# Comparison of pregnant and dry pasture-based broodmares using mask technology to monitor effects of weather conditions, physiological state, and management.

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# Abstract

Effective broodmare management is essential in maintaining animal welfare, reproductive performance and operational efficiency within commercial equine breeding systems. This study aimed to assess the influence of weather conditions, paddock and grouping characteristics on broodmare behaviour and spatial distribution of pregnant and dry mares with the help of a sensor mask technology. The practical application of the wearable sensor was considered for improving broodmare management and early detection of health and welfare changes. The study was conducted during September 2024 on a commercial pasture-based Thoroughbred breeding farm located in Auckland, New Zealand. A subset of mares from a larger herd was selected based on physiological state that included pregnant mares (n = 8) and dry mares (n = 7). Behavioural data was collected using wearable sensor mask equipped with accelerometer and GPS tracking. Movement patterns in broodmares were primarily structured by time of day with both pregnant and dry mares exhibiting clear diurnal rhythms characterised by increased movement during daylight hours and reduced activity overnight. Physiological state significantly influenced overall activity levels with dry mares walking on average approximately 19-20 more steps per hour than pregnant mares. Effect of day had minimal influence on movement patterns, with dry mares exhibiting almost the same step counts on days of heavy rainfall compared pregnant mares, suggesting short-term behavioural responses to adverse weather conditions. Spatial analysis revealed non-uniform paddock utilisation with distinct clusters of high and low mare density indicating space selection. Hotspots were frequently associated with paddock features such as shelter belts, water troughs and gateways, highlighting the influence of resource distribution and paddock design on mare movement patterns. Overall, the findings demonstrate that broodmare movement patterns were shaped by a combination of temporal, physiological and environmental factors. The integration of accelerometer and GPS sensor technologies provided valuable insights into individual mare behavioural patterns that are difficult to detect through conventional observation. Such technologies offer considerable potential for improving broodmare monitoring, enabling more management decisions, and potentially enhancing reproductive outcomes in commercial equine breeding programs.

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# Chapter 1. Literature review

## 1.1 Introduction

### 1.1.1 New Zealand equine breeding industry

The equine breeding sector in New Zealand forms an important part of the country's agricultural and sporting economy, generating nearly NZD 1.9 billion in value-added economic contribution in 2022/23 with a significant proportion of its revenue derived through racing income, stud farm activity, horse sales, and international exports (New Zealand Thoroughbred Racing, 2024; New Zealand Treasury, 2024). Although comparatively small on a global scale, New Zealand is widely recognised for producing robust, athletic horses with favourable performance traits. This reputation is closely linked to New Zealand's reliance on pasture-based rearing systems and focused genetic selection within its major breeding populations (Rogers et al., 2022). The industry is centred primarily on the production of two breeds of horses, Thoroughbred and Standardbred, which support the galloping and harness racing industries, while interest in sport horse breeding has steadily increased, particularly in disciplines such as show jumping and eventing (Bolwell & Rogers, 2018).

Breeding farms are concentrated in regions offering reliable pasture growth, moderate climates, and established equine services, with Waikato and Canterbury regions of Auckland, hosting many prominent operations (Biddle et al., 2020). These environments provide high-quality grazing and access to reproductive veterinary expertise, factors that support efficient mare and foal management. New Zealand's southern hemisphere breeding schedule also provides a strategic advantage, as it enables breeders to market foals and yearlings to northern hemisphere buyers at optimal times in the global sales cycle (Arango-Sabogal et al., 2022).

A characteristic feature of New Zealand's breeding systems is the predominance of extensive pasture management. Keeping mares in large paddocks supports natural movement, social interaction, and positive behavioural expression, while also contributing to musculoskeletal development and welfare outcomes (Harris et al., 2017). Thoroughbred breeding operations employ more controlled reproductive management such as structured teasing programs and frequent veterinary reproductive monitoring. Mares are still typically kept in group paddock systems rather than being housed indoors.

However, the industry continues to navigate a series of current challenges. Economic pressures, including rising operational costs and a reduction in the number of breeding mares, threaten long-term viability (Chin et al., 2022; Bryant & Stowe, 2020). Climate-related shifts in pasture productivity, labour shortages, and increasing global competition place further strain on breeding enterprises (Rogers et al., 2022).

Horses that are managed in groups are often assumed to respond uniformly to environmental, nutritional, or management conditions; however, variations occur between individuals in behaviour, activity patterns, physiological state, and responses to environmental challenges. Sensor technologies help capture individual locomotor activity thus enabling managers to detect deviations from each horse's normal behavioural baseline, facilitating earlier identification of changes in health, or welfare. Sensors make it possible to monitor behaviour in large numbers of horses over a given period. It allows for continuous, non-invasive surveillance of a horse's behaviour for personalised care and insurance of health and welfare. It has potential to provide long-term, real-time data for accurate analysis and animal monitoring with minimised human intervention and personnel cost.

### *1.1.1 The Thoroughbred Horse*

Thoroughbred horses are a selectively bred equine population developed for athletic performance, particularly racing. As a result of intensive selection for speed, stamina, and competitiveness, Thoroughbreds exhibit distinct behavioural and reproductive characteristics when compared with other horse breeds. From a behavioural perspective, Thoroughbreds are generally characterised by heightened reactivity, increased locomotor activity, and greater sensitivity to environmental stimuli (McGreevy and McLean, 2010). They tend to display higher baseline arousal levels and may be more responsive to handling and management changes than less selectively bred or draught-type horses (Visser et al., 2001).

