Associations between pen management characteristics and bovine respiratory disease incidence in the first 45 days post-arrival in feedlot cattle

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Abstract

The purpose of this study was to utilize retrospective commercial feedlot data to evaluate the potential associations between pen housing management factors and first treatment BRD incidence during the first 45 days on feed (DOF). Our study population included 1,733 cohorts of feedlot cattle representing 188,188 total animals from 2018 to 2020. Our explanatory variables of interest in this study were pen area per animal and bunk space per animal. These variables were categorized as either having below, adequate, or above recommended pen area/bunk space per animal-based guidelines from the central United States. Our data were analyzed with a generalized linear mixed model utilizing a binomial link function. Results demonstrated that pen housing management factors were significantly ($P < 0.05$) associated with BRD incidence in the first 45 DOF, but their effects were modified by relevant cattle demographic factors (cohort size at arrival, average arrival weight, sex, and quarter of arrival). For example, cohorts with an average arrival weight between 900 to 1,000 lb. (409 to 453 kg) had a higher probability of BRD incidence in the first 45 DOF when provided below recommended pen area per head compared to similar weighted cohorts that had adequate, or above, recommended pen area per head. Our results from this study identify potential situations where pen housing management factors, combined with cattle demographics, may impact the risk of BRD in feedlot cattle. Further defining these situations may allow feedlot managers to utilize these estimates to manage feedlot cattle health more effectively.

Key words: Bovine respiratory disease, feedlot, bunk space, pen space

Introduction

Bovine respiratory disease (BRD) is the most common disease that contributes to morbidity and mortality in feedlot cattle.[1] In addition, the average antimicrobial treatment cost for a single case of BRD has increased from $12.59 to $23.60 between 1999-2013.[2] Annual costs for BRD were estimated to be greater than $500 million per year which includes costs of treatment and loss of production from the disease.[3] Management practices attempting to control BRD morbidity in feedlot cattle may be difficult as the disease etiology is multifactorial resulting from several host-, environment- and pathogen-level factors. Several risk factors are associated with increased BRD risk including transport, commingling, body weight, weather, sex and more.[4–8] Knowledge gaps remain regarding potential associations with housing factors that could influence BRD incidence risk in feedlot cattle. Factors related to pen-level feedlot cattle housing conditions such as pen area per head and bunk space per head have been sparsely investigated. A recent Australian report evaluated the effects of several pen housing factors and their associations with BRD incidence.[9] However, the report did not look at the potential interactions between pen housing conditions and other factors that have been identified as risk factors towards BRD incidence.

The objective of this study was to evaluate the potential associations between pen housing management factors (pen area per head and bunk space per head), cattle attributes and BRD incidence in the first 45 days on feed (DOF) utilizing retrospective data collected from commercial feedlot operations. Quantifying the effects of housing parameters relative to BRD incidence may be useful as it may allow feedlot managers to calculate potential cost-benefits and modify their current management techniques. For example, if pen area per head is associated with increased BRD incidence, managers could estimate the cost of increasing/decreasing the pen area available to cattle on operational efficiency compared to the expected benefit of BRD reduction. Sparse information exists in the ideal categories of pen and bunk space per head; therefore, this paper will evaluate based on categories modified from recommendations. Our goal was to find information regarding pen housing management factors that would fill important knowledge gaps and enhance understanding of management strategies that can be utilized by commercial feedlot operations to reduce BRD incidence.

Materials and methods

Animal Care and Use Committee approval was not obtained for this study due to obtaining retrospective data from preexisting commercial feedlot data.

Retrospective data from 10 central United States feedlots between 2018 and 2020 were collected for this study. Feedlots included in the study represented typical central U.S feeding facilities with open air, dirt floor facilities with in-line bunks along one side of the pen. The shape and specific configuration of pens varied within and between feedyards. These data included information routinely collected at the cohort and individual animal levels. As some lots were made up of cattle housed in multiple physical pens, a variable representing a lot-pen ID was created and a cohort was defined as animals managed at this lot-pen level to monitor cattle movement throughout the study period accurately. Cohorts in the dataset that were not able to create a lot-pen ID were treated as missing data and were removed from the analysis. Data available at the cohort level represented cattle demographic characteristics which included sex, quarter of arrival date, average arrival weight and cohort size at arrival (Table 1). Individual animal data contained information on BRD-specific treatment events and was joined to cohort-level data using the lot-pen ID and yard ID where the BRD-related treatment occurred. BRD incidence in the first 45 DOF, our outcome, was defined as the total number of cattle that were treated at least once for BRD based on feedlot diagnosis within the first 45 DOF. The case definition for a BRD treatment was any animal that received an antimicrobial treatment for BRD during the first 45 DOF. Cases were limited to first treatments only, and any additional treatments were excluded from analysis. If an animal was treated more than once, the first treatment record was utilized. As cattle within a cohort could be moved between pens, the DOF for cohorts in each distinct pen were calculated. To effectively determine the pen cattle were housed in when treated for BRD, we limited our study population to cohorts that were only housed in 2 or fewer pens within the first 45 DOF. If a cohort was housed in one pen for the entirety of the 45 DOF period, then the dimensions of the one pen were used for analysis. If a cohort was housed in 2 pens during the 45 DOF period, then the dimensions of the second pen were used for analysis, but only when the cohort was limited to < 7 DOF in the first pen. If a cohort was housed in the initial pen past 7 DOF this cohort was excluded from the analysis. Any cohorts that were moved between 3 or more pens during the first 45 DOF were excluded from analysis.

The dataset was refined to remove potentially sparse data and enhance external validity. Cohorts that contained at least 25 animals at arrival were included in the analysis. The mean average arrival weight was confined to cohorts that weighed between 500-1,000 lb. (227-453 kg) as this weight range contained sufficient data for analysis. To avoid violating the assumption of linearity, total cohort size at arrival (25-99, 100-175, > 175) and average arrival weight (500-599 lb. (227-272 kg), 600-699 lb. (273-318 kg), 700-799 lb. (319-363 kg), 800-899 lb. (364-408 kg), 900-1,000 lb. (409-453 kg)) were categorized similarly to previous literature.[6] Heifers, steers, and mixed-sex cohorts were included in the dataset. Arrival dates were included and were categorized into quartiles based on the arrival month to determine which quarter of the year the cohort entered the feedlot for cohorts that arrived in January through March (1), April through June (2), July through September (3), and October through December (4). Cohorts with missing or incomplete data for any of these variables and criteria were excluded from the study population.

