ABSTRACT: Nineteen loads of commercial feeder cattle (BW 376 ± 39 kg, mean ± SD) transported for 18 ± 4.5 h in summer and winter seasons were used to collect data on internal temperature and humidity conditions in the deck and belly compartment of pot-bellied trailers and their relationship with shrink, cortisol, and morbidity. Measurements of temperature or humidity at ceiling or animal level did not vary with transportation factors. Temperature and humidity ratio was greater at animal-level than ambient conditions during non-highway travel and stationary periods (P < 0.01). During the 3 time periods evaluated within journeys, there was a larger difference between animal-level and ambient conditions during the winter than during the summer (P < 0.01); however, this difference was not associated with other transport factors (P > 0.05). Evening loads (1700 and 2100 h) experienced more shrink in the summer than in the winter (11.2 ± 0.5 vs. 9.0 ± 0.5% of BW; P = 0.03). A 1°C increase in difference between average animal-level temperature in transit and the mean ambient temperature during the 10 d before transport was associated with a 0.11 ± 0.03% of BW increase in shrink (P < 0.01) and 0.006 ± 0.002 ng/mL increase in post-transport cortisol concentration (P = 0.05). Animal-level temperature–humidity index (THI) events (consecutive observations of THI greater than 78°F) were more likely to last for longer than 1 h when the trailer was stationary vs. traveling (mean = 1.8, confidence level 95% = 1.33, 2.52). During THI events at animal level, the disagreement with ambient temperature regarding THI classification was lower when the vehicle was traveling vs. stationary (95.5 ± 0.01% vs. 99.7 ± 0.002% of THI event in disagreement; P < 0.01) and was greatest in events less than 1 h (99.8 ± 0.0% vs. 91.7 ± 0.03% of THI event in disagreement; P < 0.01). The average magnitude of the difference during these events was 11.4 ± 7.6°F and was not affected by transportation factors (P > 0.05). Despite association between indicators of calf welfare and microclimate, all cattle arrived in good condition and there was 0.96% treatment rate within the first 30 d after arrival. Management and auditing decisions related to transportation of feeder cattle should consider the relationship between animal-level and ambient conditions and conditions before transportation. Under the commercial conditions of the current study, the transportation process did not appear to cause distress according to the dimensions of animal welfare that were assessed.

Key words: animal welfare, environment, feeder cattle, microclimate, temperature–humidity index, transportation

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INTRODUCTION

Feeder cattle represent 22.7% of all animals transported in major beef production areas of Canada (González et al., 2012a) and are most likely to be overstocked relative to recommended space allowances, particularly within the deck and belly compartments.
Canadian recommendations for space allowances result in limited space relative to space occupied by cattle while standing (Petherick and Phillips, 2009) and overstocking has been associated with negative influences on the welfare of cattle being transported (Eldridge and Winfield, 1988; Tarrant et al., 1992; González et al., 2012c). However, there is little evidence of the effects of overstocking on the welfare of feeder cattle being transported.

Reform of transportation regulations in Canada have been discussed since 2006 (González et al., 2012a). Transportation audits that include evaluation of space allowance and environmental conditions have been developed as risk management tools for animal welfare (American Meat Institute Animal Welfare Committee, 2012). However, the scientific evidence of the relationship among space allowance, in-transit microclimate, and cattle welfare is either speculative (Cernicchiaro et al., 2012), based on ambient conditions (González et al., 2012b; Theurer et al., 2013) rather than the conditions near cattle inside trailers, or not applicable to North American practices due to differences in vehicles and space allowances (Schwartzkopf-Genswein et al., 2012). Therefore, the objectives of this study were to 1) determine if transport changes the microclimate at animal level relative to ambient conditions in the deck and belly compartment during summer and winter transport of feeder cattle, 2) determine relationships between trailer microclimate and transportation factors, and 3) evaluate the relationship between in-transit microclimate and indicators of cattle welfare.

**MATERIALS AND METHODS**

All research procedures were approved by the Animal Care and Use Committee at the Lethbridge Research Center in accordance with the Canadian Council on Animal Care (2009) guidelines.