In reproductive terms, Thoroughbred mares exhibit strong seasonality in ovarian activity, with reproductive function closely linked to photoperiod, consistent with other horse breeds; however, the industry-driven demand for early-season foals has led to intensified reproductive management practices (Ginther, 1992; Aurich, 2011). Behaviourally, mares may show increased vigilance and sensitivity during late gestation and the periparturient period (Crowell-Davis and Houpt, 1985). Compared with more extensively managed or multi-purpose breeds, Thoroughbreds may display elevated stress-related behaviours under restrictive housing or frequent management interventions, which can influence reproductive efficiency and maternal behaviour (McDonnell, 2003; Rogers et al., 2016). Consequently, management systems that support social stability, adequate space, and predictable routines are considered particularly important for maintaining behavioural welfare and reproductive success in Thoroughbred breeding operations.

### *1.1.2 The importance of equine breeding programs*

Equine breeding programs play a critical role in enhancing reproductive efficiency, maintaining genetic diversity, and supporting the long-term economic sustainability of horse industries worldwide (Davies Morel, 2003; Ginther, 1992). In New Zealand, these programs are particularly significant due to the predominance of pasture-based management systems and strong seasonal influences on reproductive activity, which together shape breeding efficiency and foaling outcomes (Ministry for Primary Industries, 2018; Rogers et al., 2016). Efficient breeding strategies are critical. Reproductive inefficiencies such as variable conception timing and gestation length directly affect stud profitability and mare turnover (Gee, Rogers, and Bolwell, 2017). This is due to the relatively short and seasonally constrained breeding season in New Zealand. This management approach promotes the expression of species-typical behaviours, including prolonged grazing, social interaction, and unrestricted locomotion, which are widely recognised as indicators of positive equine welfare (CSIRO, 2022; McDonnell, 2003; Rogers et al., 2016). Reproductive performance within pasture-based systems reports pregnancy rates averaging 83.5% ± 0.76% and foaling rates of 79.1% ± 1.04%, suggesting that extensive management supports successful conception, gestation, and parturition but there is still room to improve (CSIRO, 2022; Gee et al., 2017). Optimising pasture management and mare behaviour not only improves welfare but also enhances economic efficiency by improving fertility, reducing loss, and better preserving valuable broodmare herds.

Compared with stable-based systems, pasture-based systems have been associated with a reduced prevalence of stereotypic behaviours, lower stress-related responses, and fewer foaling complications, likely due to improved physical condition, social stability, and environmental predictability (Hausberger et al., 2004; McGreevy & McLean, 2010). However, the decentralised nature of pasture-based breeding operations and the variability in farm-level management practices contribute to inconsistencies in record keeping, monitoring intensity, and data standardisation across systems, which can limit reproductive and welfare outcomes (CSIRO, 2022; Rogers et al., 2016).

In the Thoroughbred industry, structured breeding programs are essential to meet market expectations and international competition. Studies highlight a shift toward breeding strategies driven by export demand, necessitating early-season foaling and alignment with global racing calendars (Chin et al., 2022a; Morel et al., 2002; Rogers et al., 2016). These programs also support the long-term viability of the breeding population by maintaining reproductive longevity and balancing market trends with genetic health. Broodmare management practices that consider nutrition, grazing behaviour, and the mares responses to environment are essential for improving foaling success, supporting foal development, and meeting commercial breeding goals (National Research Council, 2007; Davies Morel, 2003; Ginther, 1992).

### *1.1.3 Equine breeding system in New Zealand*

Data from mare and stallion populations over a 10-year period in New Zealand show that breeding decisions are increasingly influenced by sale prices and stallion service fees, emphasizing the commercial impact of breeding program design (Chin et al., 2022a; 2022b). Research highlights how “fashionable sires” experience rapid surges in demand following strong sale-ring results, contributing to cyclical breeding trends driven more by market perception than objective performance metrics (Bourke, 2020). These commercial dynamics also influence genetic selection, with breeders increasingly prioritising stallions that convey high commercial appeal, even when evidence of heritable performance advantage is limited (Velie et al., 2015). Collectively, these studies demonstrate that economic incentives, rather than purely biological or genetic considerations, are now central to the design and execution of modern equine breeding programs in New Zealand. Therefore, the ongoing development and refinement of equine breeding programs remain central to sustaining the competitiveness and productivity of the horse breeding sector. Studies have noted that breeders focus on improving mare body condition, utilising early-season breeding, and closely monitoring conception rates to meet commercial demands (Gee et al., 2017). From a welfare perspective, reduced reproductive stress, proper handling, and environmental stability contribute to better hormonal regulation and reduced risk of reproductive failure or behavioural issues (Chin et al., 2022b). Thus, well-managed systems not only enhance productivity but also promote the long-term health and welfare of broodmares.

McCue (2010) emphasises the importance of synchronizesed breeding management in mares, involving cycle tracking, timed insemination, and monitoring for early pregnancy issues. Davies-Morel (2003) further added that nutritional planning and careful health management directly correlate with reproductive success. In particular, the transition from gestation to lactation is considered a critical phase that demands high nutritional support and reduced environmental stressors. Clarke et al. (2009) also note that dietary formulation for broodmares must adapt to reproductive stage, weight, and pasture composition. The high-quality, carbohydrate-rich ryegrass–clover pastures common in New Zealand are generally beneficial for supporting pregnant mares, though overconsumption can risk metabolic disorders (Ferguson-Wilson, 2021).

## 1.2 Mare behaviour and management

### *1.2.1 Broodmares*

Broodmare behaviour is shaped by a combination of physiological status, reproductive stage, social environment, and management conditions, each of which influences welfare and breeding efficiency. During gestation, broodmares generally display stable behavioural patterns, although changes in posture, movement, and energy allocation can occur as pregnancy progresses, particularly in the final trimester when abdominal expansion affects mobility and comfort (Neto et al., 2015). Broodmares housed in pasture-based systems exhibit more natural behaviours, including grazing, resting, and affiliative interactions, which contribute to lower stress levels and improved reproductive outcomes (Rogers et al., 2016). Studies emphasise the importance of maintaining optimal body condition scores (BCS) throughout gestation, as mares with poor or excessive BCS have reduced conception and foaling rates (Gee, Rogers, and Bolwell, 2017).

