

Association of feedlot disease treatments on the probability of heart disease syndrome in U.S. feedlot cattle

Blaine T. Johnson,^{1,2} DVM MS; David E. Amrine,¹ DVM PhD
Robert L. Larson,^{1,3} DVM PhD ACVPM-Epidemiology, ACT; *Brad J. White,^{1,3} DVM, MS

¹Beef Cattle Institute, Kansas State University,
Manhattan, KS 66506

²Department of Diagnostic Medicine and Pathobiology, College of Veterinary Medicine, Kansas State University
Manhattan, KS, 66506

³Department of Clinical Sciences, College of Veterinary Medicine, Kansas State University
Manhattan, KS 66506

*Corresponding author: Dr. Brad White, bwhite@vet.k-state.edu

Abstract

Data from 14 U.S. feedlots from January 1, 2017, through December 31, 2020, were evaluated for disease treatment on the probability of being terminally diagnosed with heart disease (HD). The study objective was two-fold: 1) determine the association between the number of bovine respiratory disease (BRD) treatments (0,1,2,3+) and HD, and 2) determine the association of common feedlot disease treatment (AIP, BRD, Complex Disease, GI+Bloat, Other), and cohort demographics with HD. Data were analyzed using generalized mixed-effects models to evaluate the probability of terminal HD. Covariates of interest include: BRD treatments, feedlot disease category, average cohort arrival weight, arrival year, arrival quarter, feedlot elevation and sex. The number of BRD treatments was associated with HD ($P < 0.01$). Cattle requiring additional BRD treatments increased their probability of not finishing the feeding period due to HD. The magnitude of this association was influenced by average cohort arrival weight, feedlot elevation, sex and arrival quarter ($P < 0.01$). Feedlot disease categories were associated with the probability of not finishing the feeding phase due to a HD diagnosis ($P < 0.01$). The magnitude of this association was influenced by average cohort arrival weight, and feedlot elevation ($P < 0.01$). Sex was influenced by feedlot elevation on the probability of not finishing due to HD diagnosis ($P < 0.01$) with higher elevations having a greater probability of HD. The majority of HD cattle were railed prior to death at the feedlot (9 of the 15 per 10,000 cattle received).

Key words: BRD, complex disease, feedlot, heart disease,

Introduction

Bovine respiratory disease (BRD) remains the leading cause of morbidity and mortality in most feedlots and has been associated with large, negative economic effects in the feedlot industry.¹ Nonetheless, heart disease (HD) has gained interest from producers, veterinarians and geneticists as potentially increasing as a contribution to total feedlot mortalities over time.² Recent literature has documented HD increasing in prevalence over time in the feedlot population of Canadian and U.S. cattle at moderate elevations which is in contrast with the previous assumptions of HD being a problem only at high elevation.^{2,3} Common feedlot demographics have been analyzed to determine their associations to right heart

failure.²⁻⁴ Previous literature reported that cattle treated for BRD were found to be up to 3 times more likely to die from right heart failure (RHF) than cattle not treated for BRD when controlling for likelihood of dying from a digestive death, year of placement and feedlot.³ Currently, there is a gap in literature on the association of HD with number of BRD treatments as well as other feedlot diseases. The objectives of this study were 1) determine the association of the number of BRD treatments with HD and 2) determine the association of feedlot disease treatments (Atypical Interstitial Pneumonia (AIP), BRD, Gastrointestinal Disease + Bloat (GI+Bloat), heart disease (HD), Other (any disease that is not AIP, GI+Bloat, Heart Disease or BRD), and Complex (an animal treated for more than one disease category within the feeding phase period) on the probability of a terminal diagnosis of HD.

Materials and methods

Animal Care and Use Committee approval was not obtained for this study due to retrospective data being obtained from existing privatized databases from commercial feedlots.

Data source

Data used for analysis were obtained under confidentiality agreements with participating feedlots. Individual treatment, mortality and cohort data were sourced from 14 U.S. commercial feedlots located throughout the central U.S. and Plains feeding regions from 2017 through 2020. A cohort is defined as a group of cattle that were purchased, managed and marketed at a similar endpoint. The cohort may or may not have been housed and fed in the same pen throughout the finishing period. Cohort data was limited to demographic variables such as sex, arrival date, total head received, and average cohort arrival weight, that define the population of cattle placed at the feedlot. Individual animal data were collected at a time of an event during the production phase (e.g. treatment definition, treatment date, and therapy regimen, and necropsy defined death diagnosis). An event is defined as an individual record for treatment, observation or item given to an individual at the time of occurrence following the caretaker's animal health protocol previously established by a licensed veterinary health professional.

Data preparation

All data manipulations were performed in R,⁵ utilizing the tidyverse package.⁶ The original data consisted of individual treatment data – 780,776 events – with multiple events (rows) per individual. Individual treatment events were matched with individual terminal events ($n = 62,191$), which included date and diagnosis of terminal event. All terminal events were recorded by trained feedlot personnel and were defined as either death or rail events. A railed animal is considered an animal that was removed from its cohort and sold for salvage value prior to the completion of the feeding period for the cohort. Data was concatenated from 780,776 observations to 291,552 observations (number of cattle treated for disease) to get individual events to one event per row, while creating new variables (columns) to account for multiple events within the individual's feeding phase. Individual level data was matched to the cohort data, which consisted of 14,480 unique cohorts (Figure 1).

Original individual data were filtered using an inclusion criterion to create a uniform population to represent common U.S. fed cattle demographics and to limit potential confounding variables. In short, each treated animal's cohort data was tied to individual data records then filtered by inclusion criteria for completeness. Cattle used for this study were included if feedlot placement timeframe was between January 1, 2017 through December 31, 2020. Cattle were also included if average cohort placement weight was between 400 to 1,100 lbs (182 kg to 500 kg). Cohort feeding period was limited to cattle fed between 100 to 400 days on feed. Sex was limited to steers and heifers. Holsteins, mixed-sex groups of steers and heifers, as well as bulls, were not included in the current study. Furthermore, due to nature of retrospective data, castration status cannot be confirmed. An individual's treatment event was limited to ≥ -7 days on feed. Authors allowed a grace period of -7 days on feed as cattle were potentially being grouped before a cohort's defined start date was initiated. Treatment and disease diagnosis were grouped into 6 categories: heart disease (HD), atypical interstitial pneumonia (AIP), bovine respiratory disease (BRD), gastrointestinal and bloat (GI + Bloat), other (Other), and complex (Complex). Heart disease cases were limited to diseases of a non-infectious origin at diagnosis (example: heart disease, right heart failure, brisket disease, CHF, etc.). Infectious causes such as endocarditis, myocarditis and pericarditis events were removed from analysis. The category "Other" encompassed a wide variety of events and diseases. To limit "Other" to disease events, list categories that were similar to procedural events were removed (e.g. implant, reimplant, moving cattle, check weight, etc.). Complex disease treatment was defined as an animal which was pulled and treated for more than one of the previously described diseases within the feeding period. Disease categories were mutually exclusive whereas cattle could only be in one treatment category if treated for disease, otherwise if an individual were treated for multiple different diseases, it would be placed in the complex disease treatment category. The number of times individuals were treated were not evaluated for this analysis.