From June 2009 to April 2011, the deck and belly compartments (Goldhawk et al., 2014) of 30 commercial loads of mixed breed feeder cattle (BW 376 ± 39 kg, mean ± SD) were used for data collection. All cattle were traveling between feedlots, either from southern Alberta to a feedlot in the northwestern United States or within southern Alberta to a single feedlot on journeys that mimicked United States–bound journeys in time of loading, offloading for inspection, and journey duration. Journeys lasted an average of 18 ± 4.5 h and ranged from 11 h 11 min to 22 h 35 min. The trailers used were Merrit quad-axle (n = 26) or Merrit tri-axle (n = 4; Merrit Equipment Co., Henderson, CO). Space allowance was, on average, 0.9 ± 0.23 m²/animal with a range of 0.75 to 1.09 m²/animal and was on average 9.1% lower than Canadian recommendations according to the calculations in González et al. (2012d), which is similar to survey results of commercial practices in Alberta (González et al., 2012a). The average allometric constant (k), representing the amount of space relative to the body size of an animal (Petherick, 2007), was 0.017 ± 0.003 and ranged from 0.014 to 0.024 according to the calculations in Petherick (2007). Average ambient temperature during the trips was 9.4 ± 16.1°C and ranged from –25 to 45.6°C. Although maximum temperatures may seem extreme, it was within 7°C of the maximum temperature measured at the local weather station. Six journeys occurred between November and March in winter weather (average ambient temperature during journey was less than 5°C) and 13 journeys occurred between June and August in summer weather (average ambient temperature during journey was greater than 15°C).

**Microclimate Variables**

All compartments contained cattle during transport and there was a range of 69 to 78 animals in each trailer across all journeys. However, the upper and lower center compartments, the deck and belly, respectively (Goldhawk et al., 2014), were chosen as focal compartments of the 5 compartments in trailers, due to constraints in handling multiple cattle from each compartment and indication from survey data that these compartments were most commonly overstocked during commercial transportation of feeder cattle (González et al., 2012c). Data were collected on microclimate and journey characteristics for
all journeys. Each trailer was fitted with temperature and humidity data loggers (Hygrochron iButtons, temperature DS1923; Dallas Semiconductor Corp., Dallas, TX) affixed to the compartment ceiling in the deck and belly and the driver’s and passenger’s mirrors outside of the tractors as an ambient location. Loggers at the ambient locations were covered by opaque plastic shields with small ventilations holes to reduce the influence of solar radiation. Animal-level temperature and humidity were monitored using an ear tag on 10 to 100% of the cattle in a compartment. The ear tag (Allflex Feedlot Tags; Allflex Canada, St. Hyacinthe, QC, Canada) had an iButton logger attached such that the tag itself prevented direct contact between the logger and the skin of the animal. Ear tags were affixed to the ear of the animals using previous ear tag holes whenever possible. All loggers were synchronized before placement and set to record at 1-min intervals. The loggers were affixed approximately 3 to 5 cm below the ceiling of the compartments to prevent contact with the aluminum surface of the trailer and animals within the compartments. According to manufacturer specifications, the trailers used in this study had a total compartment height of approximately 174.9 and 169.1 cm in the deck and belly, respectively, leaving 170 and 166 cm of free vertical space below loggers in these 2 compartments. For all journeys, the compartment size to ceiling-level data logger ratio was held constant. Consequently, 10 data loggers were placed in the deck and belly of quad-axel trailers and 8 data loggers in the deck and belly of tri-axel trailers. Weather data were collected from the weather station nearest to the origin feedlots (approximately 30 km away) for the 10 d before the journey to provide an indication of acclimatization of cattle before transport.

Each tractor was fitted with a global positioning system (GPS) unit before leaving the origin feedlot (Q-Starz BTQ 1000 Platinum; Qstarz International Co., Ltd., Ming Chuan, Taiwan). The GPS system was programmed to log the time, latitude, longitude, and ground speed at 1-min intervals in sync with the recording of the iButtons. Drivers recorded the number of animals in each compartment, departure and arrival times, reasons and durations of stationary periods, and cattle condition. Furthermore, GPS units were used in combination with driver records to indicate events within a journey. The start of the journey was defined as the time when the load exited the origin. The end of each journey was defined as the point when each load entered the unloading area of the receiving feedlot.

Data Analysis

Of the 30 loads used for data collection, 5 had incomplete animal information, 3 had data collected only on trailer microclimate, and trailer-level instruments failed during 3 winter loads, leaving 19 loads with complete microclimate datasets that were used for analysis. Data analyses were performed using SAS (version 9.1; SAS Inst., Inc., Cary, NC). Due to the temperature dependence of relative humidity, all analyses of humidity were conducted on the humidity ratio, which was calculated as described by Albright (1990) using the barometric pressure along the journey based on GPS coordinates and available weather information.

