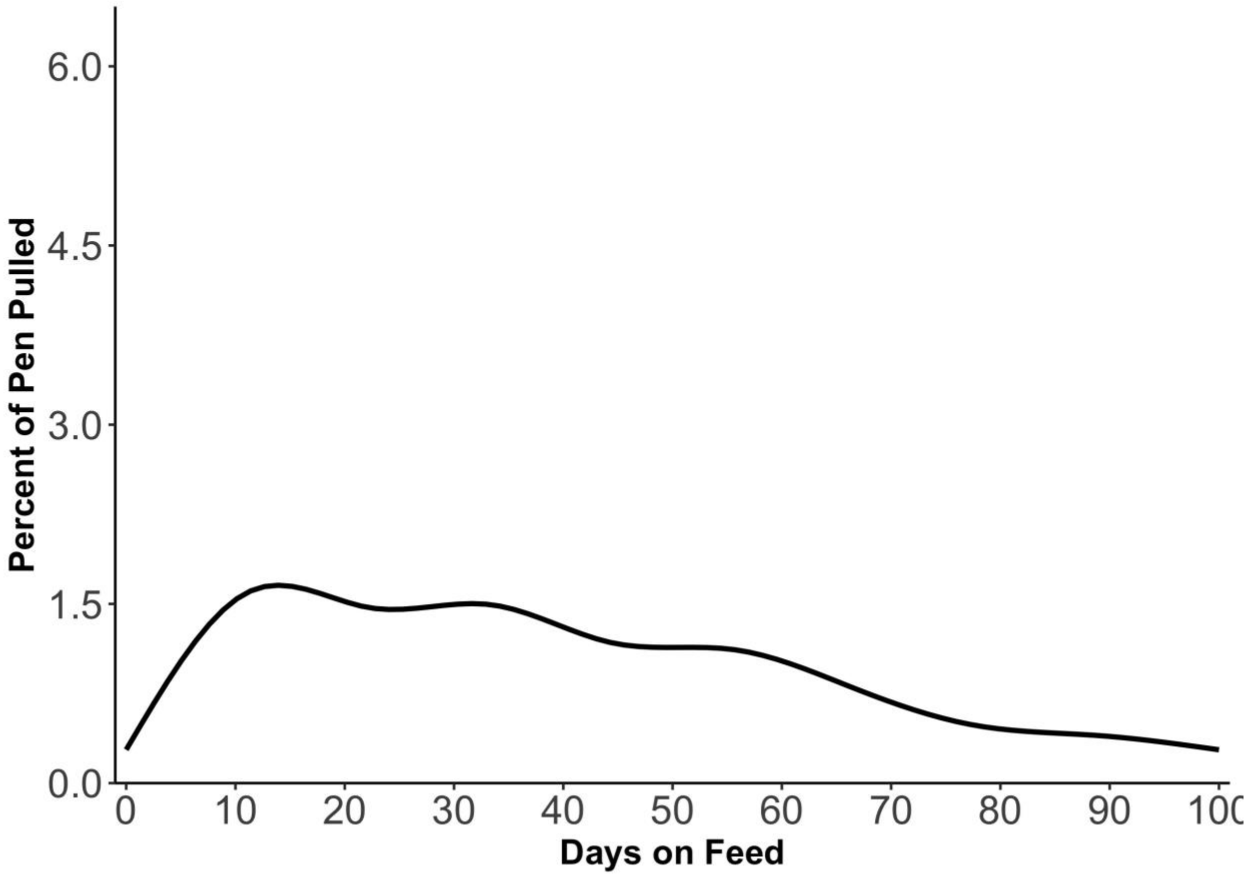


Figure A.16

Cluster 16 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 217 different cohorts and was determined to be early-feeding stage morbidity by majority of veterinarians consulted.