Collected data were aligned with inclusion criteria, validated, categorized and limited to only those with BRD-specific treatments (Figure 1). Pen housing dimensions related to pen area (ft^2) and bunk space per animal (ft.) were measured for each pen included in our dataset and were tied to each cohort that was present in each pen during the duration of the study period. Dimensions of each pen were measured utilizing online software. A pen area was calculated by multiplying the length of the pen by width of the pen if the shape of the pen was a square or rectangular shape. If the pen had an irregular polygonal structure, then the "polygon tool" was utilized to estimate the area of the pen in square meters. Bunk space was measured linearly by measuring the length of the bunk feeding trough in each pen. These new measurements were added as variables to the dataset and tied to their corresponding pen number so each cohort had the pen dimensions during the first 45 DOF. Pen area available per animal was calculated by dividing pen area (ft^2) by the number of distinct cattle housed in each pen. The cattle count for each pen was based on the number of cattle arriving with the cohort. Pen bunk space available per animal was calculated by dividing the pen bunk space length by the number of cattle housed in each pen.

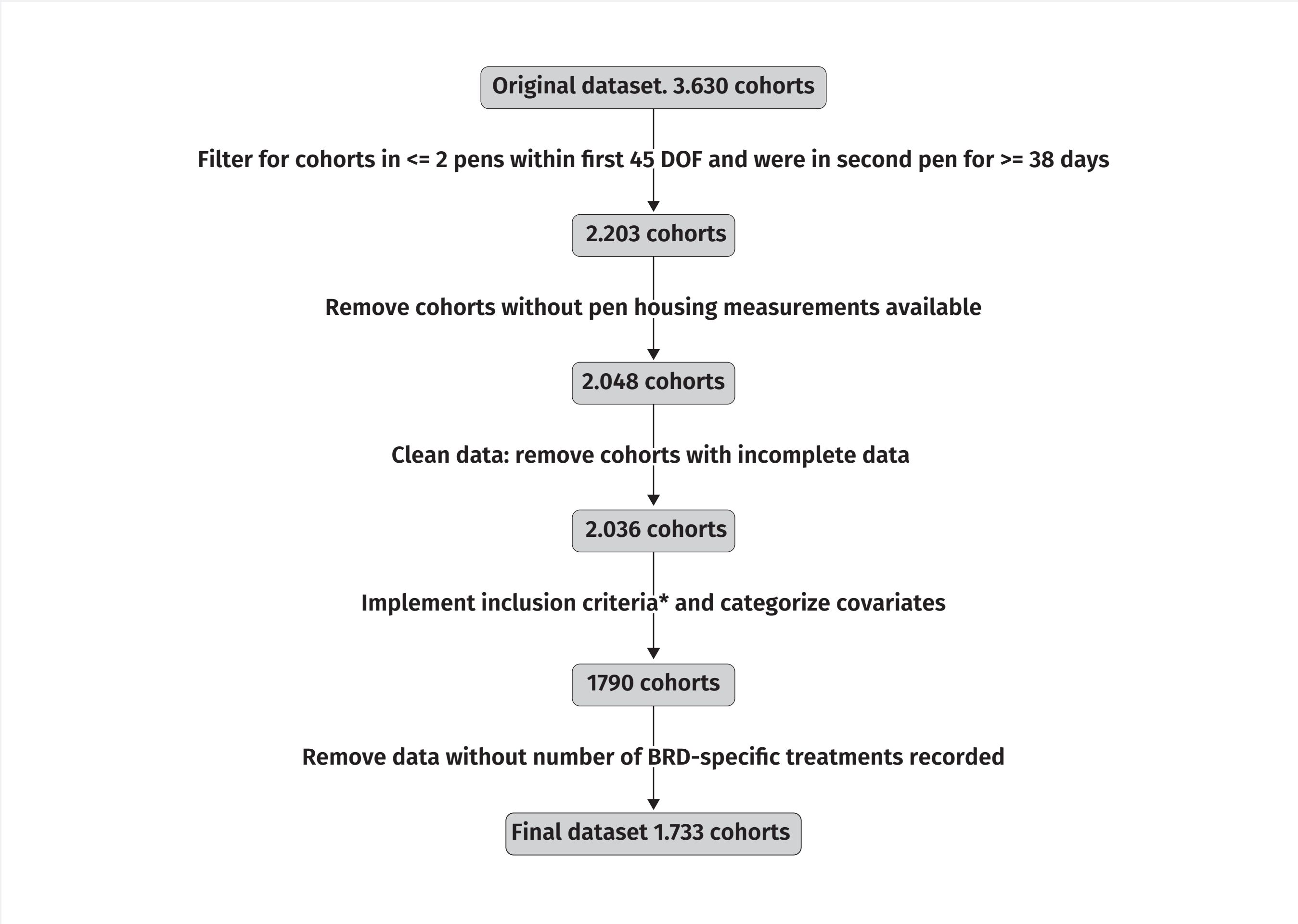
The primary covariates of interest (pen space per animal and bunk space per animal) were categorized based on expected non-linear relationships between these variables and the outcome of interest (BRD incidence within 45 DOF). Recommendations from Kansas State Research and Extension were used to create three categories for both variables of interest.[10] The categories were not based on peer-reviewed research, but rather expert opinion in the Extension bulletin combined with the author's modifications to provide a more equal division of existing data. The first category represented values that were below recommendations, the second category represented values that met the adequate recommendations, and the third category represented values that were above recommendations. The categories for pen area per animal were ≤ 250 ft^2 (≤ 23.22m^2), 251-350 ft^2 (23.23 - 32.52 m^2), and > 350 ft^2 (> 32.52 m^2). The categories for bunk space per animal were ≤ 1 ft. (≤ 0.3 m), 1.01-1.5 ft. (0.31-0.46 m), and > 1.5 ft. (> 0.46 m).

Table 1: Descriptive statistics for the study population cohorts (*n* = 1,733) from 10 US feedlots.