Aberrant values in temperature and humidity data may arise from animals licking or mouthing sensors or failure of sensors in transit. Aberrant values were identified by load and compartment as values more than 1.5 times the interquartile range (Hoaglin et al., 1986) and removed from the dataset after visual confirmation that the values were uncharacteristic relative to data from the

Animal Variables

All loads monitored were commercial loads of cattle and differences among facilities prevented collection of all variables from all loads. Cattle were weighed either individually in a chute scale (n = 4; winter loads) or by compartment on a group scale (n = 18; 5 winter and 13 summer loads) immediately before loading at the feedlot of origin and again immediately following unloading at the receiving feedlot. Shrink was calculated at the compartment level as the percentage of original weight lost during transit: \((\frac{BW_{initial} - BW_{final}}{BW_{initial}}) \times 100\%\). Drivers maintained a log of the condition of the animals before loading, at unloading at the border, and at unloading at the destination feedlot. Drivers recorded the number of cattle that were dead, recumbent and unable to stand, or lame. Experienced animal health personnel monitored the calves and diagnosed animals according to lot-specific health treatment protocols under supervision of the attending veterinarian. Feedlot records of the diagnoses of health disorders, treatments, and mortalities for calves were gathered for the first 30 d on feed (DOF) after arrival (day of arrival = 0) for 15 loads, representing 622 feeder cattle (6 summer and 9 winter loads).

Salivary cortisol concentrations were measured in 15 loads (11 summer and 4 winter loads) using a cotton swab to collect saliva immediately before loading and immediately after unloading. The swabs were stored on ice during sampling and stored in a –20°C freezer until analyzed, as described by Cook and Schaefer (2002). All cattle in the 4 winter loads were sampled, whereas 20% of the cattle in each compartment were sampled from the 11 summer loads. Of the 15 loads with pre- and post-transport salivary cortisol samples, 7 were loaded in the morning of the summer, 6 in the evening of the summer, and 4 in the evening of the winter. The 11 summer loads used Merrit quad-axel trailers, whereas the 4 winter loads used a Merrit tri-axel trailer.
specific logger at that point in time and the data from other loggers within the same load and compartment at the same point in time. All analyses were performed on the edited dataset. Manufacturer specifications were used as estimates of systematic error in measurements of temperature and humidity (±0.5°C and ±5% relative humidity; Dallas Semiconductor Corp.). In accordance with standard methods for uncertainty analysis (National Aeronautics and Space Association, 2010), the root sum square (RSS) method was used to combine random and systematic errors to estimate total uncertainty in a measured value and to propagate the total uncertainty through all calculations. Total uncertainties were used for adjustment of the standard errors in all models to account for both random and systematic uncertainty before calculating P-values. Only significant factors and interactions remained in final models.

To evaluate the effect of transportation factors on in-transit microclimate throughout journeys, 3 time periods were selected that represented consistent events amongst journeys. The first hour of transport after leaving the place of loading was selected to represent a dynamic period of transportation where a steady state between internal and external temperature and moisture may not yet exist. The first 15 min following reloading of cattle after inspection at the border was selected to represent a stationary period, confirmed by GPS, during transportation that was consistent in duration, location of trailer, and handling of cattle. The last time period evaluated was the last hour of highway transport before arrival at the receiving feedlot, as visual inspection of microclimate data revealed that this period was most likely to have steady state conditions for temperature and humidity ratio based on less than 5°C deviation in temperature within locations and less than 5°C change in the difference between inside and outside of the trailer. The methods of identifying steady state periods are similar to methods used in evaluation of microclimate during commercial transport of poultry (Burlinguette et al., 2012) and swine (Brown et al., 2011). Time periods were combined into 1 dataset to allow for comparison of effects during different events. At each minute within the time periods evaluated, temperature and humidity ratio was averaged across all loggers at animal, compartment ceiling, and outside locations within each load and compartment (e.g., at each minute within the time periods, data from all animal-level loggers within a compartment of a load were averaged together to represent conditions at animal level). Generalized linear mixed models (GLMM) were used to evaluate the effect of location of measurement (animal or compartment ceiling), compartment, allometric constant, time period, ambient temperature or humidity, trailer type, and speed on temperature and humidity ratio. Both linear and quadratic effects were tested for ambient conditions. Separate GLMM were run for temperature and humidity. Speed of the trailer was converted to a categorical variable that was coded as less than 10, 10 to 50, 50 to 90, and greater than 90 km/h. Space provided relative to body size was also converted to a categorical variable that was coded as allometric constant values greater than 0.015 or less than 0.015. The type of trailer (quad- vs. tri-axle) was removed from the model as tri-axle trailers were used for 4 loads in the winter season and there was no difference between trailer types within the winter season (P > 0.01). The 1-min samples within time period were treated as a repeated measurement for each compartment within each load using a first order autoregressive covariance structure. The location of measurement was treated as a random effect within load and compartment, and load was treated as a random effect. Only the interactions between levels of measurement and fixed effects were evaluated to determine if levels of measurement differed with transportation factors. Least-squares means were used for fixed effect comparisons to account for unequal sample sizes arising from different durations of the selected time periods.