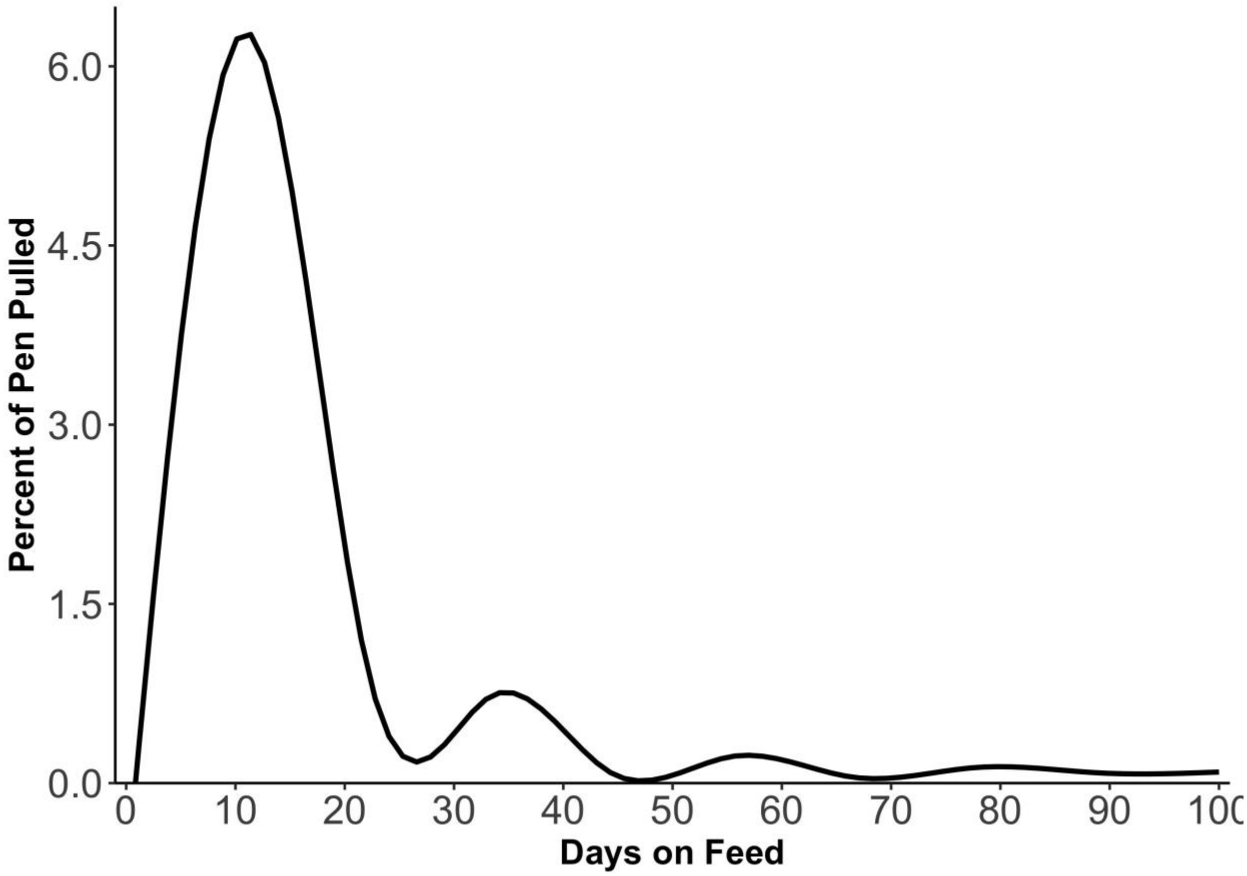


Figure A.17

Cluster 17 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 98 different cohorts and was determined to be early-feeding stage morbidity by majority of veterinarians consulted.