Variable	Mean	SD†	Median	Range	Interquartile range
Cohort size at arrival	108.55	54.73	89	25 to 324	65 to 142
Average arrival weight, lb	760.50	244.16	762.99	503.00 to 1,000	693.99 to 832.00
Area per animal, ft^2	308.27	181.69	265.65	51.34 to 2,685.28	218.72 to 333.89
BRD incidence*, %	6.36	8.93	3.22	0 – 74.07	1.28 – 7.69

* First treatment bovine respiratory disease (BRD) incidence was our outcome variable and was calculated only for the initial 45 days on feed
† SD = Standard deviation

Figure 1: Flowchart of inclusion/ exclusion criteria process for removal of cohorts and construction of the final dataset from the original dataset from 10 U.S. feedlots. *Inclusion criteria included: cohort size restricted to >= 25 animal; only include cattle between 500-1,000 lbs; include heifer, steer and mixed cohorts.



The data originated from a retrospective dataset provided from several commercial feedlot operations. As a result, vaccination programs from each operation were unavailable for this analysis. In addition, variables such as the distance cattle traveled to the feedlot, preconditioning status, and dietary profile were also unavailable for inclusion in the analysis.

Statistical methods

A generalized linear mixed-model was fitted with the "lme4: package[11] in a statistical software packageb to assess potential associations of pen housing factors with BRD within the first 45 DOF. The outcome variable of interest was BRD incidence in the first 45 DOF and was calculated as the total number of first BRD treatments in the first 45 DOF (events)/total animals in the pen (trials). Covariates included average arrival weight, cohort size at arrival, arrival date quarter, sex, area per animal and bunk space per animal (Table 2). Several interaction terms were incorporated based on previous research which included sex with average arrival weight, average arrival weight with arrival date quarter, area per animal with sex, arrival weight, cohort size at arrival, and arrival date quarter, bunk space per animal with sex, average arrival weight, total animals received and arrival date quarter.[6,12,13] Random intercepts for feedlot and arrival year were included to account for the hierarchical structure of the data. Variables that have been previously determined to be associated with BRD (quarter of arrival, arrival weight, sex, cohort size at arrival) were retained in the model regardless of statistical significance. Remaining variables (including interactions) were retained only if they were significantly associated ($P < 0.05$) with the outcome or were part of a significant interaction term. All main effects were included regardless of significance if they were part of a significant ($P < 0.05$) interaction. Statistical models generated model-estimated probabilities which were transformed (multiplied by 100) to percent of the relevant group for presentation of results.

Results

The final dataset used for analysis consisted of 1,733 cohorts representing a study population of 188,118 individual animals over 10 feedlots in two states. There were 11,028 (5.9% of study population) cases of BRD within the 45-day evaluation period, with a mean of 6.3% and a range of 0-74% percent of the cohort treated for BRD. Figure 2 shows the distribution of the total percent of the cohort treated for BRD. The distribution of cohorts in each area per animal and bunk space per animal category are shown in Table 2.

Variables significantly associated ($P < 0.05$) with BRD incidence in the first 45 DOF included sex, cohort size at arrival, average arrival weight, arrival date quarter, area per animal and bunk space per animal (Table 3). All interactions between pen housing characteristics (area per animal, bunk space per animal) and cattle attributes (sex, cohort size at arrival, average arrival weight, arrival date quarter) were significantly associated ($P < 0.05$) with BRD incidence in the first 45 DOF. Model estimated probabilities transformed to percentages and standard error for BRD incidence in first 45 DOF were calculated for all interactions. All interactions included in the model were significantly ($P < 0.05$) associated with BRD incidence in the first 45 DOF (Table 4).

The average arrival weight of the cohort modified the effect of area per animal on BRD incidence in the first 45 DOF (Figure 3). For example, a significant contrast was seen as cohorts with an average arrival weight of 900-1,000 lb. (409 - 453 kg) had a higher probability of BRD incidence (3.6% ± 0.64) if they were placed in pens that had ≤ 250 ft2 (≤ 23.23 m^2) of pen area per animal available compared to the BRD incidence seen in similar weight cattle placed in pens that had 251350 ft2 (23.23 - 32.52 m^2) (2.05% ± 0.39) or > 350 ft^2 (> 32.52 m^2) (2.47% ± 0.47) of pen area per animal available.

Total cohort size at arrival also modified the effect of area per animal on BRD incidence in the first 45 DOF (Figure 4). Cohort sizes with 25-99 or 100-175 showed no differences in the effect of area per animal on BRD incidence. However, the probability of BRD incidence was higher in cohort sizes > 175 animals when given ≤ 250 ft^2 (≤ 23.22 m^2) (4.46% ± 0.83) of pen area per animal compared to similar cohort sizes with 251 - 350 ft^2 (23.23 - 32.52 m^2) pen area per animal (2.83% ± 0.54) or > 350 ft^2 (> 32.52 m^2) (2.40% ± 0.46) pen area per animal available. There was an association between area per

Table 2: Distribution of variables used for analysis from 10 feedlots representing 1,733 cohorts from 2018-2020.

Variable & category	Number (%) of cohorts
Cohort size at arrival	
25-99	946 (54.58)
100-175	537 (30.99)
> 175	250 (14.43)
Average arrival weight, lb.	
500 to 599	131 (7.56)
600 to 699	351 (20.25)
700 to 799	650 (37.51)
800 to 899	455 (26.26)
900 to 1,000	146 (8.42)
Sex	
Heifers	922 (53.20)
Steers	678 (39.12)
Mixed	133 (7.68)
Arrival date quarter	
Jan-March (1)	473 (27.29)
April-June (2)	471 (27.18)
July-September (3)	481 (27.76)
October-December (4)	308 (17.77)
Area available per animal, ft2	
≤ 250	733 (42.30)
251 to 350	540 (31.16)
> 350	460 (26.54)
Bunk space available per animal, ft.	
≤ 1	539 (31.10)
1.01 to 1.5	808 (46.62)
> 1.5	386 (22.28)

Figure 2: Distribution of percent of cohort treated for BRD by percent of cohorts in first 45 DOF that were fed at 10 U.S. feedlots during 2018-2020. BRD treatment criteria consisted of cattle identified as clinically ill by feedlot personnel and treated with an antimicrobial. A total of 1,733 cohorts are represented.

