USE OF UNMANNED AERIAL VEHICLES TO STUDY CATTLE HEAT STRESS

by

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ABSTRACT

Heat stress in cattle is a growing problem for the North American cattle industry. Heat stress negatively affects production as it reduces foraging, growth, metabolic efficiency, and may increase mortality rates. Heat stress also negatively affects animal welfare and consumers are increasingly wanting their products sourced from producers that foster good animal welfare. Climate change models predict that average summer temperatures and the frequency and magnitude of heat waves will increase.

Given the worsening problem of heat stress, the industry needs to develop and adopt best practices to mitigate losses in production. In principle, increasing heat tolerance may be an effective strategy but measuring heat tolerance is challenging, especially in large-scale studies. Monitoring physiological indicators of heat stress requires invasive devices that are reliable but may be cost prohibitive and logistically challenging. Monitoring behavioral indicators may be practical but still are time- and labor-intensive for large-scale studies. Consumer-grade unmanned aerial vehicles (UAVs) have the potential to be practical and effective tools in studying heat stress behavior.

In the second chapter of my thesis, I used thermal-based imagery acquired by a UAV to compare surface temperature between color variants of Black Angus x Canadian Speckle Park cattle. Light-coated animals exhibited lower surface temperatures than dark-coated animals during peak sunlight. This may suggest that light-coated variants are less susceptible to heat stress; however, further research is needed to determine this.

In the third chapter of my thesis, I developed a practical and effective method to measure respiration rate using UAVs and Observer XT software. I recorded video at 5-10 meters above steers in feedlot pens and cows on pasture throughout a summer heat wave. Observer XT software was used to analyze behavior from UAV-based video. Respiration rates were determined by quantifying flank movements observable on video. Consistent with similar studies, respiration rate was the highest in black cattle, followed by red cattle, then white cattle in the feedlot. Coat color did not affect respiration rate in cows on pasture;

however, temperatures on pasture were lower than in feedlots and the effect of coat color may not manifest until a certain temperature threshold of heat load index (HLI).

In conclusion, consumer-grade UAVs seem to be an effective tool for measuring heat stress behavior of cattle in large-scale operations. Future research could further improve the efficacy of UAVs with the addition of extra sensors and with the use of automation through machine learning methods. UAV-borne thermal imagers provide limited information and warrant further improvement. It is likely that, in the feedlot, dark-coated cattle are less productive than light-coated cattle during high heat loads but further research is needed to make a direct comparison of productivity. The inclusion of Canadian Speckle Park animals in primarily Black Angus commercial breeding programs has the potential to introduce thermotolerant traits into the popular Angus breed. However, further research is needed to determine if coat color has an effect on heat stress and productivity.

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CHAPTER 1: GENERAL INTRODUCTION

Cattle (*Bos taurus*) are considered heat stressed when their internal temperature increases above their thermal neutral range due to an imbalance of heat gain and heat loss (Andrade et al. 2017; Bernabucci et al. 2010). In their thermal neutral zone (TNZ) of environmental heat load, cattle regulate their internal temperature within a narrow range without changing their behavior or expending extra energy above their normal maintenance requirements (Herbut et al. 2019; Henry et al. 2012). Under environmental heat loads above their TNZ, the internal temperature increases which induces behavioral and physiological changes that increase the rate of heat loss (Veisser et al. 2018; Alves et al. 2017).

Heat stress is a growing problem for production and welfare in the North American cattle industry (Bernabucci et al. 2019; Reeves & Bagne 2017). Maximum growth of cattle occurs when they are within their TNZ. When cattle are challenged with high heat loads, their coping response negatively affects their growth in multiple ways. Heat-stressed animals may consume less feed as this decreases the thermal effect of feeding (Slimen et al. 2015; Herd et al. 2009; Beatty et al. 2008). For example, O’Brien et al. (2010) showed that cattle subject to environmental conditions outside their TNZ experience a 12% decrease in dry matter intake. Heat stress also reduces the metabolic efficiency of converting feed to tissue (Lees et al. 2019; Hahn et al. 1999; Ames et al. 1980). The annual economic loss caused by heat stress is estimated at $1.69—2.36 billion for the dairy industry and $370 million for the beef industry in the US. (St-Pierre et al. 2003).

Heat stress negatively impacts animal welfare (Nardone et al. 2010; Gaughan et al. 2009) and consumers are increasingly wanting their products sourced from producers that foster good animal welfare (Drouillard 2018). Decreased production efficiency is linked to increased greenhouse gas emissions, so there is also an indirect environmental cost of heat stress (Grossi et al. 2019). Unfortunately, climate change models predict that the number of days on which cattle experience heat stress will increase (Reeves & Bagne 2016).

Furthermore, in both Canadian and American production settings, a single heat wave can have a detrimental economic impact since the risk of mortality increases (Lees et al.

2019; Bishop-Williams et al. 2015). In rural southern Ontario, the rate of dairy cattle mortality is predicted to be 1.23 times higher during a typical heat wave compared to that of normal summer conditions. A heat wave is generally defined as a period of consecutive hot days above a certain threshold of a chosen weather parameter (e.g., ambient air temperature, temperature-humitidy index) (Morignat et al. 2019; Lees et al. 2019). Climate change models predict that heat waves will be increasingly hotter and more frequent throughout this century (Pasqui et al. 2019).

In keeping with increasing consumer demands for beef over the last few decades, cattle have been selected for high productivity (Grossi et al. 2019; Bernabucci et al. 2010; Gaughan et al. 2009). In addition, the industry has selected for larger animals as both the average mature weight of cattle and carcass size have increased (Beck et al. 2018; Wiseman et al. 2018; Thornton 2010). Despite the obvious economic benefit, increased productivity is a trade-off with increased heat stress susceptibility (Carabano et al. 2019; Gaughan et al. 2009). Productivity is typically measured by daily growth rate, which is determined by metabolism. Cattle with high metabolic rates generate more internal heat than cattle with lower metabolic rates (Bernabucci et al. 2010). Furthermore, as size increases, the surface area to volume ratio decreases, which decreases the animal's ability to lose heat from their internal tissues to the environment (Brown-Brandl & Jones 2011). This is exacerbated in cattle with high fat cover, such as feedlot cattle close to their finishing weights (Gaughan et al. 2008; Brown-Brandl et al. 2006).

In 1978, the Certified Angus Beef ® brand was created, with which producers could brand their products if specific criteria were met (Bass 2018). This was created with the intent of increasing the demand for Angus cattle and to establish a method to identify high-quality beef (Zimmerman & Schroeder 2011). Since its conception, and along with marketing campaigns, Angus has become the predominant breed of cattle in the North American industry. In the US, approximately 60% of cattle fed for slaughter have Angus ancestry (Drouillard et al. 2018). According to the Canadian Beef Breed Council, approximately half of all registered cattle in Canada are Angus (CBBC 2017). This breed is highly productive and possesses desirable traits to producers. They are calm and naturally polled, which makes them easy to handle. They also consistently produce marbled carcasses, which produce high quality cuts of meat. While selecting Black Angus has been a successful direction for the cattle industry, increasingly hot summer conditions and heat waves may call for change.

Black Angus are highly susceptible to heat stress compared to other breeds such as Hereford and Charolais (Gaughan et al. 2010; Brown-Brandl et al. 2006). The risk of mortality in a heat wave is much higher in black-coated cattle compared to cattle with lighter coats (Mader et al. 2001; Hungerford et al. 2000). For example, Hungerford et al. (2000) found that in a heat wave that resulted in 5000 cattle deaths in Nebraska, black-coated cattle had a mortality risk 5.7 times higher than that of other cattle. Darker coats, having a lower albedo, absorb more solar radiation than light colored ones, which can increase heat gain compared to light coats (Hillman et al. 2005; Finch 1985). The solar absorptivity of the hair coat of Black Angus is two times higher than that of Charolais (Hillmen et al. 2005).

Given the worsening problem of heat stress and the heat stress susceptibility of commonly raised breeds, there is a need to determine effective mitigation strategies. Increasing the heat tolerance of cattle is one approach that has gained much interest (Carabano et al. 2019; Renaudeau et al. 2012; Bernabucci et al. 2010). Heat tolerance describes how environmental heat load affects thermal balance, production and reproductive performance, which is often measured by physiological and behavioral indicators of heat stress (Carabano et al. 2019; Dikmen et al. 2008). There are multiple approaches to increasing heat tolerance of cattle. For example, genetic markers of heat tolerance can be identified and selected for in breeding programs (Carabano et al. 2010; Bernabucci et al. 2010). Heat tolerant traits such as light coat color can be selected within a population (Dikmen et al. 2017). Heat tolerant traits can also be introduced; for example, Dikmen et al. (2014) introduced the SLICK gene into Holstein cattle via gene introgression, and this gene is associated with greater sweating rates and thinner coats. Selectively raising breeds that are known to be more heat tolerant than others (e.g., choosing Hereford cattle over Black Angus) is another strategy that would require little intervention (Gaughan et al. 2010).

Reducing heat stress by effective management practices is another mitigation strategy. Determining animal factors associated with heat stress is an important step towards effective management. Animals that are identified as being susceptible to heat stress can be selectively managed, which is more efficient than applying the same cooling strategies across all individuals (Brown-Brandl et al. 2013). It is clear that dark-coated cattle in feedlots are more susceptible to heat stress and are less productive during hot conditions compared to light coated cattle (Gaughan et al. 2010; Brown-Brandl et al. 2006). However, little work has been conducted in cows on pasture as it is logistically challenging to study heat stress on large pastures and rangelands. Furthermore, to our knowledge there is no heat stress work that has been conducted in Canadian feedlot or pasture settings.

There are a multitude of physiological and behavioral indicators of heat stress that can be monitored. Under high heat loads, cattle regulate their internal temperature through various mechanisms of heat dissipation. The most effective physiological mechanisms are increased sweating rates (convectional heat loss) and increased breathing rates (evaporative heat loss) (Finch et al. 1985). The rate of convectional and evaporative heat loss is largely affected by humidity (Finch et al. 1985; Finch et al. 1984). A significant portion of internal heat is also dissipated through conductive heat transfer between the internal tissue, skin, coat, and the surrounding layer of air around the coat. The rate of conductive heat transfer is determined by the coat’s resistance as well as the temperature gradient between the internal tissue and the environment (Finch 1985; Finch et al. 1984). Behavioral coping strategies also play a role in thermoregulation (as aforementioned). Behavioral responses to high heat load include seeking shade and water, decreasing feed intake, and minimizing activity (Lees et al. 2019).

The current methods used to measure heat stress are associated with challenges and limitations (Carabano et al. 2019). Monitoring physiological indicators of heat stress such as rumen temperature, rectal temperature, and vaginal temperature requires invasive devices that are reliable but may be cost prohibitive, especially in large-scale studies (Koltes et al. 2018). For example, Curtis et al. (2017) orally inserted bolus temperature sensors using a standard bolus gun to investigate the relationship between ambient air temperature and feed intake. Beatty et al. (2008) surgically implanted temperature loggers into the abdomen of cattle to investigate the thermal effect of feeding. Dikmen et al. (2014) vaginally inserted iButton temperature sensors and data loggers using a blank controlled internal drug releasing (CIDR) device to investigate thermotolerant traits in dairy cattle. Daltro et al. (2017) used a clinical veterinary thermometer to measure rectal temperature for assessing thermoregulatory responses to high heat loads in dairy cattle.

Monitoring behavioral indicators of heat stress such as respiration rate and panting score does not require invasive procedures (Lowe et al. 2019); however, many researchers report that they are difficult to measure in the field (Gaughan et al. 2008). Measuring behavioral responses in the field is time- and labor-intensive since it requires the observer to approach, at a close distance, individual cattle spread across a large feedlot or pasture under hot conditions (Gaughan et al. 2010). Wearable devices that can obtain automated measures of respiration rate (Brown-Brandl et al. 2005) may be expensive and logistically challenging, especially in large scale studies (Carabano et al. 2019). Given these challenges and limitations, there is a growing interest in developing more practical methods to study heat stress (Lowe et al. 2019; Koltes et al. 2018).

Consumer-grade unmanned aerial vehicles (UAVs) have great potential as effective tools for measuring behavioral indicators of heat stress. They can offer a safe and effective approach to observing animals in challenging terrain and/or animals spread throughout a large area. (Christie et al. 2016; Linchant et al. 2015). The battery life, reliability, and data collection capabilities of UAVs have led to many wildlife research applications and behavioral studies in diversity of taxa, such as songbirds (e.g., *Spizella passerina*) (Wilson et al. 2017), seals (*Halichoerus grypus*) (Seymour et al. 2017), humpback whales (*Megaptera novaeangliae*) (Hodgson et al. 2017), elephants (*Loxodonta africana*) (Vermeulen et al. 2013), and dugongs (*Dugong dugon*) (Hodgson et al. 2013).

UAVs have also recently been employed for a variety of cattle applications. For example, Andrew et al. (2017) developed a method for automated identification of Holstein cattle, based on coat color pattern recognition from UAV-based video. UAVs may also be used for automated enumeration of cattle in feedlots, which may be a more efficient approach compared to field counts (Shao et al. 2020; Whitehead et al. 2014). Nyamuryekung'e et al. (2016) used UAVs to predict feed intake and validated their predictions with ground measurements. Mufford et al. (2019) measured inter-individual distances between cows and calves to study social behavior.