Social stability is particularly important, as broodmares maintain linear dominance hierarchies that regulate access to feed and space; disruptions in herd structure can provoke aggression or anxiety, potentially affecting maternal readiness and foetal development (Kimura, 2018). Environmental management also plays a crucial role, with research showing that adequate shelter, low stocking density, and consistent grouping support positive welfare indicators and reduce stress-related behaviours such as pacing or resource guarding (Fenner et al., 2019). Nutritional management must be carefully balanced to meet the metabolic demands of pregnancy without contributing to excessive weight gain, as both undernutrition and obesity can influence broodmare behaviour and reproductive physiology.

Handling and human interaction further influence behavioural responses: broodmares accustomed to calm, predictable handling demonstrates lower reactivity, more stable temperaments, and safer behaviour during veterinary, or farrier procedures compared to mares exposed to inconsistent or aversive treatment (Hartmann et al., 2017). McDonnell (2003) categorized various equine behaviours in a comprehensive ethogram, which serves as a valuable tool for studying mares in breeding environments. The ethogram classification of behaviours range from affiliative (e.g., grooming), locomotor (walking, lying) to agonistic (e.g., kicking, biting) and has been widely used to assess how stress, management, or environmental factors influence social behaviour. Behavioural observation also extends to feeding and spatial dynamics. According to Fraser and Broom (1997), mares and foals engage in synchronised feeding patterns, particularly in the early weeks postpartum. Importantly, behavioural expression differs between broodmares depending on their reproductive stage. The term broodmare is used throughout this study to refer collectively to mares within the breeding herd, including pregnant, lactating, and dry mares. However, where behavioural or physiological differences are relevant, particularly between pregnant mares and dry mares these categories are distinguished to reflect their differing management and welfare considerations.

### *1.2.2 Pregnant mare behaviour and management*

Behaviour in pregnant mares reflect the interaction of physiological changes that are associated with gestation, endocrine regulation, social environment and management conditions, these therefore have implications for maternal welfare. Hormonal changes throughout pregnancy, particularly shift in progesterone and oestrogen concentrations further forming an association with modifications in activity levels and behavioural expression (Ginther, 1992). As gestation advances, mares commonly exhibit reduced voluntary movement and increased resting behaviour, particularly during late pregnancy, likely due to an adaptive response to conserve energy (Hausberger et al., 2004).

Gestational stage influences feeding behaviour and daily time budgets. Pregnant mares generally spend a greater proportion of the day grazing as pregnancy progresses, thus reflecting rising nutritional requirements for maintenance and foetal growth (National Research Council, 2007). According to a study by Dierendonck (2004), it was seen that social behaviour may also be altered during pregnancy, with some mares showing increased sensitivity to social instability or competition. In pasture group-based systems, pregnant mares may preferentially associate with familiar individuals and avoid aggressive interactions, highlighting the importance of stable social groupings during gestation (Christensen et al., 2011; Sigurjónsdóttir et al., 2003).

Management strategies play a crucial role in shaping behavioural outcomes in pregnant mares; for example, grazing systems that provide continuous pasture access support natural foraging rhythms, voluntary movement, and social interaction, contributing to improved welfare and reduced stress-related behaviours (Lesimple et al., 2020). In contrast, confined systems, frequent regrouping, or restricted space can disrupt established social relationships and increase behavioural signs of stress or withdrawal (Hausberger et al., 2009). A study conducted by Lansade et al. (2018), indicates that elevated stress levels during pregnancy may influence foetal development and postnatal behavioural reactivity, emphasising the need to minimise environmental and social disturbances during gestation.

### *1.2.3 Dry mare behaviour and management*

Dry mares are adult female horses that are not currently pregnant, lactating, or nursing a foal. They exhibit behavioural patterns influenced by their reproductive cycle, social environment, management conditions, and individual temperament. Understanding dry mare behaviour is important for breeding management, welfare assessment, and farm system design, as behavioural expression is closely linked to physiological changes across the oestrous cycle and to the mare's interaction with conspecifics.

Behaviour in dry mares varies substantially between the oestrous and dioestrus phases. During oestrus, mares typically display heightened sociality, increased tolerance of stallion proximity, and affiliative sexual signalling. Common oestrous indicators include tail raising, urination, clitoral eversion ("winking"), and seeking interaction with males (McDonnell, 2021). These behaviours are governed by fluctuations in reproductive hormones, particularly rising oestrogen levels and low progesterone. Oestrous mares may also reduce aggression toward other horses, show increased locomotor activity, and express restlessness or attention-seeking behaviours (Costa et al., 2020). These behavioural cues are essential for natural breeding systems because they facilitate courtship and successful mating. In pasture-based systems, such as those commonly used for dry mares, these behavioural cues may be subtle, intermittent, or less readily observed due to large paddock sizes, low human–animal interaction, and limited continuous visual monitoring. As a result, accurately identifying oestrus based solely on direct observation can be challenging. Consequently, tools that enable remote or continuous monitoring of activity and behaviour may provide valuable support for oestrus detection in pasture-managed dry mares, improving reproductive management and breeding efficiency in extensive systems (McDonnell, 2021).

In contrast, during dioestrus, when progesterone is dominant, dry mares often exhibit reduced sociability and an increase in avoidance or aggression, particularly toward stallions. Kicking, pinned ears, squealing, and defensive posturing are common dioestrus responses when approached by a male, reflecting physiological preparation for potential pregnancy and a reduced receptivity to mating (Aurich, 2011). Dioestrus mares may also prefer stable, predictable social environments and may react negatively to regrouping or competition for resources.