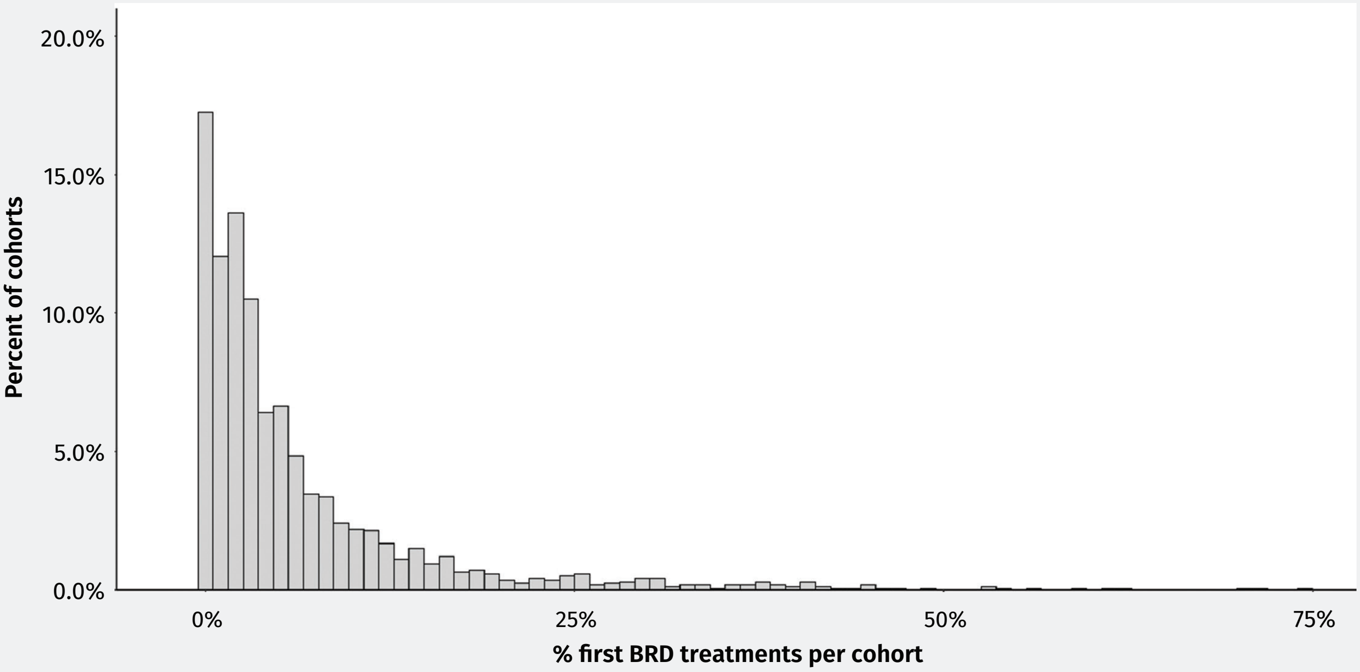


Table 3: Final generalized linear mixed-model demonstrating housing characteristics and cattle demographic factors and their association with bovine respiratory disease incidence during the first 45 DOF in a dataset obtained from 1,733 cohorts from 10 U.S. feedlots between 2018-2020. BRD case definition was cattle identified as clinically ill by feedlot personnel and treated with an antimicrobial.

Variable	*P*-value
Sex	< 0.01
Cohort size at arrival	< 0.01
Average arrival weight	< 0.01
Arrival date quarter	< 0.01
Area per animal	< 0.01
Bunk space per animal	< 0.01
Sex × average arrival weight	< 0.01
Average arrival weight × arrival date quarter	< 0.01
Sex × area per animal	< 0.01
Average arrival weight × area per animal	< 0.01
Cohort size at arrival × area per animal	< 0.01
Arrival date quarter × area per animal	< 0.01
Sex × bunk space per animal	< 0.01
Average arrival weight × bunk space per animal	< 0.01
Cohort size at arrival × bunk space per animal	< 0.01
Arrival date quarter × bunk space per animal	< 0.01

Table 4: Estimated mean probabilities transformed to percentages (%) and corresponding standard error for BRD incidence in first 45 DOF for all significant (P < 0.05) interactions from 1,733 cohorts fed at 10 U.S. feedlots from 2018-2020.

Interaction	Estimated percent	Standard error
Arrival weight, lbs. × area per animal, ft^2		
500 – 599 × ≤ 250	6.46%	1.18
600 – 699 × ≤ 250	9.21%	1.63
700 – 799 × ≤ 250	5.10%	0.94
800 – 899 × ≤ 250	3.04%	0.57
900 - 1,000 × ≤ 250	3.60%	0.64
500 – 599 × 251-350	8.73%	1.55
600 – 699 × 251-350	8.91%	1.58
700 – 799 × 251-350	5.49%	1.01
800 – 899 × 251-350	2.21%	0.42
900 - 1,000 × 251-350	2.05%	0.39
500 - 599 × > 350	7.24%	1.31
600 - 699 × > 350	6.94%	1.26
700 – 799 × > 350	5.54%	1.02
800 – 899 × > 350	2.02%	0.39
900 - 1,000 × >350	2.47%	0.47
Arrival weight, lbs. x bunk space per animal, ft		
500 – 599 × ≤ 1	6.86%	1.24
600 – 699 × ≤ 1	7.92%	1.42
700 – 799 × ≤ 1	5.15%	0.95
800 – 899 × ≤ 1	1.98%	0.38
900 - 1,000 × ≤ 1	1.91%	0.37
500 - 599 × 1.01 - 1.5	8.66%	1.54
600 – 699 × 1.01 - 1.5	7.76%	1.39
700 – 799 × 1.01 - 1.5	5.88%	1.08
800 – 899 × 1.01 - 1.5	2.56%	0.49
900 - 1,000 × 1.01 - 1.5	3.34%	0.63
500 – 599 × > 1.5	6.88%	1.25
600 – 699 × > 1.5	9.29%	1.64
700 – 799 × > 1.5	5.12%	0.95
800 – 899 × > 1.5	2.68%	0.51
900 - 1,000 × > 1.5	2.86%	0.54