To investigate if transportation altered animal-level microclimate, GLMM were run to determine the effect of compartment, allometric constant, time period, season, trailer type, and speed on the difference between animal-level and ambient temperature and humidity ratio. As for the previously described models on temperature and humidity at animal and ceiling level within trailers, separate models were run for temperature and humidity ratio, with speed and allometric constant converted to categorical variables. The 1-min samples within time period were treated as a repeated measurement for each compartment within each load using a first order autoregressive covariance structure, and load was treated as a random effect. Interactions were tested first, with multiple comparisons used to determine if there was a true interaction between effects or if effects could be parsed into main effects. Least-squares means were used for fixed effect comparisons to account for unequal sample sizes arising from different durations of the selected time periods.

The duration of continuous temperature–humidity index (THI) above the “danger” threshold of 78°F (Brown-Brandl et al., 2005) was calculated to determine exposure during transport to conditions of concern to the thermoregulation of cattle. The “danger” threshold was selected as it is the lowest threshold of concern and therefore includes higher THI classifications, such as “emergency” (Brown-Brandl et al., 2005). The duration of the events was determined using the number of consecutive 1-min observations that were classified as above the “danger” threshold. If events were separated by 1 min, they were considered to be part of the same event. Events lasting for only 1 min were not included in the final analysis.

The effect of compartment, allometric constant, motion status during THI event, and whether or not ambi-
ent THI was categorized as danger within the event on the risk of a THI event at animal level being greater than the danger threshold for more than 1 h was analyzed using a GLMM. The selection of 1 h as the threshold for consideration was done heuristically, based on hour as the length of time used in previous assessments of THI (Hahn et al., 2009), due to a dearth of information regarding the effect of length of exposure to elevated THI during transport and effects on animal welfare. Events greater than 1 h where THI was above the danger threshold \( (n = 41; 9 \text{ events occurred while stationary within 8 loads and 32 events occurred while traveling within 6 loads}) \) were compared to events greater than 1 h that were not above the danger threshold \( (n = 77; 19 \text{ events while stationary that occurred within 7 loads and 58 events while traveling that occurred within 19 loads}) \). One-hour periods were selected as representing conditions of sufficient duration of exposure to have potential negative consequences for animal welfare while in transit. For analysis of THI events at animal level, allometric constant was coded as greater or less than 0.015 and motion of the trailer was coded as traveling (speed greater than 10 km/h) or stationary (speed less than 10 km/h) based on average speed during the event, with no event having more than 10% classified as different speed categories. The model used a logit link function (the default link function for binomial data in logistic regression using SAS for GLMM) and treated events as repeated measures for each compartment within each load.

At each minute within events, animal-level THI was considered to disagree with ambient-level THI if ambient THI was lower than the “danger” threshold by more than the total uncertainty in the ambient THI. The effect of compartment, duration of the event, allometric constant, and motion status during THI event on the percent of a THI event where ambient disagreed with animal level was analyzed using a GLMM. The GLMM for percent of event in disagreement used a logit link function with a binomial distribution, with load as a random effect and events as repeated measures for each compartment within each load. The effect of compartment, duration of the event, allometric constant, and motion status during THI event on the magnitude of the difference between animal-level and ambient THI when the 2 locations disagreed was also evaluated using a GLMM, with load as a random effect and events as repeated measures for each compartment within each load. Both GLMM evaluated all interactions and main effects; however, only significant effects remained in the final model.