Simulated individual data

To account for cattle which did not require any treatment and finished the feeding phase as part of the cohort, a simulated "indicator" observations (new row of data) were created. Simulated observations were created by taking the difference between number of cattle placed within a cohort and

subtracting the number of individual records (death and/or treatment records) within cohort to get the number of cattle not requiring treatments and not dying within the feeding period ("non-treated cattle" = total cattle placed within cohort – total number of unique/distinct observations within cohort). Deaths and treatment records were cross referenced to only have on record per individual. A total of 2,216,121 observations were created to represent the cattle which did not require treatment and finished the feeding phase. Matching column variables were created to bind the simulated data to the filtered master data set. Lot demographic data was tied to the simulated observations.

Variable creation

New variables were created to group and filter cattle into categories for data analysis and modeling of non-infectious heart disease death. Continuous variables were grouped into categorical variables based on biological break points to avoid violating assumptions of linearity. The study case definition of BRD was an animal pulled for BRD and treated with an antimicrobial. A new variable (brd_trt_cat) was created with 4 categories: 0, 1, 2, 3+ based on the number of individual BRD treatments. Cattle were only represented in their highest respective category, (i.e. cattle treated 3 times were only included in the 3+ category and not counted in 1 or 2 brd_trt_cat). A unique identifier number (UID2) was created to tie an individual observation to lot demographic data represented the concatenation of "yardid", "lotid", and "lot arrival year". A second unique identifier was created to group multiple events to one individual using an individual's yardid, lotid, arrival year and tag number. To account for total number of treatments, a variable called treatment count (Trt_Count) was created which grouped data to one observation (one row per individual) by summing up all treatment counts on an individual to one row of all treatment counts (Trt_Count). Binary variable categories were created to account for whether an animal was ever treated for one of the 6 mutually exclusive disease categories (HD, AIP, BRD, GI + Bloat, Other, and Complex). A "1" indicated an animal was treated for a specific disease category and "0" indicated no treatment for the specific disease category.

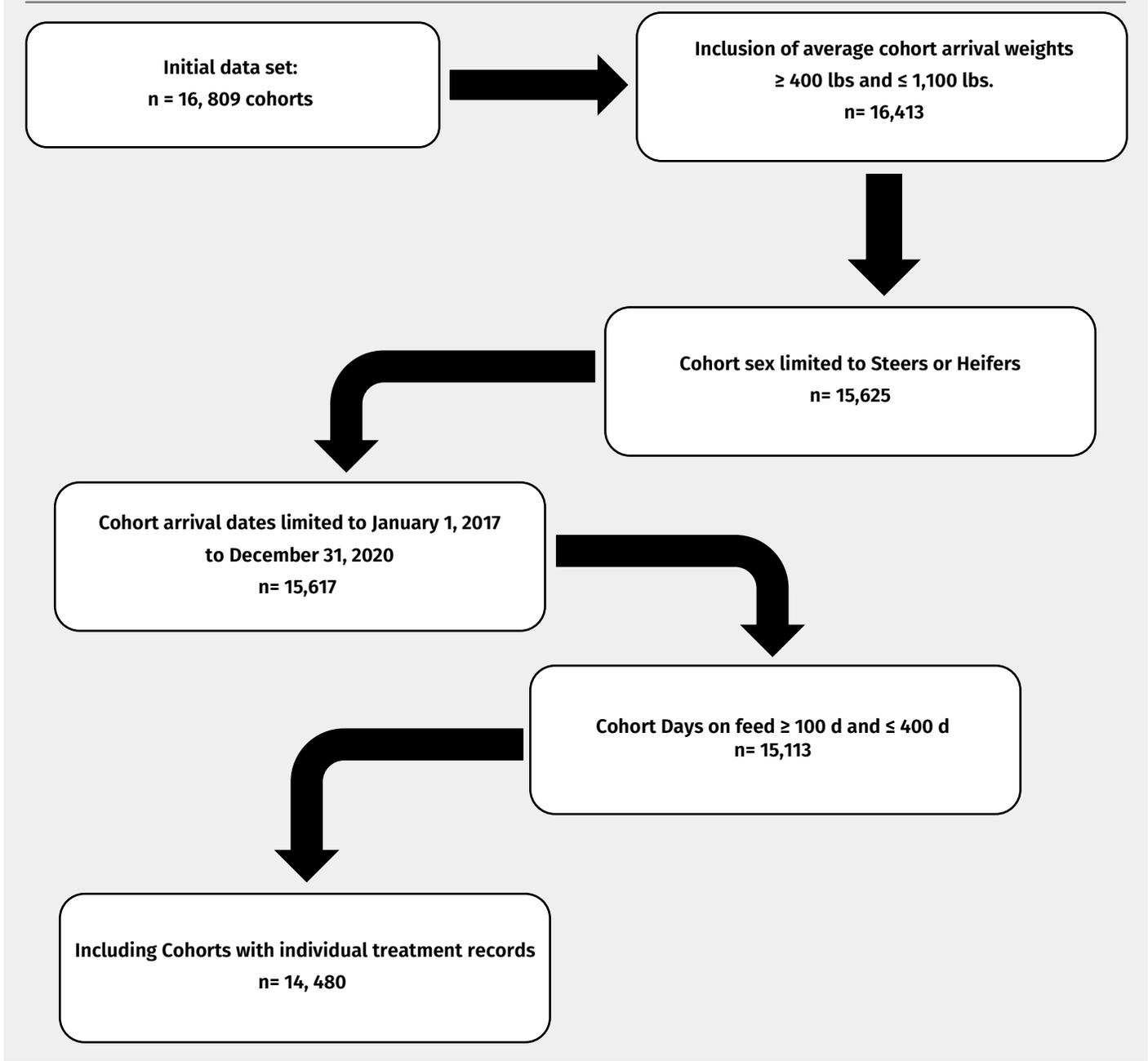
To account for arrival period, cattle were grouped by the quarter which they arrived. The variable was created from the feedlot arrival date (arrival_qrt). Cattle that arrived from January to March were labeled as 1, cattle that arrived April to June were labeled as 2, July to September were labeled as 3, and October through December were labeled as 4.

A variable for feedlot elevation was developed (elevation_cat_ft). The specific feedlot elevation was found using readily available websites and the feedlot's current mailing address.^{7,8} Elevations were grouped in 3 categories: < 3000 ft, 3,001 ft to 3,999ft, $\geq 4,000$ ft (< 914.4 m, 914.7 m to 1218.9 m, ≥ 1219.2 m). All 14 feedlots were as equally distributed as possible within the 3 mutually exclusive categories ($n = 4, 5, \text{ and } 5$ feedlots per respective category).