Special sensors such as thermal imaging radiometers (TIR) that can be mounted on UAVs may also be effective tools for studying heat stress. Thermal imaging has many useful veterinary applications such as identifying estrus, measuring inflammation, and diagnosing disease (McManus et al. 2016; Rekant et al. 2016). Thermal imaging can also be used to determine methane production (Montanholi et al. 2008), assess residual feed intake (Martello et al. 2015), and measure respiration rate (Lowe et al. 2018). Researchers have explored the use of thermal imaging to study heat stress as well. For example, Unruh et al. (2017) demonstrated that the surface temperature of the side (i.e., from the spine to the abdomen) is associated with panting score. Yadav et al. (2016) showed that the skin temperature of the hind and fore limb is correlated with rectal temperature. Kotrba et al. (2007) imaged various regions of the body at a perpendicular angle to compare thermoregulation between elands (*Taurotragus oryx*) and dairy cattle (*Bos taurus*). Daltro et al. (2017) showed that the surface temperature of the udder in Holstein cattle is highly correlated to rectal temperature.

However, using handheld thermal imagers in the field is logistically challenging (Unruh et al. 2017). Handheld imagers may require intensive handling of animals since image capture needs to occur within a close distance to the animal (Daltro et al. 2017; Paim et al. 2018) Animal handling as well as the close proximity between the observer and the animal may induce stress and confound measurements taken by thermal imagers (McManus et al. 2016). Many researchers that use thermal imagers keep their subjects within a small, controlled pen as it is time- and labor-intensive to image cattle that are spread throughout a large pasture (Martello et al. 2015; Kortba et al. 2007). UAV-borne TIR sensors may address these limitations, as they are highly mobile and capable of capturing thermal-based images of animals in their environment without handling or modifying their environment.

The research objective in the second chapter of my thesis was to measure the surface temperature of Canadian Speckle Park x Black Angus cattle using a UAV-borne TIR sensor. The purpose of this objective was to collect preliminary data as part of a larger research question that extends beyond the scope of my thesis: Are light-coated variants more tolerant to solar radiation than dark-coated variants?

I compared surface temperatures between white-coated and black-coated individuals. I expected that light variants would have lower surface temperatures during peak solar radiation at the hair coat compared to dark variants. This may suggest that light coats gain less heat and therefor confers greater heat tolerance compared to dark. Since light coats have a higher albedo it should be expected that light coats would be cooler during peak solar radiation; however other coat characteristics such as reflectivity, density, and thickness may affect heat gain to a greater extent compared to the effect of coat color (Walsberg 1983).

There were two research objectives in the third chapter of my thesis:

1) Develop a method to study heat stress behavior using UAVs

2) Determine the effect of coat color on respiration rate in feedlot and pasture cattle

I developed a practical and effective method to measure respiration rate using UAV-based video and Observer XT software. I first developed this technique for feedlot cattle to examine the effect of coat color on respiration rate. After determining the logistical feasibility of this method to measure heat stress behavior, I then applied this method to compare respiration rate between red cattle and white cattle in a cow-calf pasture. The results of this study may help inform best heat stress management practices in Canadian beef production settings. The method developed in this study may also help address the current limitations and challenges associated with the current methods used to study heat stress in cattle.

The second chapter was written as a manuscript for potential publication in the Journal of Unmanned Vehicle Systems. The third chapter was also written as a manuscript for potential publication in the Canadian Journal of Animal Science. The introduction (chapter 1) and the general discussion chapter (chapter 4) were written to be published in the Thompson Rivers University open access digital archive of graduate research.

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CHAPTER 2: USING AERIAL THERMAL IMAGING TO COMPARE SURFACE TEMPERATURES BETWEEN LIGHT AND DARK VARIANTS OF BLACK ANGUS X CANADIAN SPECKLE PARK CATTLE

Introduction

Climate change models project that the number of days during which cattle experience heat stress will increase in many North American rangelands (Reeves & Bagne 2016). Heat stress is emerging as a major concern for the cattle industry in both tropical and temperate regions as it reduces foraging, growth, metabolic efficiency, and may increase mortality rates (Reeves & Bagne 2016; Bernabucci et al. 2010). In response, the industry needs to develop and adopt best management practices to mitigate losses in production.

Selecting for traits that confer tolerance towards solar radiation is a potential strategy to mitigate production loss in hot climates. Breeds with dark coats such as Black Angus and MARC III (1/4 Hereford, 1/4 Angus, 1/4 Pinzgauer, and 1/4 Red Poll) have a stronger thermoregulatory response (i.e., higher respiration rate and panting scores) to high radiative heat loads compared to breeds with light and/or thin coats such as Gelbvieh and Charolais (Brown-Brandl et al. 2006). Darker coats, having a lower albedo, absorb more solar radiation than light ones, which can increase heat gain compared to light coats (Finch 1985; Finch et al. 1984).

In North America, Black Angus is commonly used in beef production despite their susceptibility to heat stress compared to other breeds (Brown-Brandl et al. 2006). Cross breeding Angus with Canadian Speckle Park cattle and selecting for coat color may be a practical strategy to mitigate production loss caused by heat stress. Offspring produced by crossing Black Angus with Canadian Speckle Park are characterized by variation in coat color; they can be predominantly white, predominantly black, or mixed (i.e., varying ratios of black to white). Canadian Speckle Park was originally developed in Canada by selective crossbreeding between Tesswater Shorthorn, Aberdeen Angus, and British White cattle. In 2006, Canadian Speckle Park became officially recognized as a distinct breed in Canada.

This breed has similar characteristics (e.g., naturally polled, calm temperament) and carcass quality to Black Angus and may be more heat tolerant due to their light coat color.

In this study, we investigated differences in the surface temperature between dark and light variants of Black Angus x Canadian Speckle Park calves to examine the effect of coat color on surface temperature. We used a novel and non-invasive approach to measure the surface temperature of cattle coats in a field setting using data acquired by an unmanned aerial vehicle (UAV) borne thermal imaging radiometer (TIR). We expected that light coats would have lower surface temperatures compared to black coats when the sun is at peak height.

Methods

All the procedures used in our experiments were approved by the Animal Care Committee of Thompson Rivers University (Kamloops, B.C., Canada) (File number: 101909).

Animals and Study Site

Our study animals consisted of 24 calves, between two and three months old, produced from cross-breeding Black Angus heifers with Canadian Speckle Park bulls. Of these 23 calves, 15 were completely black. The other eight calves had either a leopard or speckled coat color pattern. The leopard pattern is defined by a white head and rump, a wide white stripe along the center of the back, and a speckled black and white pattern on the legs, feet and rounds. The speckled pattern is defined by a black head and rump, a wide white stripe along the center of the back, and a speckled black and white pattern on the legs, feet and rounds. We deemed the 15 black calves as dark variants and the eight remaining as light variants. Animals were held in an enclosed pen, near Monte Lake, British Columbia (N50°35’19.80”, W119°55’9.33”).

Image Acquisition and Environmental Data

To ensure that cattle behavior was not impacted by the presence of the UAV, the animals were habituated to the presence of the UAV in a gradual process that started three weeks prior to the data collection. During the first week of habituation, we flew our UAV at 40 meters above ground level (magl) over the cattle enclosure. In the second week, the UAV flight-level was lowered to 30 magl during the habituation flights, and in the third week, the flight level was further reduced to 16 magl. By the end of the third week, none of the cattle showed any behavioural response to the UAV flying above in a stationary position at 16 magl. Behavioral responses including sudden changes in position (i.e., lying to standing or standing to a fast walking pace), rapid head turns, and frequent tail flicking. Any cattle exhibiting these any of these behaviors during data collection were not included in the study. Cattle that did not show a behavioral response were considered habituated and were included in the study.

Image acquisition flights were performed on 21 June 2019, beginning at 1300 hours. The timing of the flights was selected to be within 1 hour of solar noon, which occurred at 1211 hours. Imaging flights were conducted at a flight-level of 16 magl. Thermal (TIR) and visual imagery was acquired by a DJI Zenmuse XT2 dual camera integrated with a DJI Inspire M210 V2 quadcopter (SZ DJI Technology Co. Ltd., Shenshen, China). This camera consists of a FLIR Tau 2 TIR imager and 4KL visual camera that captures TIR and red-green-blue (RGB) images simultaneously. The imager was attached directly to the UAV gimbal and was pointed in the downward direction (NADIR) during level flight.

The ambient air temperature, black globe temperature, max wind speed, and relative humidity were measured and automatically recorded at 10-minute intervals using a Kestrel 5400AG portable weather station (Nielsen-Kellerman Company, Boothwyn, PA, USA).

TIR Image Measurements

The TIR images are composed of 640 x 514 pixels and formatted as radiometric JPEG. Pixel temperatures were calculated using FLIR Tools + software (FLIR Systems, Inc., OR, USA) which applies Planck's Law and a user specified emissivity of 0.98; this is an appropriate value for measuring the surface temperature of cattle (McManus et al. 2016). A blackbody reference was not available in the field, so a calibration of the images beyond the factory calibration of the FLIR Tau 2 was not be performed. Although we did not field-calibrate the acquired TIR imagery because of logistical constraints, meaningful temperature differences between objects within the same image can still be calculated. According to the manufacturer's statement, the accuracy of the TIR imager is affected by the temperature of the sensor. However, because we only compared objects present within a single image, it is reasonable to assume that effect was constant for all objects within the image and thus, would not impact the computed within-image temperature differences.

The surface temperature of an individual animal’s coat was estimated by averaging the pixel temperatures within a polygon defining the animal’s back. This area was chosen because it receives the most direct sunlight around solar noon; the chosen width ensured that the background around the silhouette of the animal wasn’t unintentionally included. The polygons were manually digitized around the length of the spine from the shoulders to the rump; the width of each polygon evenly encompassed half the width of the animal on each side of the spine (Figure 1.1). The mean number of pixels ($n = 24$) within a polygon was 79 ($SD = 23$). Variation in body size of the calves, variable ground resolved distance (GRD) of pixels within the image, and error inherent in manual digitization of the animals are likely contributors to the variation of pixels within the polygons.

Because the images used in this study were not orthorectified, the GRD of pixels within the image will increase with distance from the focal center of the image. However, using reference features that appeared within moderate range of the focal point of the images, we estimated the GRD within moderate range of the focal center of the image to be approximately 3.3 cm^2. This was determined by measuring the number of pixels across a reference object in the image; the length of the reference object in centimeters was measured in the field.

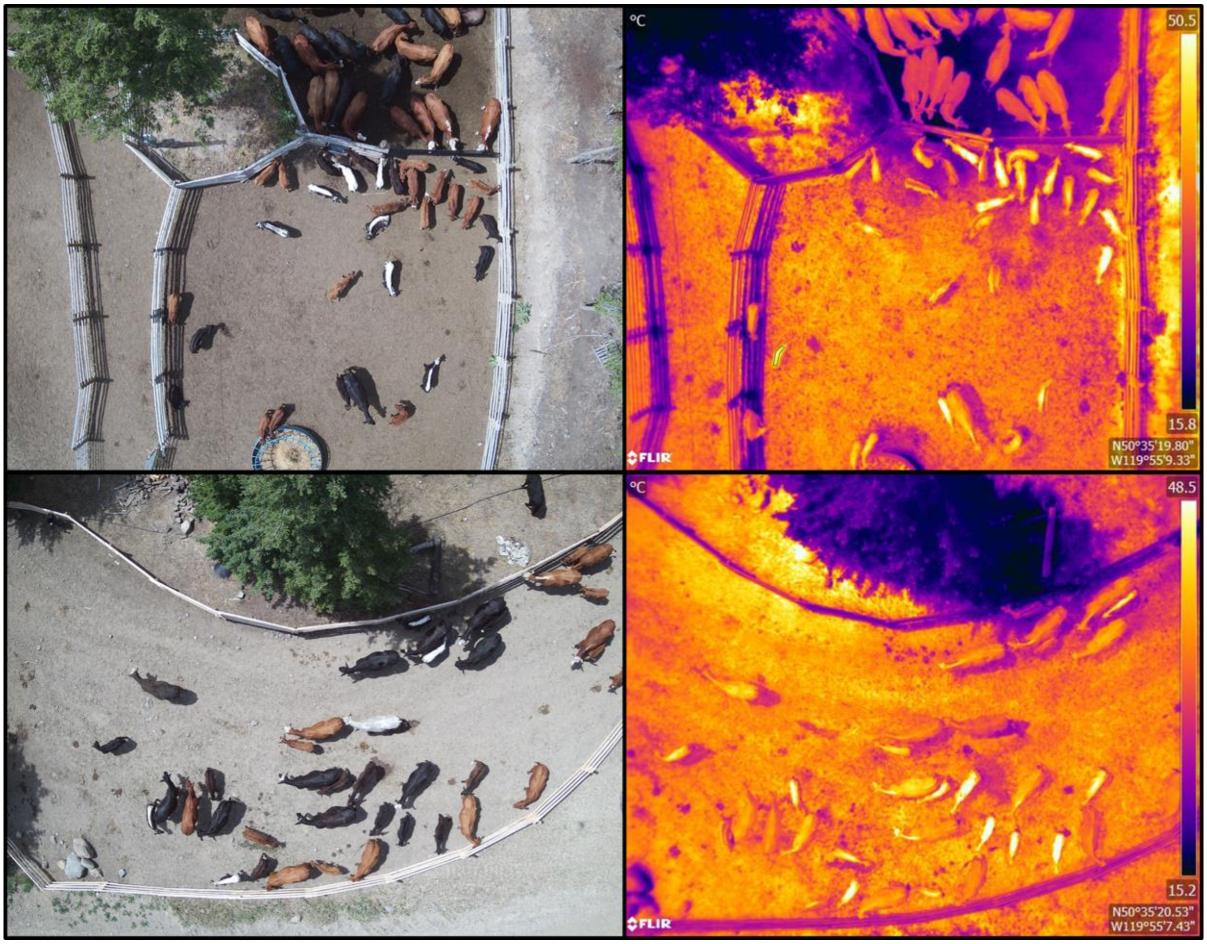

Figure 1.1 Radiometric jpeg images of beef cattle (right) and regular jpeg images (left) captured simultaneously. Imaged were captured by a quadcopter integrated with a TIR imager (640 x 512 pixels) and a 4KL visual camera to simultaneously capture a radiometric jpeg and an RGB image. A polygon around the surface of the back was manually drawn, in which the mean temperature of pixels was calculated, using FLIR Tools + Software; an example of a polygon is shown in green (top right).