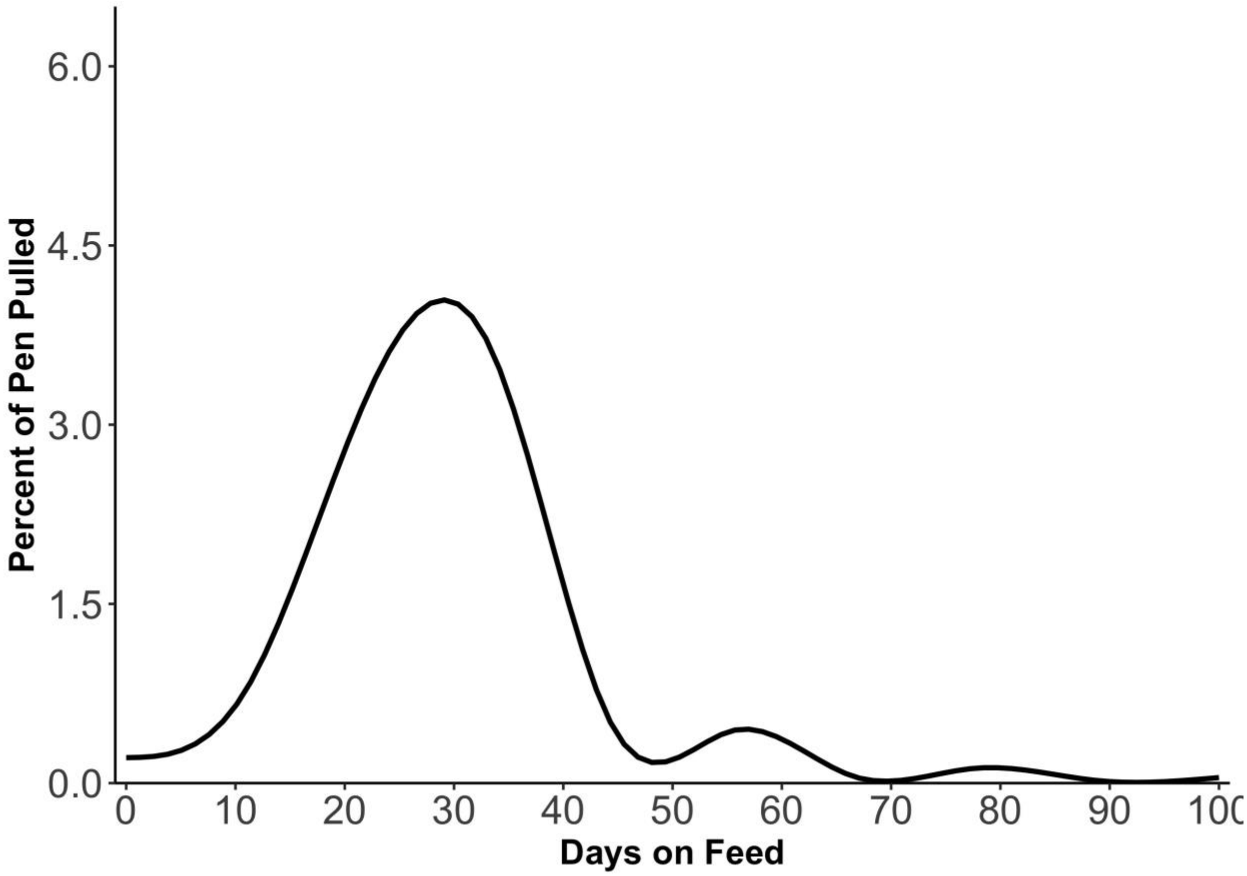


Figure A.18

Cluster 18 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 223 different cohorts and was determined to be early-feeding stage morbidity by majority of veterinarians consulted.