The response of animals to transportation and variation in microclimate was evaluated using animal condition as evaluated throughout transportation by drivers, shrink, pre- and post-transport cortisol concentrations, and morbidity and mortality records during the first 30 DOF at the arrival feedlot. The deck of 1 winter load was removed due to an extremely high value for shrink (19.4% of BW) relative to all other loads and other compartments within that load, which was most likely due to measurement error. Certain variables of interest were found to be confounded when evaluating shrink in the 19 loads within the final dataset. All winter loads were loaded in the evening (between 1700 and 2100 h; \( n = 6 \)), whereas 6 summer loads were loaded in the evening (between 1700 and 2200 h) and 7 were loaded in the morning (between 0500 and 0700 h). The duration of transport for loads that were loaded in the morning was approximately half that of loads that were loaded in the evening. The number of THI events greater than the danger threshold at animal level was greater in loads that were loaded in the evening than in the morning. Therefore, to avoid assessing correlated variables in modeling of shrink, only time of loading (a.m. or p.m.) was evaluated. There was no effect of trailer type on shrink; therefore, trailer types were pooled. The effect of season, duration, in-transit deviation from previous temperature exposure, compartment, and space relative to body size on shrink was evaluated using the subset of loads that were loaded in the evening \( (n = 12) \). Thirteen summer loads were used to evaluate the effect of time of loading, in-transit deviation from previous temperature exposure, compartment, and space relative to body size on shrink. The in-transit deviation from previous temperature exposure was calculated by subtracting the mean temperature for 10 d before transport, as a measure of the acclimatization of the cattle before transport, from the mean temperature during the journey. Space relative to body size was categorized using the same allometric constant classifications as previously described. Both subsets for shrink were analyzed using GLMM, with load as a random effect.

Salivary cortisol concentrations were analyzed using 2 subsets of data from 15 loads where cortisol was sampled. In all models, post-transport salivary cortisol was the dependent variable with pretransport cortisol as a covariate. Load was treated as a random variable, with individual animals as a random effect within load and compartment using an unstructured covariance structure. To avoid the confounding issue of loading during evening or morning, 4 randomly selected evening summer loads were selected for comparison with the 4 winter loads using a GLMM with the fixed effects of season, compartment, duration of journey, in-transit deviation from previous temperature exposure, and space provided relative to body size. Summer loads that were loaded in the evening were randomly selected for comparison to winter loads using a random number generator to assign dummy identification numbers to loads and selecting odd-numbered loads until 4 loads were selected. A separate GLMM was performed comparing the morning versus evening time of loading within the 11 summer loads. The number of THI events greater than the danger
threshold at animal level was greater in loads that were loaded in the evening than in the morning; therefore, to avoid confounding in the model, only time of loading was evaluated. The fixed effects in the second model were time of loading, compartment, in-transit deviation from previous temperature exposure, and space provided relative to body size.

RESULTS

Box plots of the distribution of data collected at 1-min sampling intervals from all journeys, after removal of aberrant values, is displayed according to the level of measurement and season for temperature (°C), humidity ratio (g water per kg dry air), and THI (°F; Fig. 1, 2, and 3, respectively). For box plots only, the deck and belly compartment are displayed within the same box plot for both animal and compartment ceiling level of measurement. Temperature and humidity ratio did not differ at animal or ceiling level due to compartment, allometric constant, time period, or speed ($P > 0.1$). The effect of ambient conditions was different between animal and ceiling level. The effect of ambient conditions was different for temperature and humidity measured at animal or ceiling level, across seasons. A 1°C increase in ambient temperature from the mean of $13.9 \pm 17.2^\circ$C increased temperature at animal level by $0.18 \pm 0.01^\circ$C and increased ceiling level temperature by $0.21 \pm 0.01^\circ$C ($P < 0.01$). A 1 g water/kg dry air increase in ambient humidity ratio from the mean of $4.6 \pm 2.7$ g water/kg dry air increased humidity ratio at animal level by $0.37 \pm 0.04$ g water/kg dry air and increased humidity ratio at ceiling level by $0.40 \pm 0.04$ g water/kg dry air ($P < 0.01$). Within each of the time periods evaluated, there was a larger difference between animal-level temperature and ambient temperature in winter than in summer (Table 1). However, there was no difference from ambient temperature during highway travel in the summer or between animal-level and ambient humidity during the winter (Table 1). The lack of difference between animal-level and ambient humidity during the winter is supported by the similar distribution of humidity ratio data at animal level, ceiling, and ambient locations (Fig. 3).