Statistical analysis

The current study used generalized mixed effects multivariate logistic regression to analyze study objectives. Data was analyzed in R using the glmer function in the lme⁴ package.^{5,9} The first objective modeled the probability of developing HD and not finishing the feeding phase as the outcome variable. Factors of interest include: BRD treatment categories (0,1,2,3),

Figure 1: Flow chart showing inclusion of cohort level data from 14 U.S. commercial feedlot used for final model.



average cohort arrival weight, arrival quarter, elevation category and sex as covariates. Authors limited the number of interactions included to: BRD category and elevation category, sex and BRD category, BRD category and average cohort arrival weight, and BRD and cohort arrival quarter due to biological reasoning.

To accomplish the second objective, authors modeled the probability of developing HD and not finishing the feeding phase as the outcome variable while conditioning on disease category (AIP, BRD, GI + Bloat, Other, and Complex Disease), average cohort arrival weight, elevation category and sex. Interactions in the second model were limited to sex and disease category, average cohort arrival weight and disease category, elevation category and disease category, elevation category and average cohort arrival weight, and elevation category and sex.

Random intercepts of lot within yard and arrival year were included in both analyses to account for lack of independence and hierarchical structure of the data. A significance of $P < 0.05$ was established a priori.

Predetermined interactions were included in the model and removed using a backward elimination process to finalize the model.¹⁰ Final model was selected by comparing models and selecting the model with the lowest Bayesian Information Criterion (BIC). Pairwise comparisons for significant interactions or main effects were performed for each model using emmeans package with Tukey method adjustment for family-wise error rate.¹¹

Results

The final model data set included 2,380,165 individual cattle. There were 182,620 cattle treated for BRD (67.2%) out of 271,814 individual treatment records. Data included 14,480 distinct cohorts and individual data comprised of 732,932 heifers and 1,647,233 steers. Maximum feedlot elevation was 4,551 ft (1,387 m) and minimum was 1,949 ft (594 m). Table 1 shows number of cattle received by year and feedlot elevation as well as the percent of cattle treated for BRD and subsequently diagnosed with heart disease. Table 2 shows counts of cattle not finishing, either by death or railed events, and treatments by disease code. There were 3,656 cattle with HD observed in the data set which represented 1,174 heifers and 2,482 steers from both railer and death events. Heart disease events accounted for 0.15% of total cattle received (15 per 10,000 cattle) during the four-year study period. There were 2,130 cattle railed due to HD and 1,526 cattle died due to HD over the four-year study period. Prevalence of HD death was found to be 0.06% (6 in 10,000 cattle), and prevalence of HD rails was 0.09% (9 in 10,000 cattle) over the four-year study period. In 2017, there were 384 terminal HD diagnoses observed in a population of 109,591 cattle received (0.35%; 35 per 10,000 cattle). Whereas 2018 had 1,246 terminal HD diagnosis observed from a population of 801,267 cattle (16 per 10,000 cattle). The lowest frequency of HD was observed in 2019 at 1,373 cattle from a population of 1,088,621 (13 per 10,000 cattle). The final year of the current study had 653 terminal HD observed in 420,026 received cattle (16 per 10,000 cattle).

Objective one: BRD and HD association

The number of times cattle were treated for BRD was associated with HD ($P < 0.001$), and this effect was modified by arrival weight ($P < 0.01$), sex ($P = 0.01$), and arrival quarter ($P < 0.01$). The model-estimated probability for HD increased as arrival weight increased and increased with additional BRD treatments (Figure 2). For example, Cattle placed at 600lbs to 700lbs and never treated for BRD (274 to 318kg) had an estimated probability 0.03% (SE = 0.02%) of developing HD. The probability increased with increasing number of BRD treatments from 0.27% (SE = 0.14%), to 0.45 (SE = 0.23%), and 0.73% (SE = 0.38%) for BRD categories 1, 2, and +3, respectively.

Quarter of placement influenced the effect of BRD treatment category on an individual's HD probability (Figure 2). Cattle in the 0 BRD treatment category had the lowest HD estimated probability, with cattle placed in quarter two having the lowest overall estimated probability of a HD diagnosis at 0.014%. As the number of BRD treatments increased for quarter 2 placed cattle, the estimated probability of a HD increased from 0.30% (SE = 0.10%) to 0.66% (SE = 0.30%), and finally 0.70% (SE = 0.40%), respectively. Cattle in the 3+ BRD treatment category had the highest estimated probability of HD when placed in quarter 1 (1.1%, SE = 0.60%). However, the probability was not different within the 3+ BRD treatment category across all placement quarters. No difference was seen in cattle placed in quarter 2 with 3+ BRD treatments compared to cattle in BRD treatment category 2 and BRD treatment category 1 in quarters 1, 2 and 4. Cattle fed at higher elevations had a numerically greater probability of being diagnosed with HD. The magnitude of the probability was influenced by number of BRD treatments (Figure 3). The highest model-estimated mean probability was seen in cattle treated 3 or more times and fed at elevations > 4,000 ft at 2.35% (SE = 1.80%). Cattle fed at lower elevations had numerically lower model adjusted probabilities of HD. However,

animals that were never treated for BRD had the lowest model adjusted probability of developing HD at < 0.06%.

Objective two: Feedlot disease association with HD

The final model found that 3 interactions were associated with not finishing due to a terminal diagnosis of HD. Arrival weight by disease treatment category was associated with not finishing due to HD ($P < 0.01$). Lighter placed cattle and non-diseased had the lowest probability of not finishing the feeding period due to HD with estimated probabilities < 0.01% (Figure 6). Cattle placed and treated as complex disease (requiring treatment for multiple diseases) treatments had between 1.79% and 2.85% (SE = 1.06% and SE = 1.74%, respectively) estimated probability of not finishing the feeding period due to HD. Cattle placed at 501 to 600lbs (227 to 272 kg) and treated for AIP had an estimated probability of not finishing the feeding period due to HD at 3.38% (SE = 3.01%).

Feedlot disease treatment category was influenced by feedlot elevation category on its associated with not finishing due to HD ($P < 0.001$). Cattle treated for complex disease category and fed in feedlots >4,000 ft (1219 m) had the highest numerical model-estimated probability of not finishing the feeding period due to HD (3.55% and 5.53% respectively). Cattle having no disease treatments had the lowest estimated probability of not finishing the feeding period due to HD regardless of their feedlot elevation (Figure 4).