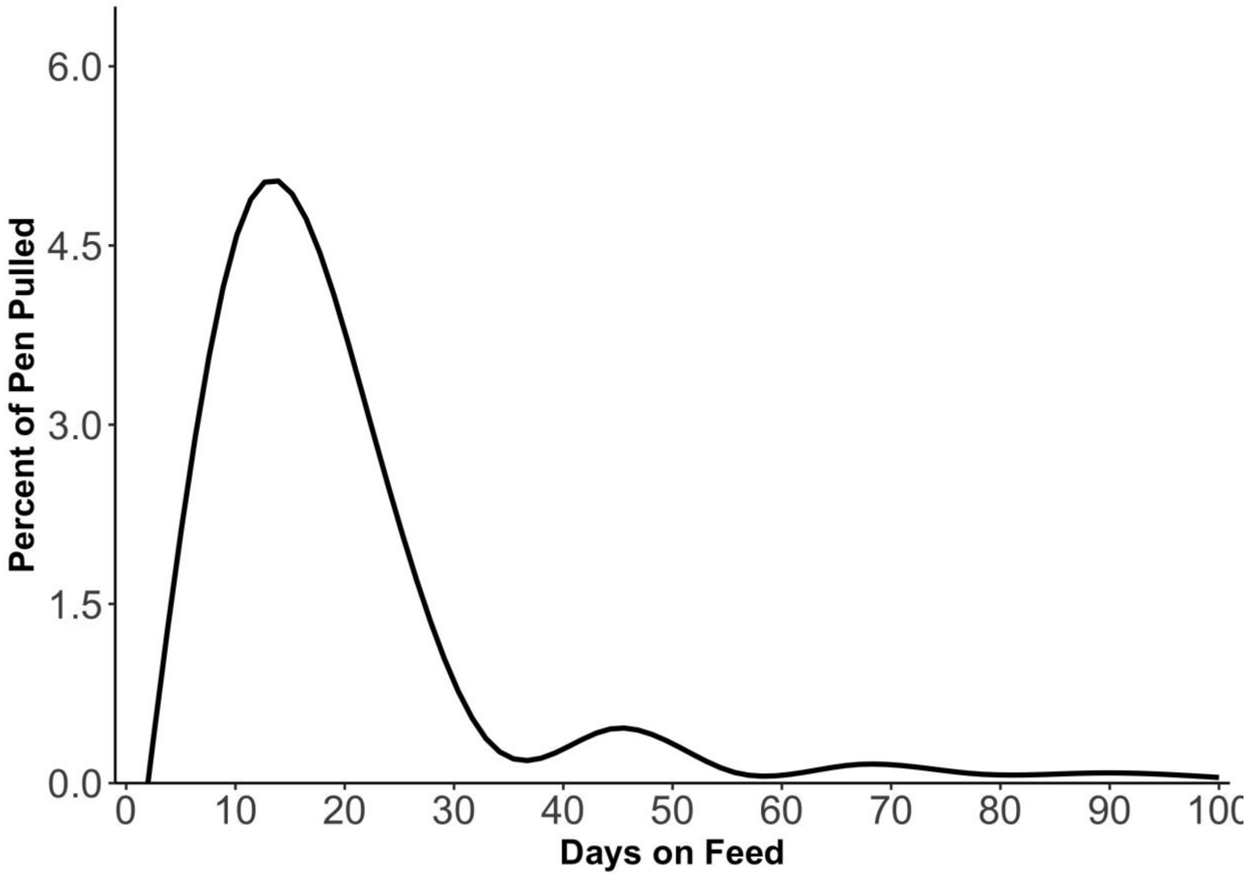


Figure A.19

Cluster 19 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 264 different cohorts and was determined to be early-feeding stage morbidity by majority of veterinarians consulted.