Table 4: Continued

Cohort size at arrival × area per animal, ft^2		
25-99 × ≤ 250	6.36%	1.16
100-175 × ≤ 250	4.62%	0.86
> 175 × ≤ 250	4.46%	0.83
25-99 × 251-350	6.50%	1.18
100-175 × 251-350	5.20%	0.96
> 175 × 251-350	2.83%	0.54
25-99 × > 350	6.86%	1.24
100-175 × > 350	4.70%	0.87
> 175 × > 350	2.40%	0.46
Cohort size at arrival × bunk space per animal, ft		
25-99 × ≤ 1	5.88%	1.08
100-175 × ≤ 1	4.24%	0.79
> 175 × ≤ 1	2.66%	0.50
25-99 × 1.01-1.5	7.30%	1.32
100-175 × 1.01-1.5	5.65%	1.04
> 175 × 1.01-1.5	3.20%	0.60
25-99 × > 1.5	6.60%	1.20
100-175 × > 1.5	4.71%	0.87
> 175 × > 1.5	3.57%	0.67
Arrival date quarter × area per animal, ft^2		
Jan-March (1) × ≤ 250	5.15%	0.95
April-June (2) × ≤ 250	4.07%	0.76
July-September (3) × ≤ 250	5.48%	1.01
October-December (4) × ≤ 250	5.81%	1.06
Jan-March (1) × 251-350	3.48%	0.65
April-June (2) × 251-350	4.22%	0.79
July-September (3) × 251-350	4.10%	0.77
October-December (4) × 251-350	7.29%	1.32
Jan-March (1) × > 350	4.39%	0.82
April-June (2) × > 350	4.32%	0.80
July-September (3) × > 350	3.07%	0.58
October-December (4) × > 350	5.75%	1.05

Table 4: Continued

Arrival date quarter x bunk space per animal, ft		
Jan-March (1) × ≤ 1	3.48%	0.65
April-June (2) × ≤ 1	3.88%	0.73
July-September (3) × ≤ 1	3.43%	0.64
October-December (4) × ≤ 1	5.84%	1.07
Jan-March (1) × 1.01-1.5	5.35%	0.98
April-June (2) × 1.01-1.5	4.29%	0.80
July-September (3) × 1.01-1.5	4.60%	0.85
October-December (4) × 1.01-1.5	6.44%	1.17
Jan-March (1) × > 1.5	4.22%	0.79
April-June (2) × > 1.5	4.46%	0.83
July-September (3) × > 1.5	4.40%	0.82
October-December (4) × > 1.5	6.48%	1.18
Sex × area per animal, ft^2		
Heifers × ≤ 250	4.42%	0.82
Steers × ≤ 250	4.87%	0.90
Mixed × ≤ 250	6.09%	1.11
Heifers × 23.23-32.52	3.70%	0.69
Steers × 23.23-32.52	4.48%	0.83
Mixed × 23.23-32.52	5.81%	1.06
Heifers × > 32.52	3.83%	0.72
Steers × > 32.52	4.01%	0.75
Mixed × > 32.52	5.10%	0.94
Sex × bunk space per animal, ft		
Heifers × ≤ 1	3.78%	0.71
Steers × ≤ 1	3.42%	0.64
Mixed × ≤ 1	5.17%	0.95
Heifers × 1.01-1.5	4.01%	0.75
Steers × 1.01-1.5	6.27%	1.14
Mixed × 1.01-1.5	5.28%	0.97
Heifers × > 1.5	4.13%	0.77
Steers × > 1.5	4.07%	0.76
Mixed × > 1.5	6.61%	1.20

Figure 3: Model estimated mean probability of BRD incidence by area per animal and arrival weight category in commercial feedlot cattle during the first 45 DOF fed at 10 U.S. feedlots from 2018-2020. Error bars represent SE of least square means. ft². An asterisk indicates statistical difference ($P < 0.05$) among bars within average arrival weight category.