Statistical Analysis

We conducted a 2-sample t-test to compare the mean surface temperature between dark variants and light variants; we did this separately for each image. Prior to conducting the T-Tests, the data were tested and found to be normally distributed and homoscedastic using a Shapiro normality test ($p > 0.1$) and an F-Test ($p > 0.1$), respectively. All tests were performed in R 3.4.3 statistical software (R Core Team 2017).

Results

In both images, the average surface temperature of dark calves was higher than that of light calves ($p < 0.001$) (Table 1.1).

Table 1.1. The mean surface temperature of dark variants and light variants, calculated from two separate TIR-based images. Different subscripts indicate that there was significant difference of mean temperature between the groups.

	Group	Mean Temperature (°C)	Standard deviation (°C)	n	T-test Result
Image 1	Dark^a	48.4	2.6	8	$p < 0.001$
	Light^b	35.4	1.7	3	
Image 2	Dark^a	48.7	3.6	7	$p < 0.001$
	Light^b	38.8	3.3	5	

The weather variables measured at the closest time before and after image capture had the following mean and standard deviations: Black globe temperature, 33.8 ± 0.5 °C; ambient air temperature, 19.7 ± 0.5 °C; relative humidity, 44.4 ± 1.3 %; max wind speed, 0.6 ± 0.2 km hr^{-1}.

Discussion

The rate of conductive heat transfer from the hair coat to the internal tissues depend on the coat’s resistance as well as the temperature gradient between the internal tissue, skin, and coat (Finch 1985). In this study, the gradient may have been greater in the dark variants as they have higher surface temperatures while their internal temperature should be similar to light variants. This suggests that dark variants may be more susceptible to heat stress as more radiant energy would be absorbed at the coat and transferred to internal tissue. Light variants with dark flanks but with a wide white stripe along the back would experience less heat gain, especially when the sun is at peak height. Further research should investigate the extent to which a high surface temperature gradient would affect internal heat gain, which could be measured by rumen temperature, rectal temperature, and/or vaginal temperature.

For future studies, the internal temperature should also be considered when imaging surface temperatures. Cattle continuously generate internal heat from metabolic activity (Finch et al. 1984), which is dissipated to peripheral tissue; this likely affects surface temperature measurements acquired by a thermal imager. In my study, I was not able to separate the effect of internally generated heat and solar heat on surface temperature. In the future, it may be a more effective approach to determine if surface temperature can be used as a proxy indicator of internal temperature (e.g., rectal temperature, vaginal temperature, rumen temperature). Although internal body temperature is considered the “gold standard” for measuring thermoregulation, there is much interest in developing tools that can easily measure proxies of internal temperature (Giro et al. 2019).

From a management perspective, measures of productivity (e.g., feed intake, average daily weight gain) should be compared between light and dark variants. If coat color affects heat gain but does not affect productivity during high radiative heat loads, then selecting for coat color may not have an economic benefit for producers. Determining the meat quality of Black Angus x Canadian Speckle Park may be another important research direction. Meat quality is an important aspect of breed selection in the beef production industry. For producers, it may be important for the meat quality of this crossbreed to be just as high as that of Black Angus.

If the selection of light color in Black Angus x Canadian Speckle Park cattle does improve thermotolerance and productivity, then breeding Canadian Speckle Park with Black Angus may be an effective approach to mitigate heat stress in Black Angus cattle. Black Angus are known to be more susceptible to heat stress than other commonly raised breeds (Gaughan et al. 2010; Brown-Brandl et al. 2006). Introducing heat tolerant traits through crossbreeding while maintaining most of the qualities that make Black Angus cattle popular can be potentially achieved through large-scale breeding programs.

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CHAPTER 3: USING UAVS TO MEASURE BEHAVIORAL INDICATORS OF HEAT STRESS IN CATTLE: THE EFFECT OF COAT COLOR ON RESPIRATION RATE

Introduction

Heat stress is a growing problem for both animal welfare and production in the cattle industry. Heat stress in cattle (*Bos taurus*) adversely affects growth, feed conversion efficiency, and reproductive performance (Bernabucci et al. 2019; Lees et al. 2019). In addition, heat waves can cause mortalities which result in economic losses (Lees et al. 2019). Climate change models predict that cattle will experience heat stress on a greater number of days (Reeves & Bagne 2016) as the average summer temperatures and the frequency and magnitude of heat waves are projected to increase (Pasqui et al. 2019; Coumou et al. 2012).

In response to the worsening problem of heat stress, there is interest in determining factors associated with heat stress susceptibility (Brown-Brandl 2013). Identifying these factors may be useful for mitigating production loss and improving animal welfare. Animals known to be susceptible to heat stress can be selectively managed; this can be more efficient than applying the same heat stress management procedure to every animal (Brown-Brandl & Jones 2011). Furthermore, determining cattle traits that either increase or reduce their susceptibility to heat stress could inform trait selection (Carabano et al. 2019).

One important factor that affects heat stress susceptibility is coat color. Darker coats, having a lower albedo, absorb more solar radiation than lighter coats (Hillman et al. 2005; Finch et al. 1985). The impact of coat color on heat stress is well studied in feedlot cattle (Brown-Brandl 2013) but little work has been conducted on cattle on pasture. Furthermore, little work has been done in Canada even though heat-stress mortality occurs in Canadian production settings (Bishop-Williams et al. 2016; Bishop-Williams et al. 2015).

Measuring indicators of heat stress in a cow-calf operation on pasture or rangeland is logistically challenging. Monitoring physiological indicators of heat stress such as rumen temperature requires invasive procedures and/or wearable devices that are reliable (Godyn et al. 2019) but may be cost prohibitive, especially in large scale studies (Carabano et al. 2019;

Koltes et al. 2018). Given these challenges and limitations, there is a growing interest in developing more effective tools to measure indicators of heat stress in cattle (Lowe et al. 2019; Koltes et al. 2018). Monitoring behavioral indicators may be logistically easier and more affordable. For example, respiration rate is a reliable indicator of heat stress that can be measured through observation without invasive surgical procedures (Lowe et al. 2019). However, respiration rate is time- and labor- intensive to measure in the field (Gaughan et al. 2010; Gaughan et al. 2008) as it requires the observer to approach, at a close distance, individual cattle spread across a large feedlot or pasture.

Unmanned aerial vehicles (UAVs) offer a non-invasive and practical approach to studying behavioral indicators of heat stress in cattle in both large-scale feedlots and pasture conditions. The battery life, affordability, and data-collection capability of consumer-grade UAVs have substantially improved in the last decade (Whitehead et al. 2014a; Whitehead et al. 2014b) and they have potential for use in cattle production and behavioural studies. UAVs have been used for identification (Andrew et al. 2017), enumeration (Shao et al. 2020; Whitehead et al. 2014b), monitoring feed intake (Nyamuryekung'e et al. 2016), and studying social behavior in cows (Mufford et al. 2019).

The first objective of this study was to develop a method to monitor behavioral indicators of heat stress in cattle using UAVs. We used aerial-based video collected from the UAV to quantify respiration rate and standing behavior. We first sought to validate this method by reproducing previous work studying factors associated with respiration rate in feedlot cattle (Brown-Brandl et al. 2006). The second objective of this study was to determine if coat color is associated with respiration rate in an extensive cow-calf pasture setting. We expected that darker-coated cattle would have stronger respiration rate responses to high radiative heat loads compared to light-coated cattle.

Methods

All the procedures used in our experiments were approved by the Animal Care Committee of Thompson Rivers University (Kamloops, B.C., Canada) (File number: 101909).

Site 1: Feedlot

The first study site was a feedlot operated by Kasco Cattle Company (Ltd.), located near Purple Springs, AB, Canada (49°50'38.2"N, 111°58'39.8"W). This feedlot contained 66 lots, each containing 100–200 beef cattle. Lots had a soil surface, and were 50 x 60 m; the feeding bunks faced an east/west orientation. In addition, lots were adjacent to each other, separated by eight-foot fencing and there were six rows of adjacent feedlots (See appendix A for aerial photograph of feedlot). Each lot contained a variety of breeds including, but not limited to, Black Angus, Hereford, Charolais, Canadian Speckle Park, Simmental and various crosses. Cattle that were recently treated for disease were identified by ear tag and excluded from the study. Grain feed was provided by truck once in the morning at 8000–1000 hours in a feed bunk along the width of each pen, which was freely accessible. Each lot contained a water trough that enabled ad libitum water intake. There were no artificial shade structures but fencing provided some shade for a few cattle depending on the time of day. Cattle along the shaded fence line were not included in the study. In total there were roughly 9000 steers throughout the feedlot. The average weight at arrival ranged between 450 to 700 kg and all individuals were kept on the lot for approximately three months.

Site 2: Pasture

The second study site was the University of Alberta Mattheis Research Ranch (50°53'41.8"N, 111°57'00.4"W). Two cow-calf herds in different pastures were included in the study. The first herd consisted of approximately 175 Black Angus cow-calf pairs and 15 Hereford cow-calf pairs; the age of the cows ranged from 5 to 10 years old. The second herd consisted of approximately 350 Hereford cow-calf pairs and 50 Black Angus cow-calf pairs; there was a wide range in age of the cows, 3 to 14 years old. Only cows were included in the study. Each pasture was approximately 300 ha of flat grassland with no shade from trees or artificial covers. Water was available in each pasture from natural sources or provided by truck to a watering trough on a consistent basis to ensure ad libitum water intake.

Data Collection

At the feedlot, data collection occurred between July 25 and Aug 2, and between Aug 8 and 10 during a morning period, 0830–1130 hours, and during an afternoon period, 1400–1700 hours. We used a DJI Mavic Pro quadcopter (Dà-Jiāng Innovations Science and Technology

Co., Ltd., Shenzhen, China) to record video of cattle at an altitude of 8–10 meters above ground level. Because we were unable to identify individuals, we ran the risk of pseudo-replication in sampling. To minimize the potential effects of pseudo-replication, during each data collection period, we flew the unmanned aerial vehicle (UAV) over randomly selected lots to record video of the cattle. After finishing recording in one lot, we immediately moved to another randomly selected lot if there was sufficient battery power. When the battery power was low, we flew the UAV back to its home point, exchanged batteries and immediately moved on to the next lot; battery exchanges took approximately 5 minutes. Within each lot we hovered the UAV over a randomly selected group of cattle, and recorded video for three minutes, with the UAV in a stationary position. After three minutes, we moved the UAV over a different randomly selected group of cattle within the same lot, recorded video and repeated this again to obtain three videos of cattle per lot. It is possible that the same individual may have been pseudo-replicated between each video if the individual moved across the lot between video recordings. However, we generally observed that within the time frame of the three recordings, most cattle did not move locations within the lot. Furthermore, the observer was able to keep track of movement throughout most of the lot through real-time video streaming between the UAV and the controller.

At the research pasture, data collection occurred between Aug 19 and 29, 2018. Each day we collected data during the morning period, 8030–1130 hours, and the afternoon period, 1400–1700 hours. The two herds studied were separated into different pastures spaced far enough apart that it was not logistically possible to collect data on both herds during the same period. On the first day we collected data on one herd for both collection periods; the second day we collected data on the other herd for both collection periods and we continued alternating herds each day. During the collection period, we flew the UAV over a randomly selected group of cattle in the herd and recorded video for three minutes at a stationary position at an altitude of approximately 8–10 m. After three minutes, we immediately flew the UAV to a different randomly selected group and recorded video if battery power allowed. If the battery power was low, we flew the UAV back to its home point, exchanged batteries, and flew back to the herd; battery exchanges took approximately 10 minutes. Exchanges required more time on pasture than on feedlot as cattle on pasture were farther away from the take-off point. We repeated this for the entire duration of the collection period. We manually flew the UAV but moved in a grid pattern to minimize the risk of sampling the same cattle.

Prior to data collection at the pasture and the feedlot, cattle were given a week to habituate to the UAV. On the first day of exposure, we flew the UAV over the cattle at an altitude of 100 m and gradually descended to 80 m, hovered stationary over the cattle and flew in various directions haphazardly above them. We descended 20 m lower each subsequent day and repeated this process each day until we reached 10 m. At 10 m, most cattle did not react to the UAV, but some showed behavioral responses, including sudden changes in position (i.e., lying to standing or standing to a fast walking pace), rapid head turns, and frequent tail flicking. Any cattle exhibiting these behaviors during the data collection period were not included in the study. Cattle that did not show a behavioral response were considered habituated and were included in the study.