Social structure plays a major role in behavioural stability among dry mares. In extensive pasture systems, mares naturally form cohesive groups with clear dominance hierarchies, which help regulate access to feed, space, and social interactions. Dominance relationships in mare bands tend to be stable over time, and higher-ranking mares typically show priority access to grazing areas and water but also assume leadership during herd movement (Sigurjónsdóttir et al., 2003). Social cohesion is important for reducing chronic stress, promoting synchronised grazing, and supporting overall welfare. Disruption to group structure, such as frequent introduction or removal of individuals, can lead to increased aggression, instability in social relationships, and heightened stress responses (Sigurjónsdóttir & Haraldsson, 2019; Christensen et al., 2012; Freymond et al., 2023).

Environmental and management factors strongly influence behavioural expression in dry mares. Horses maintained on pasture typically show more natural foraging, locomotion, and social behaviours compared to those kept in stabled or intensive systems (Lesimple et al., 2020). Confinement or limited turnout can lead to frustration, stereotypies such as weaving or crib-biting, and reduced behavioural diversity (Cooper & McGreevy, 2007; Mason & Latham, 2004; Sarrafchi & Blokhuis, 2013). Conversely, mares housed in group paddocks with adequate space and resources often display more affiliative behaviours, reduced aggression, and improved physiological welfare (Yarnell et al., 2015; Sigurjónsdóttir & Haraldsson, 2019).

Temperament and individual differences are also relevant. Some mares demonstrate consistent behavioural traits—such as boldness, reactivity, or sociability—that persist across reproductive stages. These traits can influence handling safety, reproductive performance, and suitability for management systems (Valenchon et al., 2017).

Overall, dry mare behaviour is shaped by a complex interaction of hormonal cycles, social structure, and environmental conditions. Recognising and accommodating these behavioural patterns is essential for effective reproductive management, welfare assessment, and designing systems that support natural behavioural expression.

## 1.3 Factors affecting broodmare behaviour

Environmental conditions significantly shape the behaviour and welfare of broodmares, and numerous quantitative studies demonstrate how climatic and pasture variables influence activity budgets, movement, aggression, and social cohesion. Houpt (2011) emphasises that equine behaviour is highly plastic, with environmental pressures altering daily time allocation. For example, in temperate pasture systems, horses typically graze between 50–70% of a 24-hour period, but this proportion can increase to 75–80% when pasture quality declines, as animals compensate by extending foraging time (Hampson et al., 2010). In New Zealand, Rogers and Gee (2007) observed that broodmares spent approximately 65% of daylight hours grazing during spring when pasture dry matter averaged 1,800–2,200 kg/DM/ha, but grazing time increased to over 72% in late summer when pasture dropped below 1,200 kg/DM/ha, demonstrating a clear quantitative link between forage availability and behavioural time budgets.

### *1.3.1 Pasture Quality and Shelter*

Environmental features such as pasture composition, biomass, and shelter availability act as key regulators of equine behavioural expression. Horses are highly adaptable grazers; their daily time budgets adjust according to forage distribution and quality (Houpt, 2011).

Quantitative research in New Zealand showed broodmares spent ~65% of daylight grazing during spring when pasture dry matter was 1800–2200 kg/DM/ha, increasing to over 72% in late summer when pasture dropped below 1200 kg/DM/ha (Rogers and Gee, 2007). Forage composition also influences selectivity and movement patterns. Gee et al. (2014) found horses spent up to 25% more time grazing in paddocks with high clover density compared to mixed-grass swards, which reduced locomotion and social tension. Similarly, Bengtsson et al. (2018) reported that mares walked an average of 4.2 km/day under low biomass conditions (<1000 kg/DM/ha) but only 2.1 km/day when forage was abundant (>2500 kg/DM/ha), demonstrating a clear relationship between biomass availability and energy expenditure. Feeding practices in New Zealand are primarily pasture-based, supplemented with concentrates during late gestation and lactation to meet increased energy demands (Chin et al., 2022b).

Shelter structure, whether provided by constructed shelters or vegetative cover, also affects behaviour. Horses preferentially use shaded or sheltered zones to regulate thermal comfort (Christensen et al., 2011). In the absence of effective shelter, individuals may exhibit longer resting latencies, increased scanning (vigilance), or altered group spacing. Pasture heterogeneity, coupled with available shelter, thereby influences not just feeding behaviour but overall welfare states (Kilgour & Dalton, 1984; Rørvang et al., 2019).

Collectively, these findings confirm that the natural environment functions not only as a physical resource but also as a behavioural regulator. Variations in pasture dry matter, forage quality, climatic comfort, and environmental predictability each produce measurable changes in grazing time, locomotion distances, spacing behaviour, vigilance, and social dynamics, reinforcing the need for consistent, well-managed pasture conditions to support optimal broodmare welfare and behaviour.

### *1.3.2 Effect of seasonal weather*

A study conducted by Van Laer et al. (2015) demonstrated that horses adjust their behaviour in response to variable climatic conditions with increased shelter use during hot, cold, wet and windy conditions. This highlights the role of environmental factors and weather conditions in influencing equine behaviour and welfare on pasture. Rogers et al. (2006) documented that horses maintained an average of 1.5–3 metres between individuals in comfortable conditions but increased spacing to over 6 metres in variable weather (extreme heat, low temperatures, wet conditions and strong winds), indicating behavioural adjustments to thermal discomfort. In a study examining behavioural responses to adverse conditions, horses reduced grazing by 30–35% during heavy rainfall or cold wind exposure, concurrently increasing shelter-seeking and stationary standing (Hirst, 2011). In contrast, warm and stable weather promoted increased grazing by 10–15% and reduced locomotion, indicating improved comfort levels.