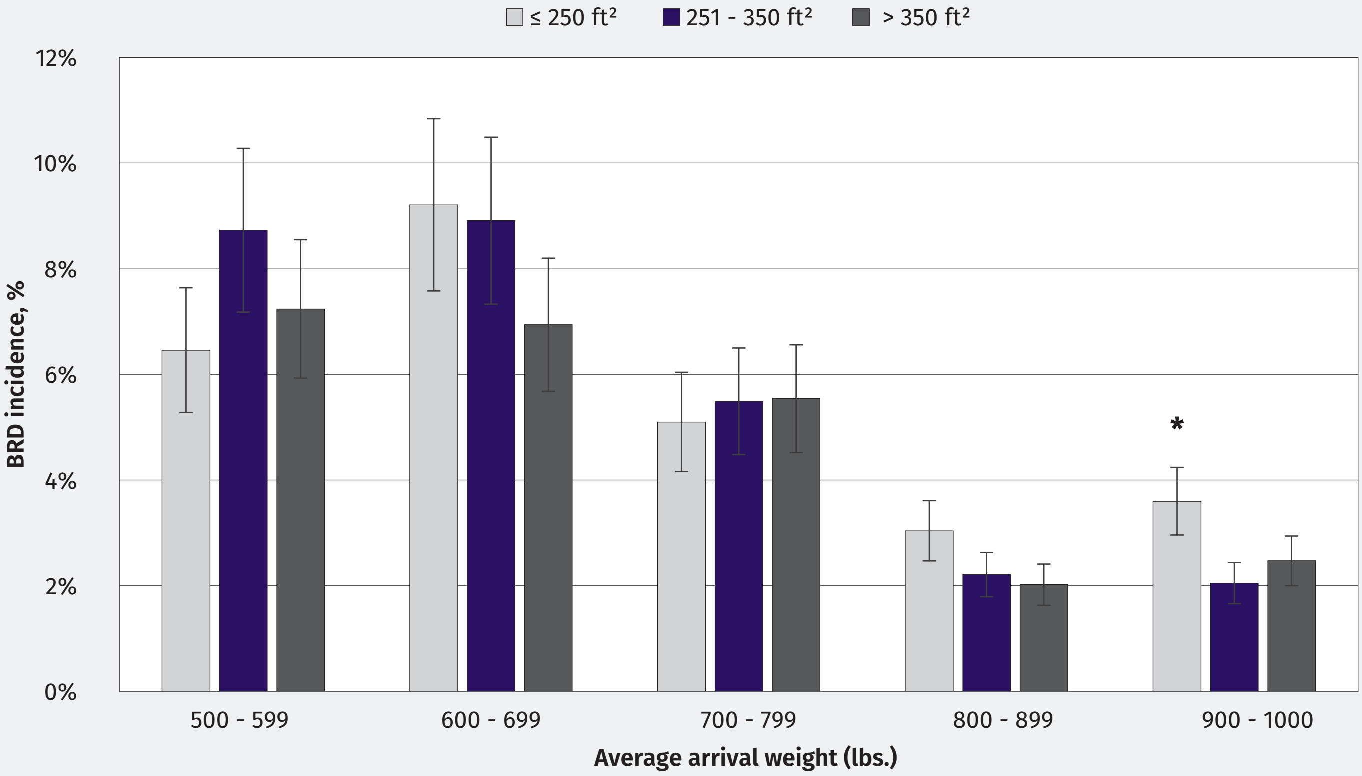
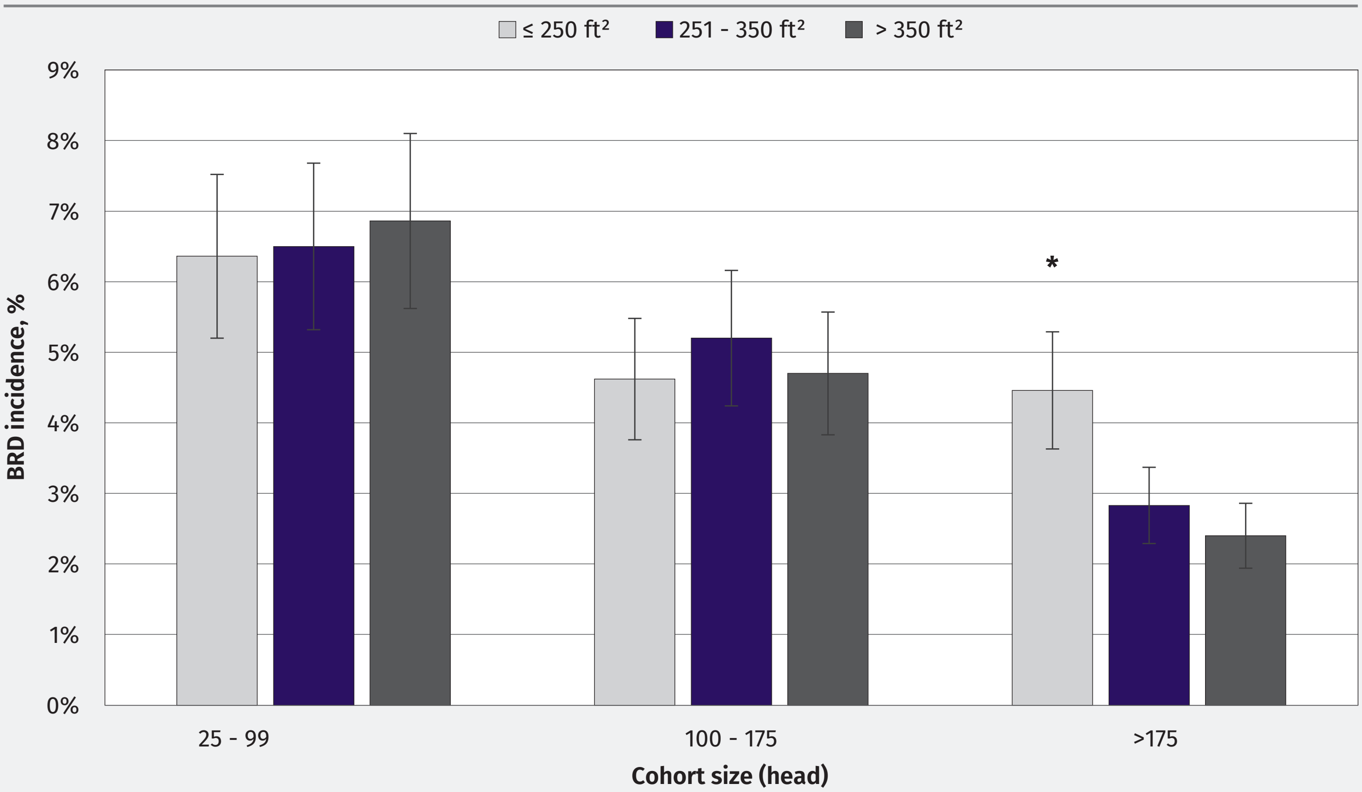


Figure 4: Model estimated mean probability of BRD incidence by area per animal and size of the cohort at arrival in commercial feedlot cattle during the first 45 DOF fed at 10 U.S. feedlots from 2018-2020. Error bars represent SE of least square means. An asterisk indicates statistical difference ($P < 0.05$) among bars within cohort size category.



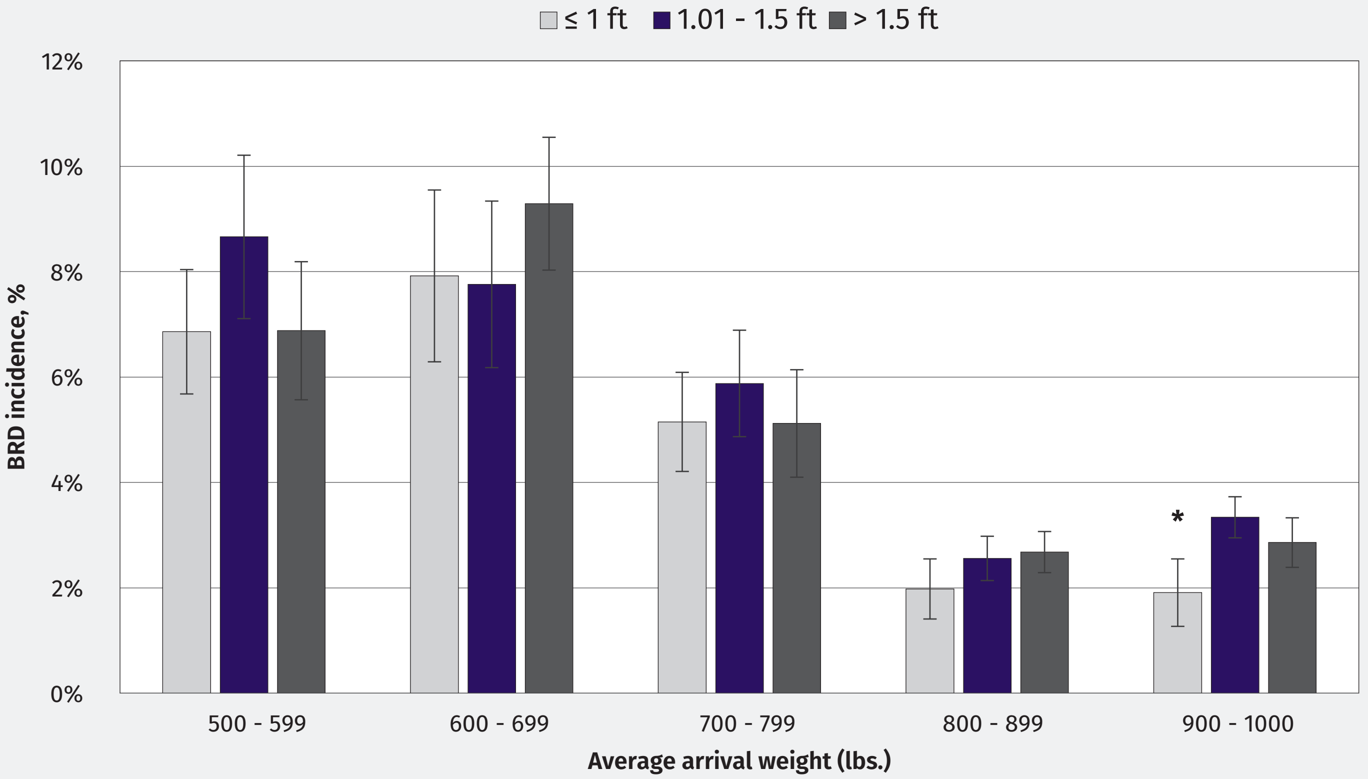
animal and BRD incidence in the first 45 DOF; however, this effect was modified ($P < 0.05$) by both the sex and arrival date quarter of the cohort. Although these two covariates (sex and arrival date quarter) were statistically significant, there was no apparent pattern for their effect on BRD incidence in the first 45 DOF as modified by pen area.