Environmental Data

A Kestrel 5400AG portable weather station (Nielsen-Kellerman Company, Boothwyn, PA, USA) was used throughout all data collection periods at both sites to measure wind speed, black globe temperature, ambient air temperature and relative humidity. These variables were used to determine the heat load index (HLI), which was calculated as follows, originally described by Gaughan et al. (2008):

If $Ta > 25$ °C, then $HLI = 8.62 + (0.38 \times RH) + (1.55 \times Tbg) - (0.5 \times WS + e(2.4 - WS))$

If $Ta < 25$ °C, then $HLI = 10.66 + (0.28 \times RH) + (1.3 \times Tbg) - WS$

where Ta is the ambient air temperature (°C), RH the relative humidity (%), Tbg the black globe temperature (°C), and WS the wind speed (m/s).

HLI is highly predictive of heat stress behavior in cattle (Brown-Brandl 2013; Gaughan et al. 2008). These conditions were measured and automatically recorded every 10 minutes. The portable weather station was mounted on a tripod within 1 km of the study animals at the feedlot and within 3 km of the study animals at the research ranch.

Data Acquisition

Videos of cattle captured by the UAV were processed in Observer XT Software (Noldus, Information Technology Wageningen, The Netherlands) to quantify respiration rate and behavior (See Table 2.1 for ethogram). Multiple animals were captured in each video so each animal was analyzed individually. Respiration rate was quantified by counting flank movements for three minutes; each flank movement was recorded and time stamped as a behavioral event. Within those three minutes, any behavior that obscured flank movement was also recorded and time stamped as a behavioral event. These behaviors included changing positions, skin twitching, grooming, and regurgitating. Lying, walking, and standing were recorded as duration behaviors. The Observer coding system was configured such that behavioral events can be recorded at the same time that standing, lying, and walking are recorded. Only observations in which the flank movements were observable for at least two minutes were included in the dataset.

Table 2.1. Ethogram of behaviors that were recorded in Observer XT. Behaviors denoted with an asterisk (*) were recorded as events; all other behaviors were recorded as durations.

Behavior	Definition
*Inhale	Flanks expand and collapse at a steady rate
*Regurgitate	Flanks abruptly expand and collapse during a break between chewing
*Skin twitch	The skin shakes and obscures view of inhale events
*Groom	Head is turned to the side to lick the coat
*Change positions	Adjusts position of the flank and/or legs while lying
Standing	All four legs are in an upright position
Lying	The flank is in contact with the ground
Walking	Both the front and back legs are moving

The time duration of a behavioral event that obscured flank movement was determined by calculating the duration of time between the flank movement that occurred before and after the behavioral event. We determined the time during which flank movements were observable by subtracting the total observation time by the total time spent exhibiting behaviors that obscured flank movement. Respiration rate was calculated by dividing the total flank movements by the time (seconds) during which flank movements were observable. This value was multiplied by 60 to obtain breaths per minute (BPM).

Analysis of videos was randomly divided between three observers. The intra- and inter-reliability was determined by comparing BPM scores. Each observer randomly selected 25 cattle and quantified BPM on each individual twice. The intra-observer reliability measured by correlation (i.e., linear regression) was 0.70, 0.80, and 0.98 for the three observers. (See Appendix B for distributions and regression models). To determine inter-observer reliability, each observer quantified BPM of the same 40 cattle, which were randomly selected. The inter-observer reliability, measured by correlation for each pair of observers was high (r2 = 0.89, 0.90, and 0.91). Both the intra- and inter-reliability scores were comparable to other behavioral studies (Vogt et al. 2017; Gutmann et al. 2015; Schutz et al. 2011).

Statistical Analysis

We first examined the factors associated with respiration rate in feedlot cattle and pasture cattle, separately. We used a linear mixed model in R 3.4.3 statistical software (R Core Team 2017). Coat color (red, black, or white), HLI, and an HLI-coat color interaction term were treated as fixed effects. Because sampling sites were repeated, we treated lot (i.e., which lot or which herd) as a random effect. The alpha level was set at 0.05. Effects were deemed significant if $p < 0.05$. Day and time of day were not included in the model since they are associated with HLI. We did not include individual in the model since we were not able to distinguish unique individual cattle.

We also wished to determine which factors were associated with posture (i.e., standing or lying treated as a binomial response) using both feedlot and pasture cattle within a single data set. To do so, we conducted a generalized linear mixed model (GLMM) with binomial error distribution and logit link function in R statistical software (R Core Team 2017). Coat color, setting, and HLI were treated as fixed effects. The HLI-setting and HLI-coat color interactions were also treated as fixed effects. Lot was treated as a random effect. The alpha level was at 0.05.

For posture behavior, very few cattle spent time walking during an observation, so any walking durations that were scored were later converted to standing durations. The time spent standing and lying were first calculated as a proportion relative to the total time of the observation. Proportions were then converted into a categorical response (i.e., standing or lying). Standing more than half of the observation time was categorized as standing. Lying more than half of the observation time was categorized as lying. We categorized posture as binomial responses because only a small fraction of the cattle spent time both lying and standing within an observation (i.e., within 3 minutes) (see Appendix A for distribution). Most of the cattle were either standing during the entire observation or lying during the entire observation.

Results

In the feedlot, coat color affected respiration rate ($F_{[2, 871]} = 20.69$, $p < 0.001$) (Table 2.2) (See Appendix C for distribution of model terms). Respiration rate was the greatest for black, followed by red and then by white animals. The rate of respiration increased with HLI ($F_{[1, 872]} = 207.5$, $p < 0.001$; Figure 2.1). The HLI:coat color interaction was not significant ($F_{[2, 871]} = 0.025$, $p = 0.98$). In the pasture, respiration increased with HLI ($F_{[1, 261]} = 88.71$, $p < 0.001$). Coat color did not influence respiration rate ($F_{[1, 261]} = 1.53$, $p = 0.22$) nor was the interaction term significant (HLI:coat color: $F_{[1, 261]} = 0.033$, $p = 0.85$).

Table 2.2. Model estimates for terms that were modelled as factors associated with respiration rate. Separate models were used for feedlot cattle and pasture cattle.

	Factor	p value	DF
Feedlot	HLI	< 0.001	1
	Color	< 0.001	2
	HLI:Color	0.97	2
Pasture	HLI	< 0.001	1
	Color	0.72	1
	HLI:Color	0.85	1

In the pilot work for this study, we found that over a three-minute period, the respiration rate within a one-minute time interval can change by 40 BPM in the subsequent one-minute time interval. Therefore, despite the inter- and intra-reliability error, taking the average respiration rate over a three-minute period was more accurate than extrapolating respiration rate from a short time interval sample.

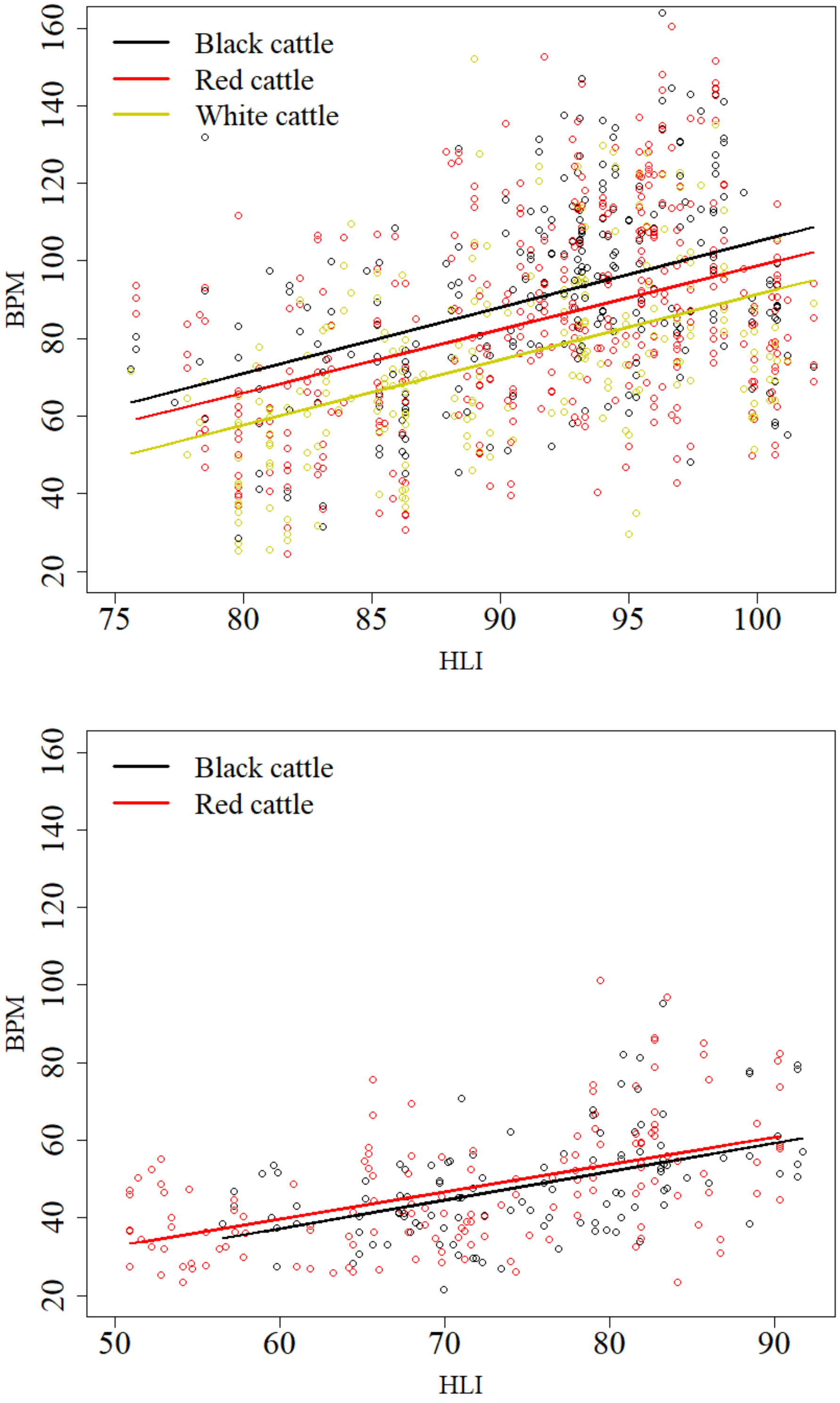

Figure 2.1. Respiration rate responses [breaths per minute (BPM)] to increasing heat load index (HLI) in feedlot steers (top) and suckling cows on pasture (bottom).

The probability that cattle would be standing, instead of lying, increased with HLI (p = 0.03) (Figure 2.2). Coat color, setting (i.e., feedlot or pasture), coat color-HLI interaction, setting-HLI interaction, and lot did not determine cattle posture (p > 0.13).

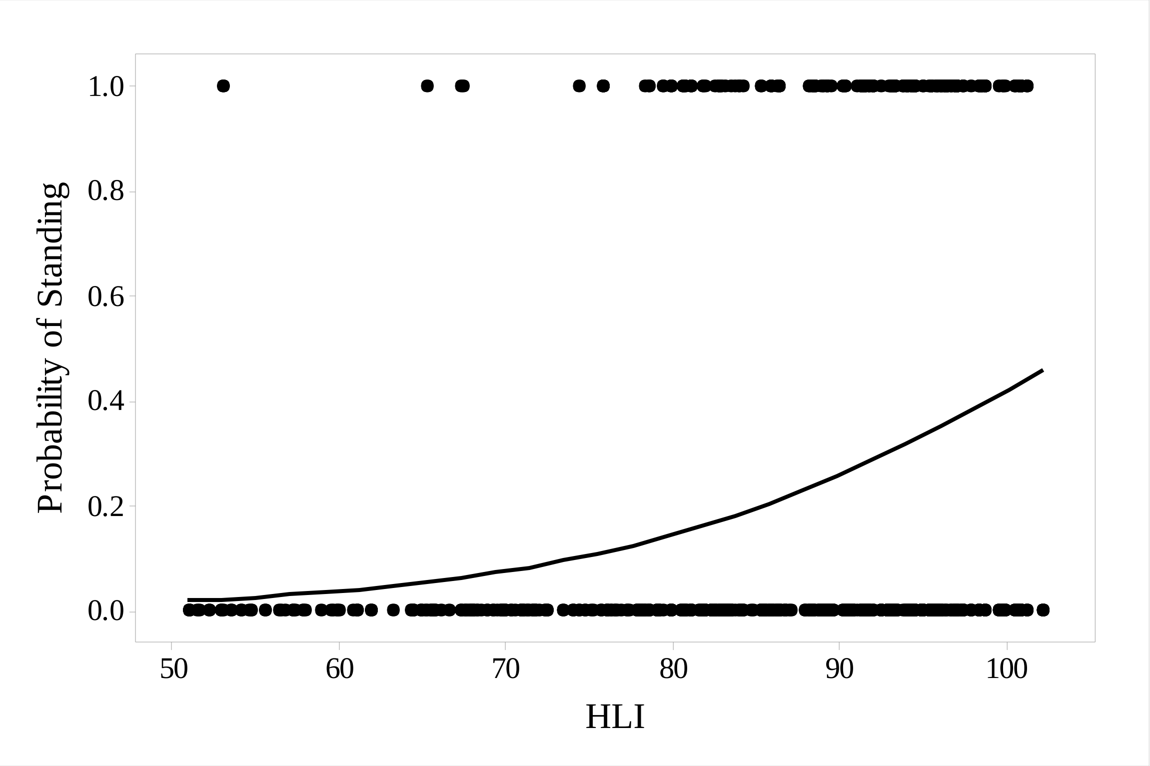

Figure 2.2. Effect of heat load index (HLI) on the probability of standing for pasture and feedlot cattle. The curve represents how the probability of standing changes as HLI increases.

