Characterization of Activity Budgets by Beef Cattle on Pasture

by

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Abstract

Much of the cattle production cycle in western Canada occurs while grazing on open-range pasture, in which cattle exhibit complex behavior. Among these behaviors is how cattle spend their time grazing, walking, and resting. While these metrics may help explain behavioral responses and associated production, few studies have examined these attributes in cattle. This study examined cattle activity budgets using leg-mounted pedometers while grazing during summer and fall within a typical native Parkland rangeland of central Alberta, Canada. Moreover, these behaviors were evaluated relative to differences in environmental conditions (e.g., weather) and inherent animal attributes (age, RFI-fat and breed composition), and also related these behaviors to heifer and cow/calf production during the grazing season.

The first study evaluated activity budgets during an unusually warm summer and fall (2021) to evaluate the impact of heat stress on behavior. Cattle were found to have greater movement, as exhibited by daily step counts, during times of elevated heat stress, as characterized by the thermal heat index (THI). Additionally, heifers had higher movement rates than cows with calves, particularly in summer. Heat stress conditions not only altered daily movement rates and lying/resting times, but also altered diurnal patterns of activity, with increased movement overnight and at midday during heat stress conditions, and reduced activity in the morning and afternoon. Fewer impacts of heat stress were found in fall as compared to summer, despite the continued occurrence of short periods of heat stress (less than a day).

In a subsequent study using data from five cattle herds tested over 3 years, cow age was found to alter activity, with higher movement rates (and greater lying times) in heifers than cows, with movement further declining in older cows (up to 9 yr of age). In contrast, cattle activity on pasture had little association with either breed composition or RFI-fat (tested as a yearling in drylot). Cattle production metrics were found to depend on animal activity, with cows and heifers having greater weight gain in animals having greater daily movement rates (step counts) and reduced lying times. Additionally, several complex interactions were found between activity (step counts) and cattle age, particularly on the weight gain of calves, suggesting a need for further studies to better understand the role of beef cattle behavior (activity) on pasture, its underlying causes, and subsequent impact on cattle productivity.

Preface

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Dedication

I dedicate this work to God almighty, the creator of the heaven and earth, the one who formed me before I was conceived. Also to Madam Ofure Rachael Eromosele, I can't forget your kindness till eternity.

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List of Abbreviations

Hr	Hour
BC	Breed composition
RFI-Fat	Residual Feed Intake Fat adjusted
THI	Temperature Humidity Index
SC	Step count
LT	Lying time
%	Percentage
WTG	Weight Gain
ADG	Average daily gain
3D	3 Dimensional
SEM	Standard error of the mean
SD	Standard deviation
AIC	Akaike Information Criterion
ΔAIC	Delta Akaike Information Criterion
NRC	National Research Council

Chapter 1. Review of cattle activity budget and production dynamics in beef cattle grazing systems

1.1 Global population demands and beef cattle production

The human population is projected to reach 9.3 billion by 2050, according to estimations from the Food and Agriculture Organization of the United Nations (Alexandratos et al., 2012). The effects of the fast-growing population, as stated by Eisler et al. (2014), also impact access to food, leading people to an undernourished condition, especially protein deficiency. To help balance population growth with providing nutritious food sources, it is clear that livestock production will need to contribute, with no net decrease in the amount of meat consumed per capita, over the past 10 years per capita meat consumption (Alexandratos et al., 2012). Within this context, beef cattle production emerges as an essential mechanism for the agricultural sector to address the escalating protein deficit accompanying demographic expansion.

According to the 2024 World Markets and Trade report by the United States Department of Agriculture, the current total beginning stocks for cattle worldwide amounted to 944 million head (USDA, 2024). At the same time, there is a challenge in further increasing the number of cattle as this process could impact competition for food between animals and humans, as well as pose further difficulties in maintaining the health of livestock. Approximately 70% of the grains utilized globally are allocated to animal feed, and 40% are specifically utilized by ruminants, particularly cattle (Alexandratos et al., 2012). Therefore, increasing the number of cattle could lead to issues in terms of food competition, especially in developing countries. Moreover, a larger population of animals necessitates enhanced hygiene and health management practices to prevent the spread of infectious diseases and maintain individual animal welfare, which could have financial implications for farmers, particularly in high-density production systems (Eisler et al., 2014). As a result, seeking alternative strategies supporting sustainable livestock production, is essential to mitigate or minimize the impact of expanding the cattle population, with a primary emphasis on animal welfare and productivity (Eisler et al., 2014; Thompson and Nardone, 1999).

1.2 Western Canada's contribution to beef cattle production

Canada holds a crucial position in beef production with 11.5 million cattle and ranking as the world's 8th-largest beef producer, including accounting for 4.4% of total global beef exports (USDA, 2024). Canada maintains a herd of 10.3 million cattle on beef operations, and a significant majority (86%), or approximately 8.9 million head, are produced and processed in western Canada, which includes Alberta, British Columbia, Saskatchewan, and Manitoba (Statistics Canada, 2023). With 5 million head in beef operations, Alberta has the largest cattle herd in Canada, contributing 43.2% to the national total inventory, followed by Saskatchewan (20.5%) and Ontario (13.2%) (Statistics Canada, 2023). Typical Canadian beef production systems are represented by an initial cow-calf stage, followed by backgrounder or stocker, and finally feedlot (or finishing) operations, with many commercial farms having more than one operation category (Sheppard et al., 2015).

The cow-calf stage is characterized by a forage-based system, where calves stay with the cows until weaning (Pogue et al., 2018), and that usually requires minimal external resources, with the pasture playing an important role in cattle diets (Alemu et al., 2017). Beef production operational inputs become crucial in the winter months, when pregnant cows remain either on pasture or in confined feeding areas, and in most situations are fed with supplemental hay and/or straw (Alemu et al., 2017). This is due to the nutrition necessary for pregnant cows when the natural forage may be limited or unavailable in the winter period. According to Sheppard et al.

(2015) the majority of cattle farms (91%) define themselves as cow-calf operators. A backgrounder farmer specializes in feeding weaned calves until they are ready to be finished. Backgrounder operations vary in their strategies to achieve post-weaning growth, which is either on pasture and/or confinement in drylot, depending on the season, before eventually being moved to finishing operations where they are fed to achieve market weight (Alemu et al., 2017; Pogue et al., 2018). Finally, feedlot operators are farmers who focus on finishing steers and heifers using a high-grain diet (Pogue et al., 2018), with 13% of cattle farmers operating with this approach (Sheppard et al., 2015). Given the large footprint of the cow/calf sector, the Canadian beef cattle breeding herd inevitably relies on a significant amount of grazing land to support its production, especially during the primary grazing season from May to October, that can potentially extend into the dormant season (Legesse et al., 2016). Based on the characteristics of these beef cattle systems, it is clear that grazing is an essential component of cattle diets and their management.

Given the prevalent role of the cow-calf production operation in Canada (Sheppard et al., 2015), and how this activity heavily relies on the use of pastures (Bailey, 2010; Vallentine, 2016), cattle activity may increase due to the large expanse of land in which grazing occurs. Cattle graze on about 36 M ha across the Prairie provinces, which include Manitoba, Saskatchewan, and Alberta. The area consists of 4 M ha of cultivated pasture, 6 M ha of tame (planted) forage crops, and 26 M ha of natural (never cultivated) grazing land. Because the majority of the production area is natural pastures, understanding the determinants involved in regulating grazing-based production is central to ensuring an economically sustainable beef production industry.

1.3 Determinants of success in a pasture-based beef cattle production

Grazing is the process whereby herbivores consume plants to obtain energy and nutrients. Moreover, grazing is typically embedded within an ecological system of a given geographic area, in which complex interactions (interrelationships and interdependence) occur among all living organisms, including in relation to the local environment with specific physical and/or chemical attributes (Heitschmidt and Stuth, 1991). During free-range grazing, especially in natural (i.e., native) pastures, animals make decisions to select (i.e., locate and consume) plants in different habitats, thereby enhancing their nutritional intake at minimal energetic cost (Senft et al., 1987; Kaufmann et al., 2013). Habitats constitute all the physical and geographical circumstances that make conditions favorable for supporting life, including individuals or communities, as a result of favorable biotic and abiotic interactions (Yapp, 1922; Heitschmidt and Stuth, 1991).

Within the native pastures of western Canada, available habitats vary widely in a relatively small area, and can include, for example, open grasslands, wetlands, or closed canopy forests (Kaufmann et al., 2013; Wheeler, 1976; Arthur, 1983), making the process of habitat selection potentially complex. Therefore, beef production on pasture involves a variety of biotic and abiotic factors that influence the growth, health, behavior, and productivity of cattle. These factors include variation in the quality, quantity, and diversity of forages (Senft et al., 1987; Bailey et al., 1996; Bork et al., 2012; Kaufmann et al., 2013), genetic components of the animal (Mwangi et al., 2019; Walmsley et al., 2016), animal health (Lamy et al., 2012), animal bioenergetics (Webster, 1989), water supply (Veira, 2007), residual feed intake (Arthur and Herd, 2009), climatic and weather conditions (Gauly et al., 2013), and even the use of technology (Lamb et al., 2016).

Forage quality and availability are pivotal where the production system is based on the grazing process. Plant community composition, and variation in the seasonal phenological development of vegetation, both affect foraging opportunities (Dzowela et al., 1990; Lamy et al., 2012). As Canada has a distinctly temperate environment, with strongly seasonal conditions (Zhang et al., 2000), this seasonal dynamic alters both the environment and foraging conditions under which grazing occurs, including for example, between summer, fall, and winter. With the ongoing seasonal use of pastures in cow-calf production systems, it is important to understand how cattle may alter their activity throughout the different seasons.

Changes in pasture quality and quantity, as well as the availability of drinking water, may alter the length of time that cattle spend searching for forage, feeding, and resting/ruminating (Schlecht et al., 2006). The quality and quantity of forage available are important factors that affect animal productivity, and these, in turn, change markedly across seasons (Melo et al., 2022). For instance, during the summer there is often abundant biomass available, and this forage is typically high in quality (protein and energy) due to adequate rainfall, warm temperatures, and the presence of extended sunlight to maintain plant growth (Grant et al., 2014). Unlike summer, however, foraging conditions are often markedly different during fall, which coincides with rapidly advancing plant senescence before winter (Buxton et al., 2003; Monteith et al., 2011). At this time, forage quantity may still be sufficient, but decreases in forage quality are likely to occur, which may alter animal behavior, including the time allocated to travel to preferred habitats, search for and locate preferential forage plants, and consume them. Reduced rainfall during fall may also dry up summer water sources, necessitating that animals move further to find drinking water, and this in turn, may pose a larger challenge for lactating cows that have higher intake requirements of water.

Another production determinant for beef cattle is the genetic component of the animal. Aharoni et al. (2009) compared activity levels (measured in hourly step counts and standing time) of Baladi and Beef Master × Simmental cross cattle and found that the Baladi cattle were more active with a higher number of daily step counts, standing time, and grazing time, despite having a higher lying time among the two breeds. Furthermore, the ratio of the energy cost of each activity metric to the metabolic body weight of the two breeds of cows was also compared, with Baladi cattle having a higher value, indicating a higher activity metric and lower metabolic body weight. In addition, Baladi cattle spent more time lying down as compared to the Beef Master cattle (Aharoni et al., 2009); however, of note is that the pattern of dry matter intake was reversed between groups, with the crossbred cattle consuming more feed. Some breeds of cattle have also been shown to generally be more docile and less temperamental, such as Simmental, Hereford, Beef Master, and British White, all of which therefore appear to be less active as compared to cattle originating from more upland environments, such as Angus (Widi et al., 2015). Within crossbred cattle, different types of breeds are combined and each breed has a percentage contribution present, which is referred to in cattle as retained heterozygosity, or breed composition (VanRaden et al., 2007). In theory, breed composition should also affect the behavior of cattle, depending on the predominant breed of cattle present within the genotype, and whether that breed is likely to be more active or less active.

Another determinant that can affect cattle production on pasture or feedlot is residual feed intake. Residual feed intake (RFI) is a measure of feed efficiency, calculated as the difference between actual and expected feed intake, and is independent of body size and growth (Koch et al., 1963; Arthur et al., 1996; Basarab et al., 2003; Nkrumah et al., 2006). RFI is generally recognized as the preferred metric for assessing beef cattle efficiency (Herd and Arthur, 2009). In a drylot setting, where the environment and feed intake are homogeneous and strictly regulated, phenotypic measurements of RFI are frequently taken in beef cattle (Basarab et al., 2003; Wang et al., 2006). Due to the difficulty in determining individual feed consumption on pasture, previous RFI investigations with cattle on pastures that involved grazing have been difficult (Meyer et al., 2008). Furthermore, because feed type, feed intake, activity levels, and surroundings might differ greatly, RFI results from the same cattle tested in a drylot and on pasture may not be identical. Cattle productivity is influenced by the forages selected, which can vary in abundance, composition, and quality over rangeland landscapes due to widespread variation in biotic and abiotic environmental factors (Bailey et al., 1996), including the habitats they are selected from. Variation in cattle activity levels can be attributed to variation in RFI (Herd et al., 2004). RFI and daily pedometer counts were found to have a phenotypic association of 0.32 (Richardson et al., 2001), and high RFI (inefficient) bulls took an average of 6% more steps per day than low RFI bulls (Arthur et al., 2001a). According to Arthur et al. (2001a), the increase in activity and energy expenditure was brought on by an increase in the distance traveled, with more time spent standing and ruminating, as well as increased energy used for feeding, walking, and ruminating (Herd et al., 2004).

Environmental factors such as the health of the herd can also affect the productivity of beef cattle. Diseased animals will be less active and less productive (Holmes, 1993; Lopes et al., 2012). Sick animals will have reduced weight gain, which is an important metric for measuring output from the herd, particularly of animals grazing on pasture (Keyserling et al., 2009). Environmental factors can also affect the productivity of the herd through changes in nutrition, as both a low supply of forage, and the intake of forages low in energy content (such as carbohydrates) will not provide the nutrition needed for optimal maintenance, growth and reproduction (Herd and Sprout, 1986).

The productivity of beef cattle can also be affected by climatic and environmental variables such as air temperature, humidity, and rainfall, primarily by changing cattle behavioral responses during either excessively cold periods or heat wave events (Morignat et al., 2014). Several researchers have identified animal death as one of the significant effects of heat stress on livestock (Stull et al., 2008; Vitali et al., 2009). During 2011 heat waves were recorded to have killed over 4,000 cattle in Iowa (Lees et al., 2019). Livestock death not only led to direct welfare impairment of the cattle herd, but also reduced beef production profitability (Barrett et al., 2020). St-Pierre et al. (2003) reported that heat stress within dairy cattle cost the industry about $900 M annually in the United States, by negatively affecting reproduction, dietary intake, milk production, and animal survival (Coventry and Philips, 2000).

1.4 Cattle grazing behavior and activity budgets on pasture

Rangelands are characterized by distinct topography and microclimates, giving rise to diverse plant communities with varying forage quality and productivity across seasons. The availability of forage therefore varies markedly in space, but also fluctuates temporally, which affects the seasonal and diurnal grazing activity of free-ranging cattle (Owen-Smith, 2008). It has been suggested that pastoral systems may require cattle to use more energy while foraging due to the need to travel to, search within, and select their diets from these complex ecosystems, which could impact the growth of beef or dairy cattle (Bailey et al., 1996; Di Marco and Aello, 1998).

Cattle typically spend most of their day grazing and moving around, covering 2 to 8 km distances, and grazing for 8 to 10 hr (Herbel and Nelson, 1966). Therefore, the selective behavior of cattle can markedly alter their activity, and therefore performance, on pasture. Heterogeneous landscapes at various spatial scales, such as feeding stations, plant communities (habitats), and landscapes, allow for highly selective foraging, which can alter their activity budgets, including the time dedicated to grazing, walking, and resting (lying down) on pasture (Bailey et al., 1996; Coughenour, 1991; Senft et al., 1987).

The choice of grazing habitat has been commonly investigated in relation to different cattle breeds (Bailey et al., 2001; VanWagoner et al., 2006). Research by Bailey et al. (2001) concluded that breeds adapted to steeper slopes (such as Tarantaise) make better use of mountainous terrain than Herefords, which were historically bred and adapted to environments with more level ground. The adaptability of different breeds to different landscapes (i.e., slopes) can impact the distance traveled, and therefore area covered, during routine daily activities (Walker, 1995). With Piedmontese-sired animals using steeper slopes and greater vertical and horizontal separation distances from water than Angus cattle, VanWagoner et al. (2006) discovered comparable results. In a later investigation, Bailey et al. (2015) demonstrated that grazing behavior was a heritable feature, where they identified 5 quantitative trait loci (QTL) in cattle that contributed to a Terrain Use Index. Bailey et al. (2015) concluded that the selection by cattle for high-elevation ranges could be partly explained by cattle genetics. Another vital consideration to genetic potential is that grazing animals tend to learn grazing behaviors as young animals from their dams, fellow herd members, as well as via post-ingestive sensory feedback. Simitzis et al. (2008) found that flavor preference development begins as early as *in-utero*, and continues through suckling (Nolte and Provenza, 1992a) and the first exposure to solid forages (Nolte and Provenza, 1992b) when infants are exposed to flavors by mimicking their mother. Over time, the attention and subsequent recall of flavor increases, thereby strengthening the persistence of preference for early-life flavors (Nolte and Provenza, 1992b).

Regardless of whether an animal was raised by its mother or a different dam as a calf, cattle will graze in the same places in the environment from where they were introduced, and are strongly impacted by their early life herd members (Howery et al., 1998). Young animal feeding and movement routines will be repeated throughout their lifetime, and may even be more persistent than later-learned habits (Launchbaugh and Howery, 2005; Provenza and Balph, 1988). With calves being able to learn from their dams, the distance of ground covered while searching for forage, as well as the actual time spent consuming forage, can also vary due to social interaction. Collectively, animal food preferences are shaped by these behaviors and post-ingestive feedback (Provenza, 1995), which are part of the social and biophysical environments that interact with the animal's genome during development, and allow the animal to adapt its specific diet to the local environment and foraging conditions (Galyean and Gunter, 2016).

The amount of time an animal spends ruminating each day will also depend on the state of the pasture (Welch and Smith, 1970). Cattle likely ruminate for five to nine hours daily on average (Evans et al., 1973; Pahl et al., 2014). Most rumination happens when cattle are resting at night, although it also happens between feeding bouts during the day. Due to the lengthy time required to break down mature forage, daily intake may eventually be limited when highly mature, low-quality forage is ingested, thereby reducing passage rates and associated forage intake levels, particularly in ruminants. Given the key role of changes in forage quality in altering digestive physiology, the season of grazing can also affect feeding patterns and associated activity budgets. In a study conducted by Jochims et al. (2020), they reported that grazing time in summer was 57% of the total length of the day, while during winter this declined to about 47%. These investigators further reported that daylight duration affected animals as they tended to spend more time grazing during summer when there was more daylight than in winter.

Activities such as standing time, lying time, and step counts were also found to have an energy cost in different studies with sheep and cattle (Blaxter and Wainman, 1962; Forbes et al., 1927; Osuji, 1974), with energy expenditure increases of 11% and 15% for sheep and cattle, respectively, when grazing on rangeland as compared to being fed in a pen (Blaxter, 1967).

Walking is an important activity with associated bioenergetic costs for animals (Fancy and White, 2018; Kramer and Sylvester, 2011). Walking on pasture may be tied to travel time when moving from resting or sheltered areas to preferred foraging habitats, or to search time while foraging within preferred habitats, as well as the energy expended by cattle in traveling to and consuming available drinking water (Maurya et al., 2012). Walking of unrestrained cattle on open range is associated with the use of 45 to 60 kcal per 100 kg of body weight (Osuji, 1974; ARC, 1980; CSlRO, 1990), and most cows will further increase the energy expended in the search for forage and water to sustain lactation for their calves (Grant and Albright, 1995). Therefore, since walking uses considerable energy, understanding the effort expended on specific behaviors such as walking may help cattle producers select cows that conserve energy while optimizing nutrient intake within complex pasture environments.

1.5 Measuring cattle activity budgets on pasture

Measuring the activity of beef cattle on pasture will help correlate their activity with production, and thereby better understand how activity may be modified to enhance performance. Early studies on cattle activity were unclear on whether activity was a precise reflector of their performance (Claperton, 1961; Macoon et al., 2003). However, other studies have reported that there are no significant changes in cattle performance relative to activity budgets such as walking time and distance; instead, poor performance was attributed to poor forage quality and quantity restrictions during the dry season (Nicholson, 1987). Despite this, a more recent study investigating grazing cattle performance reported that cattle that grazed under an intensive silvopastoral system had better performance than those in a conventional system, and attributed the difference to a reduction in movement (walking) of cattle (Cardona et al., 2013). Nonetheless, most studies have not explored the effect of cattle activity directly on cow performance. Dohme-Meier et al. (2014) suggested that cattle activity on pasture might not have a significant effect on cattle performance, as grazing cattle have a reduced response in their milk production, which he attributed to the cow's ability to mobilize body reserves to support the additional energy required when cattle activity (walking) increased in their search for forage.

Activity budgets of animals can be measured using pedometers. Many studies have reported that pedometers can be used on animals other than cattle and have even been tested on small ruminants like sheep and goats (Askar et al., 2013, 2015; Beker et al., 2010). Different travel patterns can affect how quickly an animal is moving. According to Anderson and Kothman (1980) the horizontal movement of animals while grazing requires more energy, which results in more trips. Roefols et al. (2005) concluded that pedometers are useful tools to measure an animal's activity, including identifying an animal's estrus status, particularly in dairy cattle. Additionally, pedometers are frequently used to determine whether a cow is lame (Mazrier et al., 2006). However, it has also been reported that pedometers can be used in the automatic detection of lameness within cattle (Alsaaod et al., 2019), although this capability does appear to be present in older pedometer designs.

According to Edward and Tozer (2004) tracking changes in a person's behavioral activity in terms of walking, lying down, and standing up, pedometers can help in detecting illness and metabolic abnormalities. Pedometers are frequently used to track behavioral changes in animals undergoing experimental trials or undergoing physiological changes such as between pre- and post-partum (Askar et al., 2015; Bachmann et al., 2014). However, pedometers were manually set up in this study, with animals brought in weekly to download data from pedometers. Pedometers have primarily been used in feedlots for dairy cattle and/or beef cattle (Roefols et al., 2005). One of the main drawbacks of utilizing pedometers on rangeland is that, unlike cattle in feedlots, animals must be gathered and handled when downloading the data.

The accuracy of the reading of pedometers was mostly caused by specific operations and designs of the pedometers, as the distance covered by the animal will be accurate if the pedometers are in good condition (Walker et al., 1985). With contemporary improvements in the current designs of pedometers, pedometers can send notifications of activity wirelessly to the computer station, and notify the producer of different situations for the herd. Regular monitoring of animals will increase the effectiveness of the pedometer and improve the welfare of the animal, including whether the fitted straps of the pedometers become too tight, in turn, avoiding animal discomfort or health complications.

1.6 Measuring cattle performance on pasture

Cattle performance is essential for determining and optimizing beef productivity on pasture (Dunks and Guye, 2022; Fordyce et al., 2021). Different metrics are used in determining cattle performance. They include cow weight gain, calf weight gain, cow-calf weight gain, and cow backfat thickness. Cow weight gain is the increase in weight over a particular grazing period, which could be seasonal (summer or fall) or an aggregate weight gain over a prolonged grazing period (summer and fall combined). This is a measure of the herd performance, including their production determinants, such as nutrition, pasture quality and quantity, and health status of the animals (Laske et al., 2012; Romanzini et al., 2018).

Furthermore, another measurement of cow/calf herd performance is the associated calf weight gain. This represents the mothering ability of the cow as the associated weight gain of the calf over a grazing season (Gelsinger et al., 2016; Peischel et al., 1980). With favorable calf weight gain, producers will have higher weaning weights, leading to an increase in profitability, as demonstrated by the sale of weaned calves (Ghodasara et al., 2015). Another similarly important metric may be the aggregate weight gain of the cow-calf unit, which is the combined cow weight gain and that of the 205–day adjusted weaning weight of the calf (Richardson, 1979). These metrics are most valued by producers as they signify the ability of both cows and calves to achieve increased weight gain over a given grazing period, thereby improving the sale value of the calf at year end, and the condition of the dam heading into winter, both of which directly impact economic profitability (Elmore and Mullenix, 2022).

Another important economic trait is backfat thickness, which indicates the energy reserves of the cow, an overall body condition score, and a potential carcass quality determinant (Schröder and Staufenbiel, 2006; Yukun et al., 2019). Cow backfat thickness is measured using an ultrasound scanner to quantify the backfat of cows before and after a given grazing period (Brethour, 1992; Schröder and Staufenbiel, 2006). This information can then be used to determine how the amount of fat deposited during the grazing season relates to various other factors, including cow activity budgets.