Wind, precipitation intensity, and thermal stress shape spatial distribution within paddocks, often increasing inter-individual spacing and reducing social cohesion to enable microclimate avoidance (Rogers et al., 2006). Unfamiliar or rapidly changing weather events can trigger a three-fold increase in vigilance and a 40% reduction in resting behaviour (Winskill et al., 1996).

Other research highlights the role of solar radiation and temperature extremes on time budgets. Horses in high heat load conditions can reduce grazing time by 20–30% and increase shade use, simultaneously elevating frequencies of thermoregulatory behaviours such as flank licking and wallowing (Silva et al., 2013). Conversely, mild conditions support more uniform activity patterns and lower physiologic stress markers such as heart rate and cortisol concentrations (Paul and Kuchel, 2016).

### *1.3.3 Role of human interaction on behaviour*

Human interaction is widely recognised as a major determinant of equine behaviour and stress physiology. Although human–horse interactions were not examined as variables in the present thesis, they represent a central external factor capable of exerting both positive and negative influences on behavioural expression and welfare. Substantial consideration has been given to this topic in the literature, with comprehensive reviews demonstrating that handling style, consistency, and previous experiences with humans strongly shape horses' behavioural responses, learning capacity, and physiological indicators of stress (Hausberger et al., 2008; Kelly et al., 2021; Merkies & Franzin, 2021; Sankey et al., 2010). Collectively, these reviews highlight that calm, predictable handling and positive reinforcement are associated with reduced stress responses and improved behavioural outcomes, whereas aversive or inconsistent interactions increase reactivity and anxiety.

Experimental studies further support these conclusions, showing that positive human contact can reduce fearfulness behaviours, while negative handling increases heart rate, behavioural avoidance, and defensive reactions (Sankey et al., 2010; Visser et al., 2001). Together, this body of work demonstrates that human interaction constitutes a substantial area of equine behavioural research with clear implications for welfare and performance, even though it lay outside the specific scope of the current thesis.

### *1.3.4 Role of housing on behaviour*

Similarly, the effects of housing and shelter on equine welfare are well established. In this context, housing refers to indoor stabling systems, while shelter denotes outdoor protection provided by constructed structures or vegetative cover within paddocks. Although these factors were standardised within the management system used in this study and were therefore not experimentally assessed, existing literature indicates that both stabling practices and access to outdoor shelter substantially influence behaviour and stress (Fureix et al., 2012; Lesimple et al., 2011). Individual stabling and restricted social contact have been associated with elevated stress indicators and increased prevalence of abnormal behaviours, whereas group housing and turnout promote natural activities such as grazing, locomotion, and social grooming (Hausberger et al., 2008; Lesimple et al., 2011). Overcrowding and limited space availability have also been linked to increased aggression and reduced resting behaviour, indicating compromised welfare (Fureix et al., 2012).

### *1.3.5 Effects of stocking density*

Studies show that pasture size, stocking density, and paddock rotation significantly influence horses' daily activity budgets, and these effects are particularly pronounced in broodmares whose behavioural patterns are closely linked to reproductive status. Larger pasture areas generally promote greater movement, more dispersed grazing, and lower incidences of agonistic interactions. Schramel et al. (2019), for example, demonstrated that horses kept in larger paddocks (>2 ha) engaged in significantly more walking and exploratory activity, with accelerometer data showing a 25–30% increase in daily step count compared with horses in smaller enclosures. Similarly, Bengtsson et al. (2018) found that when pasture size increased from 0.5 ha to 1.5 ha per horse, grazing time increased from 48% to 60% of daylight hours, while locomotion increased proportionally, suggesting that spatial availability directly shapes time budgets and feeding–movement dynamics.

Stocking density also has clear behavioural consequences. High stocking densities (more than three horses per hectare) are associated with increased competition for forage resources, elevated aggression, and altered social spacing (Henderson et al., 2007). In broodmares, this competitive pressure can reduce lying time, increase vigilance, and disrupt maternal–foal interactions due to increased herd-level movement and displacement. Research by Mejdell and Bøe (2005) showed that when stocking densities were reduced, aggression decreased by 70%, and horses exhibited more synchronous grazing behaviour—an indicator of social stability and herd cohesion. These patterns are especially important for pregnant mares, whose energy demands are higher; increased competition can force them to forage inefficiently, increasing stress and reducing nutritional intake at critical reproductive stages.

Paddock rotation practices further shape behavioural patterns by influencing pasture quality and regrowth cycles. Regular rotation has been shown to improve forage availability and distribution, which reduces unnecessary walking and energy expenditure while increasing grazing efficiency. Hirst (2011) reported that broodmares in rotational grazing systems spent 10–15% more time grazing and 20% less time travelling compared with mares maintained on continuously grazed paddocks where pasture biomass was low and unevenly distributed.

Importantly, management decisions interact with physiological status to produce measurable differences in behaviour. Pregnant mares tend to reduce locomotion and increase resting behaviours in late gestation, but insufficient pasture availability or high stocking density can force increased movement, potentially increasing fatigue and reducing energy allocation to fetal growth (Boccia et al., 2020). When environmental constraints limit access to forage or space, this heightened energetic demand can compromise body condition and milk production, subsequently affecting foal growth rates (Ralston, 2015).

### *1.3.6 Impacts on maternal care and social structure*

In pasture-based systems, the stability of the herd and the cohesion of social relationships play a central role in shaping maternal care and influencing mare–foal behavioural development. Consistent social groupings reduce conflict and allow mares to engage in uninterrupted nurturing behaviours such as nursing, grooming, and protective vigilance (Crowell-Davis and Weeks, 2005). Stable herds develop predictable dominance hierarchies, which limit the frequency of aggressive encounters and promote calmer maternal environments. Disruptions in herd composition such as moving mares between paddocks, introducing new individuals, or fragmenting established groups can destabilise social order and trigger behavioural stress responses. Studies have shown that regrouping increases agonistic interactions by up to 50% in the first 24–48 hours as mares re-establish hierarchy, which may reduce the time available for feeding, resting, or attending to the foal (Hartmann et al., 2017).