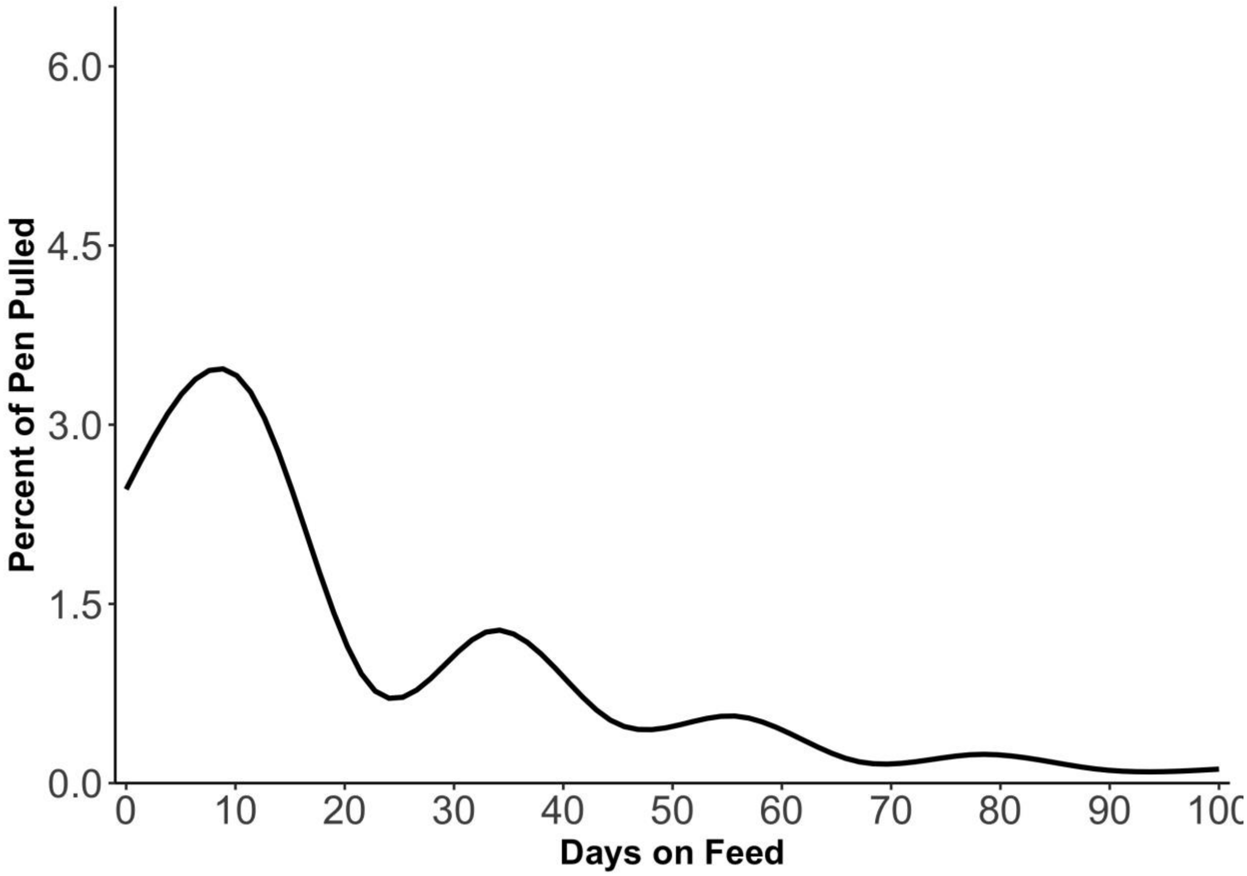
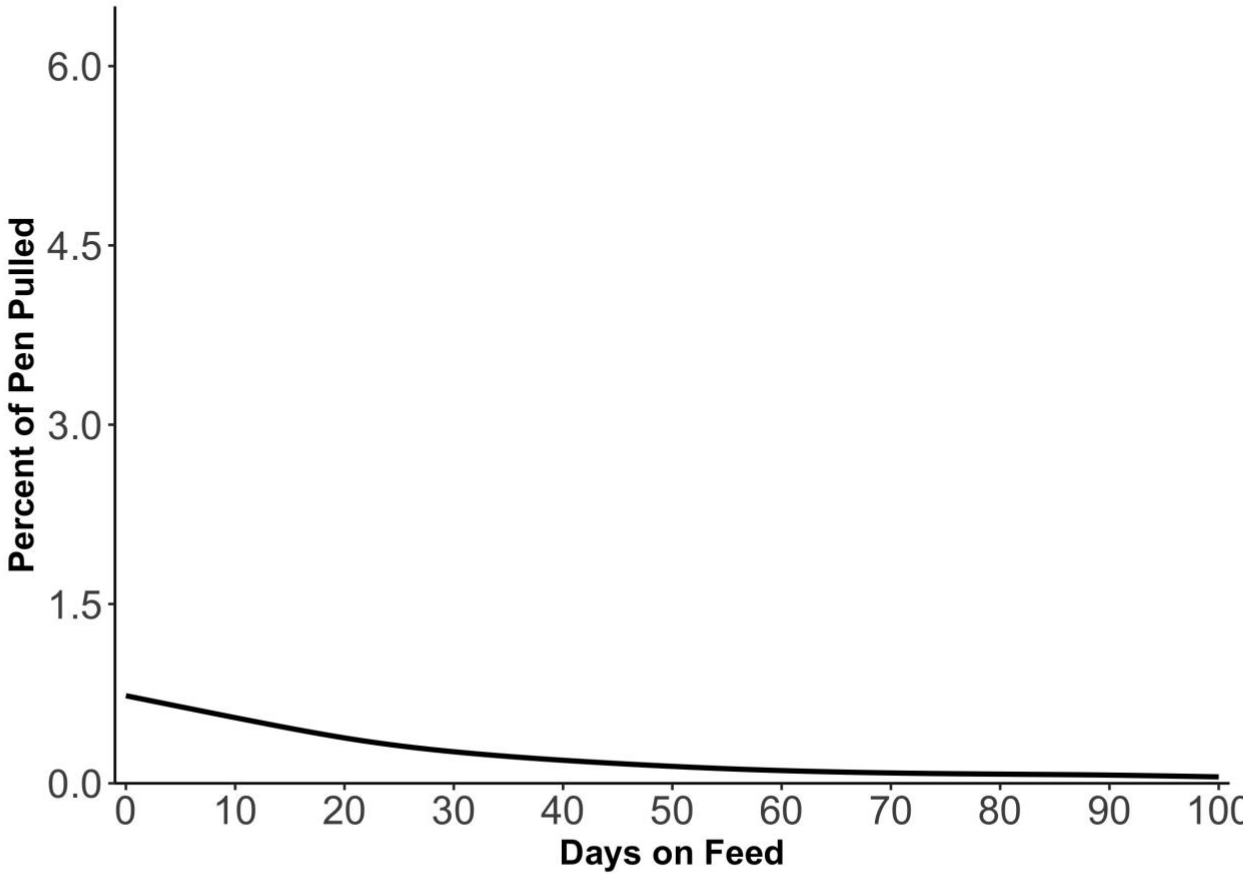


Figure A.20

Cluster 20 of incidence for the percent of a pen pulled from day 0 to 100 DOF. This cluster represents 115 different cohorts and was determined to be early-feeding stage morbidity by majority of veterinarians consulted.



Appendix B - Supplementary Chapter 3 Material

Table B.1

Final model[1] results from significant (P <0.05) interactions demonstrating estimated probabilities of an individual animals first treatment for bovine respiratory disease (BRD) being EARLY, MID, or LATE.