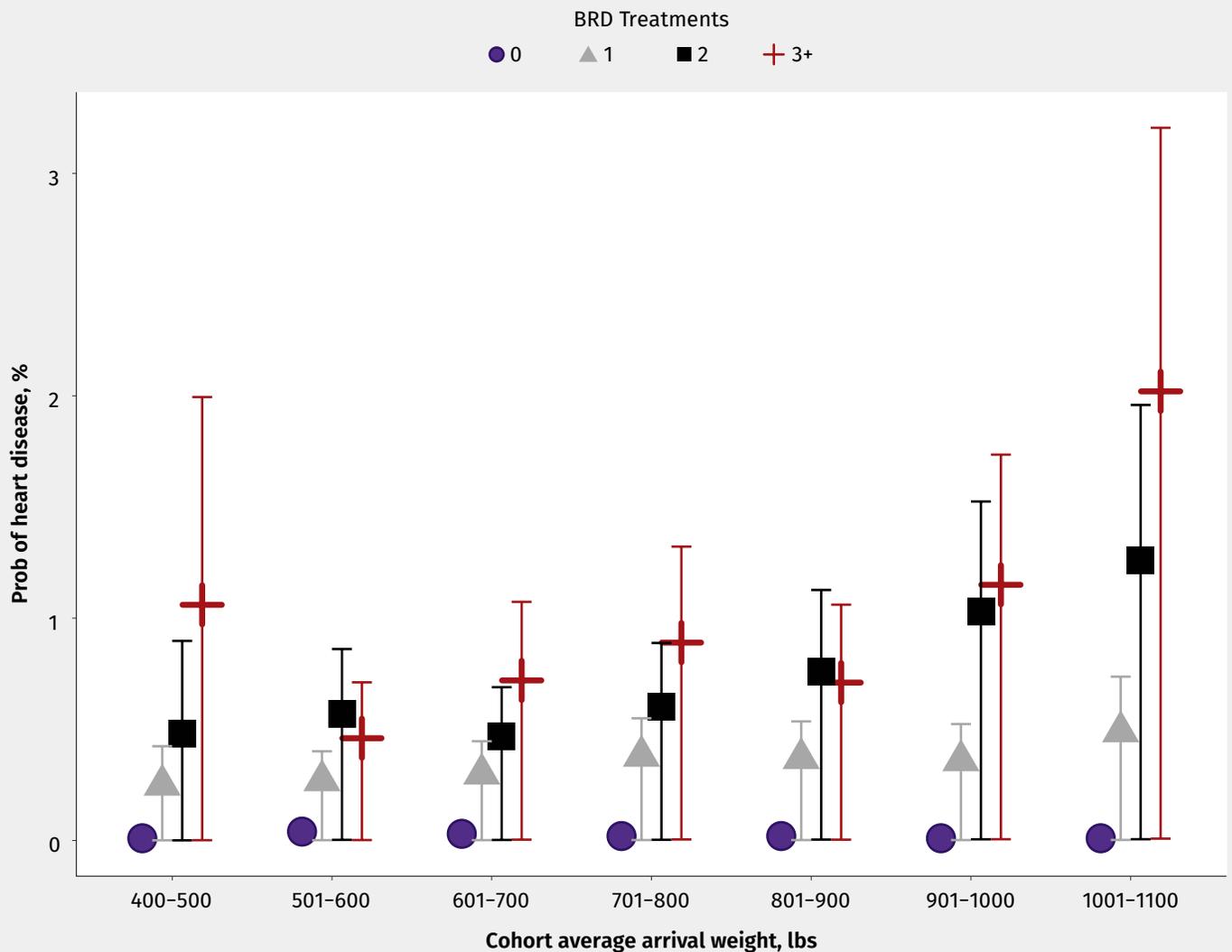
Finally, sex by feedlot elevation category interaction was associated with not finishing the feeding period due to HD ($P < 0.01$). There were numerically different estimated probabilities influenced by feedlot elevation but were not different between sex and feedlot elevation.

Discussion

Previous data reported that HD in feedlot cattle was 4 in 10,000 cattle and 7 to 8 in 10,000 cattle received.^{3,2} The current study found 15 in 10,000 cattle were railed or died due to HD. To the authors knowledge, this is the first study to include railed cattle in terminal diagnosis for HD. Previous studies only reported cattle diagnosed with HD at necropsy. Over the four-year period, the number of cattle that died due to HD were found to be 6.4 in 10,000 cattle received. The number of cattle railed due to HD diagnosis was approximately 9 in 10,000 cattle received. These data indicate that HD is being identified regularly with over half of the total disease cases railed prior to death. However, confirmation of true disease remains ambiguous. Case definitions varied greatly from yard to yard as in previous literature.² Data generated from the current study gives a more comprehensive industry prevalence of HD. Heart disease varied greatly from year to year in prevalence. Many factors could have played a role in the variation seen from year to year such as cattle type, market demand, and environmental factors; most of which were not able to be accounted for in the current study and could potentially contribute to confounding.¹²

Bovine respiratory disease remains the most common disease treated for in feedlot cattle.¹ Neary et al., 2016 reported cattle treated for BRD had a 2.52 to 3.14 times odds of developing right heart failure when controlling for the likelihood of death from digestive disorders, year of placement, risk of BRD/UF (undifferentiated fever), age and sex in 10 Canadian and 5 U.S. feedlots compared to cattle never treated for BRD/UF. Authors hypothesized cattle were misidentified at treatment due to similar

Figure 2: Model-estimated probabilities plus one SE for heart disease by cohort arrival weight (lbs) modified by number of times treated for bovine respiratory disease. Legend shows mutually exclusive BRD treatment categories as: circle(purple) is “0 or no treatments”, triangle (grey) = “one treatment”, square(black) = “two treatments”, plus-sign(red) = “three or more treatments”. Estimates are adjusted for cohort arrival quarter, cohort sex, and feedlot elevation with random intercepts of cohort within yard and cohort arrival year.