These social disturbances can directly influence maternal care. Disruptions to maternal calmness also affect foal behaviour, with research showing that foals of stressed mares exhibit more frequent startle responses and spend less time resting, suggesting a flow-on effect of maternal stress on foal emotional regulation (Waran et al., 2008). Additionally, frequent regrouping or pasture rotation may fragment social bonds that support collective maternal behaviour, such as allo-grooming or passive protection from other mares, behaviours observed in well-established pastoral herds (McDonnell, 2003).

Overall, the literature consistently indicates that stable herd structures facilitate secure maternal care, enhance foal behavioural development, and reduce social tension, whereas frequent changes to pasture groups disrupt social networks, increase stress behaviours, and compromise the quality and consistency of maternal interactions. This underscores the importance of minimising regrouping events and maintaining socially cohesive herds to support optimal welfare outcomes for broodmares and their foals.

### *1.3.7 Effect of photoperiod*

Photoperiod is a primary environmental cue regulating reproductive physiology and behaviour in mares, mediated largely through melatonin secretion and its influence on the hypothalamic–pituitary–gonadal axis (Ginther, 1992; Sharp, 2005). As long-day seasonal breeders, mares exhibit increased ovarian activity, oestrous behaviour, and metabolic output during periods of increasing day length, typically in spring and summer (Nagy et al., 2000).

In pregnant mares, photoperiod plays a subtler but important role by influencing endocrine regulation, gestational timing, and foetal development. Although pregnancy is generally maintained across seasons, increasing photoperiod toward late gestation has been associated with alterations in prolactin and melatonin secretion, which may affect mammary development, hair coat shedding, and preparation for lactation (Sharp, 2005; Thompson et al., 2014). Foals born to mares exposed to longer photoperiods during late gestation have been reported to exhibit more advanced physical maturity and altered hair coat characteristics at birth, suggesting indirect photoperiodic effects on foetal development (Nagy et al., 2000).

In contrast, dry mares respond to photoperiod primarily through reproductive seasonality rather than gestational energy demands. During shorter day lengths, dry mares typically enter seasonal anoestrus, characterised by reduced follicular development and diminished oestrous behaviour (Sharp, 2005). As day length increases, dry mares exhibit a gradual resumption of cyclicity, with photoperiod manipulation (e.g., artificial lighting) commonly used in breeding management to advance the breeding season (Nagy et al., 2000).

Overall, while photoperiod exerts a strong regulatory effect on reproductive function in both pregnant and dry mares, pregnant mares experience an added interaction between daylight exposure, metabolic load, and maternal behaviour. These differences highlight the importance of considering physiological status when assessing photoperiodic effects on mare behaviour, welfare, and reproductive performance.

### *1.3.8 Diurnal Behavioural Patterns*

In horses, diurnal activity is caused by an interaction between circadian rhythms, foraging behaviour, and management conditions. Research states locomotor activity in horses have a clear daily rhythm, with high active behaviors occurring during daylight and lower activity at night. This is consistent with the light-dark cycle that entrains physiology and behavior in horses (Bertolucci et al, 2008; Murphy et al, 2009). Their activity patterns arise from both circadian clock mechanisms and environmental cues such as photoperiod and management conditions, thus indicating that both internal and externa factors contribute towards daytime peaks in movement (Murphy 2019). Continuous monitoring of equine locomotor behaviour indicates peak activity at mid-day and a pronounced diurnal structure of behaviour when horses are allowed to freely graze (Bertolucci et al., 2008; Murphy, 2019). Rhythmic variations in physiological markers such as salivary cortisol and other analytes have been documented to follow a circadian pattern in mares, reinforcing the presence of 24-hour biological rhythms in turn affecting behaviour and physiology (Contreras-Aguilar et al., 2020). These rhythms align behaviour with optimal environmental conditions for foraging, thermoregulation and socialising.

Physiological demands differ as per the reproductive state of the horse. While there is limited direct research on movement differences between pregnant and dry mares, general studies on physiological state indicate that behaviour, standing time and locomotory behaviour vary across the physiological states therefore, suggesting that activity budgets are sensitive to internal state (Stachurska et al., 2023). In other mammals, reproductive state influences locomotor activity. In a study conducted by Piccione et al., 2011, dairy cattle exhibit higher 24-hour locomotion activity during pregnancy compared to non-pregnant animals, reflecting increased energy and foraging requirements. By analogy, pregnant mares may similarly express elevated step counts during the day, as the energetic cost of gestation drive increases foraging and movement between feeding and resting sites. Reproductive hormonal cycles also modulate behavioural and physiological indices; hence mares have been shown to display changes in standing and locomotor behaviour across the oestrous cycle, which may interact with broader daily activity rhythms (Stachurska et al., 2023). Moreover, studies on diurnal variation in horses confirm that internal timing mechanisms influence multiple aspects of equine physiology, form hormone rhythms to metabolic parameters, thus impacting the expression of activity patterns in depending on reproductive state (Murphy, 2019; Contreras-Aguilar et al., 2020).

## 1.4 Measuring behaviour

### *1.4.1 Description of key behaviour patterns*

Equine behaviour is characterised by a predictable sequence of postural, locomotive, and social actions that reflect physiological state, energy expenditure, and responses to environmental or social stimuli. Fundamental behaviours such as standing, grazing, and walking dominate a mare's daily time budget and are considered reliable indicators of welfare and adaptation to the environment. In extensive pasture systems, broodmares typically graze for 50–70% of daylight hours and stand or rest for 20–30% of the time, with lying bouts accounting for only 5–7% of the 24-hour period (Heleski et al., 2002; Martin et al., 2016). Standing behaviour includes relaxed standing and alert vigilance. This reflects both comfort and environmental demands. For example, mares may increase alert standing when predators, unfamiliar horses, or perceived threats are present, demonstrating heightened maternal protectiveness (Sigurjónsdóttir et al., 2003). Conversely, prolonged standing accompanied by reduced mobility may indicate lameness, discomfort, or poor welfare.