1.7 Knowledge gaps, thesis goals, and objectives

Many studies examining cattle activity budgets, heat stress, and weight gain have been conducted, primarily on dairy cattle within feedlot environments. However, few studies have been conducted on beef cattle, including in open rangelands where behavioral changes in cattle activity can be complex, and be influenced by important covariates such as the season of grazing (and associated foraging conditions), animal age, breed composition, and previously established

RFI of cattle, or the climatic conditions, including temperature and humidity. The goal of this study was to characterize the behavioral activity of beef cattle while grazing on open rangeland, and relate this activity to different biotic and abiotic factors. Furthermore, this activity will be linked to important cattle production metrics such as cow weight gain, calf weight gain, cow-calf aggregate weight gain, and changes in backfat thickness.

More specifically, I examined how potential heat stress, season of grazing, animal age, and time of the day affect cattle activity budgets while on pasture, including step counts of animals and their lying time. In Chapter 2, I quantified the impact of heat stress on cattle activity during the extreme (warm) temperatures experienced by cattle during the summer of 2021, including responses to these covariates, for instance, how step counts or lying time changes with an increase in thermal heat index (THI) during heat stress periods. Chapter 3 focuses on how cattle production varies in relation to activity budgets of cattle monitored over three grazing seasons from 2021 through 2023. The primary objective here was to see if production metrics can be explained using observed activity metrics, such as step counts, lying time, and standing time. Targeted production metrics include cow weight gain, calf weight gain, cow-calf weight gain, and changes in backfat thickness. In doing so, this will evaluate whether cows put on more weight at the expense of their calves, support greater weight gain in their calves at the expense of their gain, or alternatively, have independent growth responses in their calves as compared to their own fitness gains.

The overall goal of this thesis was to identify how commercial beef cattle grazing under open-range conditions allocate their energy to different activities, thereby influencing their performance (primarily weight gain). The final chapter, Chapter 4, will review the results of this research, its application to the beef industry, and its implications for science and technology, as well as identify future research opportunities

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Chapter 2: Potential heat stress impacts on beef cattle activity budgets while on pasture

2.1 Introduction

Mammals, which include large herbivores, are homeotherms that maintain a constant internal body temperature independent of external temperature (Piccione et al., 2020). Homeotherms have a physiologic mechanism called thermal homeostasis, a regulatory process that generates biological responses, like shivering or sweating, to maintain constant body temperature, despite a variable external environment (Fernández-Peña et al., 2023). In this context, each species has a thermoneutral zone, defined as the temperature range in which the animal does not expend energy to stay warm or cool. According to Kadzere et al. (2002), the thermoneutral zone is important for livestock since it contributes to a minimal physiological cost and maximal productivity.

Heat stress is a condition of exposure to temperatures outside the thermoneutral zone, when the body temperature increases to some level that animals cannot dissipate sufficient body heat to maintain thermal homeostasis, and occurs in an environment with high humidity, temperature, or low air movement (Morrison, 1983; Bernabucci et al., 2010). Temperatures above the thermoneutral zone exceed the upper critical temperature while temperatures below the thermoneutral zone are below the lower critical temperature (Kingma et al., 2014). Global climate change has been reported to alter various environmental conditions such as air temperature, water availability, and carbon dioxide levels in the atmosphere, in turn, resulting in heat stress on crops and livestock (Hatfield et al., 2011). To provide more context, according to climate change predictions, the average global surface temperature has increased by 1.09 °C since 1900, and is expected to continue increasing by another 1.5°C between 2030 and 2052 (Calvin et al., 2023).

Heat stress has negative effects on livestock production and can be fatal in the worst situations (Stull et al., 2008; Vitali et al., 2009; Carvajal et al., 2021). Considering this scenario, Carvajal et al. (2021), studying the thermal comfort indices and climate projection in livestock across 10 agroclimatic zones, concluded that around 7% of the global cattle population is currently exposed to dangerous heat conditions. Moreover, based on their projection, this percentage will increase to around 48% of cattle by 2100. As a consequence, heat stress also has the potential to affect important socioeconomic variables. For instance, heat stress creates a total annual economic loss to livestock industries of between \$1.69 and \$2.36 B across the United States (St-Pierre et al., 2003). Of this amount, between \$897 to \$1500 million (USD) is attributed to the dairy industry, and \$370 million (USD) to the beef industry. In Australia, heat stress brings annual economic loss to feedlots of around \$16.5 million (AUD) (Sackett , 2006). Canada also contends with analogous challenges; for instance, dairy cows in Western Canada endure heat stress for an estimated 40% of the summer (Ominski et al., 2002). Moreover, dairy cows experienced heat stress for 135.8 days a year in Southwest Quebec, and 95.3 days annually in Eastern Quebec, between 2010 and 2015 (Ouellet et al., 2021). Heat stress affects milk production, leading to an estimated \$34.5 million (CAD) annual economic loss for Ontario and Quebec (Campos et al., 2022). Livestock exposure to conditions outside the thermoneutral zone is not just a productivity and economic issue, but may also generate concerns over animal welfare (Polsky and Von Keyserlingk, 2017).

Behavioral changes caused by heat stress are potential useful indicators to livestock managers because they can occur before the decrease in animal fitness and productivity, suggesting it is important to recognize and understand behavioral changes early on so that mitigative action can be undertaken prior to an economic loss (Schütz et al., 2011, Lynch and Rechcigl, 2018). Previous studies have identified heat stress on animals through different behavioral responses, such as an increase in lying time, the seeking of shade, and physiological responses such as changes in heart rate or decreased feed intake (Bouraoui et al., 2002; Schütz et al., 2011; Collier and Gebremedhin, 2015).

Heat stress has previously been measured using the body temperature of the animal (De Rensis et al., 2015); however, the use of easily measured environmental conditions has also been found to be reliable and directly reflects the environmental hazard being mitigated (Dikmen et al., 2008). While air temperature can be used to quantify potential heat stress, the use of a single-aggregate variable combining temperature and relative humidity, in a variable called the Temperature-Humidity Index (THI), has also been popular (St-Pierre et al., 2003; West, 2003; Bernabucci et al., 2014). The THI was first introduced by Thom (1959) as a 'discomfort index' to describe the effect of ambient temperature on humans, but Bianca (1962) adapted the form of THI to model the rectal temperature of bull calves. The THI application to livestock goes back to assessments of decreasing milk production in dairy cows, where it was a promising tool to evaluate heat stress on production traits (Berry et al., 1964).

As a combination of humidity and temperature the THI is crucial due to the added role that high humidity plays in further increasing the negative impacts of high temperature on animal stress (West, 2003; Bernabucci et al., 2014), primarily due to an increased impairment in the ability of the organism to cool itself via sweating (Armstrong, 1994). Several studies have shown that estimates of THI are related to the rectal temperatures of cattle experiencing heat stress, which indicates how an environmental index can be associated with thermal homeostasis (Dikmen and Hansen, 2009). The THI can be divided into different categories that potentially indicate the level of heat stress, but definitions vary between researchers and conditions

(Segnalini et al., 2013; Wang et al., 2020). Armstrong (Armstrong, 1994) used THI < 71 as a thermal comfort zone, while De Rensis et al. (2015) defined THI < 68 to be outside the thermal danger zone for cows, with a drastic production decline when THI ≥ 75. Following that, Zimbelman et al. (2009) found that as THI reduced from 72 to a threshold of 68, milk production levels increased from about 15 $kg·cow^{-1}·day^{-1}$ to around 30 $kg·cow^{-1}·day^{-1}$ after the initial THI equation was established. However, Gorniak et al. (2014) reported the upper THI threshold might be as low as 60, denoting a reduction in feed intake and milk production for temperate climates in Germany. Moreover, a similar threshold was also reported by Hammami et al. (2013) from an experiment in Luxembourg. Because THI has different model adaptions and is applied to different climates and breeds around the world, the threshold depends on a combination of factors. In particular, even if breed, nutrition, housing type, and other factors can modify the susceptibility of animals to hot conditions, cattle studies suggested that a THI < 68 is generally a safe condition, while mild discomfort occurs around 68 ≤ THI < 72, and high discomfort with THI ≥ 75 (Bouraoui et al., 2002; Hahn et al., 2003).

Cattle maintain thermal regulation through homeostasis, where they regulate their internal body temperature within acceptable limits (Godyn et al., 2019). Homeothermy charts shows that there are three different zones in which environmental temperature can affect livestock: the thermoneutral zone, homeothermal zone and survival zone (Ehrlemark and Sallvik, 1996). The thermoneutral zone is the zone when animals are within the acceptable thermal comfort and do not need any physiological mechanism to maintain their internal heat as well as a balance with the environment in order for maximum production and performance (Godyn et al., 2019). Increases in THI ≥ 68 move the body temperature towards the upper critical temperature and when it exceeds the cattle’s tolerance, they respond physiologically by modifying their behavior in order to dissipate heat and maintain a balance in their internal heat, for example increasing water intake, decreasing dry matter intake or seeking of shade (Allen et al., 2015). In extreme temperatures when the body temperature moves beyond the upper critical temperature or below the lower critical temperatures, the condition of hyperthermia and hypothermia sets in, respectively (Godyn et al., 2019). In this zone animals struggle to maintain a balance with their internal temperatures, thereby resulting in damage of the normal physiological functions (Bettaieb and Averill-Bates 2015). In a bid to maintain and dissipate heat, physiological changes occur such as an increase in rectal temperature where the animal dissipates heat through the rectum in order to maintain homeostasis (Cook et al., 2007; Rashamol et al., 2018). Increases in respiratory rates are another physiological means of dissipating excess heat in the animal, with an average of 41 breaths per minute on optimal heat condition (Cardoso et al., 2015); animals tend to lose heat to the environment by increasing their respiratory rate, which was exemplified by an increase up to 80 breaths per minute (Baena et al., 2019).

This study examines the activity budgets of commercial beef cattle grazing on pasture during the 2021 grazing season in Western Canada, which coincided with an unprecedented heat wave that covered much of North America, and even other northern temperate regions globally. More specifically, we address the following objectives: 1) identify heat stress days experienced by beef cattle while grazing on Aspen Parkland pastures in central Alberta, Canada, during the summer and fall of 2021, 2) report cattle daily activity patterns on pasture in terms of hourly step counts and lying time, and 3) compare differences in cattle activity budgets with respect to animal age class (i.e., cows vs heifers), diurnal cycles (i.e., time of day), and projected heat stress and non-heat stress periods. In addition, we use THI as a proxy for heat stress to report on activity responses (step counts and lying time) across two different temporal scales, including at the daily level, and at the hourly level in relation to diurnal changes in heat stress exposure.

Finally, we identify thresholds of THI where beef cattle appear to alter their behavior, as evidenced by step counts.

2.2 Materials and Methods

2.2.1 Study area

The study area was located in east central Alberta at the 5,000 ha University of Alberta Roy Berg Kinsella Research Ranch (53°01'N; 111° 34' W), situated 140 km SE of Edmonton, Alberta, Canada. The station is within the Aspen Parkland natural subregion, a complex mosaic of *Populus tremuloides* forest, *Symphoricarpos occidentalis* shrublands, hydrophytic riparian wetlands dominated by *Carex* spp., and upland grasslands comprised of C_3 grasses such as *Festuca hallii*, *Hesperostipa curtiseta*, *Pascopyrum smithii*, and *Koeleria macrantha*, at approximately 700 m elevation. Specific details about the general area are available at Natural Regions and Subregions of Alberta (2006).

The trial occurred in 2021 during the summer and fall seasons, where cattle were treated as a single herd in two different native pastures, moving from summer to fall pasture in late August. Summer and fall pastures were approximately 69.3 and 61.6 hectares, respectively. Summer grazing occurred from 24 June to 26 August, while the fall grazing season was from 27 August to 10 November of the current year.

2.2.2 Cattle herd

This study examined the behavior of Kinsella Composite (KC) crossbred cattle comprised of progenies of three synthetic lines that were maintained separately at the University of Alberta

Kinsella Research Ranch during 1960 to 1989, and were subsequently pooled (Berg et al., 2014). The KC cattle are descendants of three synthetic lines; Beef Synthetic 1 (BS1) which mainly consisted of Angus, Charolais, and Galloway; Beef Synthetic 2 (BS2) mainly of Angus, Charolais, Galloway, and Hereford; a Dairy Synthetic (DS) of Brown Swiss, Holstein, Simmental. More details about breed composition is discussed by Goonewardene et al. (2003). Briefly, beef Synthetic line 1 was composed of approximately 33% Angus and Charolais, approximately 20% Galloway, and the remainder of other beef breeds; Beef Synthetic line 2 with approximately 60% Hereford and 40% other beef breeds; and the Dairy × Beef Synthetic was composed of approximately 60% dairy cattle (Holstein, Brown Swiss, or Simmental) and approximately 40% of other breeds, mainly Angus and Charolais. After 1994, four years of crosses (BS1 x DS, BS2 x DS, BS1 x BS2) were conducted, and in the fourth year all herds were combined into one herd. Selection since merging of the synthetic herds was based on growth and yearling weight in heifers, and KC bulls were selected based on pasture and feedlot growth performance, and birth weight was limited to 42.6 kg. The net result of the crossed herds led to cattle with approximately 33% Black Angus, 15% Hereford, 8% Charolais, and 56% other breeds. Some experimentation with purebred Angus and Charolais bulls crossed with KC cows was conducted after the merging, but always the same selection criteria was placed on replacement heifers and bulls. Beefbooster M4 bulls, consisting mainly of Limousin and Gelbvieh, were also introduced in 2013.

A total of 58 KC cattle, including 37 cows (552.2 ± 38.3 kg; 3 years old) with calves at side (91.8 ± 13.3 kg), and 21 heifers (387.9 ± 18.7 kg; 1 yr old) were included in the trial. Additionally, two bulls were grazed with the breeding herd but not tested for behavior. At the start of the summer 2021 grazing period, all heifers and cows, as well as accompanying calves, were handled, and pedometers attached to the left hind leg of heifers and cows on June 24.

IceQube+ pedometers (Peacock Technology Ltd., Stirling, Scotland) were placed above the fetlock using velcro straps. These pedometers are designed to collect cow activity data within 15 min intervals continuously for each animal while deployed. Pedometers were read when animals were processed on 26 August at the transition from summer to fall pasture, and for those animals who lost pedometers, a replacement was deployed. Thereafter, pedometers remained on the animals until 10 November, 2021, at which time they were removed and read.

Pedometers were read using a portable IceHub™ unit, and subsequently downloaded to the IceRobotics Cloud™, and later retrieved for analysis. Compiled data included information on step counts (number) and lying time (used to derive % of time spent lying down) across individual 15 min intervals for the 140-day long grazing period. Data were not available for animals that lost pedometers while grazing on pasture, which was more common in summer than fall, at 9 and 0 pedometers, respectively. Additionally, 5 animals did not receive pedometers for the fall period in 2021 due to animal welfare considerations. All animal handling and pedometer use was approved through Animal Use Protocol #00003850 at the University of Alberta.

2.2.3 Environmental data collection and derivation of THI

The study area has a continental climate, a region characterized by long cold winters and short warm summers with elevated precipitation. Average annual precipitation is approximately 391.6 mm, with more than half occurring during the growing season (May to August), with a peak in July (data of 1991-2020, Agriculture and Irrigation, Alberta Forestry and Parks, Alberta Environment and Protected Areas and Environment Canada). In 2021 specifically, accumulated rainfall throughout the summer and fall grazing periods was 103 mm.

Weather conditions during the 2021 grazing season, particularly summer, also coincided with unusually high temperatures, including over prolonged periods of time (Figure 2.1), making it an ideal situation to evaluate cattle behavioral responses to potential heat stress. Historical conditions for the study area indicate that the number of days with maximum temperatures above 30ºC is relatively low. For example, between 2011 and 2020 the city of Edmonton, Alberta experienced an average of 3.9 days annually with a maximum air temperature above 30ºC, which ranged from 1 day in each of 2016 and 2019, to a peak of 7 days in 2018. However, during 2021 the number of days with maximum temperatures above 30ºC increased sharply to 17. At Kinsella, the number of days with maximum temperatures above 30ºC was 14 during 2021 (Table 2.1), including 3 days with maximum temperatures above 35ºC (Kinsella ACIS, 2021).

Here, THI was used as a proxy for determining where, when and how much potential heat stress beef cows may have been experienced during the 2021 grazing season. Computations of THI were as follows:

$$THI = (1.8 \times T + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times T - 26)], \quad (1)$$

where T is the average temperature in °C and RH is average relative humidity in % (National Research Council, 1971). Hourly and daily THI were calculated from hourly T and RH, and average T and RH of each day, respectively.

Temperature and humidity data were obtained for the Kinsella weather station of the Alberta Climate Information Service (Kinsella ACIS, 2021); this station was situated approximately 5 km south of the study pasture. The following parameters were retrieved: long-term (30 yr) historical daily means, together with actual daily values for average air temperature, maximum air temperature, minimum air temperature, mean relative humidity, maximum relative humidity, and minimum relative humidity, all of which are summarized in Table 2.1.

Specific weather data were downloaded for the period coinciding with the grazing periods during summer and fall 2021, specifically 24 June to 8 November, 2021 (Table 2.1). This period was characterized by extended periods of extreme high temperatures and drought in summer, and cold temperatures in November. Average daily temperatures ranged from 35.3 ºC to -13.8 ºC over the 4.5 months (Figure 2.1), while the relative humidity ranged from 16.7 to 100%.

2.2.4. Data analysis

Data analysis was done in R version 4.3.2. (R Core Team, 2023) using the set of packages available on 'tidyverse' library version 2.0.0 (Wickham et al., 2019). Raw activity data from pedometers placed on individual animals were initially downloaded and examined to identify missing data and eliminate any periods associated with malfunctioning pedometers or the effects of human animal handling. In this context, the first 4 days after initial processing and during early pasture turnout (June 24-27, 2021) were excluded, owing to the fact of two consecutive animal handling days, during which time cattle may not have been exhibiting their normal voluntary activity and behavior, as well as to allow for acclimation to initial summer grazing. Similarly, data from August 25-27, 2021 were excluded as animals were being gathered for processing, then moved from summer to fall pasture, and finally year end processing on November 9-10.

The primary response variables from the pedometers included hourly and daily step counts, together with the proportional time spent standing and lying down. After downloading all data, a final visual assessment was done, and any days for a specific animal that had less than 23 hr of data on step counts or lying time were removed. This process eliminated less than 2% of the total data, but prevented underestimation of average step counts or lying time due to unequal sampling throughout the day. Finally, animals were removed from further analysis if they had data for less than 50% of all days within a given grazing season; only two animals were removed in summer and none in fall. Finally, data on step counts, provided in 15 min intervals, were aggregated to both individual hours (steps hr^{-1}) and individual days. Hourly data were used to facilitate testing of differences in daily activity budgets, or across individual hours throughout the 24-hr day. Actual lying times were used to compute the % of time that animals spent laying down, again either on a daily basis, or aggregated to hourly time bins throughout each day. All analyses were conducted separately for the summer and fall grazing periods due to the changeover in pasture in late August of 2021.

In this study, a daily THI at or exceeding 68 was initially used as a threshold to identify individual days with potential heat stress conditions (Bernacubbi et al., 2014). Thus, individual days while cattle were on pasture in which the mean computed daily THI was at or above 68 was considered a heat stress day (Figure 2.2A). All other days were considered to be non-heat stress days. Next, data on daily mean step counts and lying times were evaluated using an Analysis of Variance (ANOVA) with PROC MIXED in SAS software (Stroup et al., 2018), using heat stress days based on THI as a fixed effect. This analysis was initially done using THI as a continuous covariate, together with animal age class (heifer vs cow) and their interaction, as fixed effects, with individual animals included as random effects. This approach led to estimates for fixed effects along with standard errors. Modeling the covariance structure is particularly crucial when analyzing repeated measures data, as measurements taken in close temporal proximity exhibit a higher correlation compared to those taken at greater time intervals. The analysis was done separately for summer and fall, with statistical significance set at $P < 0.05$. Where interactions were found using THI as a continuous covariate, cattle activity (either step counts or lying times) were regressed against THI for each animal age class, to further characterize the differences in activity pattern in response to increasing heat stress. Relationships were assessed using their significance (p-value), adjusted R^2, and the resulting equations. In addition, as mean daily THI levels were found to exceed the threshold of 68 during summer, but not fall, an additional ANOVA was run for summer using THI as a categorical treatment, in which THI (heat wave vs non-heat wave), animal age class, and their interaction, were tested as fixed effects, for their effect on daily step counts and lying times. Individual animals were considered random.

To further understand the diurnal behavior patterns of cattle and how they were altered by heat stress, we computed the THI for each individual hour throughout the grazing trial (Figure 2.2B). As periods of heat stress were more common in summer, this analysis was limited to summer, and was done on both cows and heifers combined, as initial examination of the diurnal responses indicated cows and heifers responded similarly. A mixed model ANOVA was conducted on hourly step counts and lying times, using the known heat wave status for each individual day (above or below a THI of 68) and time of day as fixed effects, along with their interaction. Individual animals and days were included as random effects. Where significant interactions of heat wave status and time of day occurred, we graphed the diurnal pattern of activity across the 24h daily cycle, and conducted paired comparisons between heat wave and non-heat wave conditions within each hour. This analysis provided insight into nuanced temporal patterns of animal activity throughout the 24h diurnal cycle in relation to known heat wave conditions. Finally, to identify different thresholds of THI and how they may alter cattle behavior in terms of average step counts, we used classification and regression trees (CART). CART graphs were created with R packages including “rpart” version 4.1–23 (Therneau and Atkinson, 2023), “rattle” version 5.5.1 (Williams, 2011), in R software. This process identified thresholds in THI separating cattle activity (step counts) into different activity classes (e.g., low, medium and high). This was done separately for each grazing season (summer and fall).

2.3 Results

2.3.1 Identification of heat stress days

The number of days with a computed THI value at or above 68, the threshold for potential heat stress in this study, was found to be 16 days out of 58 days (27.5%) for the summer grazing period (Table 2.1). There were three extended periods during summer in which daily THI values exceeded 68 (Figure 2.2A). Based on that daily THI, Figure 3 shows that heat stress times on these 16 days were primarily between 8 am and 11 pm. In contrast, during the fall no days of potential heat stress occurred from 28 August to 8 November using this 'average' daily threshold (Figure 2.2A). However, when THI was examined on an hourly basis, the duration of periods over which cattle were exposed to THI levels greater than 68 notably increased during summer (Figure 2.2B), with animals consistently facing heat stress from 7 am through 2 am, providing more depth to understanding daily heat stress exposure. Moreover, there were also short periods of time on several days during fall when THI values briefly exceeded a threshold of 68 (Figure 2.2B), specifically in the afternoon between 11 am and 6 pm.

2.3.2 Cattle daily activity during summer and fall with respect to THI

A summary of descriptive statistics from this study is reported in Table 2.2. In summer, the animal age class (cow or heifer) and potential heat stress conditions, represented by the nominal variable THI, consistently effected daily cattle mean step counts and lying times (Table 2.3). Days associated with potential heat stress led to a 14% increase ($P < 0.0001$) in total daily step counts (THI $\geq 68 = 4962.1 \pm 50.3$ SEM steps d^{-1}; THI $< 68 = 4351.4 \pm 30.8$ steps d^{-1}), a response consistent between animal classes. Correspondingly, lying times declined by <1% on days with potential heat stress ($P < 0.0001$) from 9 hr 43 min (± 2 min 18 s) to 9 hr 34 min (± 3 min 43 s). While mean daily step counts did not differ between heifers (4695.6 ± 53.2 SEM steps d^{-1}) and cows (4422.2 ± 30.2 steps d^{-1}) during summer ($P = 0.15$), lying times were impacted by animal age class ($P = 0.009$). Cows spent 12.0% less time lying down (9 hr 18 min ± 2 min 18 s) compared to heifers (10 hr 34 min ± 2 min 59 s).

When THI was assessed as a continuous variable in conjunction with age class, interactions of animal age class by THI ($P < 0.05$) were detected during the summer grazing period on both daily step counts and lying times (Table 2.3). While step counts generally increased for both cows and heifers as daily THI increased (Figure 2.4A), heifers tended to increase their step counts to a greater extent relative to cows as THI intensified. Also, a sigmoid response was evident, with relatively stable step counts between a THI of 54 and 68, proposing a thermal comfort zone, wherein animals were not changing behavior, while step counts increased sharply for both age classes when THI exceeded 68. In contrast, lying time tended to decline more markedly in heifers as THI increased, while cows did not change the amount of lying time and was independent of THI (Figure 2.4C), corroborating the results in Table 2.3.

During the fall grazing period, both daily step counts and lying times of cattle were affected by animal age class ($P \leq 0.04$) and the interaction of age class by THI ($P < 0.01$; Table 2.3). Cows had greater step counts than heifers (cows: 3404.4 ± 23.2 SEM steps d^{-1}; heifers: 3326.0 ± 34.1 steps d^{-1}) at this time of year, with the interaction reflecting a tendency for cows to have lower step counts than heifers at very low THI, but elevated step counts relative to heifers at elevated THI (Figure 2.4B), particularly where THI exceeded 55. Similar to the pattern observed in summer, daily lying times of heifers (11hr 25 min ± 2 min 10s) during fall generally exceeded that ($P = 0.04$) of cows (9 hr 55 min ± 1 min 40 s), with the interaction reflecting that while both cows and heifers spent less time lying down with increasing THI, this reduction was greater for cows than heifers as THI increased (Figure 2.4D).