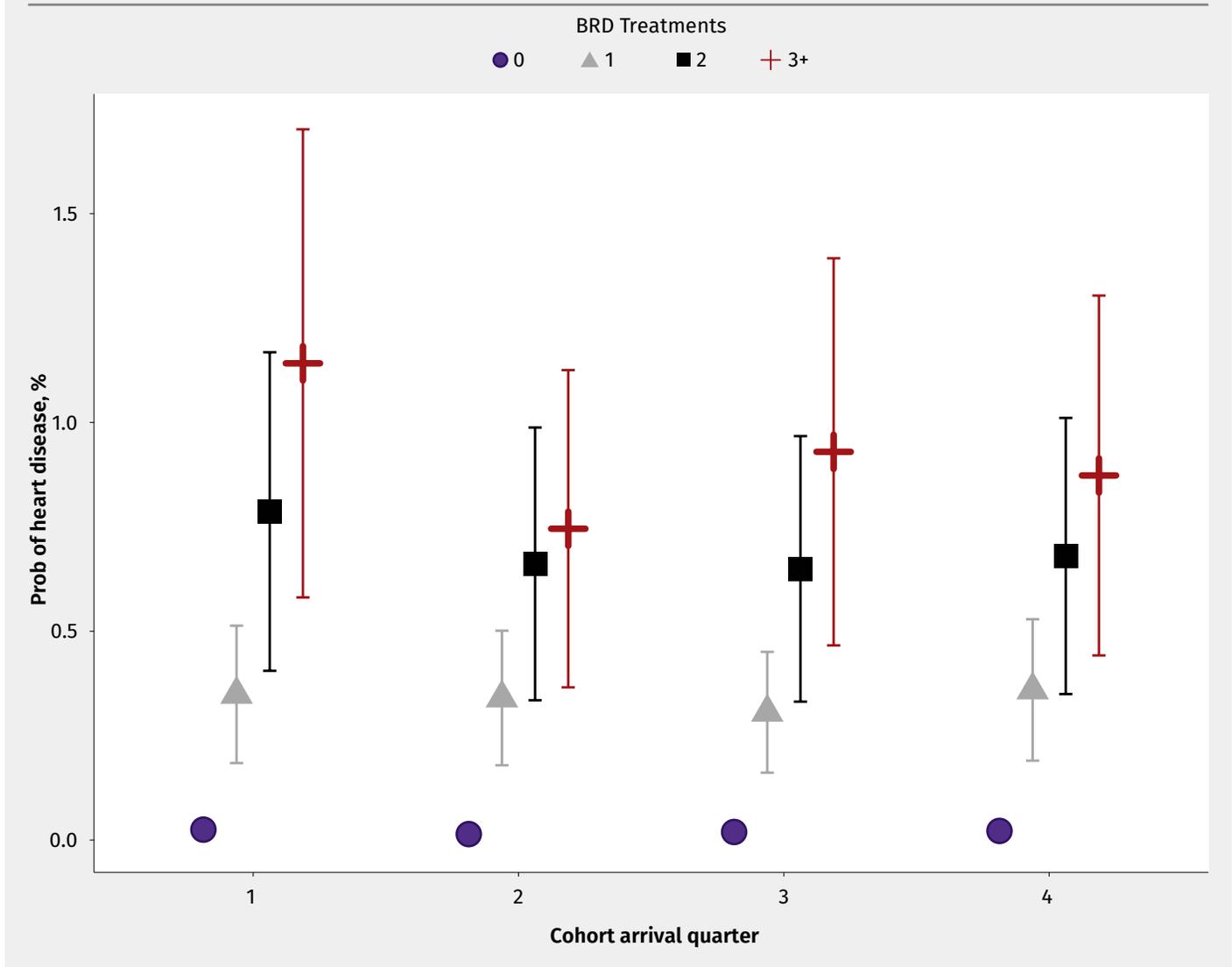


clinical signs of disease (BRD and HD). Cattle pulled for BRD exhibit clinical signs of disease such as depression, labored breathing/respiratory issues, and anorexia.¹³ Likewise, cattle with HD have been described in detail as in respiratory distress, open-mouthed breathing, abducted elbows, sunken eyes, off feed, brisket edema, swayed back and distended abdomen.¹⁴ There is potential for misclassification of disease, especially early in the disease process. Accuracy of BRD identification remains a major obstacle for feeding operations.¹⁵ Prevalence of BRD morbidity is far greater than HD in the findings of the current study (BRD = 7.55% of cattle received, HD = 0.11% of cattle received). USDA 2011 reported 16.2% of cattle placed were affected by shipping fever (BRD) throughout a wide range in different regions. The difference in prevalence between diseases make cattle more likely to have experienced BRD during the feeding phase compared to HD. In addition, BRD has abundant therapeutic options for treatment and prevention with average cost of therapy close to \$24 per animal (USDA, 2011). Whereas therapeutic options for cattle with HD are limited and likely

result in railing the animal earlier in the feeding phase for salvage value, unless in the advanced clinical stages with euthanasia being the only humane option.

The role of elevation’s influence with BRD on HD has not been previously described. Interestingly, risk of HD seems to increase with additional BRD treatments suggesting that cattle could be misclassified (incorrectly identified for a particular disease). Brisket or “high mountain” disease has been documented and well-established.^{3,16-18} Cattle in higher elevations are more susceptible to brisket disease due to low oxygen saturation and the cattle’s poor lung capacity to body size ratio.¹⁸ Cattle with compromised cardiovascular/pulmonary systems at higher elevations could be more prone to pulmonary hypertension. This can lead to restricted blood flow and cardiac overload in the right heart leading either to successful compensation or the animal will succumb to disease. The current study included feedlot elevation in the modeling process. However, all feedlots in the current study would be deemed to be in low-to-moderate elevations (< 5,280 ft (1600 m)).¹⁹ Other

Figure 3: Model-estimated probabilities plus one SE of developing heart disease influenced by BRD treatment categories. Legend shows mutually exclusive BRD treatment categories as: circle (purple) is “0 or no treatments”, triangle (grey) = “one treatment”, square (black) = “two treatments”, plus-sign (red) = “three or more treatments”. Estimates are adjusted for average cohort arrival weight (lbs.), cohort sex, and feedlot elevation. Model also included random intercepts for cohort within yard, yard, and cohort arrival year.