Covariate	Level	EARLY		MID		LATE	
		Prob (%)	95% CI	Prob (%)	95% CI	Prob (%)	95% CI
Quarter of arrival x arrival weight category (kg)	1 x (227 – 272)	75.2	69.3, 81.0	18.7	14.7, 22.7	6.1	4.3, 8.0
	1 x (272 – 318)	68.6	64.5, 72.7	23.1	20.5, 25.7	8.3	6.8, 9.8
	1 x (318 – 363)	67.5	63.3, 71.8	23.7	21.1, 26.4	8.8	7.1, 10.4
	1 x (363 – 409)	61.0	56.2, 65.7	27.8	25.1, 30.5	11.3	9.2, 13.3
	1 x (409 – 454)	52.5	46.9, 58.1	32.2	29.7, 34.9	15.2	12.2, 18.3
	2 x (227 – 272)	73.7	66.7, 80.7	19.7	15.0, 24.5	6.6	4.3, 8.8
	2 x (272 – 318)	72.7	68.3, 77.2	20.4	17.4, 23.4	6.8	5.4, 8.3
	2 x (318 – 363)	67.4	62.5, 72.2	23.9	20.9, 27.0	8.7	6.9, 10.5
	2 x (363 – 409)	60.9	55.6, 66.3	27.9	24.9, 31.0	11.2	8.9, 13.5
	2 x (409 – 454)	52.1	46.1, 58.1	32.6	29.8, 35.5	15.2	12.0, 18.4
	3 x (227 – 272)	88.4	84.8, 91.9	9.1	6.4, 11.8	2.5	1.7, 3.3
	3 x (272 – 318)	84.5	81.7, 87.3	12.0	10.0, 14.1	3.4	2.7, 4.2
	3 x (318 – 363)	81.9	78.8, 85.0	14.0	11.7, 16.2	4.1	3.3, 5.0
	3 x (363 – 409)	78.2	74.5, 81.8	16.7	14.1, 19.3	5.2	4.1, 6.2

	3 x (409 – 454)	72.9	68.2, 77.5	20.4	17.2, 23.5	6.8	5.3, 8.2
	4 x (227 – 272)	78.4	73.3, 83.6	16.4	12.7, 20.0	5.2	3.7, 6.7
	4 x (272 – 318)	79.9	76.8, 83.0	15.4	13.2, 17.6	4.7	3.8, 5.6
	4 x (318 – 363)	77.3	74.0, 80.7	17.2	14.8, 19.5	5.5	4.5, 6.5
	4 x (363 – 409)	76.3	72.7, 79.9	18.0	15.4, 20.5	5.7	4.6, 6.8
	4 x (409 – 454)	74.4	70.0, 78.8	19.3	16.3, 22.3	6.3	4.9, 7.7
Sex x arrival weight category (kg)	Heifer x (227 – 272)	75.6	71.4, 79.8	18.3	15.5, 21.2	6.1	4.7, 7.5
	Heifer x (272 – 318)	73.5	70.0, 77.0	19.7	17.4, 22.1	6.7	5.6, 7.9
	Heifer x (318 – 363)	68.4	64.5, 72.3	23.1	20.7, 25.6	8.5	7.0, 9.9
	Heifer x (363 – 409)	65.2	61.0, 69.3	25.1	22.6, 27.5	9.8	8.1, 11.5
	Heifer x (409 – 454)	59.2	53.9, 64.5	28.3	25.5, 31.1	12.5	10.0, 15.1
	Steer x (227 – 272)	82.3	77.4, 87.1	13.6	10.1, 17.2	4.1	2.8, 5.4
	Steer x (272 – 318)	79.4	76.4, 82.3	15.7	13.6, 17.8	4.9	4.0, 5.8
	Steer x (318 – 363)	78.7	75.7, 81.6	16.3	14.2, 18.4	5.1	4.2, 6.0
	Steer x (363 – 409)	73.0	69.6, 76.4	20.1	17.8, 22.4	6.9	5.7, 8.0
	Steer x (409 – 454)	66.8	62.8, 70.7	24.0	21.6, 26.4	9.2	7.7, 10.8
Quarter of arrival x lot size category	1 x (20 – 100)	68.7	64.4, 73.0	22.7	20.0, 25.4	8.6	6.9, 10.2
	1 x (100 – 200)	64.2	59.8, 68.6	25.6	23.1, 28.2	10.2	8.4, 12.0
	1 x (200 – 300)	64.2	59.5, 68.9	25.7	22.9, 28.5	10.1	8.2, 12.0
	1 x (300 – 400)	62.7	58.1, 67.3	26.4	23.7, 29.0	10.9	8.9, 13.0
	2 x (20 – 100)	68.8	63.9, 73.7	22.7	19.6, 25.8	8.5	6.6, 10.3
	2 x (100 – 200)	65.0	60.1, 69.8	25.2	22.3, 28.1	9.8	7.8, 11.8