Levels of THI classified as greater than the danger threshold for cattle occurred only in the summer season (Fig. 3), lasting an average of $19.2 \pm 31.2$ min, and duration ranged from 2 to 223 min. Within the events that were above the “danger” threshold for THI at animal level, 10.5% lasted for more than 1 h ($n = 41$ events). Animal-level events where THI was greater than the danger threshold were more likely to last for longer than 1 h when the trailer was stationary vs. traveling (mean = 1.8, confidence level = 1.4, 2.4; $P < 0.01$). The percent of an animal-level THI event above the “danger” threshold where ambient THI was below the “danger” threshold was greater when event duration was less than 1 h ($99.8 \pm 0.0\%$) compared to when event duration was greater than 1 h ($91.7 \pm 0.03\%; P < 0.01$). Disagreement with ambient was also greater when THI events at animal level occurred during stationary periods ($99.7 \pm 0.002\%$ disagreement when events occurred while the trailer was
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was 11.4 ± 7.6°F within loads that were loaded in the evening a 1°C in-when loads were loaded in the evening. Additionally, winter loads (11.2 ± 0.5 vs. 9.0 ± 0.5% of BW; = 0.03)

foot infections (1 treated case in the winter season). BW, with a range from 5.8 to 12.4% of BW for individ-

8.1 to 10.2°C during the summer season. In the sum-

tions and conditions surrounding feeder cattle in 19 commercial pot-belly trailers in 2 seasons

Table 1. Least-squares means and uncertainties1 for the difference in temperature and humidity ratio between animal-level and ambient conditions in the deck and belly compartments during the first 60 min of travel, 15 min stationary period, and last 60 min of highway travel during transportation of feeder cattle in 19 commercial pot-belly trailers in 2 seasons

<table>
<thead>
<tr>
<th>Time period</th>
<th>Season</th>
<th>Temperature, °C</th>
<th>Humidity ratio, g water/kg dry air</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean difference</td>
<td>Uncertainty1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean difference</td>
<td>Uncertainty1</td>
</tr>
<tr>
<td>First 60 min</td>
<td>Summer</td>
<td>4.08b</td>
<td>2.89</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>10.77b</td>
<td>3.45</td>
</tr>
<tr>
<td>15 min stop</td>
<td>Summer</td>
<td>2.54a</td>
<td>3.60</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>9.54b</td>
<td>2.74</td>
</tr>
<tr>
<td>Last 60 min</td>
<td>Summer</td>
<td>0.52a,1</td>
<td>1.53</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>4.94b</td>
<td>1.96</td>
</tr>
</tbody>
</table>

2,3Mean differences with different superscript letters were different within time period (P < 0.1). 1Uncertainty is the combined uncertainty in measurements due to random and systematic uncertainty. 3Mean difference not different from 0 (P > 0.1).

DISCUSSION

Temperature and humidity in the area surrounding feeder cattle during transport were different than ambient conditions. Livestock trailers in the current study are dependent on passive ventilation that is driven by pressure differences created around the periphery of the vehicle as it moves and thermal gradients, creating differences between internal trailer conditions and ambient conditions (Muirhead, 1983). Differences likely also exist between internal and ambient conditions in empty trailers, although these differences would be of smaller magnitude than when animals are present in the trailer. Varying the placement of sensors within the trailer may also influence the difference from ambient conditions, which is why the same layout of sensors was used within all compartments in the current study. In regard to animal welfare concerns, however, it is the conditions when cattle are present in trailers and the conditions surrounding cattle that are of interest. The presence of cattle will supply heat and moisture to the internal trailer environment (Randall and Patel, 1994) due to metabolic and thermoregulatory processes. In nontransport conditions, the additional heat and moisture produced by animals is dissipated to the environment or removed by mechanical ventilation (Albright, 1990). In addition to the dependency of internal trailer ventilation on vehicle movement and pressure differences, the presence of cattle in trailers will block air movement, potentially further reducing ventilation at animal level (Muirhead, 1983). Therefore, the increase in temperature at animal level likely reflects a combination of reduced ventilation at animal level compared to ambient locations in transit and the influence of the animals on their microclimate.
Transportation management, such as compartment within trailers or space allowance, did not affect microclimate despite space allowances being on average 9.1% lower than Canadian recommendations. The lack of association with space allowance supports previous mathematical predictions of minor variance in air temperature during cattle transport due to variance in stocking density (Randall and Patel, 1994). Previous research reported effects of season, compartment within trailer, and vehicle speed on the difference between internal and ambient temperature and humidity when transporting livestock such as sheep (Fisher et al., 2005), horses (Purswell et al., 2010), swine (Brown et al., 2011), and poultry (Burlingette et al., 2012). Variation in other factors not accounted for in the current study, such as crosswinds (Baker et al., 1996), may have also obscured the effect of transport factors. Differences in the results of the current study on cattle transportation and aforementioned research may be due to differences in heat production, species, animal management, trailer design, number of commercial replicates, and the novelty of including systematic uncertainty in variation estimates of microclimate measurements. Accounting for the effect of equipment variation on the probability of differences between transportation factors provided a more accurate assessment of the relationships between transportation factors and measurements of temperature and humidity in livestock transport.