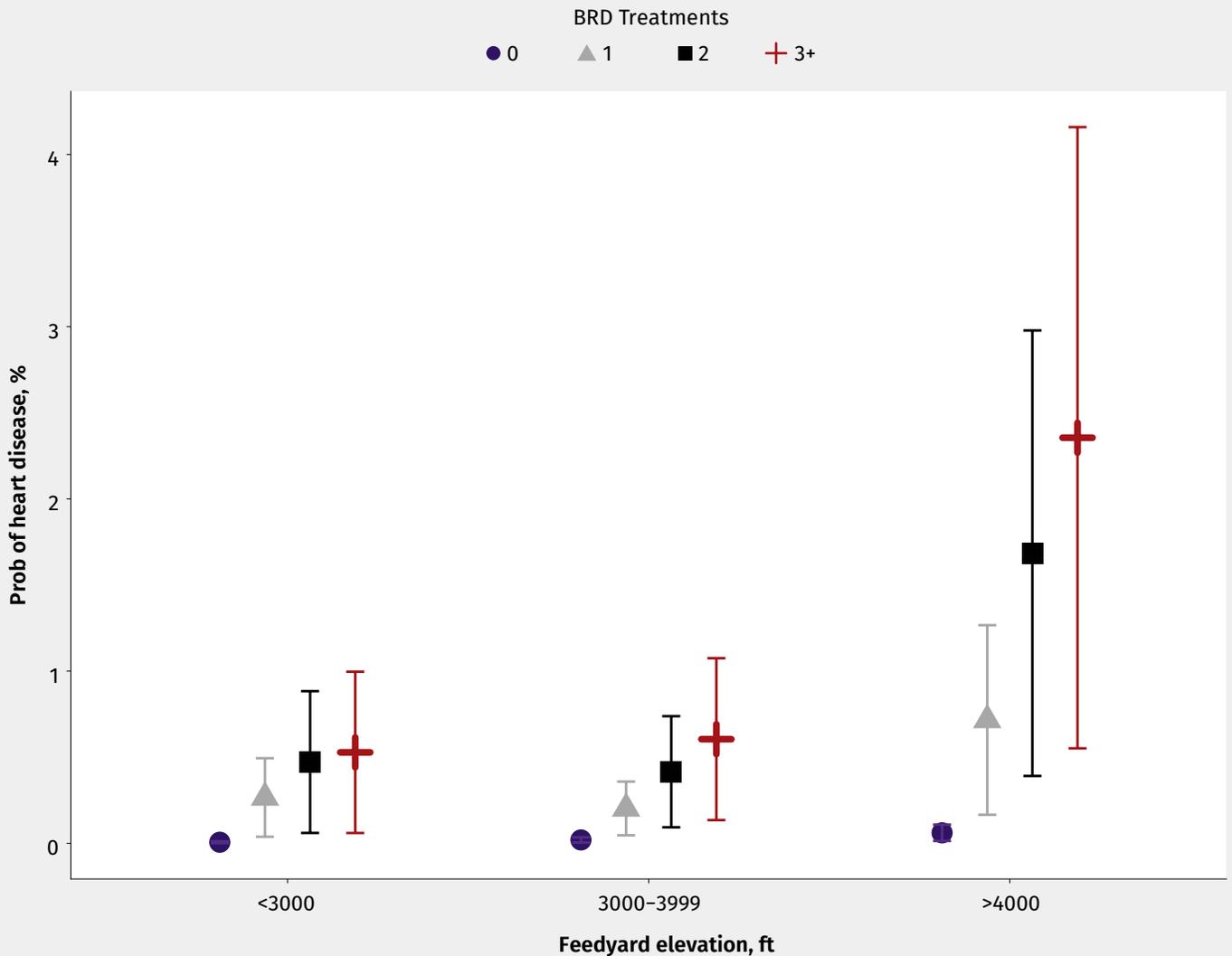
reports have shown increasing prevalence of RHF in fed cattle at moderate elevations.^{3,20} Prior cattle placement elevation could potentially add more value to the model. However, due to the limitations of data, the current study was limited to known information of feedlot location for elevation. Cattle fed at higher elevations could have been sourced from higher or similar elevations (> 5,280 ft (1600 m)). Cattle from higher elevations have been previously described of having a higher risk of HD development.¹⁹ To the author’s knowledge, elevation and BRD categories have not been used as a predictor for associating probability of HD in cattle. The current findings support anecdotal speculations of HD at greater prevalence in higher elevations. However, in cattle never treated for BRD there is no difference between elevation categories for risk of HD.

Cattle placed at heavier weights and treated multiple times for BRD were at an increased probability of not finishing the feeding period due to HD diagnosis. Previous research found risk of HD was found to be similar across weight groups of

received cattle.² However, BRD was not controlled for in the previous modeling process. The current study further supports an assumption for HD being very low in disease prevalence (compared to BRD, GI and AIP) and appears to be consistent throughout the feeding period of feedlot production, especially in cattle not treated for BRD. Other research reported mixed results that varied based on classification at arrival. Yearling cattle placed in Canadian feedlots had 60% the risk of RHF compared to calves, and 138% the risk compared to calves in U.S. feedlots.³

There is lack of published knowledge describing cattle with multiple disease treatments in U.S. feedlots. In the current study, cattle treated for at least 2 different diseases (complex disease treatment) had numerically higher model-estimated probabilities of not finishing the feeding period due to a HD diagnosis compared to most other disease categories, apart from cattle treated for HD. The most prevalent disease in fed cattle is BRD.²¹ Bovine respiratory disease treatment carries

Figure 4: Model-estimated probabilities plus one SE for heart disease by elevation category (ft) influenced by bovine respiratory disease treatment category. Legend shows mutually exclusive BRD treatment categories as: circle(purple) is “0 or no treatments”, triangle (grey) = “one treatment”, square(black) = “two treatments”, plus-sign(red) = “three or more treatments”. Estimate are adjusted for average cohort arrival weight (lbs.), cohort arrival quarter, and cohort sex. Model included random intercepts to account for data clustering for feedlot, cohort within feedlot and cohort arrival year.



an average first treatment success between 75 to 80%,²² whereas cattle failing their first BRD treatment require additional therapy. Cattle that are diseased earlier on in the feeding period could have a higher risk for future disease development. Furthermore, an insult to the respiratory system and vasculature could increase the workload on the heart which could increase the risk of future HD. One possibility is that BRD can lead to HD. The other possibility is that cattle were misclassified as BRD when they were in early HD. Due to the nature of the study, it is impossible to decipher if one disease caused another or predisposed the animal to other diseases. The need for further research on relationships of cattle treated for BRD and their risk of subsequent disease development is warranted, as well as cattle treated for complex diseases on potentially being misclassified for disease therapy. This would help better identify and diagnose cattle for more appropriate management decisions.

Limitations

Data from the current study showed a wide variation from year to year on the distribution of health events. Differences in health outcomes can be attributed to many things, in particular management decisions.¹² In observational data, differentiation between cause and event cannot be explicitly determined.¹⁰ Additionally, observational studies run a higher risk to systematic error.^{12,23} For the current study, inclusion criteria and case definitions were set in place prior to the study to help address some of the systematic bias. Overall, one should exercise caution drawing conclusions and extrapolating findings to cattle populations outside of the selected study parameters.

Conclusions

The current study found that cattle removed from feeding phase due to HD diagnosis was 15 per 10,000 cattle received over a four-year period. Railed cattle accounted for

Table 1: Descriptive of 14 U.S. commercial feedlots of cattle treated for Bovine Respiratory Disease and terminal diagnosis of heart disease.

Elevation category	Year	Cattle	Steers	Heifers	HD deaths*	HD rails†	HD and BRD cat‡	HD and BRD cat	HD and BRD cat§	HD and BRD cat¶
							0, %	1, %	2, %	3+, %
< 3,000	2017	22,884	47%	53%	11	0	0.01	0.28	0.70	0.00
3,000-3,999	2017	17,455	69%	31%	11	29	0.07	0.49	1.16	1.88
> 4,000	2017	78,759	62%	38%	108	225	0.23	2.18	3.48	5.75
< 3,000	2018	242,081	79%	21%	96	0	0.02	0.39	0.52	0.09
3,000-3,999	2018	406,370	55%	45%	183	416	0.09	0.52	1.04	1.10
> 4,000	2018	162,264	59%	41%	222	329	0.18	1.93	3.22	5.40
< 3,000	2019	355,542	60%	40%	87	1	0.01	0.33	0.37	0.61
3,000-3,999	2019	491,546	69%	31%	222	355	0.06	0.63	1.12	1.43
> 4,000	2019	203,573	78%	22%	306	402	0.19	1.65	3.70	4.07
< 3,000	2020	133,486	75%	25%	41	3	0.01	0.42	0.79	2.08
3,000-3,999	2020	182,688	77%	23%	78	169	0.07	1.03	1.40	1.42
> 4,000	2020	83,517	71%	29%	161	201	0.24	1.67	3.48	4.73

Footnotes:

*HD Deaths = Deaths diagnosed as heart disease

†HD Rails = Rails diagnosed as heart disease

‡HD and BRD Cat 0= heart disease terminal diagnosis and never treated for Bovine Respiratory Disease, expressed as percent of cattle that had terminal diagnosis of heart disease out of number of cattle with 0 BRD treatments.

||HD and BRD Cat 1= heart disease terminal diagnosis and previously treated for Bovine Respiratory Disease 1x, expressed as percent of cattle that had terminal diagnosis of heart disease out of number of cattle with 1 BRD treatment.