2.3.3 Cattle diurnal activity budgets and response to heat stress

Cattle, including both cows and heifers, exhibited a strongly diurnal pattern in animal activity (Figures 2.5 and 2.6), with most of the movement evident through large increases in step counts around midnight, and again at midday, with the latter tapering off in early afternoon, only to rise to modest levels of activity in the early evening. In contrast, a lengthy period of inactivity was evident during early to late morning. While this pattern was evident in both summer and fall, for both cows and heifers, this pattern was not as pronounced during the fall when less movement occurred, coincident with a longer window of non-activity (Figures 2.7 and 2.8).

When diurnal patterns of step counts and lying times were assessed during the summer grazing period in relation to daily periods of suspected heat wave and non-heat conditions, marked differences were evident (Figures 2.5, 2.6). Both cows and heifers exhibited marked spikes in activity, as demonstrated by step counts, at 2 am in the early morning hours during periods of known heat wave conditions, particularly in comparison to non-heat wave conditions (Figure 2.5). By 6 am, step counts declined to very low levels for both cows and heifers, with periods of heat stress likely to lead to even lower levels of movement at that time, and instead, further increase lying time (Figure 2.6). By approximately 10 am, the presence of heat stress conditions led to earlier and greater rates of movement by cattle, as exemplified by increased step counts from 10 am through 1 pm, and a concomitant reduction in lying time (Figure 2.6). This pattern again switched in mid-afternoon through early evening, as step counts were once again lower under heat stress conditions, particularly for cows in the afternoon (Figure 2.5A) and heifers in the evening (Figure 2.5B). Not surprisingly, lying times of cattle (both cows and heifers) were generally greater under heat stress conditions during this same time, before switching yet again in the late evening (~9 pm).

Likewise, when the diurnal patterns during the fall were compared to summer, the same pattern of activity was found with differences in time principally for non-activity periods (Figures 2.7, 2.8). Because no days of overall heat stress were detected in fall, both cows and heifers showed peaks in activity from 11 pm to 1 am, as demonstrated by step counts, followed by a low activity from 4 am to 11 am, which constituted a longer time window of reduced activity compared to summer (Figures 2.5, 2.7). Moreover, unlike in the summer, some level of movement was still identified in fall during this period, with a small increase in step counts between 6 and 8 am. Parallel to step count patterns, periods of lying time were also longer in fall compared to summer (Figures 2.6, 2.8). In the fall, cattle spent 30-50% of their time resting from 2 am to 12 pm (Figure 2.8). In fall greater movement by cattle occurred from 1 pm through 4 pm, and generally at greater step counts compared to the same time of day in summer (Figures 2.5, 2.7).

2.3.4 Apparent thresholds of THI regulating cattle activity

A decision tree plotted from the regression of mean step counts and THI for each of the summer and fall periods revealed contrasting results (Figure 2.9). Of the 4516 summer observations, 9% (n=220), 96% (n=2173) and 5% (n=126) of the data passed through node THI $\geq$ 70, THI between 54 and 69, and THI $<$ 54, respectively (Figure 2.9A). The regression tree therefore predicts a modest increase in step counts when animals are exposed to a THI $\geq$ 54, with the greatest increase in step counts when THI $\geq$ 70, thereby sharply intensifying overall movement during heat stress days. Notably, this pattern mirrors the non-linear responses reported earlier (Figure 2.4A). During fall, however, of the 3792 study observations, 51% (n=1868) and 49% (n=1924) of the data passed through node THI ≥47 and THI < 47, respectively (Figure 2.9B). Overall, the fall regression tree predicts an increase in step counts when animals are exposed to a THI ≥ 47.

2.4 Discussion

Heat stress is an important and alarming concern since the number of days that animals are facing having this condition is increasing (Solymosi et al., 2010). Heat stress is a physiological response to environmental conditions that cause severe symptoms such as increased heart rates, respiration, and dehydration (Bishop-Williams et al., 2015). Moreover, behaviors such as seeking shade and decreasing feed intake have previously been reported, with severe cases resulting in lost performance, reproduction, welfare, and even death (Bouraoui et al., 2002; Schütz et al., 2011; Collier and Gebremedhin, 2015; Bishop-Williams et al., 2015). Heat stress effects in animals is related to three factors: the weather conditions (American Society of Agricultural Engineers, 1997), the susceptibility of the animal (Brown-Brandl and Jones, 2011), and management practices, including feed (Brosh et al., 1998), water (Bicudo and Gates, 2002; González Pereyra et al., 2010) or handling procedures (Brown-Brandl et al., 2010).

In this study, we collected data on cow and heifer movement using pedometers in a free range pastoral system. Information such as step counts and lying time proved informative regarding changes in behavior of animals, including the diurnal pattern of activity during summer and fall. Moreover, using THI as an index of stress, we were able to quantify changes in behavior, including movement patterns throughout the day.

2.4.1 Quantification of seasonal heat stress

During the 2021 grazing season, and using an initial THI threshold of 68, we found that all the days with average daily potential heat stress conditions occurred during the summer rather than the fall grazing season. Moreover, our count of 16 days is similar to other studies such as Reiczigel et al. (2009), who reported increasing levels of THI above 68 in Hungary from 5 to 17 days/year, over a period of 30 years. The historical 30 yr normal temperatures provided by the Kinsella Weather Station are generally much lower compared to the average daily temperatures experienced during 2021, especially during the summer period (Figure 2.1). Moreover, our number of documented heat stress days in 2021 are higher than projections reported by VanderZaag et al. (2024). These authors, studying the impact of future heat stress in dairy cattle in Canada, concluded that Calgary, Edmonton and Red Deer (AB), areas near our study location, will not surpass 10 days annually with THI > 65 by 2030-2070, yet our results from 2021 defied this conclusion.

The unusually warm conditions of 2021 are also in agreement with projections of temperature changes for Canada. Qian et al. (2023) discussed climate conditions in the near, middle and distant future for soybean production in Canada, and reported a warmer climate scenario is likely, with an increase of 1.6, 2.8 and 4.1 °C in mean temperature by 2030, 2050 and 2070, respectively, for May to September. These climate conditions will not just affect crop production but also animal production, as discussed recently by VanderZaag et al. (2024), with trends for increasing temperature, humidity, and THI > 65 for most of the west coast and eastern Canada, affecting 84% of Canada's dairy herd. According to VanderZaag et al. (2024), future climate projection scenarios (2030-2070) will lead to 90% of the national cattle herd experiencing more frequent, intense, and longer durations of heat stress. Our results did not show any mean daily THI values above 68 after mid-August, which is consistent with the rapid decline in daylight and average daily temperatures experienced within the northern temperate environment of central Alberta as summer wanes.

Importantly, our assessment of cattle behavior during 2021 coincided with a year of known extremes in temperature more broadly across North America (Emerton et al., 2022; McKinnon and Simpson, 2022; Thompson et al., 2022), providing a robust test of elevated temperatures on cattle behavior. During the summer grazing season reported on here, we documented 16 days of potential heat stress (based on the mean daily THI threshold of 68) from the 55 days of grazing in that season. However, we also note that when THI values were computed on an hourly basis, that the number of days with any hourly THI values above 68 increased to 35, suggesting that the actual period of time during which potential heat stress occurred may have extended throughout much, if not most, of the 2021 summer grazing season. Moreover, when computed using hourly weather conditions (Figure 2.2B), we even found that a total of 9 days during the fall grazing season had some period of time with a THI ≥ 68, suggesting that cattle may also have experienced heat stress, albeit briefly during the day, after August 28, between 11 am and 6 pm. Where heat stress did occur, this condition was most likely to occur between late morning and early evening, coincident with peak daily temperatures, with little to no heat stress in the late overnight periods (3 – 6 am, Figure 2.3). Whether and how these short intervals of heat stress may differentially affect cattle behavior, is less understood.

2.4.2 Diurnal patterns of cattle activity on pasture

We report here on the patterns of cattle activity while grazing on pasture within the Aspen Parkland during a 24-hr diurnal cycle. During summer cattle exhibited a distinctly diphasic activity pattern, with peak activity during the overnight hours, as well as from midday through the mid-afternoon and evening. This pattern was evident as both large increases in step counts, separated by lengthy periods of time spent lying down and resting (or ruminating). Our mean daily step counts increased from 4345 to 4941 steps d^{-1} (181 steps h^{-1} to 206 steps h^{-1}) with the onset of heat stress conditions during summer. Mróz et al. (2017), studying daily activity in polish Holstein cattle, reported varying movement intensity depending on the housing system, stocking density and age of animals. Animals housed indoors at an increased stock density showed high activity in relation to other groups with outdoor access and lower density. According to Mróz et al. (2017), reduced welfare may make animals overactive due to stress. Additionally, studies report that heifers exhibit higher stress levels than cows, which make them even more active (Wójcik and Olszewski, 2015; Mróz et al., 2017), the combination of which is in agreement with our findings of greater activity in heifers than cows, especially during summer and coincident with increased heat stress periods. During fall, all cattle had lower activity compared to summer (Table 2.2). Jorns et al. (2022), comparing differences in step counts of Angus cattle grazing either large season-long pastures or smaller, mob-stocked pastures within the Collaborative Adaptive Rangeland Management study in Colorado, USA, also concluded that lower daily step counts were taken by cattle grazing traditional (season-long pastures) as the grazing season progressed. Results by Brzozowska et al. (2014) also reported an increased number of steps per day in cows during the summer months.

Ferrell and Jenkins (1985) concluded that up to 65–70% of the total energy required for growth is used for maintenance. Compared to heifers, cows have a 10 to 27% higher maintenance energy requirement because of lactation (Montaño-Bermudez et al., 1990). In this context, cows with more energy demand may have to spend more time searching for and consuming feed, and thereby spend less time lying down (Matthews et al., 2012), which could account for the increased step counts in cows relative to heifers during fall, a period when forage is becoming less available and harder to find. Parallel to that, Mróz et al. (2017) reported that animals in a more stressed environment rested frequently but only for short periods, resulting in a lower total resting time. Collectively, these studies provide support of our findings where we observed cows spending less time lying down compared to heifers, and lying times declined for both groups of cattle when THI was higher (Tables 2.2, 2.3). Moreover, according to Tucker and Schütz (2009), cows lose a considerable amount of their body heat from their underside; thus, the reduction in lying time of cattle with greater heat stress conditions may be an important thermoregulation strategy that allows animals to increase the movement of air around their body for cooling.

Cows spend 8–12% of their time moving and standing, 20–25% feeding and drinking, and most of the time (40–50%) lying down (Grant and Miner, 2007). The distinct movement pattern of cattle induced by heat stress documented here is consistent with other studies (Cook et al., 2007; Allen et al., 2015; Abeni and Galli, 2017; Heinicke et al., 2018; Herbut and Angrecka, 2018), and is likely indicative of a combination of the need to acquire feed and water on a regular basis. Notably, our results reveal that cattle had the highest movement rates based on step counts during the overnight hours, likely in an effort to achieve adequate gut fill of forage. Step counts have previously been associated with foraging effort in cattle (Jorns et al., 2022). Following sun-up in the early morning hours (typically ~4-5 am in this region of Western Canada), cattle movement slowed markedly, almost to nil, presumably due to the need to rest and ruminate following peak feeding periods, as cattle are known to have daily rumination times of 2.5 - 10 hr (Beauchemin, 2018). Reduced movement during periods of rumination were also reported by others (Adin et al., 2009; Schirmann et al., 2012), and is consistent with prior studies on beef cattle for this time of the day (Omontese et al., 2022). Of note is that aside from differences in overall step counts, we did not find any large differences in the temporal pattern of movement between heifers and cows, suggesting that this pattern was not strongly influenced by the presence of calves, nor the need for dams to support lactation. We did, however, find that heifers were generally inclined to spend more time lying down during summer overall, which could reflect the need for cows to stand and support periodic lactation, even when not feeding, as discussed previously.

Of note is that both cows and heifers exhibited large increases in movement after the morning rest period and just prior to noon, and following a spike in activity through early afternoon. This movement slowed until late afternoon, only to increase in early evening. While we did not collect supplementary information on the potential mechanisms influencing this intricate behavioral pattern, we hypothesize that two key factors contribute to this. First, following an extended period of rest with near minimal activity from 5 am until 10 am (~5 hr), we postulate that advancing digestion and passage of forage may have led to an increasing urge to begin feeding as hunger set in near noon. Moreover, this pattern was again consistent for both cows and heifers, suggesting this was independent of reproductive status.

Second, and perhaps more important, may be the need to consume drinking water. Following an extended period of rest and rising temperatures throughout the morning, particularly in summer, it is likely that cattle left their resting areas (often shaded groves of forests) to travel to water. Previous studies suggest that cattle on pasture typically consume about 35 L of water a day (Bicudo and Gates, 2002), which may trigger movement to water in the afternoon when THI is greater. While the added burden of lactation can further increase the need for water consumption by 0.87 kg of water per kg of milk produced (Winchester and Morris, 1956), other studies also report positive correlations (Murphy et al., 1983; Murphy, 1992; Meyer et al., 2004; Cardot et al., 2008). We found similar or even greater peak levels of movement by heifers relative to cows, suggesting that the presence of calves was unlikely to be regulating rates of cattle movement at midday. Following the initiation of cattle activity at noon, cattle movement slowed but did not altogether stop in the afternoon, only to increase again as evening started, before temporarily slowing near sundown (~ 10 pm). We postulate that after obtaining drinking water, cattle spent much of the afternoon and evening hours in various stages of feeding, potentially exploring different habitats, and intermittently resting, before beginning the extensive feeding cycle again overnight.

2.4.3 Cattle daily activity budgets in relation to age class and potential heat stress

In this study the impacts of heat stress on cattle were assessed using both overall daily activity budgets, as well as diurnal changes in activity. At the coarser temporal scale of individual days, cows and heifers consistently demonstrated differences in activity, including in relation to heat stress. However, previous studies that examined heat stress impacts on cattle behavior (e.g., Tucker and Schütz, 2009) have not investigated when those animals travel; hence, we also examined fine-scale temporal patterns of cattle activity in relation to heat stress. Unlike activity budgets at the daily scale, diurnal patterns of activity were similar between cows and heifers, but were instead differentiated between conditions with and without heat stress, reinforcing the importance of examining cattle activity at multiple temporal scales.

Assessed across days, cows and heifers consistently differed in their daily activity budgets, and these responses were consistently further altered by heat stress conditions. Despite having similar step counts to heifers in summer, cows had reduced lying times in summer, which may be indicative of the maternal urge among cows to support their relatively young calves (2-4 months old) through regular lactation. As heifers did not have calves this would have maximized their ability to rest during intervals between primary feeding bouts. During fall, while cows continued to have reduced lying times, cows also demonstrated higher movement rates, which were particularly evident under warmer conditions. Although the cause of this response is unknown, we hypothesize that due to their larger size, coupled with the ongoing energetic demands of lactation, cows may have had greater overall forage intake requirements, which could have necessitated longer feeding bouts. Longer feeding bouts, in turn, particularly during fall when foraging conditions were declining and calves were larger, could have led to an associated increase in both travel time and distance (to and from bedding areas), but even in this situation these animals were minimally thermal stressed and had less movement.

During summer and fall, cattle generally increased their overall movement rates during individual days of greater heat stress, suggesting a behavioral change in response to elevated temperature in general. Moreover, this increase was particularly apparent for heifers in summer, and cows in fall. Not surprisingly, elevated heat stress conditions were also associated with a reduction in lying time, particularly for heifers in summer and cows during fall. These results could indicate that cattle increased the distance of animal movement, potentially as they sought to utilize optimal cover for shade (Tucker and Schütz, 2009), or as animals moved between shaded sites and their preferred foraging areas or necessary drinking water sources. Notably, while the absence of days with an average THI above the 68 threshold during fall did not allow for a specific test of acute heat stress effects on cattle activity after August 28, our results still revealed an increase in step counts for both cows and heifers with THI increases, and a reduction in lying time, at daily THI levels through to a value of 64. Thus, our results provide clarification of the key responses in cattle activity across a wide range of climatic conditions, even levels that may previously have been considered non-stressful.

While the presence of potential heat stress conditions led to a similar overall diurnal activity pattern during the summer grazing period, both cows and heifers demonstrated two important changes with exposure to elevated daily THI. First, the diphasic pattern of cattle movement became stronger for both cows and heifers, with step counts further increasing overnight and near noon, while declining in the morning and late afternoon, and even exhibiting a third peak during the evening. This response reinforces that cattle respond to potential heat stress by increasing their activity in the evening and overnight periods, presumably to focus much of their feeding effort when conditions are cooler. Second, and in support of our earlier conjecture that the need for drinking water could be a major driver of activity at noon, we consistently observed that the presence of potential heat stress conditions caused cattle to initiate movement approximately 1 hr earlier in late morning, likely due to the more urgent need to consume water. Cattle also exhibited increased overall rates of movement during the noontime period during heat stress conditions, which could be explained by the increased distance travelled probably to acquire water, as no GPS data was analyzed. Given that our sources of drinking water did not change during the summer grazing period, these increased distances are likely due to the greater distance traveled between preferred bedding areas utilized in the morning of heat wave days (i.e., larger, more closed canopy forests offering superior shade) and the available water sources. When combined with ongoing foraging efforts at midday, the need to acquire water may explain the high cattle movement rates at this time, which were then followed by another significant resting period with reduced movement. Notably, the latter period also coincided with the hottest part of the day typically found in the study area (i.e., from 3-6 pm; Figure 3), reinforcing the impact of potential heat stress on cattle activity.

Finally, cattle movement patterns in fall were generally similar to those in summer, with two key differences. Cows and heifers had similar step counts at peak movement periods, suggesting that the presence of calves no longer restricted cow movement, possibly due to their advancing age and increasing independence from dams. Additionally, while movement patterns still exhibited large peaks in the overnight and noontime periods, cattle, particularly cows, exhibited some degree of movement during the morning period, and this could be indicative of a general increase in the urgency to continue feeding, possibly due to the increased demands of lactation with advancing calf growth. As our summer and fall grazing occurred in spatially unique pastures, we are unable to rule out the possibility that differences in habitat availability and preferred forage species abundance, as well as differences in forage phenology and associated quality, may explain the differences in cattle behavior between seasons.

2.4.4 Potential heat stress thresholds separating cattle activity levels on pasture

Past studies evaluating heat stress in cattle and their impacts on animal physiology and productivity have often utilized a threshold THI of 68 to identify stressful conditions (West, 2003; Bernabucci et al., 2014; Beauchemin, 2018), although other studies in Ontario, Canada have shown that animals subject to a THI > 74 demonstrate signs of heat stress (Husseini et al., 2020). Using a regression tree analysis to identify potential thresholds in THI relative to our beef cattle activity budgets on pasture, we found that marked differences in cattle behavior, as represented by their movement patterns (i.e., step counts), could be identified during the summer grazing period. Animals subject to hourly THI values below 54 had sharply reduced movement patterns, while animals exposed to THI values over 70 had markedly elevated movement. As relatively few studies have been done on animal behavior in relation to heat stress, particularly of free-ranging beef cattle, we suggest that a THI of 70 may be effective in identifying the level of heat stress that changes cattle behavior. This threshold is within the range reported in previous studies (68 – 74), with further research needed to better understand why these changes in behavior occur, including the specific role of heat stress. Moreover, we also identified a lower THI threshold of 54 below which cattle exhibited sharply reduced movement in summer, to levels more similar to those evident during the fall grazing season.

What remains unknown is the specific mechanism(s) regulating why cattle may have altered their behavior in relation to changes in THI, and how these mechanisms may change through moderate, high or extreme levels of heat stress exposure. As cattle in our study had consistent access to the same habitats, forage supply, and drinking water sources within each pasture over a ~2 month grazing period within each grazing season, changes in resource availability (aside from forage depletion, which remained conservative) are unlikely to be the factor altering cattle activity. Instead, marked changes in weather conditions throughout each grazing period, which were shown to vary sharply over as little as a few weeks, most likely explain the variance in cattle activity. Parallel studies have reported how heat stress conditions, including THI, modulate animal behaviors and associated production and health (Gantner et al., 2015; Jožef et al., 2018; Gantner et al., 2019; Gantner et al., 2020). Further studies are necessary to better understand how behavior alteration is associated with cattle performance in free-ranging pastoral production systems of western Canada, including to verify how cow-calf pairs are allocating their energy in association with animal movement.

2.5 Conclusions

This study is among the first to document the specific impact of changes in potential heat wave conditions, as represented by THI, on the behavior of beef cattle grazing on native rangeland pasture during summer and fall. Cattle exhibited a pronounced biphasic movement pattern during both seasons, but was even more pronounced with elevated temperatures during the summer of 2021. During summer, cattle tended to have higher movement rates overnight and at midday compared to other times. Cattle diurnal patterns of movement changed with potential heat stress conditions, with cattle increasing their daily step counts, particularly during the overnight periods, and again at midday. Cattle also initiated movement earlier in late morning with the presence of elevated THI, and reduced their movement in mid to late afternoon coincident with peak temperatures. Cows also demonstrated differential activity budgets relative to heifers, spending less time lying down in summer and fall, and walking less in summer while also exhibiting greater movement in fall. These results provide key insight as to the daily activity budgets of free-ranging beef cattle, including the potential role of heat stress on cattle activity.

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Tables and Figures

Table 2.1. Mean climatic conditions during the experimental grazing periods of 2021 between June 28 and November 8. THI is the Temperature-Humidity Index. RH is the Relative Humidity. Values in parentheses are 1 standard deviation.

Environmental Parameters	Summer (June 28 – Aug. 24)	Fall (Aug. 28 – Nov. 8)
Daily Minimum Temperature (°C)	0.6	-15.3
Daily Maximum Temperature (°C)	35.5	28.3
Daily Mean Temperature (°C)	18.3 (4.1)	6.9 (5.9)
Days of Maximum Temperature > 30 °C	14	0
Days of Mean Daily Temp. > 25 °C	3	0
RH, Minimum (%)	40	44.6
RH, Maximum (%)	94	95
RH, Mean (%)	66.6 (12.5)	66.9 (10.3)
Average Daily THI	63.4 (5.7)	46.7 (8.8)
Number of days with daily THI ≥ 68	16	0

Table 2.2. Descriptive activity summary during the experimental grazing periods of 2021 between June 28 and November 8. Values in parentheses are 1 standard deviation (sd).

		Step Count			Lying Time		
Season	Age Class	Min-Max	Avg day	Avg hour	Min-Max	Avg (hr d^{-1})	Avg (% d^{-1})
Summer (THI< 68)	Cow	1343-9487	4263 (1245)	178 (51.9)	3.2-16.7	9.3 (1.6)	38.9
	Heifer	745-9378	4516 (1506)	188 (62.7)	4.9-15.5	10.6 (1.4)	44.4
Summer (THI≥ 68)	Cow	1182-9131	4834 (1160)	201 (48.3)	3.2-15.4	9.2 (1.5)	38.5
	Heifer	1877-9324	5167 (1435)	215 (59.8)	4.8-15.1	10.4 (1.4)	43.3
Fall	Cow	1012-9388	3404 (1188)	142 (49.5)	2.78-15.1	9.9 (1.4)	41.4
	Heifer	1275-8536	3326 (1166)	139 (48.6)	4.91-15.3	11.4 (1.2)	47.7

Table 2.3. Summary ANOVA results examining mean daily step counts (steps d^{-1}) and lying time (hr d^{-1}) in relation to animal age class (cow vs heifer) and daily temperature-humidity index (THI), as well as their interaction, during each of the summer (June 28 – Aug 24) and fall (Aug 28 – Nov. 8) grazing periods during 2021.

		Step Count		Lying Time	
Season	Response	F-stat and df	P-value	F-stat	P-value
Summer*	AgeClass(AC)	2.05 (1)	0.15	31.64	**0.0086**
	THI(daily) ≥68	116.44(1)	**<.0001**	6.91	**<.0001**
	AC × THI	0.56 (1)	0.45	1.38	0.24
Summer	AgeClass(AC)	2.47 (1)	0.12	13.48	**0.0002**
	THI(daily)	215.5(1)	**<0.001**	2.44	0.12
	AC × THI	4.58 (1)	**0.03**	3.88	**0.0489**
Fall	AgeClass(AC)	4.17	**0.04**	4.28	**0.04**
	THI(daily)	659.24 (1)	**<0.001**	79.54	**<0.001**
	AC × THI	8.59 (1)	**0.0034**	15.05	**0.0001**

* Analysis used THI days as a binary variable, with days classified as either those with heat stress (daily THI ≥ 68) or without heat stress (daily THI < 68). Subsequent analyses used THI as a continuous variable.