Sex, cohort size at arrival, average arrival weight, and arrival date quarter were significantly associated ($P < 0.05$) with the effect of bunk space per animal on BRD incidence in the first 45 DOF. Average arrival weight was the only covariate that modified the effect of bunk space per animal on BRD incidence (Figure 5). A difference was seen between cohorts with an average arrival weight between 900-1,000 lb. (409 - 453 kg) as cohorts in this weight category had a lower probability of BRD incidence if they were provided ≤ 1 ft. (0.3 m) of bunk space per animal compared to similar weight cattle placed in pens that had 1.01 - 1.5 ft. (0.31 - 0.46 m) or > 1.5 ft. (0.46 m) of bunk space per animal available.

Discussion

This study was conducted to estimate the relationship between feedlot pen-level housing conditions (pen area per head and bunk space per head) and cohort-level probability for BRD incidence within the first 45 DOF. Analysis of this relationship is important to determine the potential associations between pen-level housing conditions and whether changes in these conditions could be used to mitigate BRD cases in feedlot cattle. Previous research investigating this relationship is limited.[5,9] Both studies did not identify associations between variables involving housing conditions related to pen area and bunk space; however, the interactions between housing variables, and other cattle demographic risk factors commonly associated with BRD, were not assessed. Our categories for area per animal and bunk space per animal were classified based on expert opinion and the same categories were not utilized in other studies that investigated pen housing conditions as risk factors. We chose these cutoffs for pen area/bunk space per animal to represent a category for below recommendations, meets adequate and exceeds recommendations according to feedlot guidelines.[10] These categories were modified to represent approximately equal distribution of the data among each category; however, this resulted in differing ranges of space per head in each category. While the central category was deemed "adequate" this should not be interpreted as ideal based on the method of creating the three categories. Additionally, the base information used to create the three categories were from the central U.S. and these values may differ for other regions of the country. This was implemented to improve external validity and evaluate potential differences in BRD incidence in the first 45 DOF between cohorts placed in pens that were below, met, or were above the recommendations for pen area per head and bunk space per head according to published guidelines. Our data encompassed several years from multiple commercial feedlots, and data structure allowed quantification of both effects of pen housing characteristics and interactions that have not been previously described at the cohort-level. Results of this study suggest pen housing factors related to pen area per animal and bunk space per animal are associated with BRD incidence in the first 45 DOF of the feeding period, but this impact is modified by cattle demographics. While several interactions were statistically significant, limited biological significance (or meaningful differences in BRD incidence)

Figure 5: Model estimated mean probability of BRD incidence by bunk space per animal and arrival weight category in commercial feedlot cattle during the first 45 DOF fed at 10 U.S. feedlots from 2018-2020. Error bars represent SE of least square means. An asterisk indicates statistical difference ($P < 0.05$) among bars within average arrival weight category.



were present in some interactions. Our findings are unique and provide novel explanations on how pen housing conditions, combined with cattle demographic factors, may potentially influence animal health.

Previous research reported an association between the number of animals in a cohort and risk of BRD.[6,8] Results from these studies vary on whether smaller or larger sized cohorts were associated with an increase in BRD risk. Our results demonstrated that the effect of cohort size on BRD incidence in the first 45 DOF was influenced by the amount of area per animal (ft^2) provided in each pen. Larger cohort sizes (> 175) were associated with higher BRD incidence in the below recommendations pen area per animal category when compared to smaller cohort sizes given a similar amount of pen area per head. There are several reasons that may explain why larger cohort sizes displayed a higher risk for BRD when given a lower amount of pen area per head. The impact of cohort size on BRD risk may be influenced by additional characteristics that are related to feedlot management and infrastructure. For example, increased commingling may have influenced the effect of cohort size as mixing cattle from different sources into a large-sized cohort may increase stress and leave cattle more prone to infection when having access to less pen area.[14,15] Increased commingling in larger cohort sizes can also increase the transmission of communicable BRD pathogens (Mannheimia haemolytica, Bovine Viral Diarrhea Virus, etc.) that can potentially suppress the host immune system and impact the risk of BRD.[16] The retrospective data we collected did not include sufficient metadata to measure these potentially important factors such as level of commingling that could be related to management and infrastructure and as a result our study could not properly evaluate these additional factors and their effects on cohort size.