The range of the heat load index during feedlot observations (75.6 – 102.2) was higher than that of the pasture observations (50.9 – 91.7). The range of the ambient air temperature, black globe temperature, relative humidity, and wind speed are summarized in table 2.3.

Table 2.3. The mean and range of weather conditions during feedlot observations and pasture observations.

	Feedlot		Pasture	
	Range	Mean	Range	Mean
Ambient temp (°C)	18 – 38.9	28.9	10 – 33.2	21.9
BG temp (°C)	27.3 – 51.5	41.2	15 – 40.8	32.1
Rh (%)	17.3 – 70.5	36	19.4 – 60	42.6
Wind speed (m/s)	0 – 3.1	1.1	1.3 – 5.7	1.9
Heat load index (HLI)	75.6 – 102.2	91.3	50.9 – 91.7	73
Temperature-humidity index (THI)	63.4 – 83.4	74.3	51.8 – 77.1	66

Discussion

We successfully used UAVs to measure behavioral indicators of heat stress in a large-scale feedlot, reproducing the work of similar feedlot studies investigating behavioral indicators of stress (i.e., panting and/or respiration rate) (Gaughan et al. 2010; Brown-Brandl et al. 2006; Brown-Brandl et al. 2005). Consistent with these studies, respiration rate increased with HLI, and dark-coated cattle were more susceptible to heat stress than light-coated cattle in the feedlot. We then applied this method to examine the effect of color on respiration rate in pasture cattle. Unlike feedlot cattle, coat color did not influence respiration rate.

In feedlot cattle, the respiration rate was the highest in black cattle (bpm), followed by red (bpm) cattle, then white cattle (bpm), across all weather conditions. This finding is consistent with other studies that modelled factors associated with behavioral indicators of heat stress in feedlots in the United States (Gaughan et al. 2010; Brown-Brandl et al. 2006). However, the HLI-coat color interaction was not significant. Based on previous work (Brown-Brandl et al. 2006), we suspect that the interaction may have been significant if we had observed cattle in cooler conditions which would have caused a convergence of breathing rates in cooler ambient conditions. All observations of feedlot cattle took place above an HLI of 75 and an HLI above 70 is considered to be above the thermal neutral zone (TNZ) for feedlot cattle (Gaughan et al. 2010). Other than individual variation, the respiration rate should not differ between cattle when they are in their TNZ. Thus, the respiration rate response between black, red, and white cattle may differ as the HLI increases above their TNZ.

To our knowledge, this is the first study to examine heat stress indicators in feedlot cattle in Canada. The feedlot in this study is located in an area with a high density of feedlot operations. Veterinarians and producers in this region anecdotally report that heat stress is a significant concern during summer heat waves (personal communications); concurrently, the magnitude and frequency of heat waves are projected to increase (Pasqui et al. 2019; Coumou et al. 2012). The results of this study suggest that dark-coated cattle are more heat stressed in hot conditions compared to light-coated cattle. It is likely that dark-coated cattle are less productive than light-coated cattle in hot conditions but further research is needed to make a direct comparison of productivity (e.g., feeding rate and growth rate). It may also be worth conducting a cost-benefit analysis of selectively applying shading structures and/or sprinkling systems to dark-coated cattle.

In contrast to the feedlot, cows in pasture with different coat colors did not differ in respiration rate. Pasture cattle were observed within an HLI range of 50.9-91.7, part of the range being above their TNZ. The lack of difference shows that coat color does not have a significant impact on heat stress in this HLI range. The effect of coat color may not manifest until a certain hotter temperature threshold. Further research should make this comparison on days with a higher heat load index.

It is possible that feedlot steers are more susceptible to heat stress compared to cows on pasture. Because feedlot cattle are on grain- and cereal-based diets, they would produce more metabolically generated heat than pasture cattle, which consume less energetically-dense forage (Summer et al. 2019; Jacob et al. 2014). The feedlot cattle included in this study may have had, on average, a higher body condition score (i.e., more fat cover directly underneath the skin) than pasture cattle. Cattle with higher condition scores have higher respiration responses to high heat loads (Brown-Brandl et al. 2006) as fat cover affects heat dissipation (Brown-Brandl & Jones 2011). Generally, feedlot cattle close to their finishing weight have high condition scores (Gaughan et al. 2008; Brown-Brandl et al. 2006) compared to cows in cow-calf operations (Nephawe et al. 2004) that need to be in moderate condition for optimal reproductive performance (Diskin & Kenny 2016). Feedlot steers may have been heavier on average than cows; heavier cattle are more susceptible to heat stress (Brown-Brandl & Jones 2011). The range of arrival weight of feedlot steers was 450 - 700 kg; there was no available data on the weight of cows in this study but the average mature weight (measured at 4 years old) of beef cows is approximately 520 kg (Nephawe et al. 2004). The effect of sex may also explain differences in heat stress susceptibility between feedlot steers and pasture cows; we are unable to separate the effects of sex from animal factors (body size and fat cover) or from the operational context (pasture vs feedlot).

We also sought to determine if this method could be used to observe posture (i.e., lying/standing), another behavioral indicator of heat stress. As HLI increases, cattle are more likely to stand, regardless of coat color, in both pasture and feedlot cattle. This is likely because more surface area is exposed while standing which facilitates greater convective heat loss. Other studies have shown that standing increases as HLI (Tucker et al. 2008), temperature-humidity index (THI) (Provolo & Riva 2009), and dry bulb temperature (Brown-Brandl et al. 2006) increase.

Future research should further improve the efficacy of UAVs as a tool for measuring heat stress behavior. For example, camera lenses with optical zoom are available on consumer grade UAVs such as the one in this study; zoom lenses would make it possible to identify individual cattle within an extensive feedlot/pasture. Identifying cattle would be necessary for relating heat stress responses to biomarkers of heat stress (e.g., blood parameters) (Carabano et al. 2019). Furthermore, identification would be useful for determining how individuals acclimate to hot environments over time (Bernabucci et al. 2010). Zoom lenses would eliminate or minimize the effect of pseudo-replication in future studies similar to this. Other behaviors associated with heat stress can also be identified by aerial-based video; for example, panting is a severe sign of heat stress and identifying this behavior would be useful from a management perspective. Potentially, quantifying respiration rate could be automated through the use of machine learning, which would substantially decrease time and labor for large-scale studies (Lowe et al. 2019; Koltes et al. 2018).

This study has demonstrated that consumer-grade UAVs can be used as an effective tool for measuring the heat stress behavior of cattle in large-scale feedlot and pasture operations. The method we have developed also has the potential to be used as a diagnostic tool for cattle health during extreme heat waves.

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CHAPTER 4: GENERAL DISCUSSION

General Discussion of Chapter 2

In the second chapter of my thesis, I used a UAV-borne thermal imager to compare the surface temperatures between black-coated variants and white-coated variants of Black Angus x Canadian Speckle Park cattle. I determined that light-coated variants had lower surface temperatures than dark-coated variants around solar noon, which was most likely due to the albedo effect. These results were consistent with studies that directly measured heat gain (Hillman et al. 2005; Finch 1985). My study may have provided a snapshot of the solar radiation absorption potential of light and dark coats (i.e., to what extent did each coat color absorb solar radiation), though we did not directly measure this.

The albedo effect is already a well-known phenomenon; however, there was merit in our surface temperature comparisons of hair coats. Other coat characteristics (e.g., density, thickness, reflectivity) can have a greater effect on heat gain than the effect of color (Walsberg 1983). It is possible that in Canadian Speckle Park cattle, coat characteristics other than color could have had a large influence on heat gain. To my knowledge, the hair coat characteristics of Canadian Speckle Park have not been studied previously.

The results of my study suggest that light-coated variants may be more tolerant to high radiative heat loads than dark-coated variants. During times of peak sunlight, it is possible that less heat from the coat would be transferred to internal tissue in light-coated animals. As a result, light-coated animals would need to dissipate less heat gained from the sun, which would increase their tolerance to high radiative heat loads. Future research is needed to determine the extent to which light coats affect internal heat gain and the extent to which this affects their balance of internal temperature.

There were technical limitations in the particular thermal imager used in this study that constrained the study design. The imager required a blackbody to calibrate the temperature measurements. Calibration is necessary to compare measurements between animals among different images. It was too logistically challenging to ensure that cattle were always near blackbodies in an open pasture. To address this issue, we compared measurements of animals within the same image frame and conducted separate statistical analyses for each image. Though we found a solution to the calibration problem, the issue would likely arise in larger pastures in which individual study animals are likely to be spaced farther apart. Therefore, the particular imager used in this study may be best suited for feedlots and small pastures. Feedlot cattle are typically grouped in higher densities so it would be feasible to image multiple animals within the same frame. It would also be easier to ensure that a blackbody is captured in the same frame as the animals in feedlot pens.

For future research, it would also be more effective and practical to use a thermal imager with greater accuracy. According to the manufacturer statement, the imager used in this study has an accuracy of ± 10° Celsius, which depends on the temperature of the imaging sensor. While we were able to make meaningful comparisons between animals despite the low accuracy, we were not confident to report the absolute temperature of individual animals nor the mean temperature of groups. Accurate measurements of absolute temperature would be required to address certain research questions — for example, determining the relationship between surface temperature and internal temperature.

The analysis of thermal-based images can potentially be improved through automation (Jorquera-Chavez et al. 2019). In my study, the silhouette of an animal was manually digitized as a polygon to define the region in which the average temperature of pixels was measured. Manual digitization is time intensive and it is difficult to standardize the size of each polygon with consistency. Furthermore, with manual digitization, there is the risk of inadvertently including pixels associated with the background terrain into the polygon of interest (i.e., edge effect). Defining the area of interest can be potentially automated through machine learning methods. This would greatly reduce the time required of this method, reduce the risk of edge effects, and ensure that the size of each polygon is consistent. Potentially, a program could also be developed to identify/define the area of interest and calculate the surface temperature in real time on the UAV controller display. This would reduce the time- and labor- associated with data collection and allow for real-time monitoring.

General Discussion of Chapter 3

In the third chapter of my thesis, I used UAVs and Observer XT software to measure the respiration rate of cattle on pasture and in feedlot pens. I determined that in feedlot cattle, the respiration rate was the highest in black cattle, followed by red cattle, and in turn white cattle during hot conditions. These results are consistent to similar studies that examined the effect of coat color on heat stress behavior (Gaughan et al. 2010; Brown-Brandl et al. 2006; Brown-Brandl et al. 2005) in feedlot cattle in the US. Unexpectedly, in pasture cattle, I did not observe any differences in respiration rate between red cattle and white cattle.

The high respiration rates observed in hot conditions by UAV-based video in this study is comparable to other studies where high respiration rates were associated with decreased productivity (Dikmen et al. 2014). Thus, it is likely that heat stress caused productivity loss in feedlot cattle. It is also possible that dark-coated cattle in this study were less productive than light-coated cattle.

The heat wave observed in this study was similar in magnitude and duration to heat waves that occurred in recent summers. Thus, feedlot producers in the Southern Alberta region may benefit from implementing cooling systems for cattle that do not already have them in place (e.g., shading structures, sprinkling). Veterinarians and producers in this region report that heat stress is a significant concern during summer heat waves, yet many feedlots do not have cooling systems (personal communications).

Further research should compare measures of productivity between dark-coated and light-coated feedlot animals. The effect of heat load on productivity should also be determined. It possible that cattle may exhibit behavioral responses to heat stress while maintaining their regular rate of productivity. For feedlot producers, the cost of implementing cooling systems may not be worth the economic return of reducing heat stress.

Future research should also determine if coat color affects heat stress behavior in hotter conditions for pasture cattle. Although we did not observe a difference between red cattle and black cattle in pasture cattle, pasture cows may be more heat tolerant than feedlot steers due to differences in size, fat cover, and diet. If coat color does affect heat stress in pasture cattle, there are potentially effective ways to selectively manage dark-coated cattle since herds are often grouped by breed. For example, in pastures with multiple pens, producers could rotate Black Angus cattle through pens that have plenty of natural shade structures and rotate Hereford cattle through pens that lack natural shade structures.

Using UAVs to measure respiration rate in cattle can be improved in future research. The camera used in this study was able to resolve ear tags that directly faced the camera. Ear tags that were angled from the camera and/or reflected sunlight were difficult to read from video. Using a camera with optical zoom — for example, the camera built into the DJI Mavic 2 Zoom — would make identification much easier. Better identification of study animals would eliminate or minimize the effect of pseudo-replication and provide more data on individuals such as breed and age. Quantifying respiration rate on video could be potentially automated with the use of machine learning. This would reduce the time required of this method, which would benefit large-scale studies. A software program could be developed to determine respiration rate from a 15-second sample of video in real time on the UAV controller interface. This would again reduce the time- and labor- associated with data collection and allow for real-time monitoring.