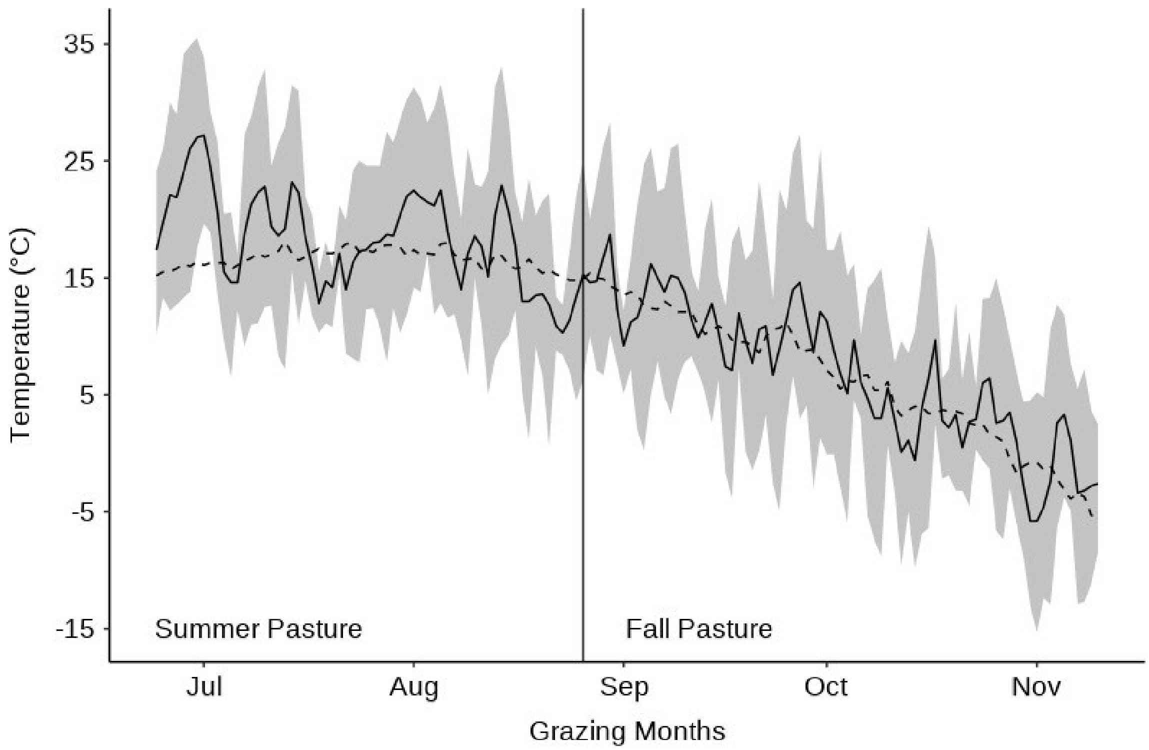
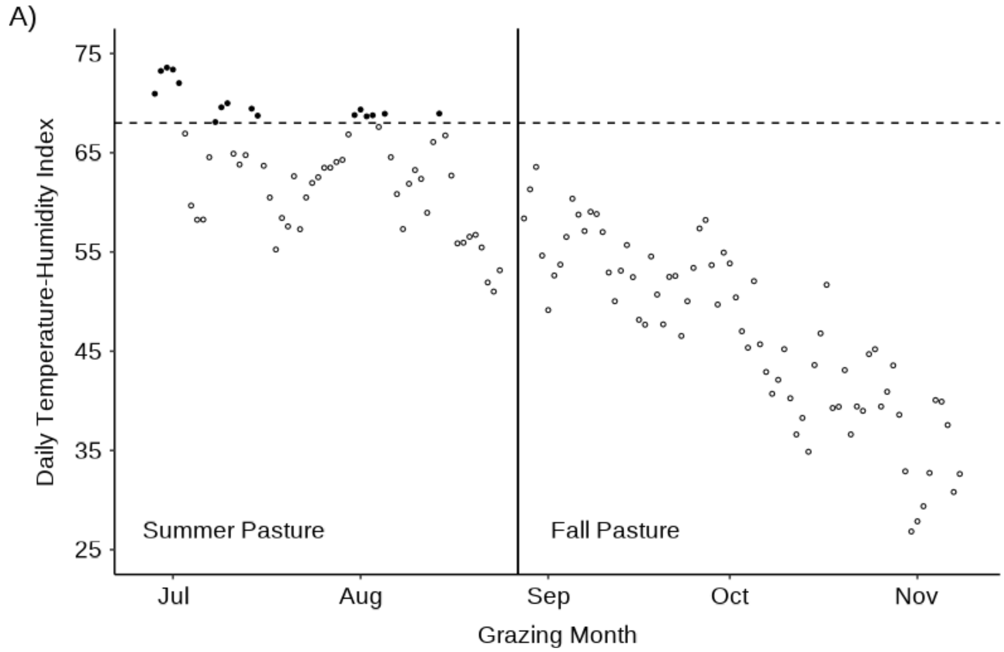


Figure 2.1. Mean daily temperatures (solid line) during the grazing trial. Also shown are the maximum and minimum temperature ranges per day (grey) and the historical 30 yr norm (1991-2020, dashed line).



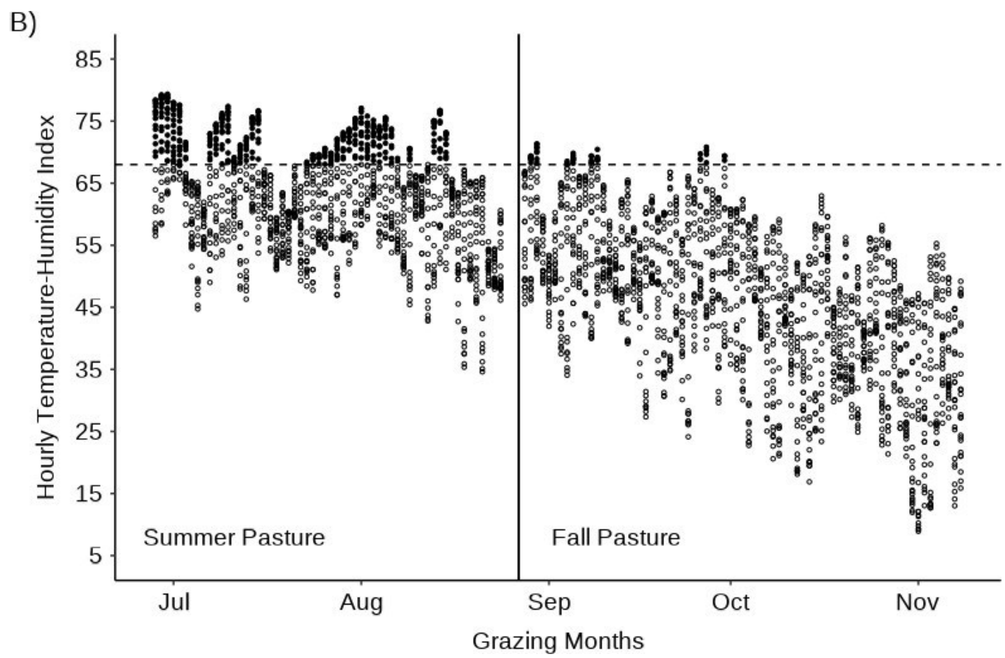


Figure 2.2. Summary of mean temperature-humidity index (THI) values that cattle were exposed to while grazing based on either A) daily THI values, or B) hourly THI values, throughout the 2021 summer grazing season at the Kinsella Research Station. Data include the summer (left) and fall (right) periods.

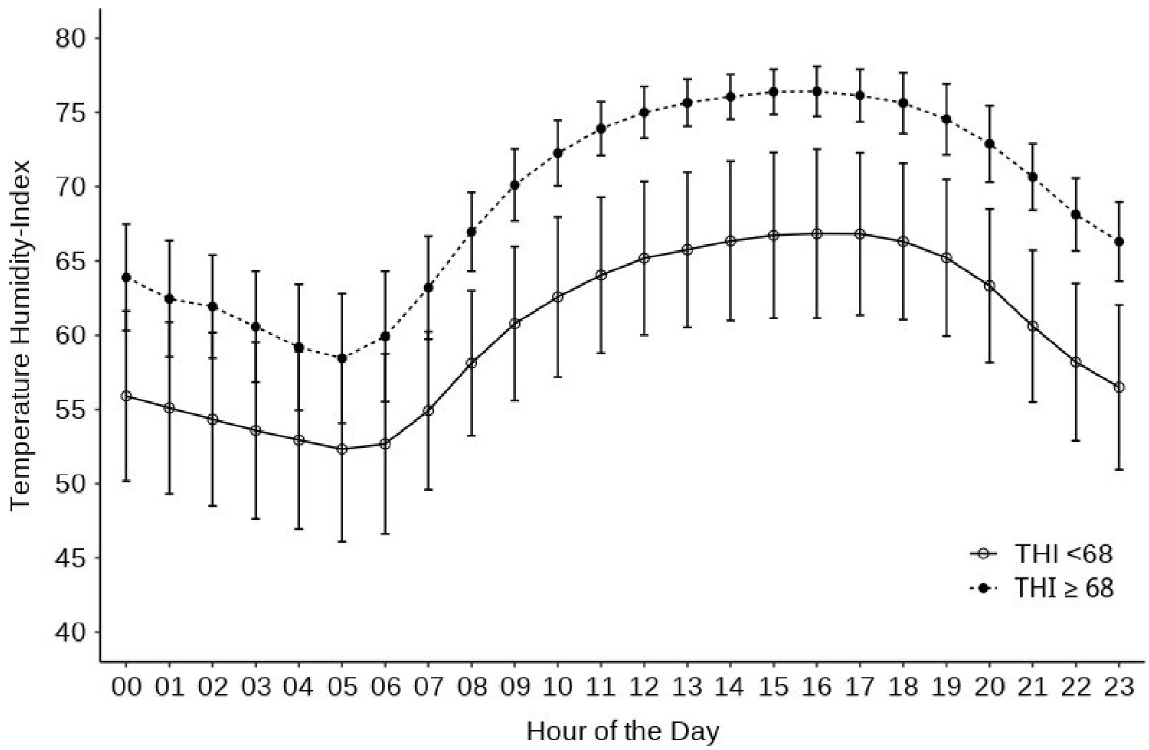
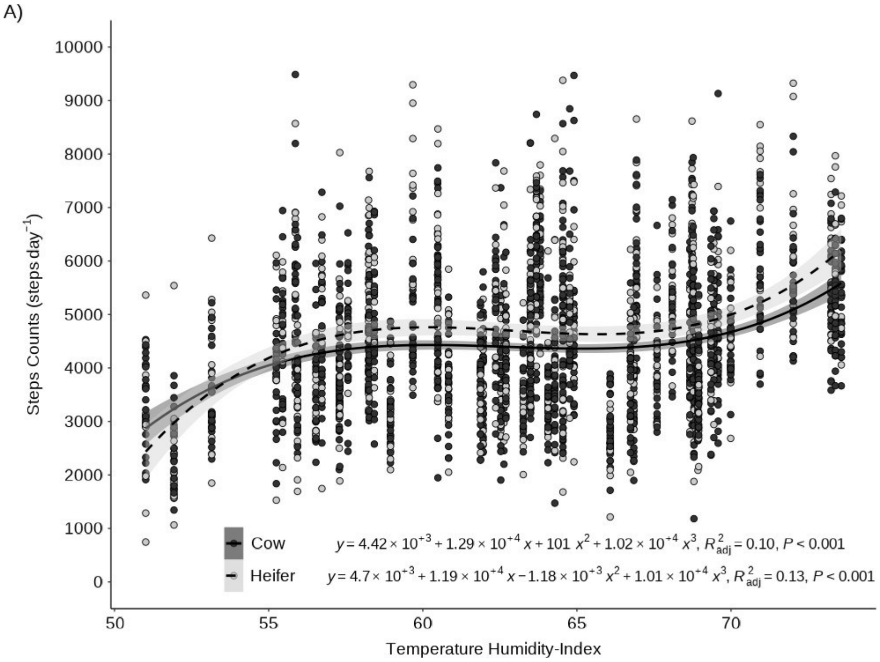


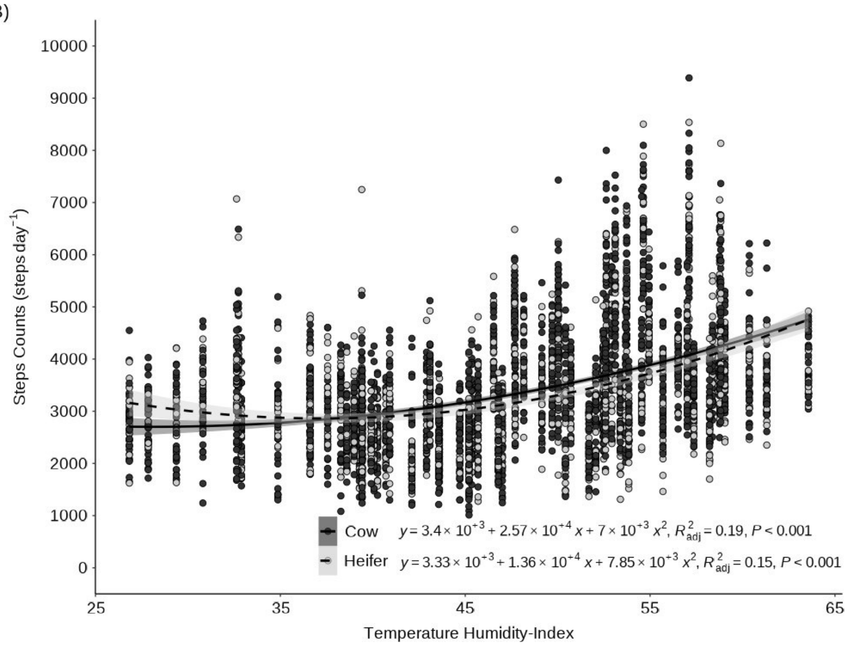
Figure 2.3. Changes in mean (±SD) temperature-humidity index (THI) computed on an hourly basis for each of the days with presumed heat stress (THI ≥ 68; n = 16) and days without heat stress (THI < 68; n = 42) during the summer 2021 grazing period.

A)

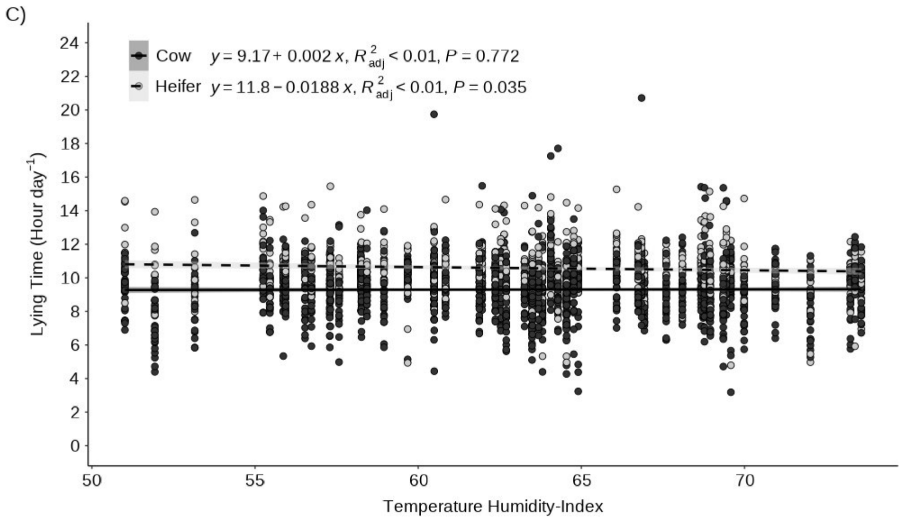


Steps Counts (steps day^{-1})
Temperature Humidity-Index
Cow $y = 4.42 \times 10^{+3} + 1.29 \times 10^{+4}\,x + 101\,x^2 + 1.02 \times 10^{+4}\,x^3$, $R^2_{adj} = 0.10$, $P < 0.001$
Heifer $y = 4.7 \times 10^{-3} + 1.19 \times 10^{-4}\,x - 1.18 \times 10^{-3}\,x^2 + 1.01 \times 10^{+4}\,x^3$, $R^2_{adj} = 0.13$, $P < 0.001$

B)



Steps Counts (steps day^{-1})
Temperature Humidity-Index
Cow $y = 3.4 \times 10^{+3} + 2.57 \times 10^{+4}\,x + 7 \times 10^{+3}\,x^2$, $R^2_{adj} = 0.19$, $P < 0.001$
Heifer $y = 3.33 \times 10^{-3} + 1.36 \times 10^{+4}\,x + 7.85 \times 10^{-3}\,x^2$, $R^2_{adj} = 0.15$, $P < 0.001$



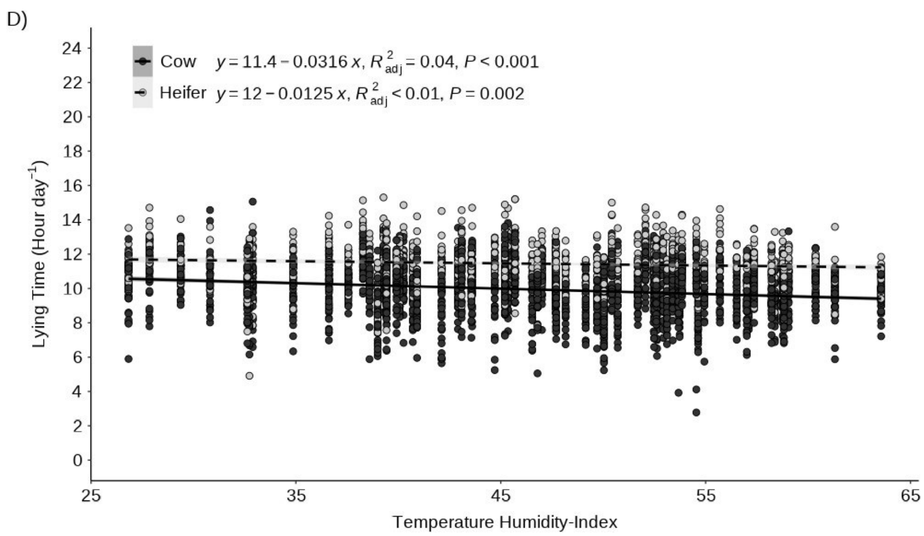


Figure 2.4. Relationship between mean daily step counts of either cows or heifers, and temperature-humidity index (THI) during A) the 2021 summer grazing season, and B) the 2021 fall grazing season, at the Kinsella Research Ranch. Also depicted are the relationship between mean daily lying time of either cows or heifers, and heat stress level (THI), during C) the 2021 summer grazing season, and D) the 2021 fall grazing season. Interactions between animal class × THI are all significant at $P \leq 0.05$. Equations indicate the significance of the individual relationships. Shaded areas represent the standard error for each response.

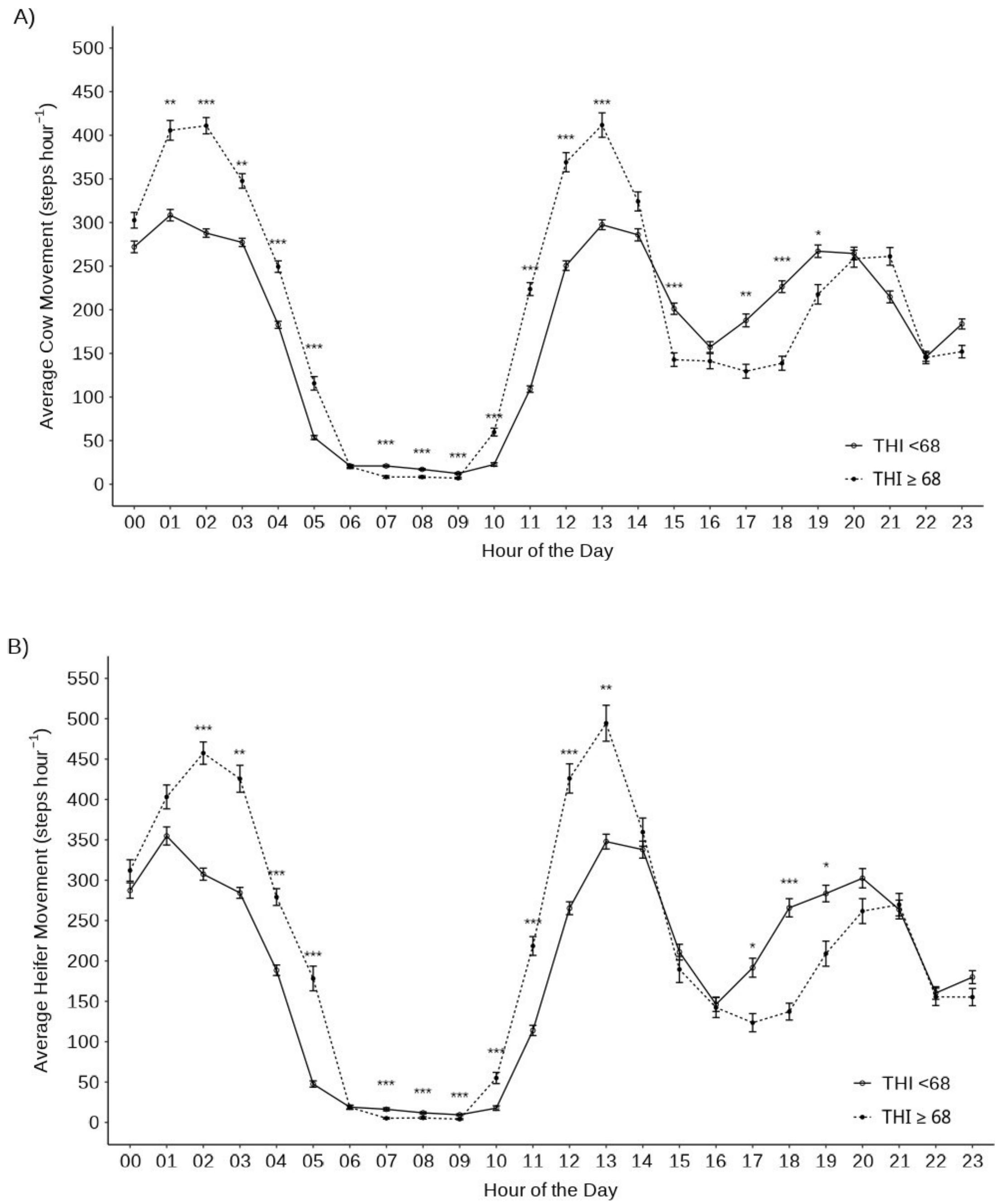


Figure 2.5. Changes in mean diurnal step counts (±SEM) over a 24-hr period during days of presumed heat stress exposure (temperature-humidity index, THI ≥ 68; n = 16) and non-stress (THI < 68; n = 42) days, for A) cows and B) heifers. Data are from the summer grazing period (June 28 – August 24) during 2021. Within an age class and hour, paired step counts denoted with an * differ, P < 0.05.

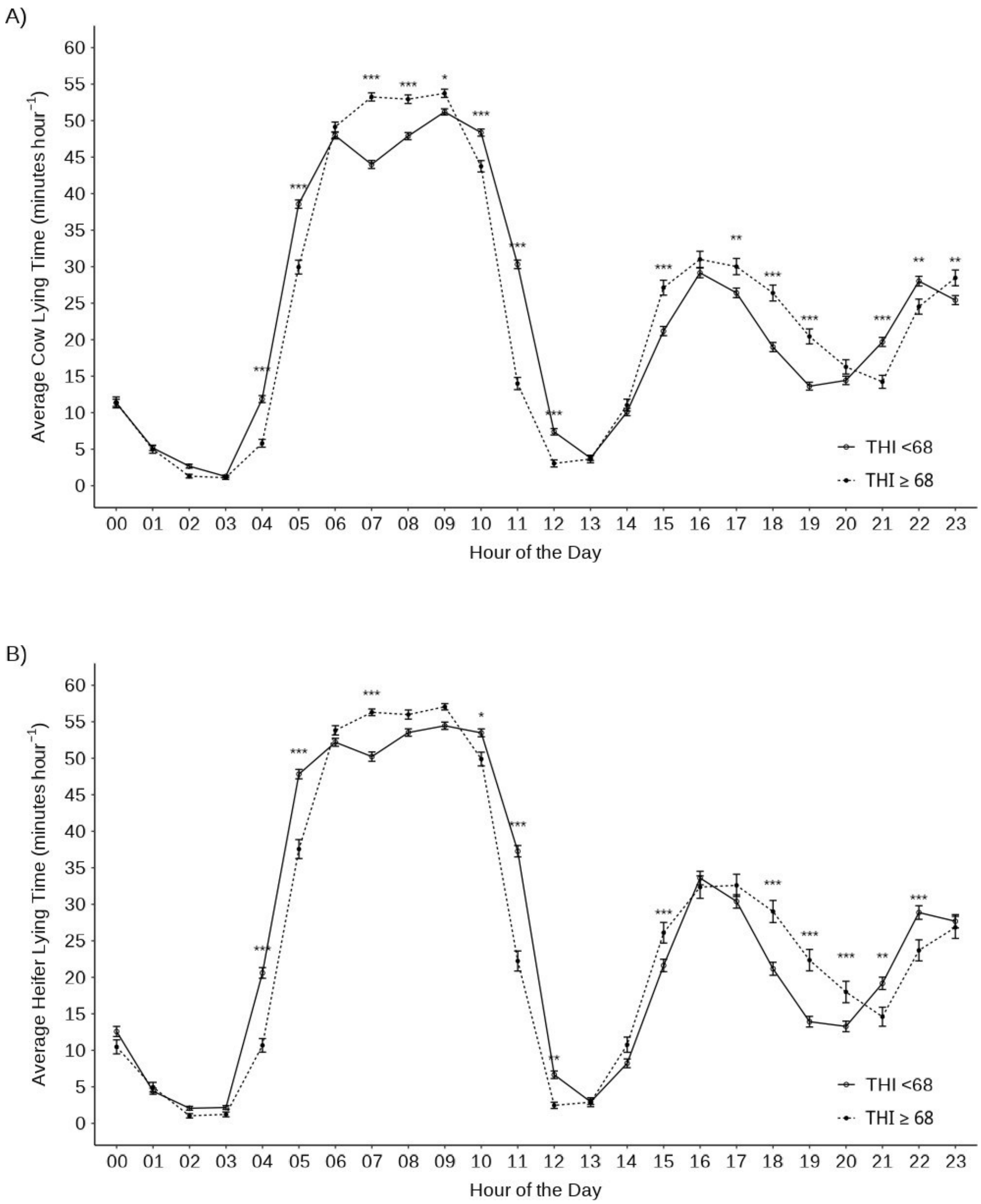


Figure 2.6. Changes in mean diurnal lying time (±SE) over a 24-hr period during days of presumed heat stress exposure (temperature-humidity index, THI ≥ 68; n = 16) and non-stress (THI < 68; n = 42) days, for A) cows and B) heifers. Data are from the summer grazing period (June 28 – August 24) during 2021. Within an age class and hour, paired step counts denoted with an * differ, P < 0.05.