The interaction between average arrival weight and pen area per head was significantly associated with BRD incidence in the first 45 DOF. Across all categories of pen area per head and bunk space per head, the probability of BRD incidence was the highest in the lowest arrival weight categories (500 -599 lb. [227kg - 272kg] and 600 - 699 lb. [273kg - 318kg]) and lowest in the highest arrival weight categories (800 - 899 lb. [364kg - 408kg] and 900 - 1,000 lb. [409kg - 453kg]). These findings are consistent with previous research that determined lightweight cattle are more susceptible to BRD compared to heavier cattle.[7,12,17] However, our study results demonstrated that cattle in the heaviest weight category (900 - 1,000 lb. [409 - 453 kg]) had an increased BRD incidence when given less pen area per animal (23.22 ft^2) compared to similar-weighted cattle given more area per animal. This was the only average arrival weight category that displayed a difference in BRD risk across the pen area per head categories. Heavyweight cattle given fewer square feet per animal may be at greater risk of BRD in smaller pen space allocations (< 23.22 ft^2 per animal) because cohorts of heavyweight cattle will have less pen area per animal to utilize compared to a lighter weight animal given the same pen area with equal cohort sizes. Age may also be a correlated with BRD morbidity and can be related to the average arrival weight for cattle arriving to a feedlot.[7] Our data indicated that in heavier weighted cohorts (900 - 1,000 lb. [409 - 453 kg]), the smallest bunk space per animal category (≤ 1 ft. [< 0.3m]) was associated with lower BRD incidence when compared to cohorts in larger bunk space per animal categories (1.01 - 1.5 ft. [0.31m - 0.46m], > 1.5ft. [> 0.46m]). Differences in this heavyweight category could be attributable to cattle age and these animals have likely been started on feed, received vaccinations, and overall be atypical of an animal that would be at an elevated risk of BRD morbidity (lightweight animals). The risk factors evaluated in this study (pen and bunk space) may have only minor impacts only visible when the overall level of BRD is low due to confounding of risk factors of greater magnitude in other classes of cattle.

Previously, feeding behavior related to feeding timing has been investigated as a potential factor that may be associated with BRD morbidity.[18] We hypothesized that, in addition to feeding behavior, the amount of bunk space allocated to cattle may contribute to BRD risk. All interactions between bunk space per animal and the risk factors included in the model were significantly associated with the probability of BRD incidence. However, average arrival weight was the only risk factor that modified the effect of bunk space per animal on BRD incidence in the first 45 DOF. Our data indicated heavier weighted cohorts (900 - 1,000 lb. (409 - 453 kg)) were associated with lower BRD incidence in the smallest bunk space per animal category (≤ 1 ft. (< 0.3m)) when compared to cohorts in larger bunk space per animal categories (1.01 - 1.5 ft. (0.31m-0.46m), > 1.5ft. (> 0.46m)). An important aspect to consider is the retrospective nature of this study and the potential for confounding and bias based on choices made by the feedlot. For example, heavier cattle may have been older and already started on feed as a group, or heavier cattle may have been recently purchased and commingled. The finding that heavier cattle with a smaller bunk space had lower BRD incidence could be explained by the type of cattle placed in this pen configuration. Managers may choose to have a larger bunk space for cattle not acclimated to a feeding program or as a social group. Therefore, the finding related to bunk space may be more related to managerial selection based on calf risk differentiation within cattle of the same weight category, rather than a physical impact of the amount of bunk available. Bunk space per head was only associated with BRD risk in one small subgroup indicating that other factors are likely more important in overall risk of BRD. Results of another study indicate that BRD risk was not different between different bunk space per animal categories.[9] However, our bunk space per animal categories were categorized according to feedlot guidelines, while their categories for bunk space per animal were less than 0.59 ft. (0.18 m) and greater than or equal to 0.59 ft (0.18 m) which are a cutoffs intended for Australian feedlot cattle. We also used three categories based on guidelines from the central United States for our cutoffs, whereas the previous study used two cutoffs which could contribute to the differences in results.

A potential limitation of our study is that it is a retrospective analysis looking at pre-existing observational data. Retrospective studies may be subject to confounding and cannot determine causation, only associations. The results are also confined to the feedlots that were included in the dataset utilized and may not be applicable to feedlots outside of our dataset due to differences in management, dates of data recorded, geography, cattle types, different case definitions for BRD, and many other potential differences. Commercial feedlot data are often inherently “messy” and may contain unknown biases or errors. In addition, the data came from multiple feedlot operations. As a result, vaccination programs from each operation and metaphylaxis status of each cohort were unavailable for this analysis. In addition, other metadata that might have been useful to explore including the distance cattle traveled to the feedyard, risk status and preconditioning status were also unavailable.

The categories used to evaluate the amount of bunk and pen space were subjective and based on expert opinion from one region (central U.S.) rather than peer-reviewed research which means other regions or divisions of these categories could yield differing results. The time frame during which we evaluated BRD treatments was only during the first 45 DOF, so we only incorporated first-pull BRD treatments during the first 45 DOF, and not all total BRD treatments throughout the entire feeding phase. It is possible that some of the risk factors we explored related to BRD incidence are significantly associated with risk of retreatment, risk of becoming a chronic animal, or risk of dying; our analysis did not include those outcomes due to limitations of the dataset. Additional studies will be needed to evaluate those other important outcomes and their relationship with management-related risk factors. Several cohorts were also removed from the dataset if they were housed in more than two pens throughout the first 45 DOF as it was difficult to track which pen they were in when they developed BRD. There are many possible reasons related to cattle flow and management decisions that may have caused cohorts to move several times throughout the first 45 DOF. A future, well-controlled prospective study examining the risk of BRD in association with pen housing conditions should be conducted to help determine the differences in BRD incidence.

Conclusions

Our results provide initial estimates of how pen housing characteristics related to pen area per animal and bunk space per animal affect BRD incidence in the first 45 DOF. Our retrospective study determined that the probability of BRD incidence in the first 45 DOF is associated with pen housing conditions related to area per animal, bunk space per animal, and their interactions with cattle demographics. Pen housing conditions and their estimated impact on BRD incidence have not been thoroughly evaluated, and our results suggests that the associations of those pen housing condition variables with BRD incidence in the first 45 DOF are modified by other well-known risk factors. Further research in this area will lead to a better understanding of the impacts of housing conditions for feedlot cattle and how these conditions can potentially be modified to reduce the risk of BRD in the feedlot industry.

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Conflicts of interest statement

Authors have no financial or non-financial conflicts of interest relative to the contents of the manuscript.

Endnotes

[a] Google Earth Pro, Version 7.3.3.7786, Google., Mountain View, CA

[b] Rstudio, Version 7.3.3.7786, R Core Team, Vienna, Austria

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