The growing problem of heat stress in the cattle industry due to climate change prompts researchers and producers to ask the question: How do we adapt? (Bernabucci et al. 2019). Adapting cattle by increasing their heat tolerance is a potential strategy that has gained much interest. In principle, increasing heat tolerance may be an effective strategy but it is challenging to measure heat tolerance, especially in large-scale studies (Carabano et al. 2019). Developing practical and effective methods to measure heat tolerance would help drive this research forward. Indeed, various researchers have recently developed novel methods to measure behavioral/physiological indices of heat stress. For example, Jorquera-Chavez et al. (2019) used machine learning methods to automate measurements of respiration rate and heart rate from thermal-based video.

Most studies on heat stress involve examining one or a combination of behavioral/physiological responses such as respiration rate, panting behavior, and internal temperature. These measures have been useful for evaluating the efficacy of cooling techniques (e.g., shading, sprinkling), compare heat tolerance between breeds, and evaluate traits that are hypothesized to confer heat tolerance (Dikmen et al. 2014; Brown-Brandl et al.

2010; Gaughan et al. 2010). However, studies that only measure behavioral/physiological responses to heat stress lack any information on productivity (e.g., growth rate, daily feed intake). Thus, heat stress measures alone cannot inform changes in management because producers may need an economic-based justification. Yet, very few studies determine both measures of heat stress and measures of productivity. This may be because of logistical and practical challenges.

One potential research direction to address these challenges would be to develop practical, automated tools that can collect physiological/behavioral data and productivity data as well as aid in animal management. For example, RFID ear-tags are incredibly useful for animal management as they can be used for identification and store information about the owner and the medical history of the animal (Voulodimos et al. 2010). Recently, ear-tags have been developed with an accelerometer to measure feeding behavior (Wolfger et al. 2015). They can potentially be built to measure tympanic temperature (Giro et al. 2019), which has shown to be correlated with internal temperature (Godyn et al. 2019). Implementing an ear tag with these capabilities would provide useful measures of heat stress and productivity to answer research questions while providing an economic benefit to the producer.

UAVs can also be developed to simultaneously track measures of productivity and heat stress. Larger UAVs can be equipped with multiple sensors to collect various types of data; for example, a UAV equipped with a thermal imager and a video camera containing zoom lenses. Potentially, the video camera could be used to identify the animal, determine the GPS location of the animal, and measure behavioral signs of heat stress. At the same time, the thermal imager could measure physiological signs of heat stress. Potentially, UAV-based imagery could also be used to predict body weight (Gomes et al. 2016).

Furthermore, UAVs can also serve as a mobile radio-telemetry receiver for an internal temperature sensor implanted inside individual cattle. This may be an effective method to examine thermoregulation of cattle in large-scale operations. Typically, internal temperature sensors communicate with a receiver that is stationed somewhere near the study site (for example, see Curtis et al. 2017). This system restricts the size of the study site since the communication between the transmitter and receiver weakens over long distances (Godyn et al. 2019) This issue can be solved by waiting to obtain the data until after the study ends; however, with this approach, faulty transmitters and improper insertions cannot be detected until it is too late.

Conclusion

In my thesis, I explored the use of UAVs and UAV-borne thermal imagers as tools to measure cattle heat stress. I have demonstrated that consumer-grade UAVs can be used as an effective, practical and affordable tool to measure heat stress behavior in cattle. I have also demonstrated that UAV-borne thermal imagers can potentially be an effective research tool; however, research and investigation is needed to develop the tool further.

To my knowledge, this is the first study examining heat stress in a western Canadian feedlot and pasture. As the average summer temperatures and heat waves will worsen due to climate change in coming years, especially in western Canada, producers likely need to adapt both their animals and management practices. In my study, feedlot cattle and pasture cattle showed clear behavioral responses to high heat loads typical of current Canadian production environments. I also observed that dark-coated cattle showed stronger heat stress responses, and gained more solar heat at the coat surface, compared to light-coated cattle. This highlights the potential for producers to selectively manage dark-coated cattle, and the potential merit of introducing the light coat color trait into the popular Black Angus, by crossbreeding with Canadian Speckle Park cattle.

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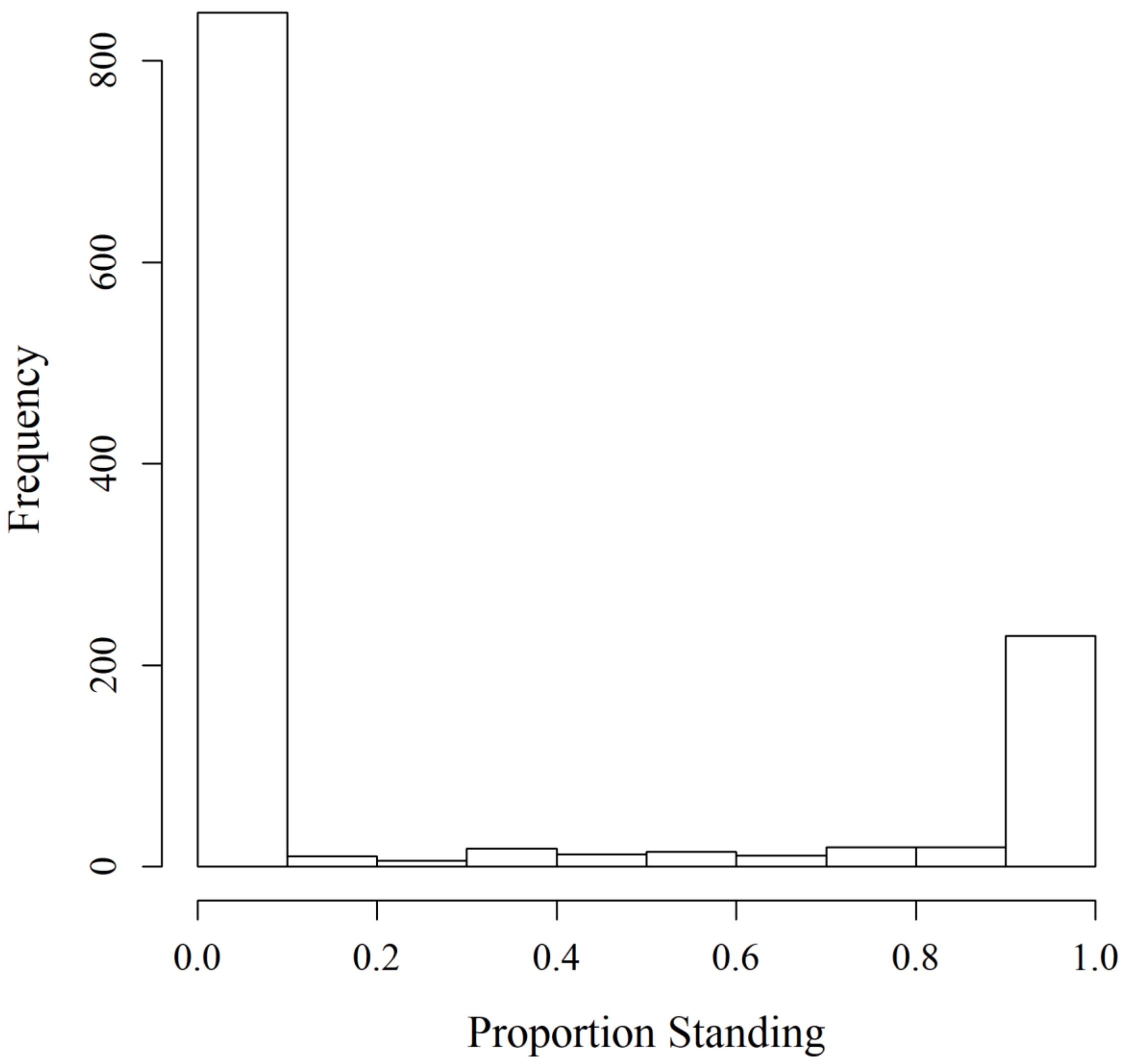
APPENDIX A

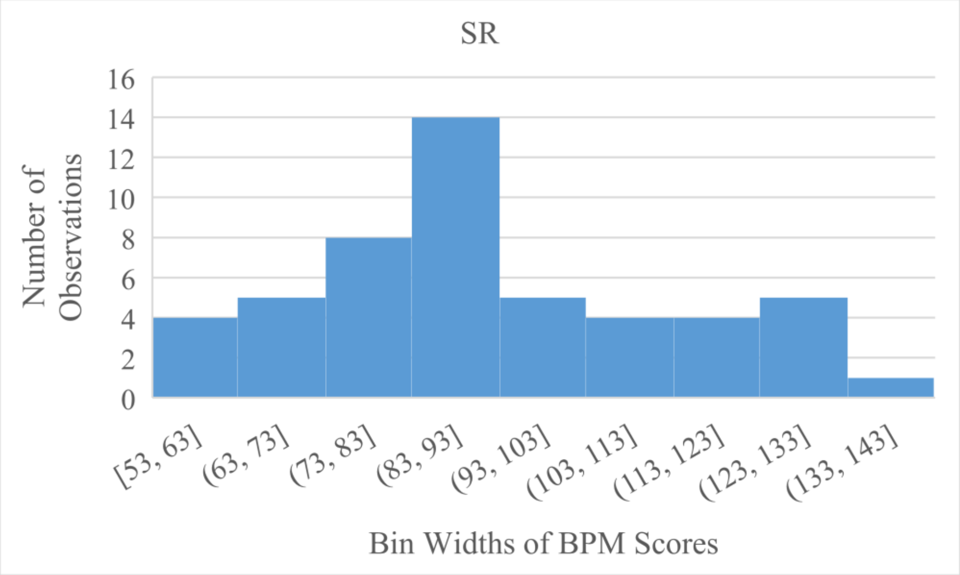
Study site 1: Kasco Cattle Company (Ltd.) (49°50'38.2"N, 111°58'39.8"W).

Frequency distribution of proportion of time standing within a 3-minute observation period for all feedlot and pasture cattle.

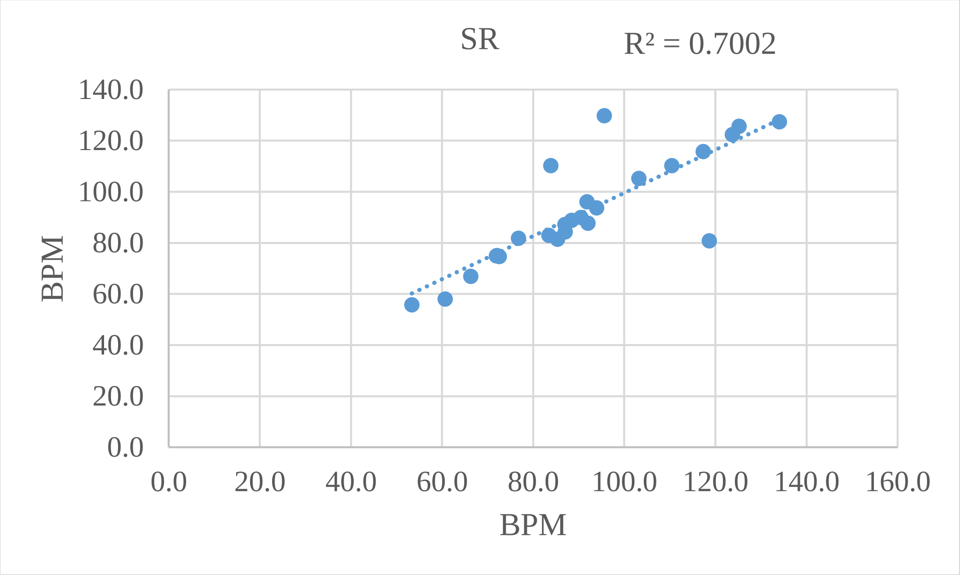


APPENDIX B

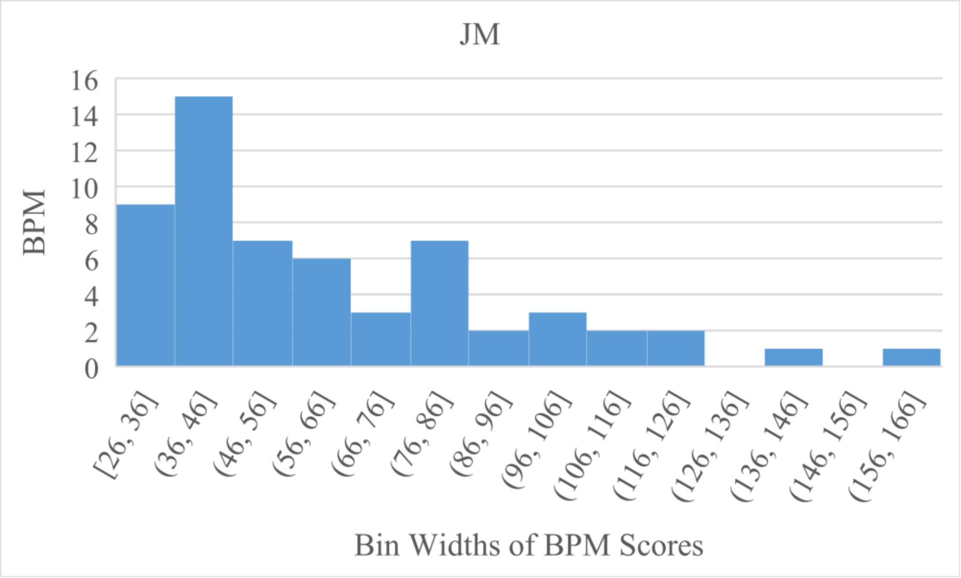
Intra-reliability tests: Regression models and distributions