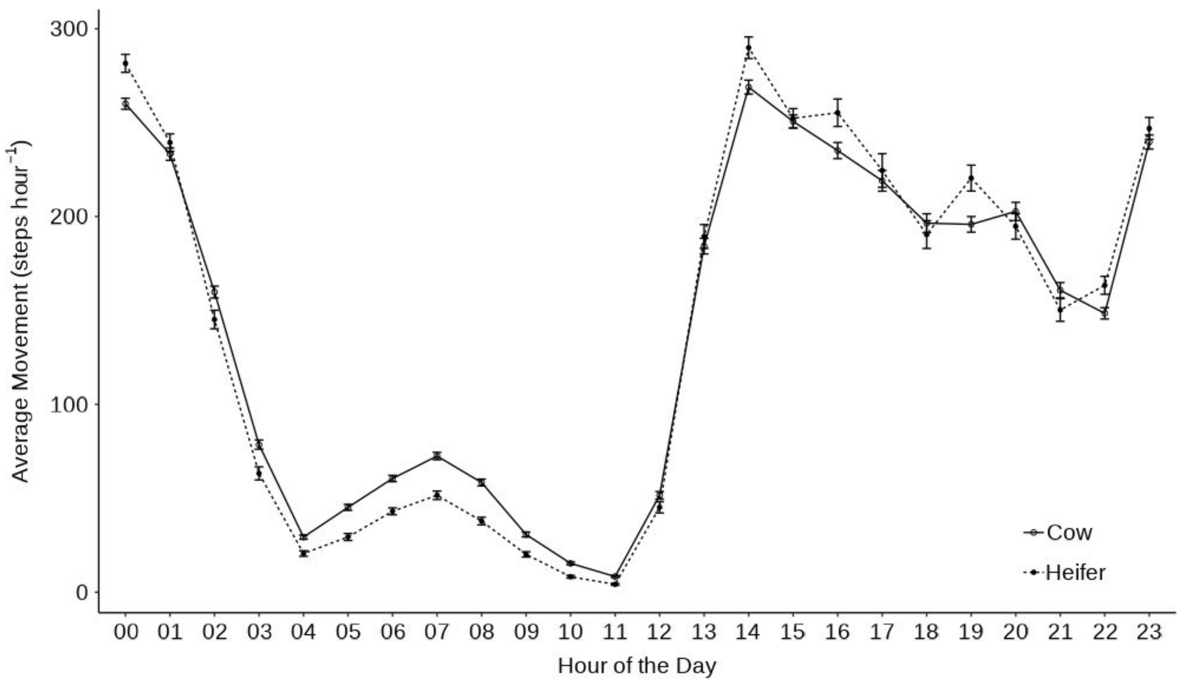


Figure 2.7. Changes in mean diurnal step counts (±SE) over a 24-hr period during fall for cows and heifers. Data are from the fall grazing period (August 28 – November 8) during 2021.

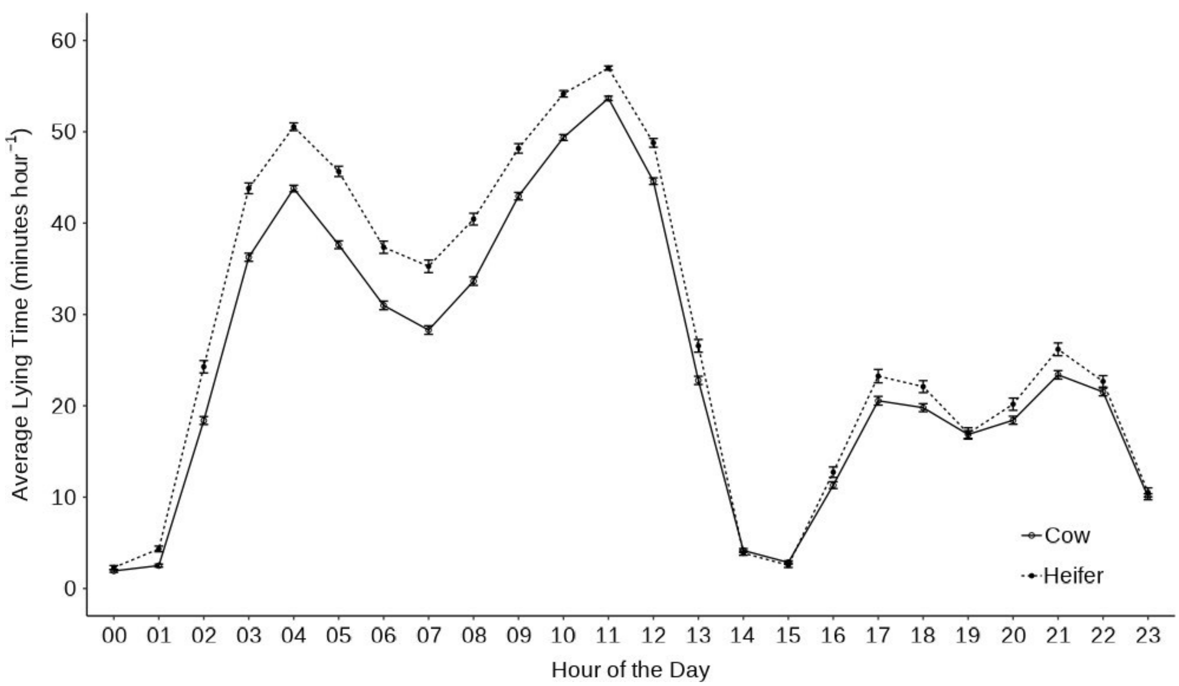


Figure 2.8. Changes in mean diurnal lying time (±SE) over a 24-hr period during fall for cows and heifers. Data are from the fall grazing period (August 28 – November 8) during 2021.

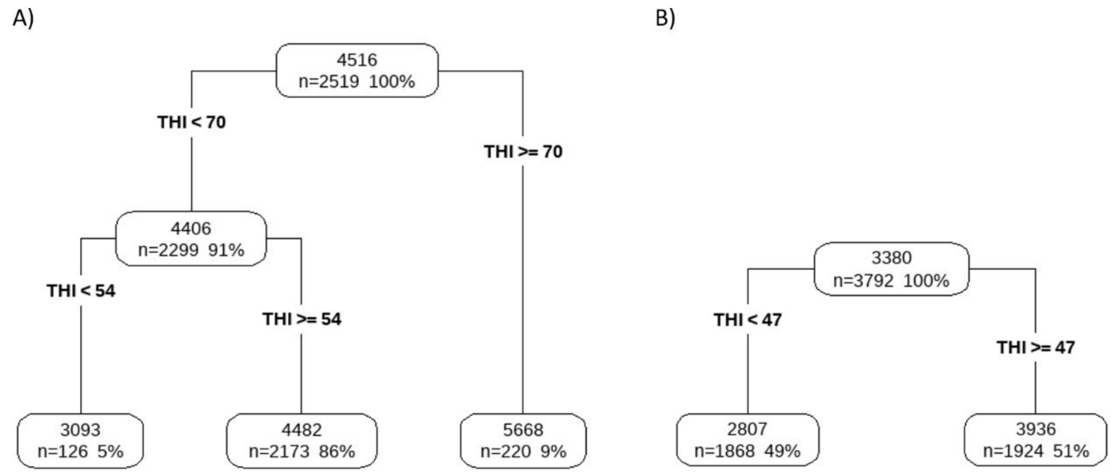


Figure 2.9. Regression tree-CART model results depicting the impact of daily THI (Temperature-Humidity Index) values on changes in observed daily step counts, presented separately for each of the A) summer grazing period, and B) fall grazing period, during 2021. The percentage at the bottom right represents the size of the sample passing through each node per split, while the value at the bottom left is the corresponding number of observations. The number at the top of the node represents the predicted step counts in a day with the specific condition of THI. Step counts were greater in summer when THI values exceeded 70, and lower with THI values below 54, while in fall THI values over 47 predicted an increase in daily movement.

Chapter 3: Linking cattle activity budgets on pasture to animal attributes and performance

3.1 Introduction

Pedometers can be used to track animal activity monitoring, welfare, and behavior, including that of free-ranging cattle while on pasture (Walker, 1995; Bailey et al., 1996). Previous studies using pedometers on cattle have verified their ability to detect estrus relative to visual detection in dairy cattle (Robert et al., 2009; Nielsen et al., 2010; Mayo et al., 2019), and also in determining the onset of lameness (O'Callaghan et al., 2003; Mazrier et al., 2006). These authors observed varying lying times on the day of estrus using pedometers from different manufacturers, but in all cases estrus detection was improved from pedometers compared to visual observation.

Increased animal activity can also directly elevate energy requirements. For example, Gangnat et al. (2017) found that calves with higher step counts were associated with a pasture having a steep slope, which in turn, led to a two- to eightfold increase in energy expenditure as compared to calves with lower step counts occupying a flatter pasture. This result is also supported by other studies, where higher energy expenditure was associated with cows having higher step counts (Brosh et al., 2010; Lachia et al., 1997).

In addition, intrinsic animal factors such as residual feed intake (RFI) and cow age can affect animal activity on pasture, as well as their productivity. A study conducted by Parsons et al. (2021) examined the influence of RFI and cow age on beef cattle performance and grazing behavior. They reported that inefficient cows travelled further in search of forage than efficient animals; however, what remained unclear is the role of animal activity in cattle decision-making to meet their minimum energy maintenance requirement, as the former study was conducted during winter, a season characterized by low forage quality and quantity conditions (Nelson and Moser, 1994; Oates et al. 2011). Parsons et al. (2021) further stressed that cow age affected the distance travelled by animals on pasture, with 2-year old cows travelling an average distance of 3 km each day, while 8-year old animals covered approximately 2.5 km. It remained unclear, however, whether these distances were traversed over different periods of time (durations). Cows that cover a long distance in a short period are likely to burn more energy, thereby increasing their requirement for energy, as increased movement rates in cows and mammals have been previously associated with glycogen depletion (Tarrant, 1989). Thus, the examination of average step counts in a day may be an appropriate tool to evaluate cattle movement and associated performance.

Additionally, cattle breeds may have different activity levels on pasture, including their movement patterns, which in turn, can influence their energy budgets and associated production. In a study by Russel et al. (2012) examining the grazing distribution and diet quality of Angus, Brangus, and Brahman cows, Angus cows maintained more linear grazing paths than the other two breeds, suggesting reduced use of energy while traversing pastures. Thus, the examination of breed composition may help explain how cattle activity on pasture varies, including in relation to production.

The specific objectives of this study were to:

1. Identify the effect of animal factors such as previously established RFI, breed composition, and age of the animal, on observed cattle activity budgets, as measured by mean step counts, and percentage lying time, and,
2. Evaluate the relationship between activity budgets (mean step counts, and percentage lying time) and observed animal production performance (cow weight gain, calf weight

gain, and cow-calf weight gain), as measured during the summer and fall grazing seasons while on open-range pasture.

3.2 Materials and Methods

3.2.1 Study area

The study was conducted within native pastures at the University of Alberta Roy Berg Kinsella Research Ranch (KRR), situated approximately 140 km southeast of Edmonton, Alberta, Canada (53°02'N; 111°34'W). This area is represented by Aspen Parkland rangeland occupying hummocky terrain landscapes, with a high diversity of vegetation. Primary habitat types include open grasslands (< 10% shrub cover), shrublands occupied by either low-statured shrub species [*Symphoricarpos occidentalis* (western snowberry)] or tall shrubs (*Elaeagnus commutata*), interspersed patches of relatively dense forest (*Populus tremuloides*) or scattered low lying riparian wetlands (dominated by hydrophytic *Carex* spp.). The climate of this region is cool continental, with 394 mm of annual rainfall, with most (70%) occurring during the growing season (May through September). Forage growth is typically high during May through July, then slows in August, with senescence progressing rapidly in September and October as autumn transitions into winter.

The cattle grazing trials conducted here occurred during the summer and fall seasons of 2021 through 2023 inclusive, with cattle examined while grazing on native (previously uncultivated) pastures. Further details are provided below.

3.2.2 Cattle herds

All animals used in this study and the accompanying protocols were approved by the Institutional Animal Care and Use Committee of the University of Alberta (AUP #00003850). A total of 251 cattle (varying from 1-12 yr in age and ranging in weight from 379 – 634 kg) were evaluated during the summer and fall grazing periods of 2021 – 2023 (Table 3.1). A total of 5 experimental herds were monitored for activity using pedometers.

Two groups of cattle were subsets of larger herds grazing on relatively large native pastures. This included a group of 61 black Angus cows (591 ± 84 kg) with calves at side grazing in 2022 from July 14 to September 12. Within these same pastures during 2023, a group of 45 KC cows with calves were tested as part of a larger herd, from July 11 to Nov. 10 (Table 3.1).

Finally, during each of the years 2021, 2022, and 2023, a smaller cohort of first calf KC cows and heifers were grazed together (the 'small KC' herd) within the same pastures during summer and fall each year (n=49 - 58 head each year; see Table 3.1), with a different set of animals representing these same age classes each year. Summer and fall pastures were 69.3 ha and 61.6 ha in size, respectively. Summer grazing occurred from June 24 to August 26, 2021, while fall grazing was from August 27 to November 10, 2021. In 2022, grazing of these same two pastures occurred from June 24 – September 6, 2022, and from September 7 – September 23, 2022. Pedometers were removed earlier than normal in 2022 due to concerns over pedometer fit, specifically for the original pedometer design that used a narrow (1.5 cm) strap. In 2023, all pedometers deployed used a wider strap for improved comfort for animals (~2.5 cm), although pedometers were not placed on heifers to avoid pedometer overtightening on the leg with rapid growth of youthful animals. The small KC cattle herd grazed on the same pastures in 2023 from July 11 – September 12, and September 12 – November 10, for the summer and fall, respectively.

All KC cattle had been previously tested in feedlot for Residual Feed Intake (RFI), a metric evaluating feed efficiency that is independent of animal size and growth, while the Angus cattle were not tested for RFI. Furthermore, during the selection of KC animals for the 'small herd' of KC cattle each year, cattle were further stratified in selection according to their phenotypic RFI, where 20 cows were relatively more efficient (low RFI; Table 3.1), 20 were intermediate in RFI (controls), and 20 were relatively less efficient (high RFI) (Table 3.1) for ease of use during analysis.

3.2.3. Quantification of cattle activity

Activity on all five herds were tested using IceQube+ pedometers (Peacock Technology Ltd., Stirling, Scotland). Pedometers were applied to the left hind leg in late June or early July, then monitored for the balance of the grazing season or until removed. Pedometers were checked frequently for comfort and fit, including at the time of transition from summer to fall pasture, when all animals were weighed.

IceQube+ pedometers are designed to collect activity data on cattle within fifteen-minute intervals for each animal while deployed. Pedometers generally remained on animals until early November, at which time they were removed and read using a portable IceHub unit, and then subsequently downloaded to the IceRobotics Cloud, and later retrieved for analysis. Compiled data included information on the step counts (steps hr^{-1} d^{-1}) and lying time (% of total time evaluated) across each grazing period, as represented by either summer only, fall only, or the summer and fall period combined.

Compiled activity data included information on cattle step counts (steps hd^{-1} d^{-1}, further separated by hourly counts) and lying time (%) across the 71 and 76-day-long grazing seasons for the large KC herd and Angus cattle, respectively. In addition, for the small KC herd, activity data were available for first calf cows during the summer of all years (2021-23), and for these same cows in the fall of 2021 and 2023. Activity data on heifers were only available in the summer and fall of 2021, and the summer of 2022 (Table 3.1).

3.2.4 Cattle weight gain

All animals (cows, and where applicable, calves) were weighed at the beginning and end of every grazing season (summer and fall), through the use of a hydraulic squeeze (Silencer Chutes, Raymond, AB, Canada) fitted with electronic load cells for weighing. Total weight gain over the grazing season was determined as the accumulated weight change over summer and fall, computed by subtracting the initial weight (June/July) from the final weight (November).

For all calves, the 205-d adjusted weaning weight (WW) was computed using the following formula (Hobbs and Smith, 1991):

205-d WW = [(calf weaning weight – calf birth weight)/ (calf weaning date – calf birth date)] × (205 days + calf birth weight + dam age correction factor)

Finally, aggregate cow-calf (pair) weight gain was computed as the sum of cow weight gain and the calf 205-d adjusted weaning weight.

3.2.5 Data stratification and analysis

Raw data from the pedometers was provided as information on animal behavior within 15 min long bins throughout the day. Data for individual animals were initially downloaded from the Cow Alert website. Next, data were examined to identify missing values and remove days with missing activity prior to analysis. All handling days were removed to accommodate for periods of time during which cattle were being confined and thereby unable to exhibit normal activity on pasture. Two days before handling and the day after handling were also removed to accommodate their gathering from pasture. After being processed to accommodate the pre-processing and processing days, all cattle activity data were converted from 15-minute bins into daily bins. Daily cow step count and lying time (in seconds) were calculated by summing the cow step counts and lying time on 15-minute bins into 24 hr periods; a total of 96 bins were summed to obtain daily activity data. Days in which individual animal readings with less than 93 bins were removed.

Animal performance data collected on either end of the grazing period (summer and fall) were matched with the individual activity data collected from the pedometers. In addition, information was compiled on the intrinsic attributes of cattle that may affect their behavior, as indicated by the activity metrics. Intrinsic attributes included cow age (particularly for the Angus herd, in which age ranged from 3-11 yr; Table 3.1), the RFI value of the KC cattle as previously determined in drylot as a heifer, and also for KC animals the percentage breed composition comprised of black Angus, which ranged from 17 to 55%.

Given the inherent differences in animal age classes, breed composition, and grazing (pasture) locations for the different grazing trials, a separate analysis was done for each of the black Angus and large KC herds. In contrast, the small KC cattle herd was comprised of both first calf cows and heifers each year, and grazed the same pastures in summer and fall, albeit as different animals. Thus, data from the three consecutive years of grazing for the small KC herd were combined for analysis, as pasture location and size, as well as potential differences in forage quantity and quality, were considered to be negligible for that herd.

All subsequent data analysis was done in SAS (SAS version 9.4) using the packages PROC MIXED and PROC REG. For significant interaction effects, 3-D graphs were generated in R version 4.3.2 (R Core Team, 2023) using the set of packages available on ‘tidyverse’ library version 2.0.0 (Wickham et al., 2019). Given the unique set of intrinsic conditions for each study cattle herd, a separate analysis was done for the Angus, large KC herd, and small KC cattle herd (see Table 3.2 for a summary of behavior by these herds). This accounted for differences in pasture locations, size, conditions, as well as breed differences and prior performance evaluation (i.e., RFI).

Within each analysis, two discrete steps were performed, the first evaluating potential effects of intrinsic animal attributes, using PROC MIXED where (age, RFI, breed composition were the fixed effects) on activity budgets (mean daily step counts and mean daily lying time percentage were the dependent variable), with animal ID and year treated as random variables. The second was an evaluation of the association between activity budgets and observed cattle production metrics while grazing, using PROC REG where (mean daily step counts and mean daily lying time percentage, were the fixed effect) and production metrics such as (cow weight gain, calf weight gain, and cow+calf weight gain were the dependent variable) with animal ID and year were treated as the random variables. Statistical significance was set at $P < 0.05$ for all analyses, unless otherwise noted.

3.2.5.1 Black Angus activity

To initially test the effects of different cow ages on activity budgets among the black Angus cattle, a regression was performed between cow age class (3 – 11 yr) and both mean daily step counts (steps hd^{-1} d^{-1}) and mean daily lying time (%), using all animals within this herd; this analysis was done with the PROC REG function in SAS version 9.4 (Stroup et al., 2018). Relationships were assessed using their significance (p-value), adjusted R^2, and corresponding equations.

Next, and given the demonstrated importance of cow age in altering activity budgets, black Angus cow weight gain, calf weight gain, and cow-calf aggregate weight gain, were each tested against the fixed effects of mean daily step counts (steps hd^{-1} d^{-1}), cow age, and their interaction, using PROC MIXED in SAS. A similar analysis was done for mean daily lying time within a 2-way interaction model. This identified whether the activity metrics, alone or in conjunction with cow age, effected the production variables. Individual animals were treated as random. Where significant relationships were found, particularly 2-way interactions of age × activity, a 3-D graph was constructed in R version 4.3.2. (R Core Team, 2023) using the set of packages available on 'tidyverse' library version 2.0.0 (Wickham et al., 2019).

3.5.2.2. Large KC herd

Behavior of Kinsella Composite crossbred cattle was analyzed separately in two groups: the large KC and small KC, each of which grazed a different set of pastures. Model selection was done through regression analysis to test the effect of intrinsic factors (RFI-Fat, cow age group and breed composition) as well as account for how they individually (or their possible interactions) contributed significantly to the model (where mean daily step counts and mean daily lying times were the dependent variables). Observed AIC values were used as the selection criteria, and delta AIC values were calculated. Models with a delta AIC less than 2 were considered to be equally plausible and were therefore tested further using the PROC REG function in SAS. Where there was an interaction between 2 or more treatments, the interactions were tested first, with significance set at $p < 0.05$, and the Adj-R^2 and equation used to explain any significant relationships.

To understand the effect of activity metrics (step counts and lying times) on cow weight gain and calf 205-d weaning weights, a simple regression analysis was performed with either cow weight or calf weight as the dependent variable in response to mean daily step counts or mean daily lying times (%).

3.5.2.3 Small KC herd

Differences in activity metrics (step counts and lying times) were initially tested between the two-age classes (cows vs heifers) examined within the small KC herd using PROC GLIMMIX in SAS 9.4. Where significant differences in activity existed between cows and heifers, subsequent analyses were performed separately by age cohort. Fixed effects of RFI-fat and breed composition among the small KC animals, together with their interactions, were tested on activity variables (mean daily step counts and mean daily lying times), using year of testing and individual animal as a random effect separately on cows and heifers. To understand how activity budgets affected cattle performance, simple regressions were performed with cow weight gain and heifer weight gain regressed against mean daily step counts and mean daily lying times, with year of testing and individual animal as random effectAdditionally, in the case of first calf cows, the calf 205-d weaning weights were evaluated, together with the aggregate cow+calf gain over the entire grazing season.

3.3 Results

3.3.1 Purebred Angus activity responses

Angus cow step counts were inversely related to animal age (Fig. 3.1A), with step counts decreasing by ~25% (from 4000 to 3000 steps hd^{-1} d^{-1}) as cow age increased from 3 to 11 years; no such relationship was evident for lying time and age (Fig. 3.1B). Based on these results, the subsequent analysis of activity effects on cattle weight gain included step counts in the ANOVA model (Table 3.3).

Both calf weight gain over the summer grazing period, together with cow+calf aggregate weight gain, were affected ($P < 0.002$) by the interaction of cow age and step counts among the Angus cattle (Table 3.3). Closer examination of these interactions using 3-D graphs indicated that younger cows who took fewer steps (an average of 3000 steps d^{-1}) had calves with higher weight gains (average of 110 kg), while younger cows having higher steps counts (average of 4500 steps d^{-1}) had calves with lower weight gains (averaging 85 kg; Fig. 3.2). In contrast, older Angus cows (age 11 yr) were found to have relatively similar levels of calf gain across all step count levels, although cows taking 4500 steps d^{-1} were found to have the highest calf weight gain (125 kg). Overall, this relationship was statistically significant ($p = 0.01$, Adj-$R^2 = 0.19$; Fig. 3.2).