Lying behaviour is an important welfare indicator because horses require recumbency for restorative sleep. Broodmares typically exhibit short lying bouts lasting 20–40 minutes several times a day; reduced lying behaviour can indicate stress or overcrowding (Greening et al., 2012). Locomotory behaviours such as walking, trotting, and cantering reflect both exploration and social engagement. Walking is generally low-intensity exploration, with pasture-based mares walking between 4–7 km per day depending on terrain and forage distribution (McGreevy, 2012). Trotting and cantering occur less frequently and are often associated with social play, avoidance of conspecific aggression, or maternal responses to foal movement.

More intense locomotive or expressive behaviours such as charging and rearing usually occur during conflict, defensive maternal behaviour, or competition for social resources (Kimura, 1998). Rearing is less common but may be observed during agonistic encounters or courtship contexts. These behaviours, while normal in low frequencies, may increase under stress such as restricted space, inconsistent grouping, or inadequate resource distribution, signalling compromised welfare (Hausberger et al., 2008).

The flehmen response (lip-curl) is another key behavioural pattern observed in mares. This action is linked to olfactory investigation and is commonly displayed postpartum when mares examine their foal's scent or when detecting pheromonal cues from other horses. Research shows mares exhibit more frequent flehmen responses within the first 24 hours post-foaling as part of early maternal–foal bonding processes (Crowell-Davis and Weeks, 2005).

Together, these behavioural patterns provide critical insight into mare welfare, social stability, and environmental suitability. Understanding the frequency, context, and variation of these behaviours enables more accurate assessment of management effectiveness and supports evidence-based improvements to breeding-horse husbandry systems.

### *1.4.2 The use of ethogram and understanding behavioural observations with the help of accelerometers*

Recent research validates the use of accelerometers as a robust tool for quantifying equine behaviour, particularly in extensive pasture systems where continuous visual monitoring is difficult. Accelerometers measure changes in acceleration across one or more axes, allowing behavioural states to be differentiated based on movement intensity, frequency, and pattern. Schramel et al. (2019) demonstrated that acceleration counts can reliably distinguish standing, grazing, and ambulatory behaviours in free-ranging horses, with classification accuracies exceeding 80% when using tri-axial sensors. These devices capture fine-scale movement signatures—for example, low-variance acceleration patterns associated with standing, rhythmic head-down movements characteristic of grazing, and higher-amplitude patterns reflecting locomotion. This enables behaviour to be identified objectively without relying solely on human observation, which may be prone to sampling bias or environmental constraints. Kawasumi et al. (2022) demonstrated that accelerometers integrated into headcollars could classify grazing posture and detect transitions between grazing and vigilance behaviour with high temporal precision. These advancements highlight the capacity of accelerometery to provide continuous datasets, capturing subtle variations in behavioural time budgets that may be missed with intermittent direct observation. The advantage of accelerometer-based monitoring in broodmares is particularly salient in breeding and maternal behaviour research. Continuous data allow researchers to detect changes in lying bouts, restlessness, and locomotion intensity that may correspond with late gestation, onset of parturition, or postpartum recovery (Riekena et al., 2021). It represents a valuable tool for advancing the understanding of broodmare welfare, maternal behaviour, and social interactions in both managed and naturalistic environments.

## 1.5 Technologies for understanding equine behaviour

Classification of animal behaviours from accelerometer data typically involves supervised machine learning methods that are trained and validated against retrieved data observations obtained through direct video recording or human annotation. In this workflow, raw acceleration data from tri-axial sensors are segmented into fixed time windows, and features such as mean, standard deviation, or vector magnitude are extracted to represent motion patterns within each segment (Turner and Clifford, 2025). These labelled segments are then used to train machine learning models to recognise distinct behaviour categories (Schramel et al., 2019; Parsons et al., 2024).

In many validation protocols, animals are fitted with tri-axial accelerometers that record linear acceleration across the X, Y, and Z axes, after which signal segments are time-aligned with concurrently collected video observations to label distinct behaviours for algorithm training and assessment. For example, Parsons et al. (2024) fitted cattle with GPS collars containing tri-axial accelerometers and synchronised video cameras to record grazing, resting, ruminating and walking behaviours, and subsequently trained random forest models on labelled data, achieving high classification accuracy and demonstrating distinct accelerometer signatures for each behaviour class (Schramel et al., 2019). Similar methodologies have been used to collect video-validated datasets of multiple behaviours in grazing cattle, where accelerometer signals processed with machine learning achieved classification accuracies of over 90% for key behaviours when matching raw motion data to annotated video footage (Parsons et al., 2024). These algorithms were validated using direct video observations conducted during trial periods.

## 1.6 Research objectives

In New Zealand, broodmares are managed under extensive pasture-based systems, and remain outdoors all year round, being stabled only when additional care is required. This system supports a horse's natural grazing behaviour, freedom of movement and social interaction thus in turn presenting challenges for continuous behavioural observation and management. Productivity in broodmares is influenced by health, nutritional status, behaviour patterns and weather changes. Subtle changes in weather, management, physiological state can cause alterations in movement, grazing time and activity. Having a systematic procedure to monitor broodmare behaviour provides the opportunity to create evidence-based management strategies to optimise reproductive outcomes.