Temperature and humidity measured at animal or ceiling level differed only in the magnitude of the influence of ambient conditions, which supported estimation of animal-level conditions from ceiling-level sensors when accounting for ambient conditions. The magnitude of the difference between animal-level and ambient THI was relatively stable across all transportation factors evaluated, as was the difference between animal-level and ambient temperature and humidity, which are inputs for THI. The exception to the stability of the difference between animal-level and ambient conditions was due to differences in ambient conditions associated with seasons and vehicle motion. The increased difference in temperature with cold winter temperatures may reflect an interaction between heat production at the animal level and insufficient ventilation at animal level to remove produced heat, which becomes more apparent during colder weather. Perhaps the lack of difference during highway travel in the summer is due to warm ambient temperatures during the summer approaching that of animal level, which does not occur during the cold winter. Alternatively, there may be increased airflow during highway travel that improves ventilation at animal level. During the winter, high levels of ambient moisture may increase the ambient humidity ratio to equal that of animal level during transport. Differences in sample sizes of travel and stationary periods resulting from use of 1-min sampling from 1 h traveling periods versus 15 min stationary periods may influence the estimation of variation and, although pragmatic periods for analysis based on commercial transport practices, may potentially influence results. Based on the results of the current study, the difference in the magnitude of increase in temperature and humidity at animal level during transport, which was associated with differences in ambient conditions and vehicle motion, must be considered when using ambient as proxy for animal-level conditions in monitoring transportation.

The increased risk of THI events of concern at animal level for more than 1 h when vehicles are stationary further supported the theory that vehicle motion is an important consideration in monitoring in-transit microclimate. Thresholds for THI are used to indicate when warm environmental conditions arise that challenge the homoecothermic ability of cattle and classify when index values are indicative of no stress, danger, or emergency situations. Reports of sheep transport have also identified that vehicles being stationary is of concern during transport due to elevated temperature and humidity at animal level (Fisher et al., 2005). The trailer design in the current study reduces ventilation during stationary periods, particularly at animal level. The reduction in ventilation relative to ambient conditions, in concurrence with heat and moisture produced by cattle, is likely the impetus behind the increased risk of concerning THI at animal level during when the vehicle is stationary.

The events where THI was of concern for thermoregulation had a larger disagreement with ambient conditions while the trailer was stationary. The use of THI measured at ambient locations in understanding the conditions that cattle are experiencing, for auditing or risk management decisions, will be inaccurate due to disagreement. The larger disagreement during events of shorter duration likely has less serious implications for risk management, as the duration of exposure is important in determining the ability of cattle to cope with thermal stressors, with shorter durations being of less concern for animal welfare (Hahn, 1999). The magnitude of the difference between animal-level and ambient temperature and humidity ratio and the disagreement between ambient THI and animal-level THI presented herein may serve as an estimate of correction factors. A concern is application in cold weather transport where application of the THI does not reflect thermal comfort and currently there are no objective indexes of cold stress for cattle. Additionally, extreme caution should be used, for different trailer designs may cause ventilation to vary and alter the relationship between animal-level and ambient conditions compared to the type of trailers used in the current study. A more robust understanding of the relationship between animal-level THI and ambient THI is required before applying estimates to other transport conditions, such as different types of cattle, different
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trailer designs, and other environmental conditions. Until corrective factors can be developed for the relationship between ambient and animal-level THI or systems to use ceiling level as a proxy location for monitoring animal-level conditions are developed, risk management tools must consider variation in microclimate at animal level due to ambient conditions and vehicle motion.

Biological indicators of the welfare of feeder cattle, such as weight loss and cortisol, were associated with in-transit deviations from previous temperature exposure. Transportation can increase metabolic heat production (Schrama et al., 1996) while restricting the behavioral and physiological coping responses by placing multiple animals closely together without access to feed or water. In nontransport situations, cattle respond to thermal challenges by altering bioenergetics, which can cause similar alterations to biological indicators of welfare reported in the current study (Bernabucci et al., 2010). However, what constitutes a thermal challenge for an animal is partly a function of the previous environmental conditions that they were exposed to, the magnitude and duration of exposure to adverse conditions, and adaptations to cope with exposure (Hahn et al., 2009). Deviation of in-transit microclimate relative to the narrow thermoneutral range of poultry and swine has been associated with negative welfare outcomes during transportation (Schwartzkopf-Genswein et al., 2012). Previous research on cattle transportation has reported a positive association between increasing ambient temperature in transit and weight loss during transport (González et al., 2012b). However, the association was based on driver self-reporting surveys and did not evaluate the change in temperature relative to previous exposure or known tolerances for cattle. Associations between weight loss and cortisol with the difference between pretransport temperatures and in-transit microclimate in the current study are likely the response of cattle to exposure to thermally challenging situations during transport interacting with individual tolerance and thermal acclimatization.