The interaction between cow mean daily step counts and cow age on aggregate cow-calf weight gain was also significant ($p = 0.005$, Adj-$R^2 = 0.16$; Fig. 3.3). The observed pattern for cow-calf gain was similar to the calf gain, although cow+calf gain was higher which indicated that it is being driven by the cows rather than calf gain. Younger cows (3-4 yr) taking fewer steps (~ 2500 steps d^{-1}) had by far the highest cow+calf weight gain, with aggregate gains as high as 350 kg, whereas younger cows that took more steps had the lowest overall cow+calf weight gain (averaging 85 kg). Also notable was that older cows had divergent aggregate cow+calf weight gain responses, depending on activity level (Fig. 3.3); less active cows had reduced weight gain with age, while more active cows (those with greater step counts) had greater weight gain with increasing age.

Unlike step counts, mean daily lying time had no effect on the performance of Angus cattle, either alone, or in combination with cow age ($P > 0.39$; See Table B3.11).

3.3.2 Factors regulating activity in the large KC herd and their performance

Singular fixed effects of RFI-fat, breed composition and cow age on the activity metrics (step counts and lying time) of the large KC cow herd were found to be the leading models based on a delta AIC of 2 (Appendix Tables B3.1, B3.3, B3.6, and B3.8) during both the summer and fall grazing seasons of 2023. To further test for the role of cow age, a mixed model procedure was done to compare step counts and lying times of cattle between the two age classes examined (3 vs 4 yr olds). Neither cattle step counts ($F \geq 0.03$; $P \geq 0.87$) nor lying times ($F \geq 1.83$; $P \geq 0.18$) differed in response to cow age in summer and fall. Additionally, regressions of step counts and lying times were not associated with RFI or breed composition for the large KC cattle herd during either portion of the 2023 grazing season ($P > 0.09$, Adj-$R^2 \leq 0.05$; Tables B3.2, B3.4, B3.7, and B3.9).

Finally, simple linear regression was performed to determine whether the large KC cow herd animals were trading off weight gain on themselves versus their calves. However, no trade off was found between cow weight and calf weight over the summer and fall ($P = 0.06$, Adj-$R^2 = 0.002$; Figure B3.1). In addition, no significant relationship was found between either cow weight gain or calf weight gain against cow daily step counts and daily lying time ($P \geq 0.14$, Adj-$R^2 \leq 0.03$; Tables B3.5 and B3.10).

3.3.3 Factors regulating activity and performance of the small KC herd

Animal age class within the small KC herds tested over three years was distinguished between heifers (age 1) and first-calf cows (age 3). These age groups were found to differ significantly in both mean daily lying time ($P < 0.001$) and mean daily step counts ($P = 0.06$). Heifers had 5.5% greater daily step counts, and spent 16.2% greater time lying down each day, compared to cows with calves (Fig. 3.4). Due to these differences between age classes, further analysis was done separately for each age cohort.

There were no statistically significant relationships between RFI-fat, breed composition (percentage Angus), or their interaction, in relation to cow mean daily step counts ($P \geq 0.25$, Adj-$R^2 \leq 0.03$; Table B3.12). Similar results were found between RFI-fat, breed composition (% Angus), and their interaction, to cow mean daily lying time ($P \geq 0.15$, Adj-$R^2 \leq 0.01$). Furthermore, no significant relationships were found between RFI-fat, breed composition (% Angus), and their interaction, in relation to heifer mean daily lying time ($P \geq 0.14$, Adj-$R^2 \leq 0.04$; Table B3.14).

A two-way interaction was evident, however, between RFI-fat and breed composition in relation to heifer mean daily step counts ($P = 0.0005$, Adj-$R^2 = 0.32$). Closer examination of this relationship (Fig. 3.5) indicated that efficient (negative RFI value) heifers with higher breed composition of Angus exhibited increased mean daily step counts to levels as high as 3999 steps d^{-1}. However, inefficient heifers (i.e., those with a positive RFI value) with lower Angus breed composition had the lowest activity as reflected by mean daily step counts, with step counts dropping to as low as 3119 steps d^{-1}.

A positive linear relationship was found between cow weight gain (excluding calf gain) and mean daily step counts in relation to both cows ($P = 0.02$, Adj-$R^2 = 0.06$; Fig. 3.6A) and heifers ($P = 0.015$, Adj-$R^2 = 0.16$; Fig, 3.6C) with no significant relationship in calf gain ($P \geq 0.45$; Adj-$R^2 \leq 0.001$; Table B 3.17) of the small KC herd during the summer grazing periods over the three study years. In contrast, a negative linear relationship was found between weight gain and mean daily lying time in relation to both cows ($P = 0.015$, Adj-$R^2 = 0.07$; Fig. 3.6B), and heifers ($P = 0.06$, Adj-$R^2 = 0.04$; Fig. 3.6D). Unlike the summer grazing period, observed activity levels during fall were unrelated to the weight gain of heifers or cows ($P \geq 0.31$; Adj-$R^2 \leq 0.001$, Table B 3.15 and Table B 3.16).

3.4 Discussion

3.4.1 Age effects on cattle activity budgets

Intrinsic cattle attributes that were tested for their impact on cattle activity included age, and in the case of the small KC herd, associated reproductive status confounded with age (heifers vs cows with calves). Across age cohorts, both step counts and lying times tended to vary in relation to several of these attributes. For example, the herd with the largest range of ages tested was the black Angus, for which we found a negative relationship between mean daily step count and cow age. There are several explanations for this decline in movement (i.e., step counts) with age. As older cows are often heavier than younger ones (Deniz et al., 2021; Sessim et al., 2020), this may make younger cows more mobile and active as they traverse the landscape, in turn, increasing their step counts. However, older cows may also be more familiar with their foraging environment, and therefore exhibit reduced search times when foraging due to prior knowledge of the availability of key resources. Grandl et al. (2016) previously reported that older cows had more feed retention time and longer gut fill compared to younger cows, which could also explain the reduced movement; as digestibility in that same study was not affected by age, this suggests that older cows required less feed overall compared to younger ones. Should this be the case, this pattern would reduce an animal's search time while foraging and be further reflected by a declining step count as cow age increases.

Unlike the black Angus herd where we had a wide range of cattle ages, age had no effect on either step counts or lying time for the large KC herd. However, this lack of a difference may reflect the similar ages of the animals tested, which were limited to include cows that were either 3 or 4 years old. The similarity in age but also parity (i.e., both age cohorts had calves, either as first or second parity) may have limited the expression of differences in activity for these animals.

Finally, animal age class (cows and heifers) within the small KC herd was found to have an association with activity. Heifers had greater step counts but also longer total lying time than cows with calves, consistent with the pattern observed for the black Angus herd. This result has been previously reported by other studies (Hart et al., 1993; Kilgour, 2012; Villalba et al., 2015). We suspect that heifers had greater step counts than cows as the former are not constrained by the presence of calves (Crumb et al., 2019; De Passille et al., 2010). Having young calves at side could prevent cows from expressing their true behavior (e.g., exploring the landscape in search of forage), as cows will be more likely to stay near their calves (Johansen et al., 2023; Sahu et al., 2020), for example, to provide protection from predators and support lactation.

Another possible reason for the difference in activity between heifers and cows could be their different physiological states. As heifers are younger than cows they have higher metabolic rates and energy levels (Schuermann et al., 2019; Zou et al., 2007), which could naturally contribute to their increased movements. Furthermore, the social dynamics of heifers are known to be different from cows (Neisen et al., 2009), as heifers are associated with a more active social hierarchy. The latter can be expressed by frequent bouts of play and increased interactions among their peers relative to cows (Field et al., 2023), which could ultimately increase the step counts of heifers. Longer lying times of heifers may arise due to the longer rest periods needed to recover from more active movement while standing, as well as the lack of calves, the latter of which would reduce the lying times of cows due to the periodic need to support lactation throughout the day.

3.4.2 Intrinsic genomic attributes regulating cattle activity

Cattle within the KC herds tested here had previously been tested for RFI score as a heifer in drylot, enabling an evaluation of associations between RFI and subsequent activity on pasture. Residual feed intake adjusted for backfat levels (RFI-fat) is defined as the difference between an animal's actual feed intake and its expected intake for the same growth and energy requirements within a given production system (Archer et al., 1999; Koch et al., 1963). In the current study, we initially postulated that efficient cows (low RFI cows) would walk less as they require reduced intake of forage, while inefficient cows (high RFI cows) may walk more as they require more feed to meet their energy needs. Ultimately, RFI-fat was not associated with the activity of any KC cows, including heifers, or 3 or 4 yr old cows.

These results coincide with other findings previously reporting that RFI [either as a divergent class (i.e., low RFI and High RFI) or as a continuous value] were not associated with the step counts of cows while grazing on pasture (Moore, 2018; Sprinkle et al., 2021). However, they also contradict several prior studies (e.g., Gregorini et al., 2015) reporting that low RFI is associated with reduced step counts when cattle are grazing, while a higher animal step count is associated with high RFI cattle while grazing. Cattle selection is determined at several scales, including the plant community, feeding station, and patch level (Senft et al., 1987; Kaufman et al., 2013b). Of note, we are unable to partition our step counts into when cattle were actually grazing, and when they are not (e.g., travelling to water or shade), all of which would make it difficult to identify the full effect of RFI on cattle activity budgets.

As the KC cattle examined here were all crossbred, breed composition data for each animal was also used to evaluate activity patterns. As the predominant breed was Angus within the KC cattle, we used the proportional presence of Angus as a covariate to evaluate activity responses on pasture. Breed composition (percentage Angus) was ultimately not found to be associated with cattle activity. These results are unexpected because other studies suggest that the Angus breed is a particularly active one (VanWagoner et al., 2006; Verdon et al., 2021; Russel et al., 2012), and therefore cattle with increased Angus in their composition may be expected to exhibit increased activity. However, no association was found between breed composition and activity here. This could be because of complex interactions among the constituent breeds of each animal, the fact that Angus was limited to less than 60% of the composition of each animal, or due to limited variation that exists between the breed, or that breed-based effects may be more likely to appear within older cows (i.e., all KC animals tested were 4 yrs old or less).

Finally, of note is that we did find an interaction between RFI-fat and percent Angus (in the breed composition) in relation to the mean daily step counts of cattle, but only among the KC heifers, and not the cows. A similar dependency was reported on by Parsons et al. (2020), and supports other studies documenting this interaction (Gregorini et al., 2015) whereby animals with increased RFI-fat values and high Angus composition were associated with increased daily step counts. These findings suggest that inefficient cattle (and specifically heifers, rather than cows) may dedicate increased activity to movement while traversing the landscape. This increased movement, in turn, could reduce the energy available for weight gain, hence explaining the change in feed efficiency for these high RFI animals (Hill et al., 2012), as they spend more time grazing compared to the efficient (low RFI-fat) cows (Herd et al., 2009). Alternatively, low RFI heifers may be more efficient because of their energy conserving strategy via reduced movement, which could occur if these animals are more adept at searching for and consuming forage, and therefore reach gut fill of high-quality forage faster. The further association of high step counts (i.e., movement rates) of cattle comprised of increased Angus, is consistent with this breed being very active (Verdon et al., 2021). In any case, the contingency of RFI × breed composition effects on the youngest cohort of KC cattle tested (heifers), and not cows with calves, suggest that these effects are either relatively weak, and/or disappear with age when cows may express other priority behaviors such as mothering and supporting their offspring.

3.4.3 Cattle production responses in relation to activity

Cow step counts are considered an important activity metric (Charlton et al., 2022) that relate to energy expenditure in beef cattle production (Brosh et al., 2010; Lachia et al., 1997). One of the most important production variables for beef cattle producers is ultimately weight gain (Martin et al., 2021; Semchechem et al., 2021), and differences in animal age can influence the weight on calves. We documented a negative relationship between calf weight gain and cow mean daily step counts for younger black Angus cows, with a positive response of calf weight gain with higher step counts for older black Angus cows. In contrast, within the smaller herd of KC cattle a positive relationship existed for both cow and heifer weight gain in relation to their mean daily step counts, but a negative relationship of weight gain compared to their mean daily lying time. Therefore, cow and calf weight gain ultimately had different relationships to activity budgets for the two breeds studied (purebred black Angus vs crossbred KC cattle).

In the case of the black Angus herd, while cow-calf production was affected by the interaction of age × step counts, separate examination of each group (cows vs calves) showed that this response was driven primarily by the performance of calves rather than cows. In a cow-calf relationship, cows may put energy into themselves, elevating individual weight gain (Albright, 1993), or transfer increased nutrients into lactation for their calves (Kang et al., 2022), in which case they may reduce their own performance. Alternatively, energy may be allocated in a balanced way to achieve modest increases in both cow and calf weight gain (Riley et al., 2016). The absence of a relationship between black Angus cow weight changes and mean daily step counts, but the presence of a calf response, highlights the fact that calf growth is ultimately the commercial variable impacted by cow activity level, with a further dependency on dam age. More specifically, younger cows actively taking fewer steps ended up putting more energy into their calves, as supported by the development of larger calves (Wright et al., 1994). However, our study also showed that older black Angus cows with higher steps counts led to the most weight gain on calves. While the exact cause of this changeover is unknown for older cows, this response could be attributed to cows with improved search ability being able to make better decisions in finding and consuming forage on pasture, while also conserving energy (Newberry et al., 2008). Conversely, we are unable to rule out that among the older cows, animals with higher step counts may simply be healthier, in turn, translating into improved support for the nursing calf. It should be noted that older cows typically have inherently greater energy requirements than younger cows to sustain their production or have a better body condition score than the younger animals (NRC, 2000), which in turn, may translate into a requirement for more time spent grazing (and moving about) on pasture, despite a lower overall movement rate. Thus, older cows may be moving in a more beneficial manner while grazing, thereby leading to improved energy transfer to their calves.

The generalized reduction in animal movement with increased cow age could occur due to differences in cow experience, as young animals (e.g., heifers) that end up taking more steps may be too inexperienced to make optimal decisions in selecting the superior quality forage needed to meet their nutritional requirements and support lactation (Bailey et al., 2010; Lopes et al., 2013). Moreover, as these same young animals take more steps, they may expend more energy (Lachia et al., 2005; Maurya et al., 2012), which in turn, may potentially reduce the energy available for transfer to calves and support their growth (Bazeley and Hayton, 2013). Thus, inexperienced young cows may ultimately be more likely to put increased energy into calves, but only when they take fewer steps due to energy conservation, which will create less conflict between energy allocation between the dam and her calf.

Unlike the findings from the purebred black Angus herd, a preliminary test showed that there was no trade-off between cow and calf weight gain among the Kinsella Composite (KC) crossbred cattle, instead suggesting that cow and calf gain were independent of one another. Unlike the black Angus herd, we did not find a clear association between cow or calf weight gain and dam step counts from the large KC herd, nor did weight gain responses relate to observed differences in lying times among those cattle. While we postulate that cows spending more time lying down and having reduced step counts would end up with greater weight gain due to energy conservation, we found no such association for either the older KC cow herd or their calves. The lack of a relationship for this herd may arise due to the lower sample size (38 animals) tested on pasture during 2023, which may have limited the power to detect significant associations.

In contrast to the large KC herd, an association was found among both cows and heifers of the small KC herds tested over multiple years between weight gain and both step counts and lying times, potentially due to the larger sample size of animals examined. While it is possible that the pastures used by the small KC herds may have had forage quality and quantity conditions more conducive to generating weight gain, this is unlikely given that the habitat types and foraging conditions remained similar between study areas. In any case, similar patterns were found in both the cows and heifers of the small KC herd, indicating that irrespective of their age (and reproductive status), KC cattle that walked more tended to put on more weight. This finding contradicted our expectations and suggested that cattle that walked more were not disadvantaged by increased energy expenditure, but rather benefited from greater movement, perhaps by finding and consuming better quality forage. Another study from the Mixedgrass Prairie in Alberta using pedometers on beef cattle reported a similar result (Moore et al., 2018) with a positive trend between body weight gain and decreased lying time. Moore et al. (2018) concluded that animals that had more search time had more weight gain. Our results further reinforced this, but also showed that cows who took more steps had increased weight gain on themselves, which has been reported previously (Freetly et al., 2020; Mandok et al., 2014). Overall, these findings highlight the need to further understand the mechanism behind how cattle with high step counts benefit, including via more search time, as evident by increases in weight gain for increased step counts, and decreased weight gain with increases in lying time.

Finally, it is important to note that cow step counts and lying time had no association with calf weight gain within the small KC herd tested over several years, indicating that alterations to the activity budgets of KC cows were more closely tied to individual dam performance, rather than that of their calves (Hafla et al., 2013). Additionally, no tradeoff in performance was detected between cow and calf gain for the small KC herd, although as noted previously, all cows within this herd were young (first parity), which could explain the lack of a response in calf gain, particularly as these animals were still growing, thereby creating competition in energy allocation between themselves and their offspring (Kertz et al., 1997). Along with cow age, many other factors ultimately could explain the performance of cow-calf pairs in this herd, including dam health status, and even variation in energy requirement in the dam's lactation stage, thereby altering how nutrients were transferred to the calf.

3.5 Conclusion

Our research is the first to evaluate in detail the activity budgets of cattle (step counts and lying times) grazing within native rangeland pastures of western Canada during summer and fall. Activity budgets were found to vary with animal age as younger cattle walked more than older ones. However, other intrinsic animal factors such as previously quantified RFI-fat scores (in drylot), and breed composition (percentage Angus) only influenced heifers but not cows. While increased activity (as demonstrated by greater step counts and reduced lying times) of heifers and young (first calf) cows generally led to greater weight gain within Kinsella Composite crossbred cattle, no responses in calf gain were observed for these young dams. In contrast, purebred black Angus cattle exhibited complex activity budgets in response to animal age, which was further reflected by variable calf weight gain. While young black Angus cows walking more had smaller calves, older black Angus cows walking more supported larger calves. Overall, these results highlight the importance of understanding the activity budgets of cattle, particularly that of mature cattle, including how this may alter important production outcomes.

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Tables and Figures

Table 3.1 Summary of all experimental animal used in the trials and their corresponding activity data from 2021 to 2023.

Extrinsic factor				Intrinsic animal factor			Activity metrics data			
Herd	Breed	Year	Season	Age	Breed Composition	RFIfat	--------Summer-----------		-------Fall-----------	
							mean daily step counts (step hd^{-1} d^{-1})	mean daily lying time percent	mean daily step counts (step hd^{-1} d^{-1})	mean daily lying time percent
Small	KC	2021	Summer and Fall	1 and 3	0.2 – 0.6	-2.7 – 4.1	4519 ± 603	40.4 ± 3.7	3380 ± 441	43.3 ± 3.8
Small	KC	2022	Summer	1 and 3	0.2 – 0.5	-2.7 – 2.1	5004 ± 609	40 ± 4.4	N/A	N/A
Small	KC	2023	Summer and Fall	3	0.2 – 0.5	-1.9 – 2.6	5110 ± 492	37.4 ± 2.3	3576 ± 350.1	40 ± 3.8
Large	KC	2023	Summer and Fall	3 and 4	0.03 – 0.5	-1.2 – 1.2	4264 ± 627	38.3 ± 3.4	3529 ± 446	40 ± 3.7
Large	Angus	2022	Summer	3-11	N/A	N/A	3486 ± 522	37.5 ± 4.1	N/A	N/A

RFI-Fat : This is the residual feed intake previously measured as heifers in drylot from January to March
Breed Composition: This is the percentage of black Angus in relation to other breed among the Kinsella composite cross bred cattle

Table 3.2: Summary of all experimental animals in the various trials and their corresponding production data from 2021 to 2023.

	Extrinsic animal/weather variables			Intrinsic factor	Production variables			
	Breed	Year	Season	Age	--------------Summer-------------		-------------Fall--------------	
Herd					mean cow weight gain (kg)	mean calf weight gain (kg)	mean cow weight gain gain (kg)	mean calf weight (kg)
Small	KC	2021	Summer and Fall	1 (Heifer)	19.0 ± 12.0	N/A	-6.2 ± 15.5	N/A
				3 (Cow)	19.3 ± 21.8)	66.3 ± 15.2	40.6 ±10.6	69.5 ± 9.2
Small	KC	2022	Summer	1 (Heifer)	69.8 ± 18.1	N/A	N/A	N/A
				3 (Cow)	72.4 ± 27.7	65.5 ± 6.8	N/A	N/A
Small	KC	2023	Summer and Fall	3 (Cow)	42.3 ± 18.6	60.8 ± 8.3	-3.3 ± 26.2	51.2 ± 9.6
Large	KC	2023	Summer and Fall	3 and 4 (All Cows)	27.6 ± 20.10	66.3 ± 15.2	72.4 ± 18.7	46.4 ± 6.2
Large	Angus	2022	Summer	3-11 (All Cows)	43.4 ± 23	109.7 ± 13	N/A	N/A

Table 3.3: Summary ANOVA results examining summer cow weight gain, summer calf weight gain, and cow-calf weight gain in relation to cow mean daily step counts (steps d^{-1}), age, and their interactions as evaluated for Angus cows in the summer grazing season of 2022

Production Variable	Effect	df (num, den)	F-Value	p-value
Summer Cow Weight Gain	Steps	1,33	0.13	0.72
	Age	8,33	1.03	0.44
	Steps*Age	8,33	8.33	0.42
Summer Calf Weight Gain	Steps	1,32	8.88	**0.006**
	Age	8,32	3.78	**0.003**
	Steps*Age	8,32	4.24	**0.0015**
Cow Calf Weight Gain	Steps	1,32	0.47	0.50
	Age	8,32	4.65	**0.0008**
	Steps*Age	8,32	4.67	**0.0007**

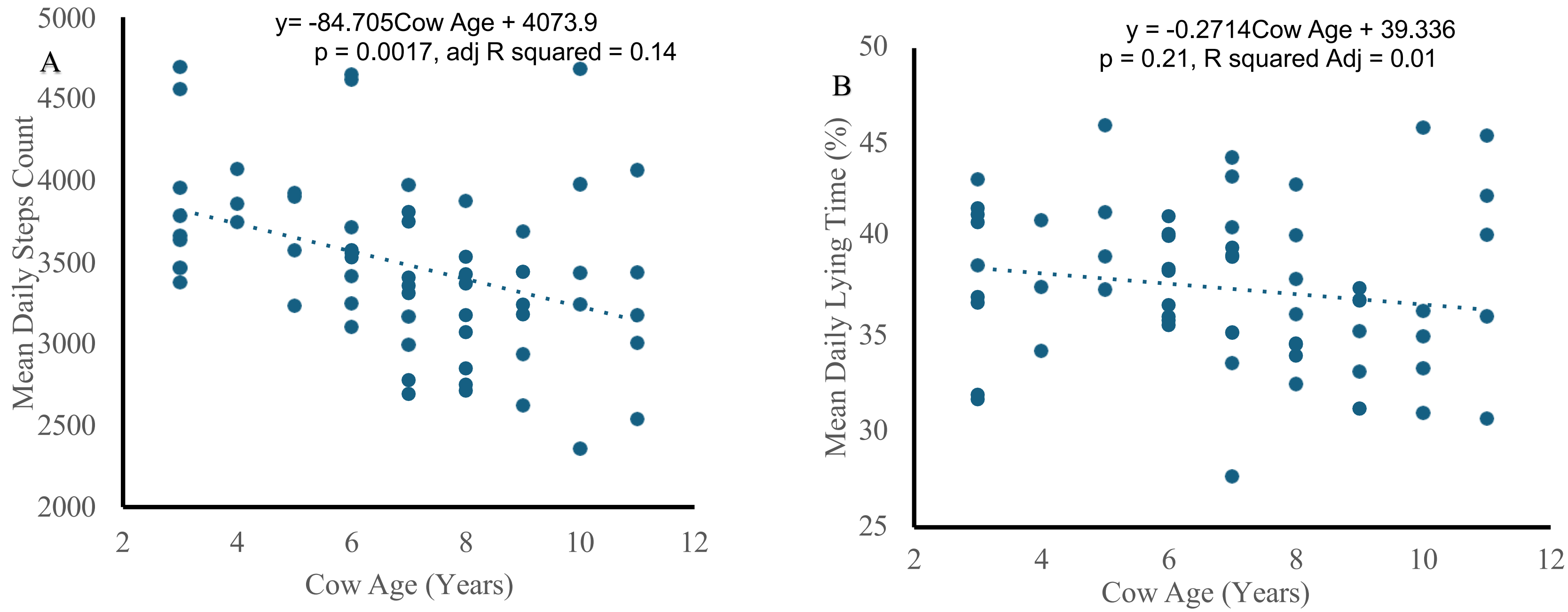


Figure 3.1 Summary of the relationship between A) mean daily steps counts and cow age, and B) mean daily lying time and cow age, as evaluated for Angus cows during the summer grazing season of 2022.