§HD and BRD Cat 2= heart disease terminal diagnosis and previously treated for Bovine Respiratory Disease 2x, expressed as percent of cattle that had terminal diagnosis of heart disease out of number of cattle with 2 BRD treatments.

¶||HD and BRD Cat 3+= heart disease terminal diagnosis and previously treated for Bovine Respiratory Disease 3 or more times, expressed as percent of cattle that had terminal diagnosis of heart disease out of number of cattle with 3 or more BRD treatments.

approximately 9 of the 15 HD diagnosed per 10,000 cattle and deaths accounted for 6 per 10,000 of the 15 diagnosed per 10,000 cattle. Heart disease would generally be considered relatively low risk compared to common feedlot disease such as BRD (16% morbidity risk or 16 per 100 cattle). The association of the number of BRD treatments with an individual's probability of HD was influenced by average cohort arrival weight, arrival quarter, sex and feedlot elevation on the individual risk of HD. In general, cattle treated 2 or more times increased their probability of not finishing their respective feeding period due to HD, and risk was further increased by heavier average cohort arrival weights. Cattle treated for multiple diseases throughout the feeding period had a greater probability of not finishing due to HD. This effect was influenced by feedlot elevation and average cohort arrival weight. The risk of HD was relatively low and consistent in cattle not treated for BRD or any feedlot disease regardless of their average cohort placement weight, quarter, sex or feedlot elevation.

Conflicts of interest

Authors report no conflicts of interest.

Contribution

All authors contributed to the design, analysis and writing of the current study.

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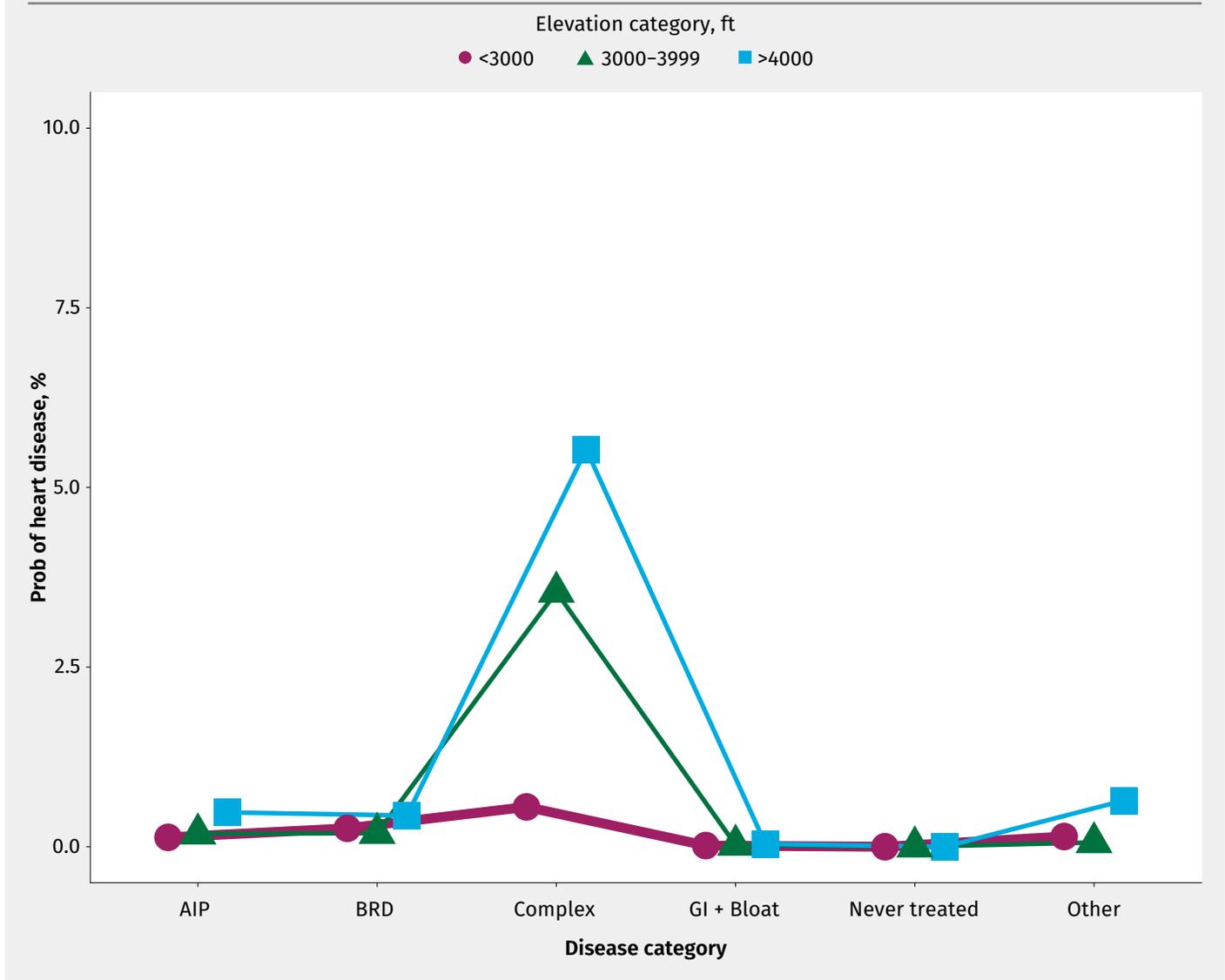
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Table 2: Data of 14 U.S. commercial feedlots showing counts of deaths and rails of cattle treated for disease and partitioned by arrival year and feedlot elevation. Each category is mutually exclusive. Cattle not treated which died or railed were not represent.