	2 x (200 – 300)	63.2	57.8, 68.6	26.4	23.1, 29.6	10.4	8.2, 12.6
	2 x (300 – 400)	64.4	59.1, 69.7	25.4	22.3, 28.6	10.1	8.0, 12.3
	3 x (20 – 100)	83.9	81.0, 86.8	12.4	10.3, 14.5	3.7	2.9, 4.4
	3 x (100 – 200)	81.3	78.2, 84.4	14.4	12.1, 16.6	4.3	3.5, 5.2
	3 x (200 – 300)	80.6	77.1, 84.0	14.9	12.4, 17.4	4.5	3.6, 5.5
	3 x (300 – 400)	78.9	75.2, 82.6	16.0	13.4, 18.7	5.1	4.0, 6.2
	4 x (20 – 100)	82.5	79.5, 85.5	13.5	11.3, 15.7	4.0	3.2, 4.8
	4 x (100 – 200)	75.6	72.0, 79.2	18.4	16.0, 20.9	6.0	4.8, 7.1
	4 x (200 – 300)	72.9	68.7, 77.1	20.3	17.5, 23.1	6.8	5.4, 8.1
	4 x (300 – 400)	78.1	74.2, 82.0	16.7	13.9, 19.5	5.2	4.1, 6.3
Quarter of arrival x sex	1 x heifer	60.0	55.5, 64.5	28.1	25.6, 30.6	12.0	9.8, 14.0
	1 x steer	70.0	66.0, 73.8	22.1	19.6, 24.6	8.0	6.6, 9.4
	2 x heifer	61.1	55.9, 66.3	27.5	24.6, 30.4	11.4	9.1, 13.7
	2 x steer	69.9	65.1, 74.1	22.3	19.4, 25.2	8.0	6.4, 9.7
	3 x heifer	79.2	75.7, 82.6	15.9	13.4, 18.3	5.0	4.0, 6.0
	3 x steer	83.1	80.3, 86.0	13.0	10.9, 15.1	3.9	3.1, 4.6
	4 x heifer	73.2	69.3, 77.1	20.1	17.5, 22.7	6.7	5.4, 7.9
	4 x steer	81.4	78.4, 84.3	14.4	12.2, 16.5	4.3	3.5, 5.1
Quarter of arrival x metaphylaxis	1 x no metaphylaxis	69.0	65.4, 72.7	22.7	20.3, 25.0	8.3	6.9, 9.6
	1 x metaphylaxis	60.8	55.7, 66.0	27.6	24.7, 30.4	11.6	9.3, 13.9
	2 x no metaphylaxis	67.2	63.4, 71.0	23.8	21.4, 26.2	9.0	7.5, 10.4
	2 x metaphylaxis	63.5	56.7, 70.3	26.0	22.0, 30.0	10.4	7.6, 13.2