The effect of in-transit microclimate on biological indicators of welfare did not translate into poor welfare at a systematic level for the majority of feeder cattle in the current study, based on evaluation of animal condition at arrival and disease following transportation. We attributed the relatively low frequency of health issues during the first 30 DOF after transport to the low-risk classification of the study population based on age, weight, and lack of comingling (Wildman et al., 2008) and the use of induction programs using prophylactic antibiotics and vaccination protocols (Taylor et al., 2010; Terrell, 2012). Additionally, the use of treatment records may be biased from misclassification due to the subjective nature of health assessments and/or differences between feedlots and across years (Cernicchiaro et al., 2012), which were not addressed in the current study design. However, the importance of the relationships between in-transit microclimate and physiological indicators of welfare reported in the current study may be of more importance for welfare high-risk feeder cattle.

The range of cortisol concentrations at both pre- and post-transport sampling were similar to ranges reported in experimental research on the cortisol response of cattle in transport and nontransport situations for baseline measurements (Grandin, 1997), handling (Herd, 1989), differences in temperament (Fell et al., 1999; Burdick et al., 2011; Fazio et al., 2012), feed and water withdrawal (Ward et al., 1992; Marques et al., 2012), and changes in thermal conditions (Christison and Johnson, 1972; Rhynes and Ewing, 1973). Perhaps the duration of journeys and timing of post-transport cortisol samples in the current study did not capture variation in response to transportation factors due to reduced cortisol secretion by the end of the journey (Cook et al., 2009), acclimatization to transport, or variation among individual cattle in their hypothalamic-pituitary-axis (HPA) activation due to differences in experience and adaptive processes (Grandin, 1997; Mormède et al., 2007). There were 2 loads of cattle, transported in the winter season, that were anecdotally noted to be extremely wild during both pre- and post-transport handling. These winter loads had the highest post-transport cortisol concentrations and average shrink across both the deck and belly that were in the top quartile for all loads evaluated and were transported under conditions with the highest deviation in animal-level temperature relative to the 10-d average before transport. Therefore, the relevance of the increase in post-transport cortisol associated with animal-level temperature in transit remains obscure as to whether it is a result of the response of cattle to thermal conditions (Christison and Johnson, 1972; Rhynes and Ewing, 1973) or of confounding issues with temperament and handling, due to small sample size in the winter season of the current study and a lack of evaluation of in-transit microclimate parameters and cortisol response in previous research on cattle transportation. The multifactorial nature of commercial cattle transport and generality of the HPA response to stressors indicated that application of cortisol as a stand-alone metric of commercial cattle well-being during transportation was likely to perpetuate the misunderstanding of the complexity of cattle’s response to stressors (Rushen, 1986) and the development of distress during transport.

Conclusions

We concluded that transportation influenced the microclimate surrounding feeder cattle and that in-transit microclimate, when interpreted relative to the accli-
matization of cattle being transported, influenced the physiological response of feeder cattle to transportation. Differences between animal-level and ambient conditions were greater during non-highway travel or stationary periods and during cold winter weather versus warm summer weather. The microclimate within the 2 compartments used to transport the majority of feeder cattle in North America did not vary with commercial space allowances, despite space allowance being reduced compared to Canadian recommendations. Accounting for both random and systematic uncertainty of measurements in the statistical analysis of transportation microclimate is a novel approach in transportation research that improves the accuracy of evaluating the effect of transportation factors on in-transit microclimate. Microclimate was influenced by ambient conditions and must be interpreted relative to the conditions that cattle were exposed to before transportation. Under the conditions of the current study, the influence of transport on microclimate did not result in poor welfare within the study population but may be of importance for higher-risk cattle. Inclusion of the relationship between ambient conditions, trailer motion (e.g., traveling versus stationary), and trailer microclimate in evaluation of risk factors for thermal challenges within compartments may improve management decisions and auditing of cattle transportation, particularly if welfare is to be assessed under commercial conditions. We concluded that the influence of ambient conditions and vehicle motion on animal-level microclimate must be considered when using ambient conditions to monitor animal level or in development of systems that use ambient or ceiling level to monitor animal-level conditions. Under the commercial conditions of the current study, the transportation process did not appear to cause distress according to the dimensions of animal welfare that were assessed.

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