Elevation	Year	Cattle	Deaths	Rails	Treatments														
					None [†]		AIP [‡]		BRD		HD [*]		Complex [§]		GI+Bloat [¶]		Other [*]		
					Rails	Deaths	Rails	Deaths	Rails	Deaths	Rails	Deaths	Rails	Deaths	Rails	Deaths	Rails	Deaths	
<3000	2017	22,884	674	0	8	0	11	0	569	0	0	0	0	0	42	0	4	0	40
3000-3999	2017	17,455	462	258	2	0	1	117	393	8	3	64	40	5	10	61	13		
>4000	2017	78,759	704	731	4	18	30	115	378	96	15	232	163	18	5	248	109		
<3000	2018	242,081	3230	500	0	47	0	28	2069	0	0	55	134	12	59	427	893		
3000-3999	2018	406,370	5330	3119	46	105	0	5	4228	262	60	576	369	36	89	1005	474		
>4000	2018	162,264	1178	975	10	9	13	28	662	116	31	224	196	22	40	370	212		
<3000	2019	355,542	3370	980	2	36	0	23	2355	0	1	399	330	8	62	511	563		
3000-3999	2019	491,546	4828	3862	90	82	1	1	3619	225	60	635	434	57	113	1308	519		
>4000	2019	203,573	1738	1175	3	20	13	62	920	165	74	331	304	26	31	390	327		
<3000	2020	133,486	1040	370	1	13	1	29	686	0	0	139	103	3	21	213	188		
3000-3999	2020	182,688	1625	1361	15	14	4	4	1203	96	21	183	111	25	47	479	225		
>4000	2020	83,517	851	528	1	6	11	23	432	60	39	131	155	15	22	212	174		
Totals	2,380,165	25,030	13,859	175	346	61	245	4,175	17,514	1,028	2,969	2,381	227	503	5,224	3,737			

* HD = Heart Disease
[†] None = Cattle not treated for any disease
[‡] AIP = Acute or Atypical Interstitial Pneumonia,
^{||} BRD = Bovine Respiratory Disease,
[§] Complex = Cattle treated for more than one of the disease categories,
[¶] GI+Bloat = Cattle treated for gastrointestinal disease or bloat,
^{*} Other = Cattle treated for any other disease not fitting any of the above categories.

Figure 5: Model-estimated probabilities of developing heart disease by feedlot treatment category influenced by feedlot elevation. Legend shows circle(red) as “< 3,000 ft”, triangle(green) as “3,000 ft to 3,999 ft” and square(blue) as “> 4,000 ft”. Estimates are adjusted for average cohort arrival weight (lbs.), sex and include random intercepts for feedlot and cohort within feedlot, and cohort arrival year.



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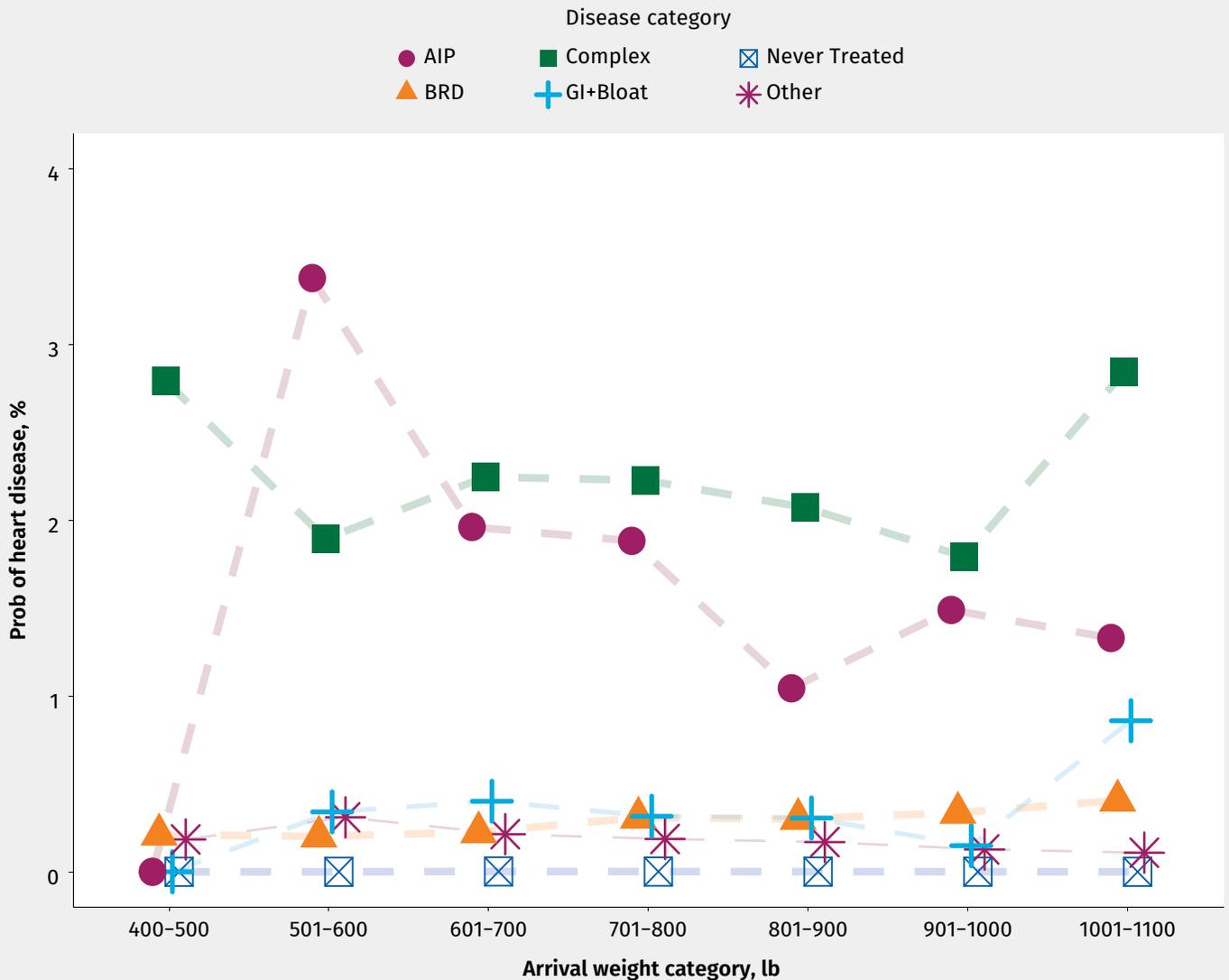
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Figure 6: Model-estimated probability of developing heart disease by average cohort arrival weight category influenced by feedlot disease treatment. Legend shows mutually exclusive disease categories being circle (red) as AIP (atypical/acute interstitial pneumonia), square (green) as Complex (cattle are treated for at least two different feedlot disease categories, cattle may have been treated multiple times), square with cross (light blue) as “cattle that were never treated for a disease”, Triangle (gold) as BRD (Bovine Respiratory Disease, cattle may have been treated more than once for BRD in this category), plus-sign (turquoise) as “GI + Bloat” (cattle treated for any gastrointestinal disease and /or bloat, may have been treated more than once within this category), Asterix (pink) as “Other” cattle which were treated for any disease not lumped into the previous categories (excluding heart disease). Heart Disease was excluded from the visual due to its high probability of animals being removed and skewing the visual. Estimates are averaged over elevation categories, sex and include random intercepts for feedlot, cohort within feedlot, and cohort arrival year.



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