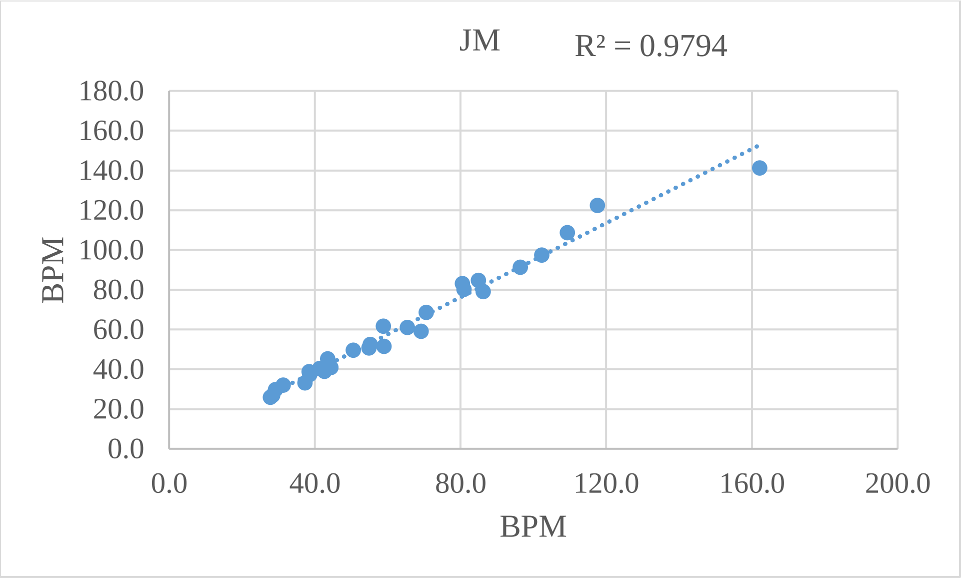
The BPM scores used for the intra-reliability test for observer “SR” are normally distributed ($p > 0.05$)



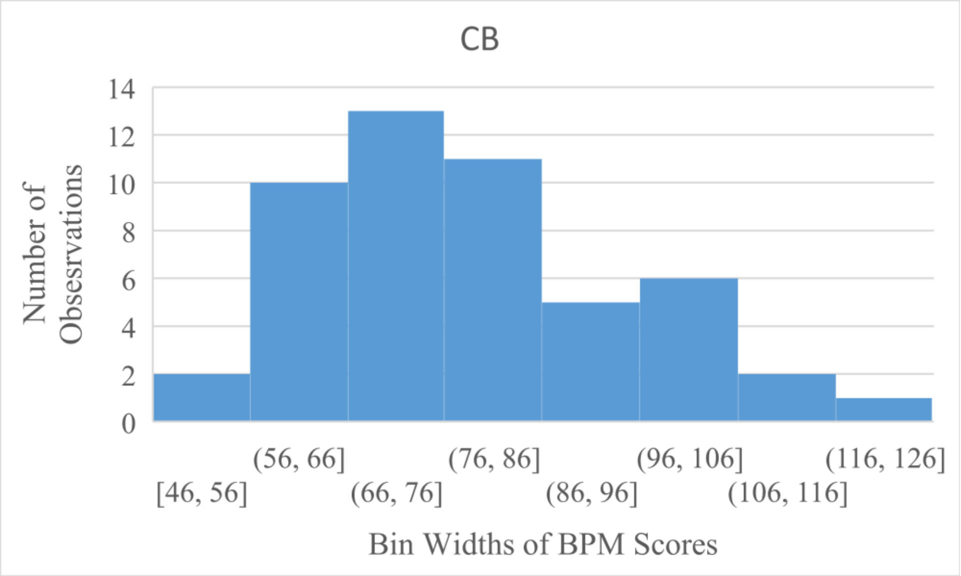
Intra-reliability score of observer “SR”: $R^2 = 0.70$ (linear regression)



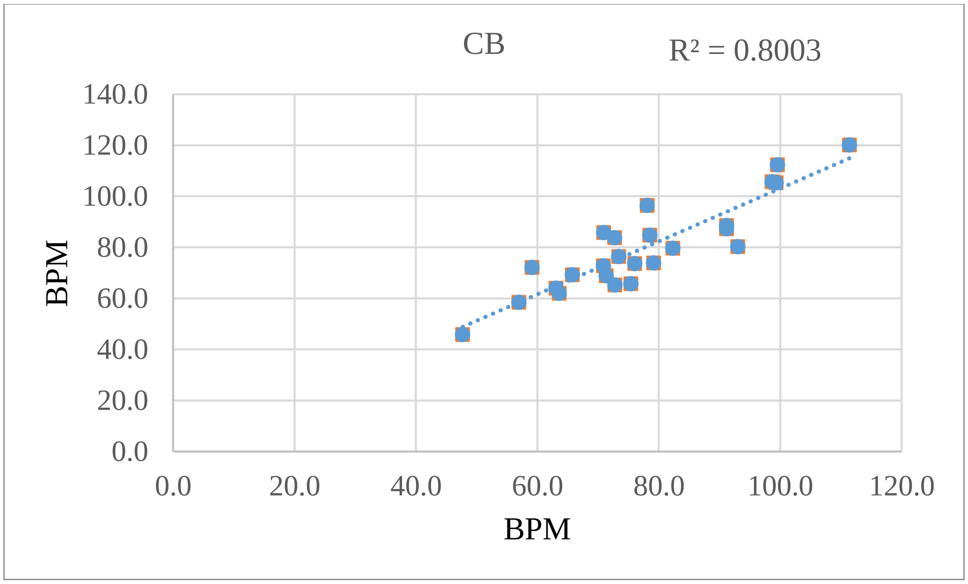
The BPM scores used for the intra-reliability test for observer "JM" are not normally distributed ($p < 0.001$)



Intra-reliability score of observer "JM": $R^2 = 0.97$ (linear regression)

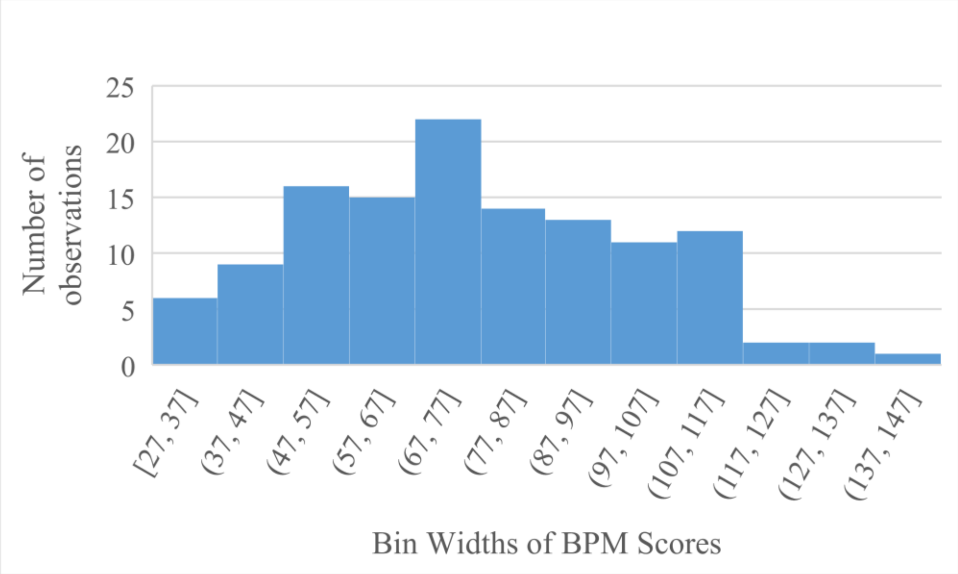


The BPM scores used for the intra-reliability test for observer “CB” are normally distributed ($p > 0.05$)

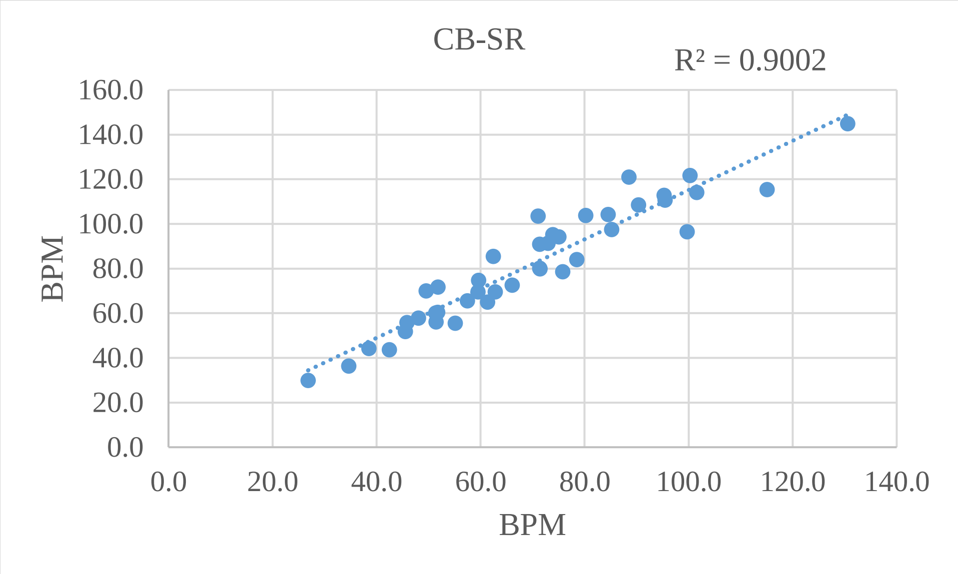


Intra-reliability score of observer “CB”: $R^2 = 0.80$ (linear regression)

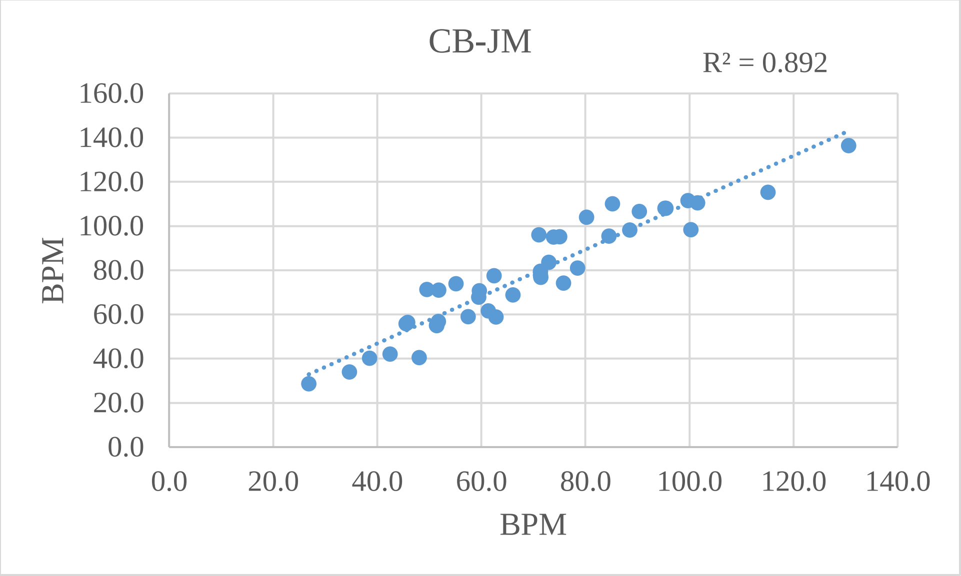
Inter-reliability tests: Regression models and distributions



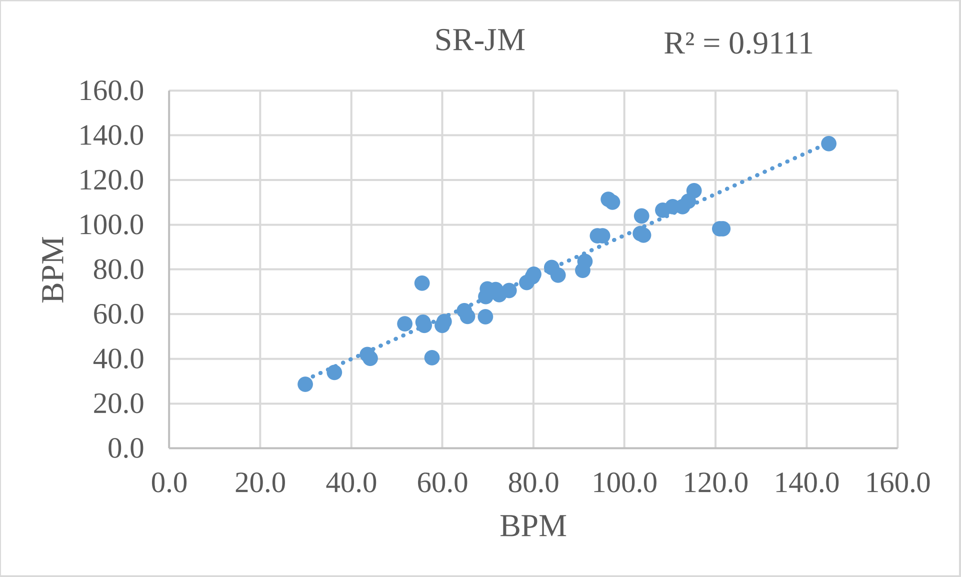
The BPM scores used for inter-reliability tests are normally distributed ($p > 0.05$)