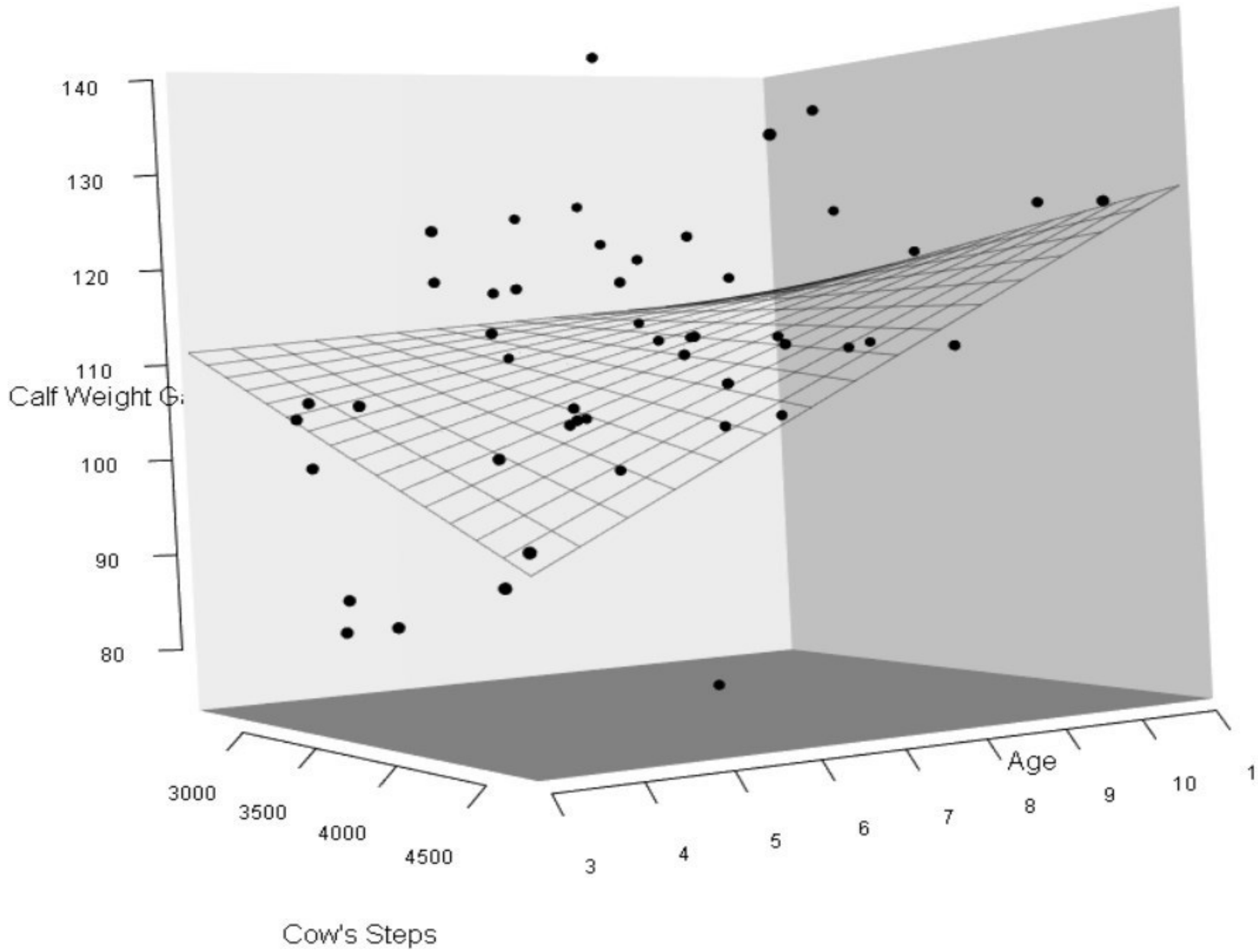


Figure 3.2: Relationship between calf weight gain and the interaction effect of cow age and mean daily step counts of Angus cows, as evaluated during the summer grazing season of 2022. The interaction is significant at $P = 0.01$, Adj-$R^2 = 0.19$.

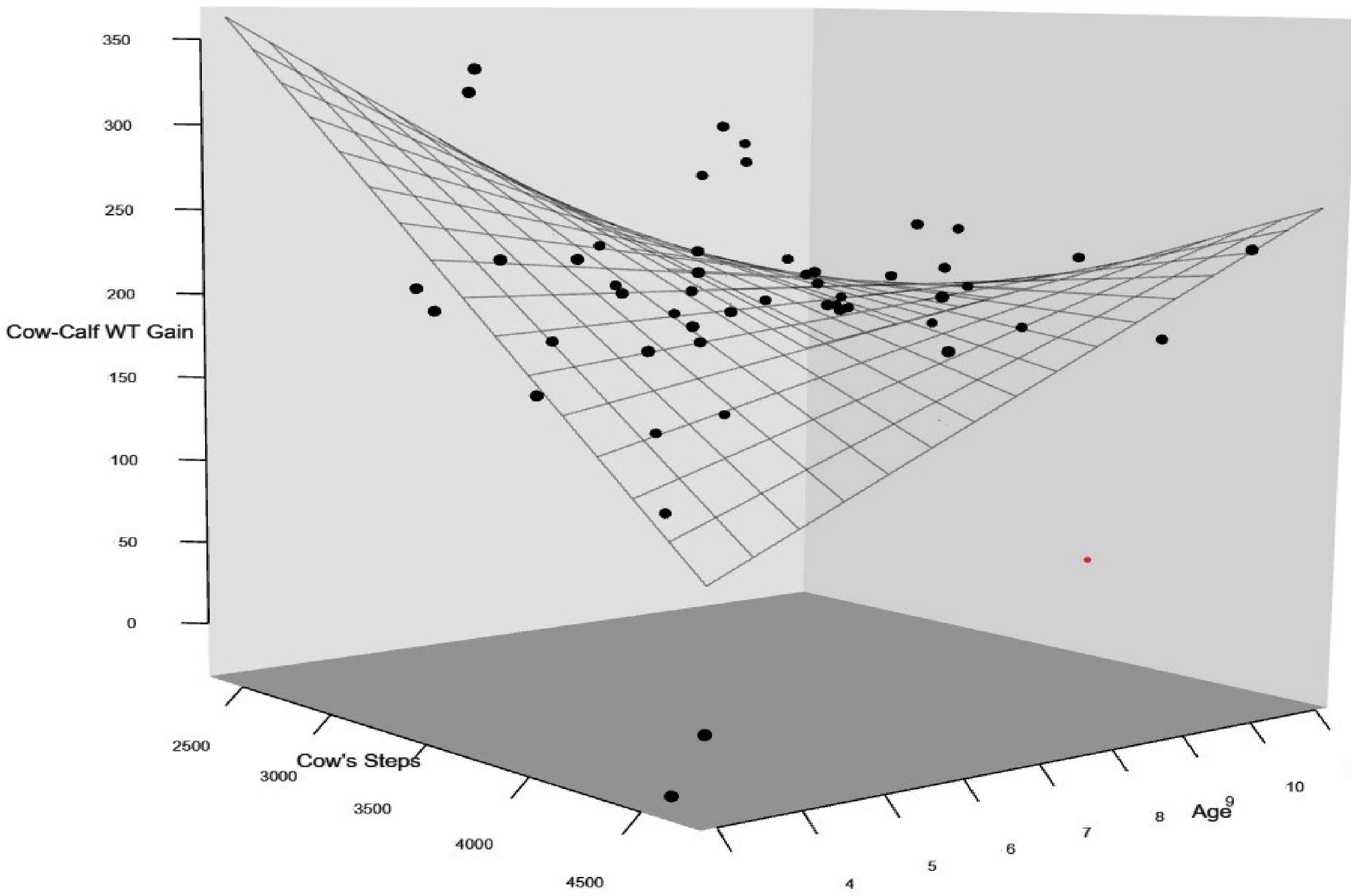


Figure 3.3: Relationship between cow-calf aggregate weight gain and the interaction of cow age and mean daily step counts, as evaluated during the summer grazing season of 2022. The interaction is significant at $p = 0.005$ and Adj $R^2 = 0.16$

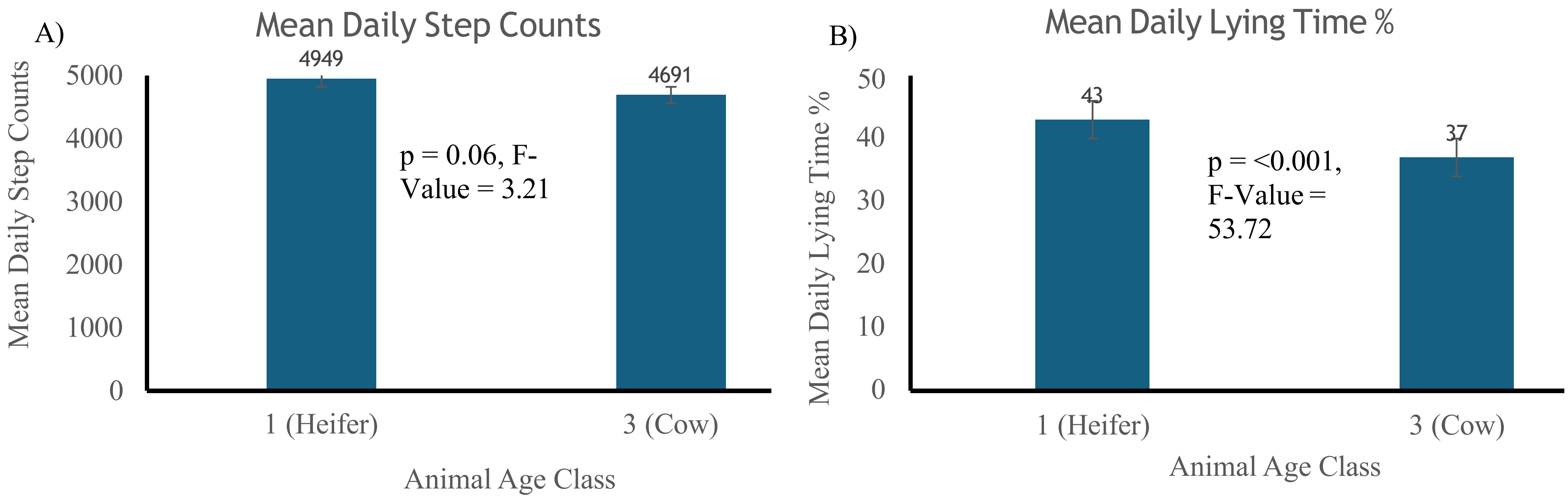


Figure 3.4: Summary of the mean comparison between A) mean daily step counts and animal age class B) mean daily lying time percent and animal age class in the summer grazing season of 2021 and 2022.

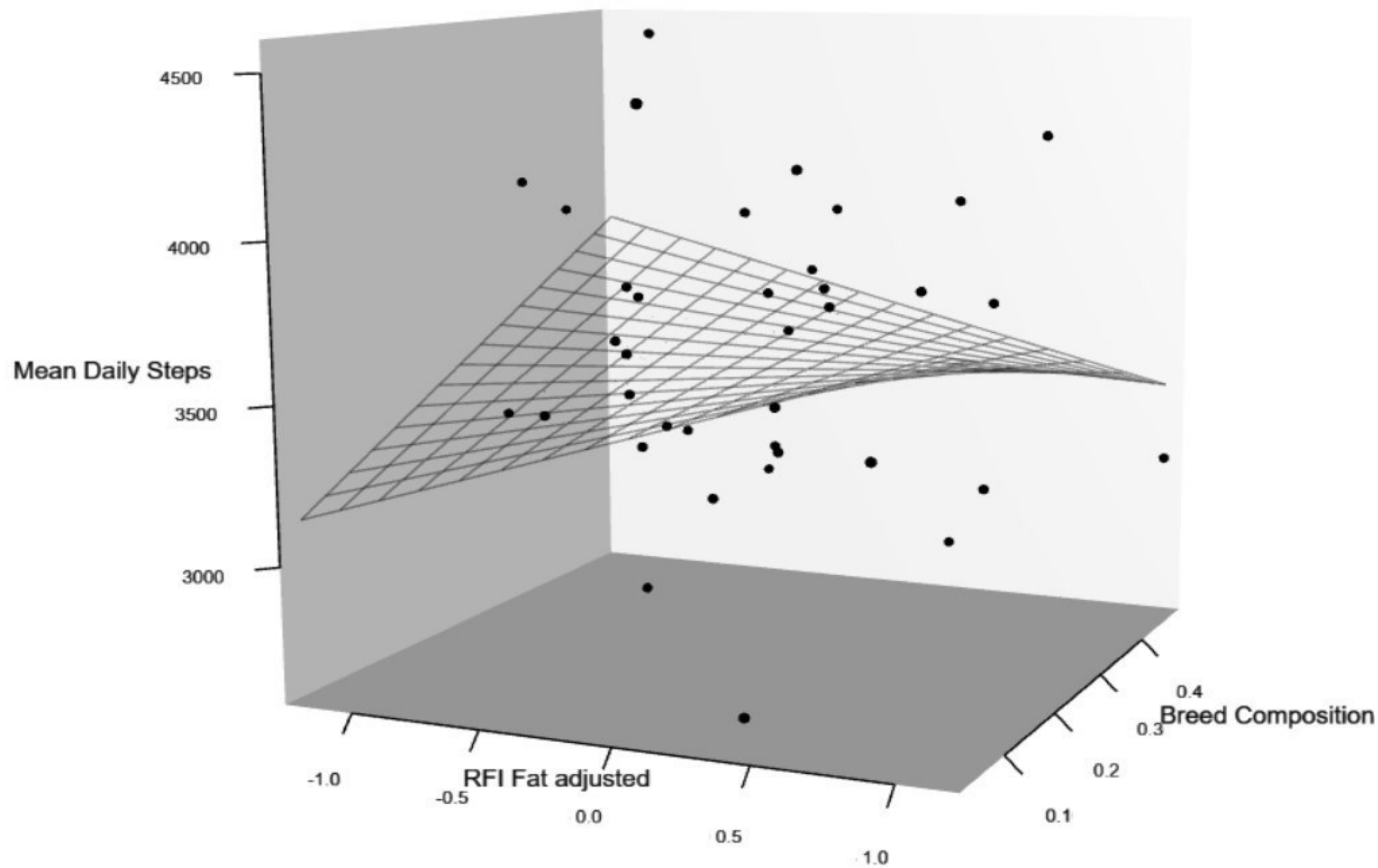
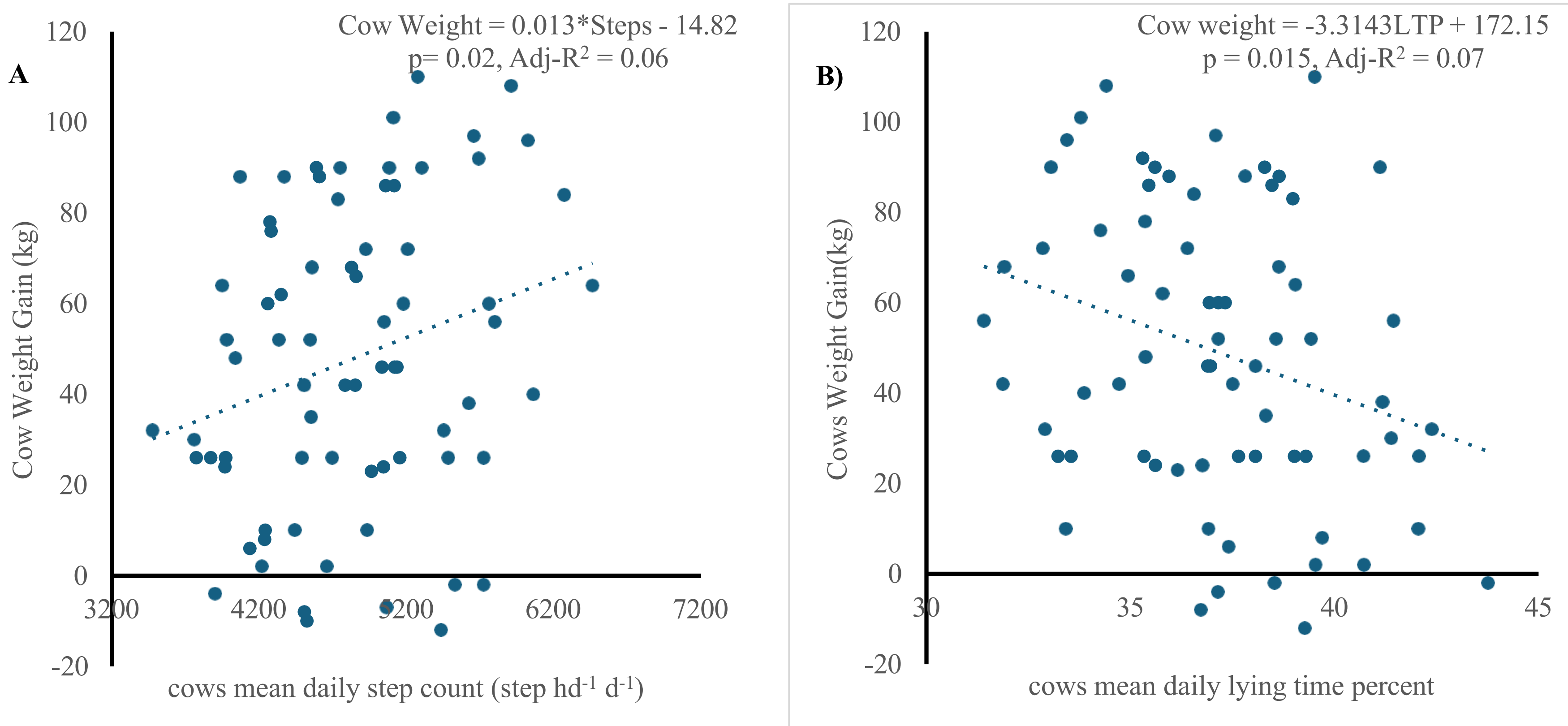


Figure 3.5: Relationship between mean daily step counts of heifers and the interaction of RFI Fat adjusted and breed composition, as evaluated during the summer grazing seasons of 2021 and 2022. The interaction is significant at $p = 0.0005$ and Adj $R^2 = 0.32$ and equation is given as: daily step counts = 3999 + 3119*BC – 943* RFI-fat + 3017 (RFI-fat*BC).



A
Cow Weight = 0.013*Steps - 14.82
p= 0.02, Adj-R^2 = 0.06
Cow Weight Gain (kg)
cows mean daily step count (step hd^{-1} d^{-1})
120
100
80
60
40
20
0
-20
3200
4200
5200
6200
7200
B)
Cow weight = -3.3143LTP + 172.15
p = 0.015, Adj-R^2 = 0.07
Cows Weight Gain(kg)
cows mean daily lying time percent
30
35
40
45

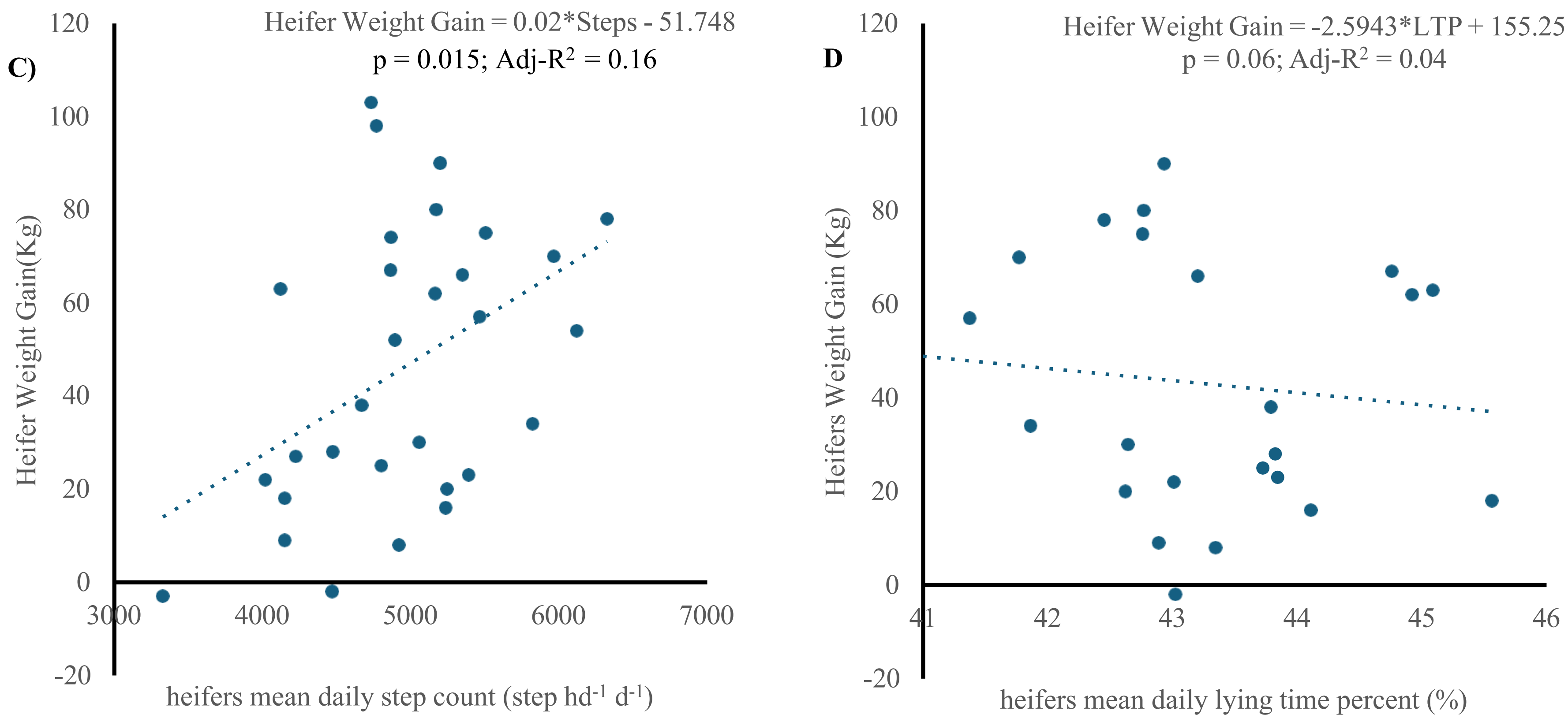


Figure 3.6: Summary of the relationship between A) cows' weight gain and cows' mean daily step counts, B) cows' weight gain and cows' mean daily lying time percent, C) heifers' weight gain and heifers' mean daily step counts, and D) heifers' weight gain and heifers' mean daily lying time percent, as evaluated for KC cattle during the summer grazing season of 2021, 2022, and 2023.

Chapter 4: Synthesis

4.1 General Overview

Beef cattle on rangelands are faced with complex decisions on how to move about and utilize pasture resources. Understanding grazing behavior of cattle on pasture may help ranchers make improved decisions to enhance pasture resource use and associated beef production. Tracking cattle activity on pasture can help ranchers understand animal response (i.e., sensitivity) to environmental conditions, including weather, resulting energetics and potential impacts on production. For instance, a continuous increase in lying time could indicate that a particular animal is challenged with poor health, which in turn, is responsible for their immobilization. Furthermore, characterizing the grazing behavior of beef cattle on pasture may help optimize forage utilization, for example, by designing pasture sizes and shapes that are consistent with preferred animal movement patterns. Finally, cattle activity patterns may be used in tracking reproductive behaviors, and may therefore have applications in reproductive herd management, for example estrus synchronization.

By conducting two focal studies on how cattle activity varies among animals and affects beef cattle production, this work is among the first to address the impact of extreme weather conditions on cattle activity, as well as the direct impact of cattle activity on important beef production metrics on pastures, including cow weight gain, calf weight gain and cow + calf aggregate weight gain. Characterizing cattle activity will not only help in understanding cattle fundamental movement patterns and monitoring welfare of the herd, but also relate these activities to animal performance, which can then be used to explore improvements in production for the entire beef cattle herd. Given the associated importance of energetics and potential impacts on production industry-wide, increasing support for beef cattle production will help the growing human population globally by allowing producers to select for cattle that make improved decisions on energy use while grazing on pasture, such as those that put on more weight for a given activity level.

4.2 Research Summary

Chapter 1 reviewed beef cattle production globally and in Canada. It reviewed determinants of pasture-based beef cattle production, which include extrinsic animal characteristics such as seasonal changes in forage quality and quantity with advancing phenological changes in the growing season. Weather and seasonal changes from the summer to fall grazing season may ultimately affect the activity budgets expressed by beef cattle. Additionally, intrinsic animal factors such as animal age, RFI (fat adjusted) feed efficiency, and breed composition were also reviewed for their effects on cattle activity on pasture. Furthermore, measurements of cattle activity through the use of pedometers were reviewed, including how activity budgets were measured and the accuracy limitations of such measurements and associated sampling time constraints. Finally, cow weight gain, calf weight gain, and cow + calf weight measurements were reviewed.

Chapter 2 specifically explored cattle movement rate (step counts) and lying time in a grazing season characterized by extreme hot weather (heat stress) conditions. Environmental weather data were downloaded, and heat stress conditions defined using the thermal heat index (THI) formula from the NRC equation. THI values of 68 and above were used as a benchmark for identifying days in which cattle were under heat stress (Bernaccubi et al., 2014). Mean step counts and mean lying times (%), calculated both on a daily and an hourly scale, were calculated from the IceQube+ pedometers fitted to cattle. Activity budgets in daily step counts and daily lying times were compared between heat stress days and non-heat stress days; we initially postulated that activity would be reduced during heat stress days. However, our results surprisingly showed that daily step counts increased during heat stress conditions. Closer examination on a diurnal basis revealed distinct changes in movement patterns, with peak movement overnight (from 11:00 pm till about 4:00 am), and again from late morning through early afternoon (11 am till 2 pm). Heat stress conditions led to increased movement (step counts) overnight, and again during mid-day, with extended periods of reduced movement and increased lying time in the interim. This shows that cattle partition their activity in distinct periods of the day, and that this partitioning is exaggerated during heat stress conditions. Moreover, these changes can likely be explained by changes in behavior while feeding (higher movement during the cooler conditions at night) and in the need to travel to access drinking watering (mid-day), although these notions warrant further testing.