	3 x no metaphylaxis	79.2	76.3, 82.0	15.9	13.9, 17.9	5.0	4.1, 5.8
	3 x metaphylaxis	83.2	79.1, 87.2	13.0	10.0, 15.9	3.8	2.8, 4.9
	4 x no metaphylaxis	77.8	74.7, 80.8	16.9	14.7, 19.1	5.3	4.4, 6.2
	4 x metaphylaxis	76.8	72.8, 80.7	17.6	14.8, 20.3	5.6	4.4, 6.8
Lot size category x arrival weight category (kg)	(20 – 100) x (227 – 272)	84.1	80.3, 87.9	12.3	9.5, 15.1	3.6	2.6, 4.6
	(100 – 200) x (227 – 272)	74.7	69.8, 79.6	18.9	15.6, 22.2	6.3	4.8, 7.9
	(200 – 300) x (227 – 272)	75.1	67.2, 83.0	18.6	13.3, 24.0	6.2	3.7, 8.7
	(300 – 400) x (227 – 272)	81.2	75.9, 87.5	14.0	9.8, 18.3	4.2	2.6, 5.8
	(20 – 100) x (272 – 318)	80.5	77.4, 83.5	14.9	12.8, 17.1	4.6	3.7, 5.5
	(100 – 200) x (272 – 318)	78.7	75.7, 81.7	16.2	14.1, 18.3	5.1	4.2, 6.0
	(200 – 300) x (272 – 318)	73.3	69.4, 77.1	19.9	17.4, 22.5	6.8	5.5, 8.0
	(300 – 400) x (272 – 318)	73.3	69.1, 77.6	19.9	17.0, 22.7	6.8	5.4, 8.2
	(20 – 100) x (318 – 363)	77.6	74.4, 81.0	16.9	14.6, 19.2	5.5	4.4, 6.5
	(100 – 200) x (318 – 363)	72.8	69.4, 76.3	20.2	17.9, 22.5	7.0	5.8, 8.2
	(200 – 300) x (318 – 363)	71.3	67.6, 75.0	21.2	18.8, 23.6	7.5	6.2, 8.8
	(300 – 400) x (318 – 363)	72.4	68.5, 76.3	20.5	17.9, 23.1	7.1	5.8, 8.5
	(20 – 100) x (363 – 409)	72.7	68.9, 76.6	20.2	17.7, 22.7	7.1	5.7, 8.4
	(100 – 200) x (363 – 409)	68.2	64.4, 72.1	23.1	20.7, 25.6	8.6	7.2, 10.1
	(200 – 300) x (363 – 409)	68.5	64.5, 72.4	23.0	20.6, 25.5	8.5	7.0, 10.0
	(300 – 400) x (363 – 409)	66.9	62.7, 71.1	23.9	21.4, 26.5	9.1	7.5, 10.8
	(20 – 100) x (409 - 454)	64.9	60.1, 69.7	25.0	22.2, 27.7	10.1	8.1, 12.2
	(100 – 200) x (409 - 454)	63.1	58.7, 67.5	26.1	23.6, 28.6	10.8	8.8, 12.7

(200 – 300) x (409 - 454)	63.0	58.2, 67.8	26.2	23.5, 29.0	10.8	8.7, 12.9
(300 – 400) x (409 - 454)	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 DOF

Probabilities added directly across columns add to 100% with respect for rounding differences.

Table B.2

Final model[1] results from significant (P <0.05) interactions demonstrating estimated probabilities of an individual animals death due to bovine respiratory disease (BRD) being EARLY, MID, or LATE

Covariate	Level	EARLY		MID		LATE	
		Prob (%)	95% CI	Prob (%)	95% CI	Prob (%)	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
	(272 – 318)	59.9	52.3, 67.6	26.6	22.7, 30.5	13.4	9.6, 17.3
	(318 – 363)	57.3	49.5, 65.1	27.9	24.1, 31.7	14.8	10.7, 18.9
	(363 – 409)	53.0	44.9, 61.0	29.8	26.3, 33.3	17.2	12.5, 21.9
	(409 – 454)	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 x sex	1 x heifer	44.8	36.2, 53.4	33.0	30.2, 35.8	22.2	16.2, 28.3
	2 x heifer	46.5	37.7, 55.3	32.5	29.4, 35.5	21.0	15.1, 26.9
	3 x heifer	58.1	49.7, 66.5	27.7	23.5, 31.9	14.2	9.9, 18.5
	4 x heifer	59.8	51.5, 68.0	26.9	22.6, 31.2	13.4	9.3, 17.4
	1 x steer	60.9	52.9, 69.0	26.4	22.1, 30.7	12.7	8.9, 16.4
	2 x steer	53.7	45.3, 62.2	29.9	26.0, 33.8	16.4	11.7, 21.0
	3 x steer	67.6	60.3, 74.9	22.7	18.3, 27.0	9.7	6.8, 12.7
	4 x steer	69.3	62.2, 76.3	21.7	17.3, 26.0	9.1	6.3, 11.9

Sex x lot size category	Heifer x (20 – 100)	61.8	53.5, 70.1	25.7	21.3, 30.2	12.5	8.5, 16.4
	Heifer x (100 – 200)	49.7	41.4, 58.0	31.2	28.0, 34.5	19.1	13.9, 24.3
	Heifer x (200 – 300)	50.1	41.4, 58.8	31.1	27.6, 34.6	18.8	13.4, 24.2
	Heifer x (300 – 400)	47.6	38.4, 56.8	32.0	28.7, 35.3	20.4	14.4, 26.5
	Steer x (20 – 100)	63.4	55.4, 71.4	24.9	20.5, 29.3	11.7	8.1, 15.4
	Steer x (100 – 200)	64.6	57.2, 72.0	24.2	20.0, 28.4	11.2	7.9, 14.4
	Steer x (200 – 300)	61.1	53.3, 68.8	26.1	22.0, 30.3	12.8	9.1, 16.5
	Steer x (300 – 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 DOF

Probabilities added directly across columns add to 100% with respect for rounding differences.