Inter-reliability score between observers “CB” and “SR”: $R^2 = 0.90$ (linear regression)



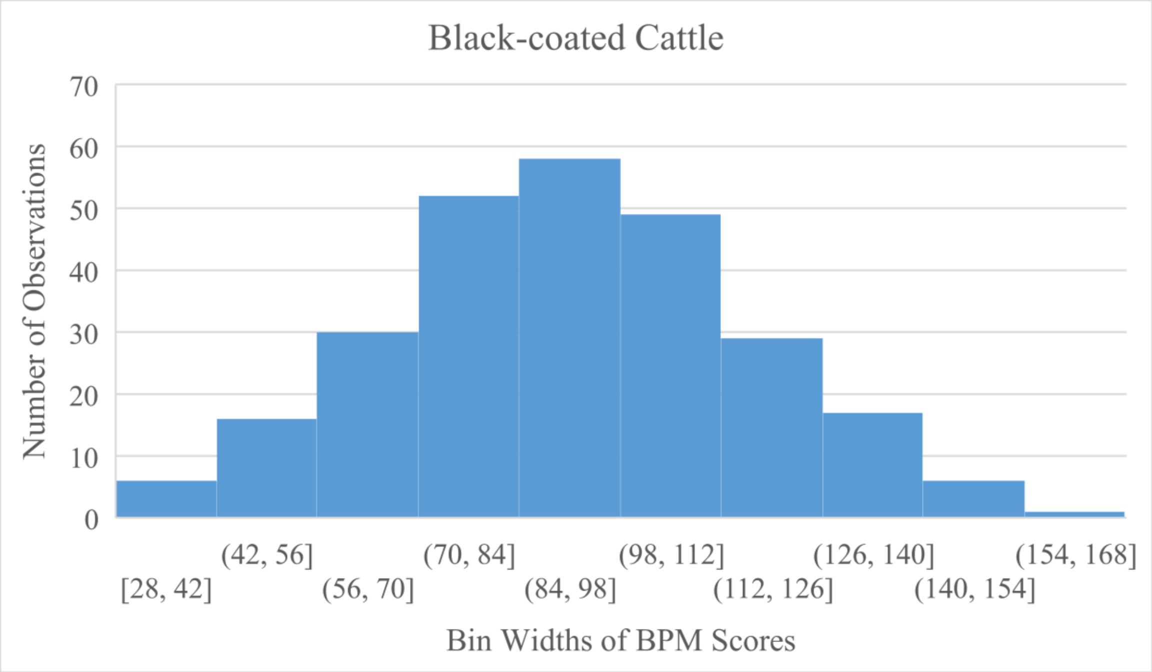
Inter-reliability score between observers “CB” and “JM”: $R^2 = 0.89$ (linear regression)

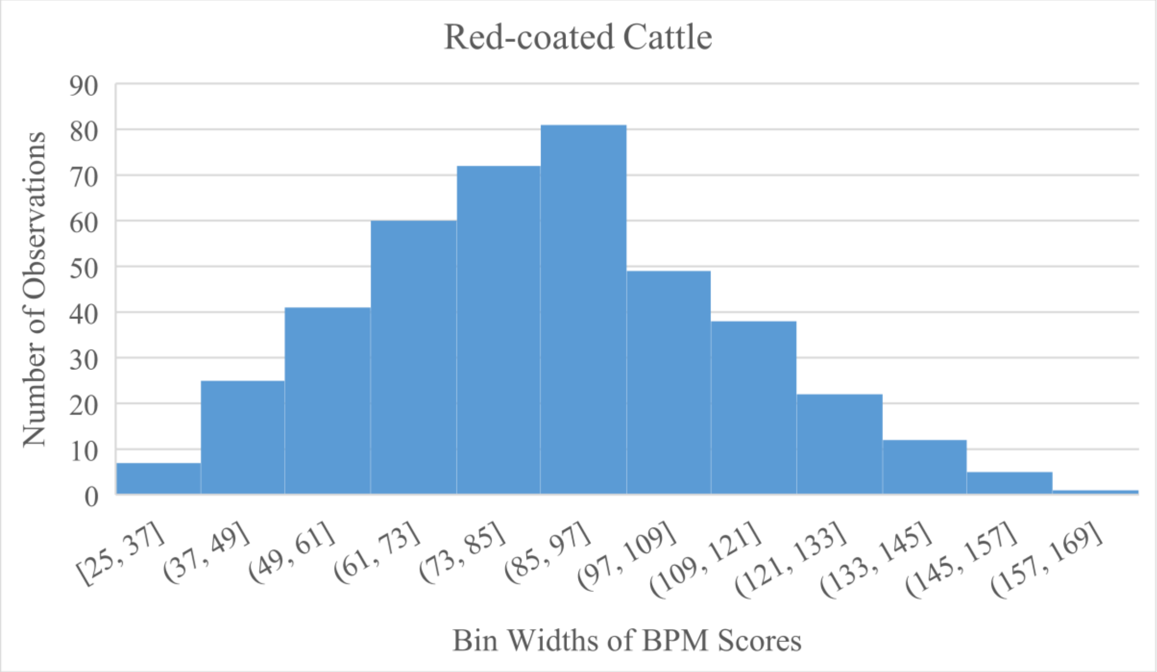


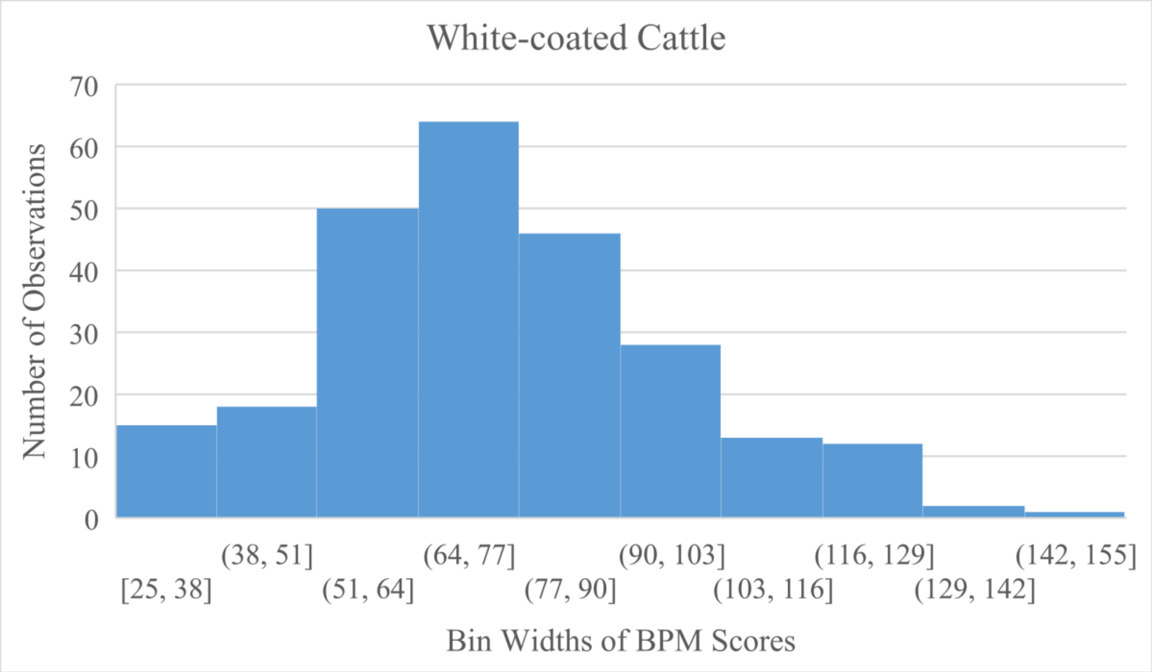
Inter-reliability score between observers “SR” and “JM”: $R^2 = 0.91$ (linear regression)

APPENDIX C

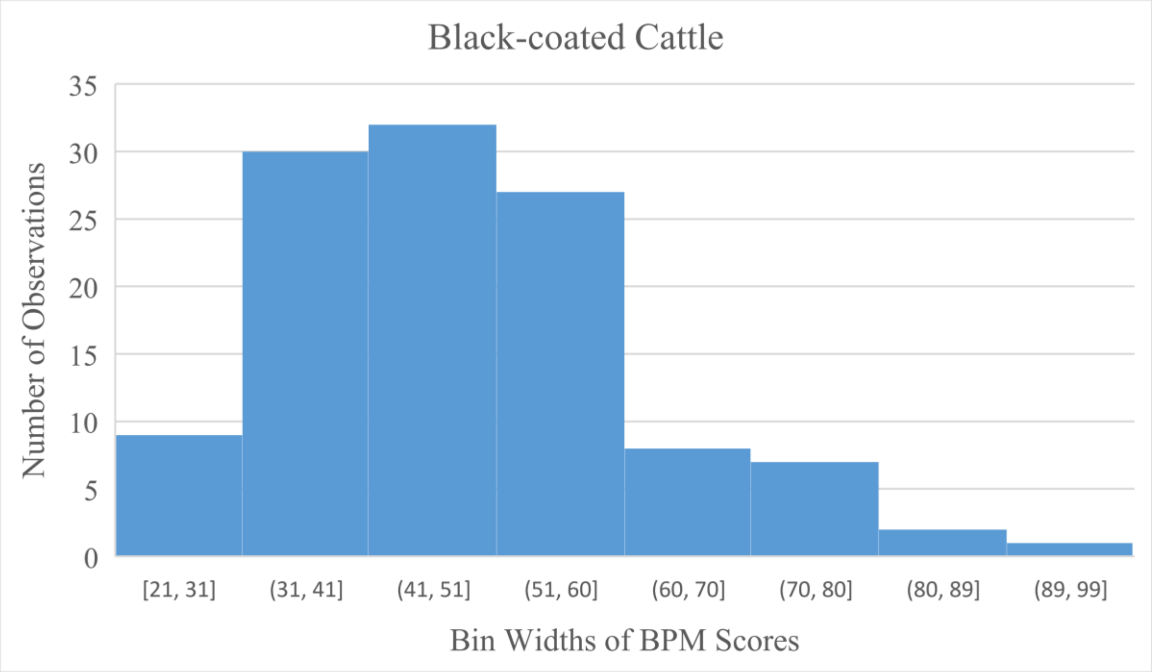
Distributions of respiration rate scores (BPM) in feedlot cattle

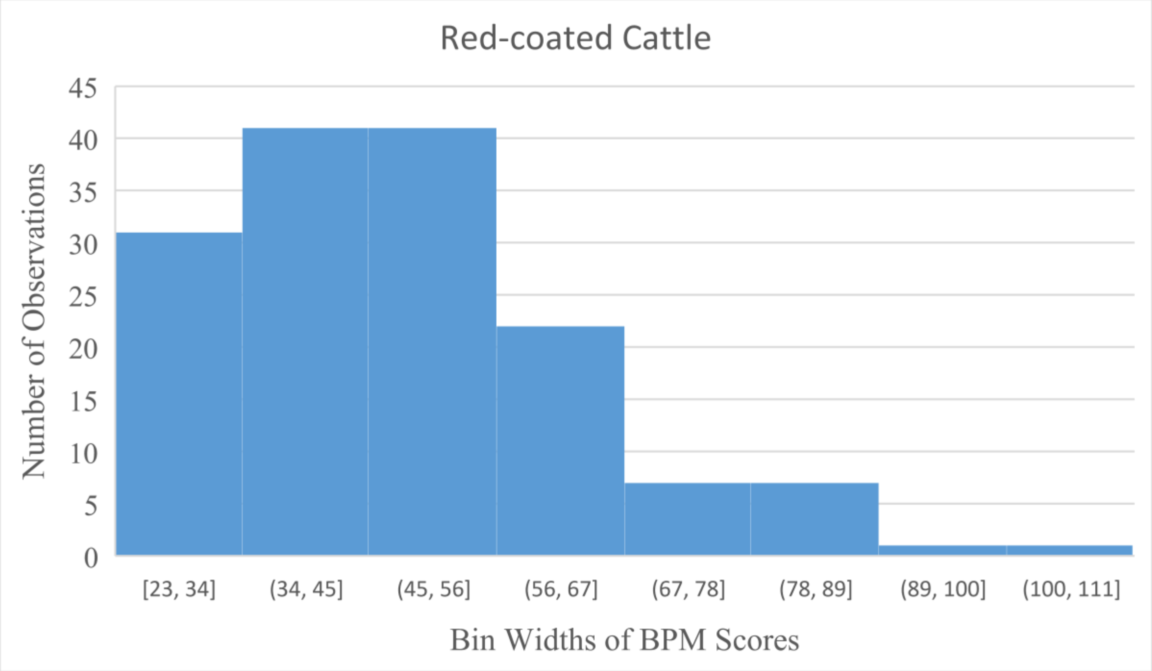





White-coated Cattle
Number of Observations
70
60
50
40
30
20
10
0
[25, 38]
(38, 51]
(51, 64]
(64, 77]
(77, 90]
(90, 103]
(103, 116]
(116, 129]
(129, 142]
(142, 155]
Bin Widths of BPM Scores

Distributions of respiration rate scores (BPM) in pasture cattle





Distributions of Heat Load Index (HLI) values