Chapter 3 examined cattle activity budgets in relation to seasonal foraging conditions (summer vs fall) and intrinsic animal factors such as cow age, RFI-fat and breed composition, and included an evaluation of cattle weight gain (cow weight gain, calf weight gain, and cow + calf aggregate weight gain) in relation to mean daily step counts and mean daily lying times. We examined two major breeds: purebred black Angus and a group of Kinsella Composite crossbred cattle. Overall, we generally found a decrease in movement activity, as demonstrated by step counts, with increased cow age. Relative to first calf cows, heifers exhibited higher step counts, but also spent greater time lying down. In contrast, little to no difference in cattle activity was observed in relation to RFI-fat or breed composition. We did, however, find that cow and/or calf weight gain was related to the activity budgets of cattle, but that this varied further depending on whether this was tested across the purebred Black Angus herd (wide age range), or relatively young KC cattle (young animals only – 3 yr old). In the case of the purebred Angus, cows traded off weight gain in relation to cows activity on calves vs themselves. Additionally, the weight gain of calves, rather than cows, largely varied in relation to dam daily step counts, but this varied further with age. While young cows travelling more had smaller calves, the opposite was found for older Angus cows. For the KC cows, all of which were relatively younger animals, no age-based dependence was detected, and instead, animals with higher step counts (both cows and heifers) and less lying time generally had greater weight gain on themselves, with no response among calves associated with these young cows.

4.3 Management Implications

Characterizing cattle activity budgets on pasture is important to understand cattle grazing behavior, and thereby understand how this behavior may translate into energy use and conservation in cattle while grazing. This goal is challenging as activity budgets alone do not account for energy use and partitioning due to other physical activities undertaken by cattle, particularly dams through lactation. Thus, it might be difficult to measure cattle energetics using pedometers alone. Despite this, our work did show several significant relationships between cattle performance (weight gain) and activity metrics, thereby reinforcing the key role that activities (including movement rates) have on beef production. In doing so, it suggests that more work be done to understand cattle activity on pasture, and delve deeper into understanding the drivers of those activity responses, as well as how they may be used by commercial beef producers to improve their productivity and/or utilization of pasture resources.

Another major concern could be technical faults of the devices (pedometers) used. In this study a number of pedometers were lost while on pasture, and could not be found, and therefore represented a loss of data and sample size. Additionally, some pedometers stopped working, or wouldn't connect to the ice hub, preventing the timely downloading of data. As our cattle were brought in only at the end of each grazing season to download data, a significant number of observations were lost, reducing the robustness of the dataset available. On a final note, one major challenge if not the most important, is the ongoing welfare of young heifers fitted with pedometers. The use of pedometers on heifers that are actively growing require frequent checking, removal and refitting of pedometers straps (e.g., every 2-4 weeks), particularly if heifers undergo significant growth spurts on summer pasture (i.e., compensatory gain). If not properly monitored the use of pedometers can become welfare issues for heifers, and necessitate that health checks be performed regularly. However, regular health checks of cattle on pasture may also cause animals to take involuntary step counts, thereby distorting the data, which is not accounted for from the activity data. This was generally more likely to occur with the Black Angus cattle, which tended to be more shy in the presence of people.

4.4 Future Research Opportunities

Many considerations for future research are topics centered around the characterization of activity budgets in extreme cold weather and how this affects the grazing behavior of cattle. While we reported cattle behavior in extreme hot weather, documenting their activity to extreme cold weather could also be important.

Furthermore, advanced research should focus on the development of more advanced biowearable devices, and these devices should not only track activity but other physiological parameters such as rumination time, time spent grazing, and heart rate. Aside from physiological parameters, it should also be able to measure environmental data such as humidity, temperature, air pressure. This device will make it easier to correlate different behavioral metrics with activities to better understand cattle behavior and ultimately performance on pasture.

While we found a relationship between the contingency of RFI × breed composition effects, amongst heifers of KC composite cattle and not with cows, further studies on why cows may express other priority behavior should be tested to understand how other priority behavior such as mothering ability and supports to offsprings can influence their activity. Also, our study showed that younger black Angus cows with higher step counts leads to lower weight gain on calves while older black Angus with higher step counts lead to most weight gain on calves, further studies should be conducted in order to understand the contributing factors to this change over effect on calves performance among diverse age groups of the black Angus cows.

Similarly, while our study on KC cattle breed showed that increase activity as evidenced in higher step counts results into higher cow and heifer weight gain with no association on the calves, the mechanism behind this should be further studied, as well as understand what influence the weight gain on cows rather than calves.

After fully understanding the activity budget impact on beef cattle production, understanding how different genetic lines or breeds of cattle allocate their activity and their impact on production is also important, our studies have at least partly shown that different breeds may allocate their activity to production differently. Thus, farmers having access to different breeds of cattle may alter the performance of beef cows, with selection potential in the future a possibility to improve production.

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Appendices A

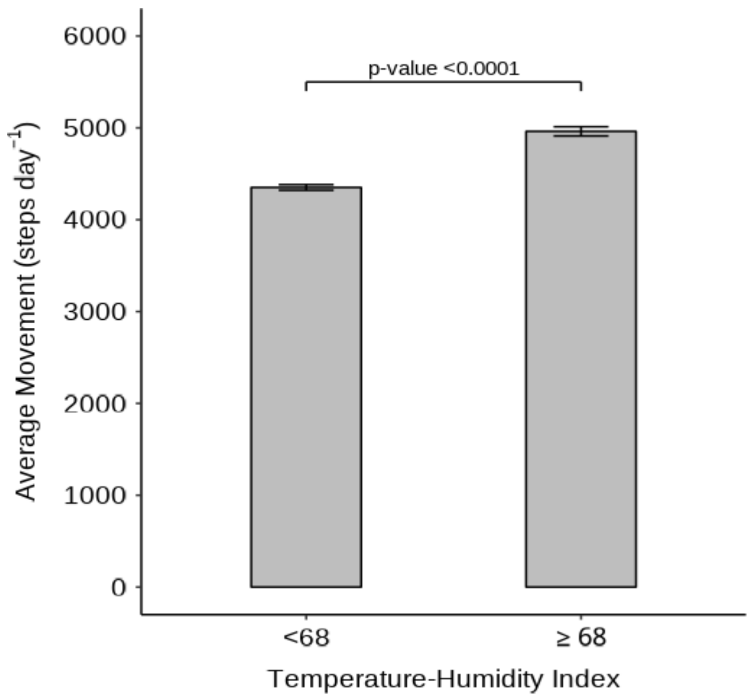

Figure A2.1. Relationship between mean daily step counts and thermal heat index (THI >68) during the 2021 summer grazing season at the Kinsella Research Ranch.

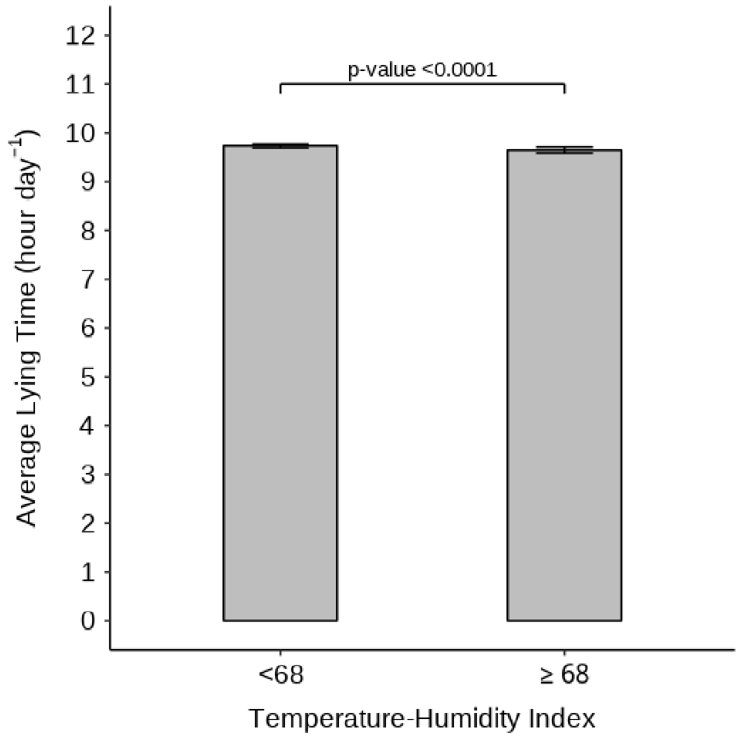

Figure A2.2. Relationship between mean daily lying time and thermal heat index (THI >68) during the 2021 summer grazing season at the Kinsella Research Ranch.

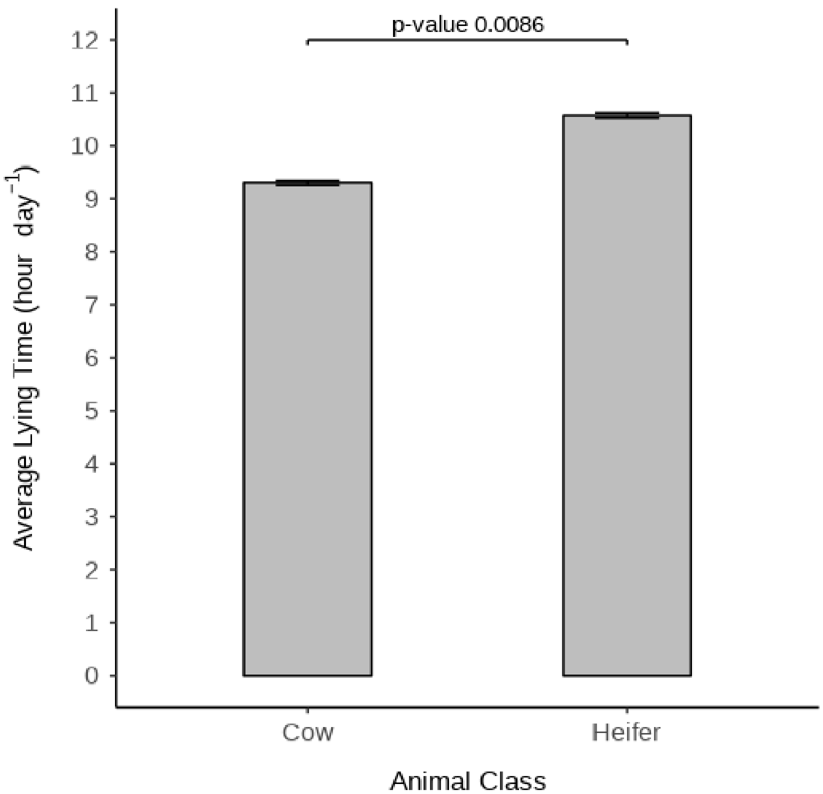

Figure A2.3. Relationship between mean daily lying time and animal class during the 2021 summer grazing season at the Kinsella Research Ranch.

Appendices B

Table B3.1 Summary of the model selection of cow mean daily step counts, evaluated in comparison to various intrinsic factors on Kinsella Composite cattle during the summer grazing season of 2023 (July 14 – Sept. 12). Intrinsic factors include cow age, breed composition (percentage Angus) and RFI-fat (measured in drylot as a heifer).

Number of Variables	Variables in Model	AIC Values	ΔAIC Values
1	Age	101.98	0.00
1	Breed Composition	102.78	0.80
1	Residual Feed Intake-Fat Adjusted	103.08	1.10
2	RFI Fat and Age	103.82	1.83
2	Breed Composition and Age	103.93	1.94
2	BC and RFI Fat	104.37	2.40
3	Age, BC, and RFIF	105.74	3.75

Table B3.2 Summary of the linear regression parameters explaining cow mean daily step counts, in relation to cow age, breed composition (percentage Angus) and RFI-fat adjusted (measured in drylot as a heifer) of Kinsella Composite crossbred cattle, as evaluated during the summer grazing season of 2023 (July 14 -Sept. 12, 2023).

Dependent Variable	Intrinsic Variable	Mean Estimate (β)	Intercept	P-Value	Adj-R^2
Daily Steps	Cow Age	-33	4375	0.87	-0.023
Daily Steps	Cow BC	-530	4425	0.57	-0.016
Daily Steps	RFI-fat	60.20	4245	0.72	-0.022

Table B3.3 Summary of the model selection of cow mean daily step counts in relation to various intrinsic factors on Kinsella Composite crossbred cows, including cow age, breed composition (percentage Angus) and RFI-fat, as evaluate during the fall grazing season of 2023 (Sept. 15 -Nov. 2).

Number of Variables	Variables in Model	AIC Values	ΔAIC Values
1	Age	518.87	0.00
1	Breed Composition	518.98	0.11
1	Residual Feed Intake-fat adjusted	518.99	0.12
2	Breed Composition and Age	520.27	1.40
2	RFI-fat and Age	520.63	1.78
2	BC and RFI-fat	520.86	2.00
3	Age, BC, and RFI-fat	521.94	3.10

Table B3.4 Summary of the linear regression parameters explaining cow mean daily step counts, in relation to cow age, breed composition (percentage Angus) and RFI-fat (measured in drylot as a heifer) of Kinsella Composite crossbred cattle, evaluated during the fall grazing season of 2023 (Sept. 15 – Nov. 2).

Dependent Variable	Intrinsic Variable	Mean Estimate (β)	Intercept	P-Value	Adj-R^2
Daily Steps	Cow Age	-249	4377	0.09	0.05
Daily Steps	Cow BC	-16	3527	0.98	-0.03
Daily Steps	RFI-fat	-48	3542	0.72	-0.02

Table B3.5: Summary of the linear regression parameters explaining cow weight and calf weight gain, in relation to cow mean daily step counts of large Kinsella Composite crossbred cattle, evaluated during the summer grazing season of 2023 (July 14– Sept. 12) and fall grazing season of 2023 (Sept. 15 – Nov. 2)

Grazing Season:	Summer 2023					Fall 2023				
Dependent variable	Activity variable	Mean Estimate (β)	Intercept	P-Value	Adj-R^2	Activity variable	Mean Estimate (β)	Intercept	P - Value	Adj-R^2
Cow Weight Gain	Cow daily step counts	-0.002	34.71	0.75	0.02	Cow daily step counts	0.01	41.94	0.23	0.01
Calf Weight Gain	Cow daily step counts	0.003	53.57	0.43	0.01	Cow daily step counts	0.00	45	0.59	0.03

Table B3.6 Summary of the model selection of cow mean daily lying time percent in relation to various intrinsic factors on Kinsella Composite crossbred cows, including cow age, breed composition (percentage Angus) and RFI-fat, as evaluate during the summer grazing season of 2023 (July. 14 - Sept. 12).

Number in Model	Variables in Model	AIC Values	ΔAIC Values
1	Age	101.98	0.00
1	Breed Composition	102.78	0.80
1	Residual Feed Intake Fat Adjusted	103.08	1.10
2	RFI Fat and Age	103.82	1.84
2	Breed Composition and Age	103.93	1.95
2	BC and RFIF	104.37	2.40
3	Age , BC, and RFIF	105.74	3.76

Table B3.7 Summary of the linear regression parameters explaining cow mean daily lying time percent, in relation to cow age, breed composition (percentage Angus) and RFI-fat (measured in drylot as a heifer) of Kinsella Composite crossbred cattle, evaluated during the summer grazing season of 2023 (July. 14 – Sept. 12).

Dependent Variable	Variable	Mean Estimate (β)	Intercept	P-Value	Adj-R^2
Lying Time (%)	Cow Age	-1.44	43.14	0.18	0.02
Lying Time (%)	Cow BC	4.49	36.92	0.37	-0.004
Lying Time (%)	RFI-fat	-0.61	38.28	0.52	-0.01

Table B3.8 Summary of the model selection of cow mean daily lying time percent in relation to various intrinsic factors on Kinsella Composite crossbred cows, including cow age, breed composition (percentage Angus) and RFI-fat, as evaluate during the fall grazing season of 2023 (Sept. 15 -Nov. 2)

Number in Model	Variables in Model	AIC Values	ΔAIC Values
1	Age	99.42	0.00
1	Breed Composition	101.38	1.96
1	Residual Feed Intake-fat Adjusted	101.41	1.99
2	Breed Composition and Age	101.47	2.05
3	Age, BC, and RFI-fat	103.35	3.93
2	RFI-fat and Age	103.47	4.05

Table B3.9 Summary of the linear regression parameters explaining cow mean daily lying time percent, in relation to cow age, breed composition (percentage Angus) and RFI-fat (measured in drylot as a heifer) of Kinsella Composite crossbred cattle, evaluated during the fall grazing season of 2023 (Sept. 15 – Nov. 2).

Dependent Variable	Variable	Mean Estimate (β)	Intercept	P-Value	Adj-R^2
Lying Time (%)	Cow Age	-1.05	40.75	0.35	0.002
Lying Time (%)	Cow BC	3.58	28.73	0.56	-0.01
Lying Time (%)	RFI-fat	-0.66	43.71	0.75	-0.05

Table B3.10 Summary of the linear regression parameters explaining cow weight and calf weight gain, in relation to cow mean daily lying time percent of large Kinsella Composite crossbred cattle, evaluated during the summer grazing season of 2023 (July 14– Sept. 12) and fall grazing season of 2023 (Sept. 15 – Nov. 2)

Grazing Season:	Summer 2023					Fall 2023				
Dependent variable	Activity variable	Mean Estimate (β)	Intercept	P-Value	Adj-R^2	Activity variable	Mean Estimate (β)	Intercept	P - Value	Adj-R^2
cow weight gain	cow daily lying time percent	0.9	45.2	0.43	0.01	cow daily lying time percent	-0.80	104.5	0.37	0.01
calf weight gain	cow daily lying time percent	-1.04	106.2	0.14	0.03	cow daily lying time percent	-0.32	59.2	0.27	0.01

Table B3.11 Summary ANOVA results examining summer cow weight gain, summer calf weight gain, and cow-calf weight gain in relation to cow mean daily lying time percent (LTP), age, and their interactions as evaluated for Angus cows in the summer grazing season of 2022

Production Variable	Effect	df (num, den)	F-Value	p-value
Summer Cow Weight Gain	lying time	1,33	0.53	0.65
	Age	8,33	1.31	0.73
	lying time*Age	8,33	5.77	0.39
Summer Calf Weight Gain.	lying time	1,32	1.88	0.55
	Age	8,32	2.65	0.49
	lying time*Age	8,32	1.67	0.70
Cow Calf Weight Gain	lying time	1,32	0.74	0.81
	Age	8,32	1.65	0.89
	lying time*Age	8,32	2.67	0.77

Table B3.12 Summary of the linear regression parameters explaining cow mean daily step counts, in relation to breed composition (percentage Angus) and RFI-fat (measured in drylot as a heifer) of Kinsella Composite crossbred cattle, evaluated during the summer grazing season of 2021(June 24 -Aug. 26), 2022 (July 6 – Sept.12) and 2023 (July14. – Sept. 12).

Dependent Variable	Variable	Mean Estimate (β)	Intercept	P-Value	Adj-R^2
Daily step counts (step d^{-1})	Cow BC	-982	5160	0.25	0.003
Daily step counts (step d^{-1})	RFI-fat	41	4855	0.60	-0.01
Daily step counts (step d^{-1})	Cow BC * RFI-fat	960	5181	0.60	-0.02

Table B3.13 Summary of the linear regression parameters explaining cow mean daily lying time percent, in relation to breed composition (percentage Angus) and RFI-fat (measured in drylot as a heifer) of Kinsella Composite crossbred cattle, evaluated during the summer grazing season of 2021(June 24 -Aug. 26), 2022 (July 6 – Sept.12) and 2023 (July14. – Sept. 12).

Dependent Variable	Variable	Mean Estimate (β)	Intercept	P-Value	Adj-R^2
Lying time (%)	Cow BC	-6.2	39.4	0.15	0.01
Lying time (%)	RFI-fat	0.27	37.2	0.50	-0.01
Lying time (%)	Cow BC * RFI-fat	-3.8	39.3	0.43	-0.002

Table B3.14 Summary of the linear regression parameters explaining heifers mean daily lying time percent, in relation to breed composition (percentage Angus) and RFI-fat (measured in drylot as a heifer) of Kinsella Composite crossbred cattle, evaluated during the summer grazing season of 2021(June 24 -Aug. 26) and 2022 (July 6 – Sept.12)

Dependent Variable	Variable	Mean Estimate (β)	Intercept	P-Value	Adj-R^2
Lying time (%)	Cow BC	-11.8	47	0.14	0.04
Lying time (%)	RFI-fat	0.31	43	0.43	-0.01
Lying time (%)	Cow BC * RFI-fat	-5.7	46.8	0.27	0.04

Table B3.15 Summary of the linear regression parameters explaining cow weight and calf weight gain, in relation to cow mean daily lying time percent of Kinsella Composite crossbred cattle, evaluated during the fall grazing season of 2021 (Aug. 27-Nov. 10), 2022 (Sept. 15 – Nov. 10) and 2023 (Sept. 15 – Nov. 2)

Animal Age Class:	Cows					Heifers				
Dependent variable	Activity variable	Mean Estimate (β)	Intercept	P-Value	Adj-R^2	Activity variable	Mean Estimate (β)	Intercept	P - Value	Adj-R^2
cow weight gain	cow daily lying time percent	-1.11	40.4	0.31	0.001	cow daily lying time percent	-1.55	47.4	0.38	-0.01
calf weight gain	cow daily lying time percent	-0.11	66.7	0.83	-0.02	cow daily lying time percent	N/A	N/A	N/A	N/A

Table B3.16 Summary of the linear regression parameters explaining cow weight and calf weight gain, in relation to cow mean daily step counts percent of Kinsella Composite crossbred cattle, evaluated during the fall grazing season of 2021 (Aug. 27-Nov. 10), 2022 (Sept. 15 – Nov. 10) and 2023 (Sept. 15 – Nov. 2)

Animal Age Class:	Cows					Heifers				
Dependent variable	Activity variable	Mean Estimate (β)	Intercept	P-Value	Adj-R^2	Activity variable	Mean Estimate (β)	Intercept	P - Value	Adj-R^2
cow weight gain	cow daily step counts	0.01	-25	0.42	-0.01	cow daily step counts	0.003	-23.5	0.75	-0.01
calf weight gain	cow daily step counts	-0.003	71.7	0.50	-0.01	cow daily step counts	N/A	N/A	N/A	N/A

Table B3.17 Summary of the linear regression parameters explaining calf weight gain, in relation to cow mean daily lying time percent of Kinsella Composite crossbred cattle, evaluated during the evaluated during the summer grazing season of 2021(June 24 -Aug. 26), 2022 (July 6 – Sept.12) and 2023 (July14. – Sept. 12).

Dependent variable	Activity variable	Mean Estimate (β)	Intercept	P-Value	Adj-R^2	Activity variable	Mean Estimate (β)	Intercept	P - Value	Adj-R^2
calf weight gain	cow daily lying time percent	-0.75	75.36	0.65	0.001	cow mean daily step counts	0.06	64.67	0.45	-0.01

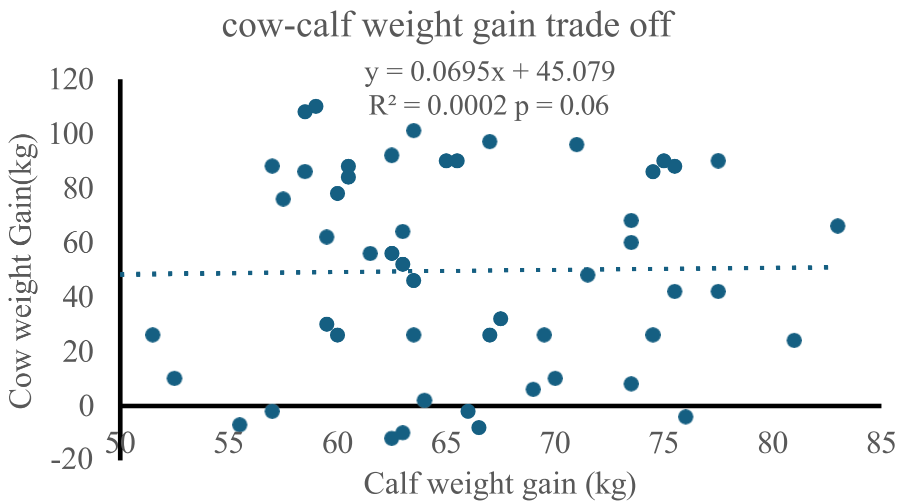

Figure B3.1 Summary of the relationship between cow weight gain and calf weight gain of the Kinsella composite cross bred cattle in the summer and fall grazing season of 2021, 2022, and 2023.