Behaviour in broodmares is influenced by a range of intrinsic and extrinsic factors. Physiological state (pregnant or dry), gestation stage, body condition and social hierarchy interact with environmental variables such as pasture availability, weather conditions, paddock design and stocking density. The temperate climate in New Zealand is associated with seasonal changes in rainfall, humidity and photoperiod which may further modify grazing patterns, movement and resting behaviour. Consequently, understanding behaviour in broodmares requires contextualisation within specific farmed environment in which animals are managed. Identifying behavioural differences with physiological state and environmental conditions can eventually enable improved interpretation of activity patterns and more precise management interventions.

Recent advances in technology have created opportunities for remote continuous monitoring of animal behaviour. Wearable sensor devices with Global Positioning System (GPS) trackers and accelerometer-based systems, can quantify locomotion, spatial distribution and activity states without the need for constant human monitoring. However, the outputs generated by such technologies represent indirect measurements (e.g., step count, spatial coordinates, behaviour positions) that must be accurately mapped to biologically meaningful behaviours such as standing, walking or lying. Robust calibration and validation of sensor-derived data against observed behaviours are important to ensure reliability and practical applicability in pasture-based broodmare systems.

Development of the HorseSafe mask is designed to monitor broodmare behaviour representing a novel innovation within equine management. The device aims to provide integrated data on movement, location, behavioural states, in turn offering the potential to support reproductive management, welfare assessment and early detection of health issues in both pregnant and dry mares. However, interpretation of the collected data requires further investigation to determine how sensor metrics correspond to specific behaviours and how these metrics differ between physiological states. With the help of research studies, it is possible to evaluate how the collected data can be translated into useful information to understand management decisions within commercial farm settings.

Therefore, the objectives of this study were to:

1. Assess the influence of weather conditions, paddock and grouping characteristics on the behaviour and spatial distribution of broodmares.
2. Compare step count during a 24-hour period and day by day between pregnant and dry mares.
3. Evaluate the practical application of mask derived behavioural data to help improve broodmare management, early detection of health concerns and support reproductive success.

By integrating behavioural science with monitoring technologies, this study aims to contribute to improved understanding of broodmare behaviour in pasture-based systems and to thus, support the development of reliable, data driven management strategies for the equine industry in New Zealand.

# Chapter 2. Materials and methods

The study procedures involving animals were carried out following approval by the Massey University Animal Ethics Committee (MUAEC 24/09).

## 2.1 Study site

The study was conducted on a coastal property called Alabar Farms, a large (120 ha) commercial Thoroughbred breeding operation located in Pukekohe, New Zealand (37.09415° S, 174.77598° E). Alabar Farms is an established facility with more than 60 years of operation and is widely recognised for its extensive breeding programmes and high-value stallion population.

## 2.2 Animals

This study was conducted on Thoroughbred broodmares managed under a commercial pasture-based system. Each paddock contained of approximately 30 broodmares. All animals were clinically healthy and were maintained in social groups within rotational grazing paddocks. Mares had *ad libitum* access to pasture and fresh water, with each paddock containing at least one large trough supplied by the farm's automatic reticulation system. All mares were managed under similar weather conditions and management practices throughout the study period. Mares were granted continuous access to their allocated paddocks both day and night with no restrictions placed on grazing behaviour during this period.

Pregnant mares used in this study were in late gestation during the study period, representing a range of gestational stages throughout this time. Dry mares were non-pregnant and non-lactating. These mares were selected to closely match the pregnant group of mares in terms of age and body condition.

## 2.3 Experimental design

Study period took place over a 30-day period from 1 September 2024 to 30 September 2024. September corresponds to early spring period in the North Island of New Zealand. According to

National Institute of Water and Atmospheric Research (NIWA) the study site in the Pukekohe region had mean daily air temperatures in September ranging from 10 to 15°C, reflecting a seasonal transition from winter to spring conditions. During this time, photoperiod increases from approximately 11.5 hours at the beginning of September to around 12.7 hours by the end of the month. This provides a longer day length that coincides with the onset of spring pasture growth (Radcliffe and Baars, 1987). Animals were managed across five paddocks (Table 2.1) under a rotational grazing system, with paddocks alternated every few days. Paddocks 1 and 2 housed pregnant mares, while paddocks 3, 4, and 5 contained dry mares.

**Table 2.1** Paddock details used in the study.

| Paddock no. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Paddock size (ha) | 1.66 | 5.03 | 4.36 | 5.97 | 8.44 |
| Physiological state | Pregnant | Pregnant | Dry | Dry | Dry |

*2.3.1 Treatment groups*

A subset of 15 treatment mares (Table 2.2) were established from two groups based on physiological states: consisting of pregnant mares (n = 8, n = 15 in the herd) and dry mares (n = 7, n = 15 in the herd) that were monitored for behavioural analysis. Pregnant mares assigned to paddocks 1 and 2 (Figure 2.1A) were rotated between these areas, while dry mares were rotated among paddocks 3, 4, and 5 (Figure 2.1B). The paddocks contained shelter belts, gates and water troughs with the terrain dominated by coastal characteristics (areas of remaining sand dunes with large patches of grazing).

For majority of the study period, mares were in their larger management groups unless they needed extra care. For instance, when an individual mare displayed poor body condition and required extra care she was relocated to a separate paddock, housed alone to receive supplementary feed independently; for example, two mares, Ideal Alice and La Soiree, were housed individually (but in visual contact with the main herd) for the duration of the study due to the requirement for additional management and care during late gestation.

**Table 2.2** Date of birth (DOB), physiological state, date of insemination, number of days in a group vs alone at pasture of each mare used in the study

| Name | DOB | Physiological state | Inseminated/Dry | No. of days in group | No. of days alone |
|---|---|---|---|---|---|
| Christanna | 02/12/2013 | Pregnant | *i 17/10/2023 | 30 | 0 |
| Cougar Bromac | 19/11/2020 | Pregnant | *i 27/10/2023 | 30 | 0 |
| Gottagocheekycheddar | 21/11/2017 | Pregnant | *i 19/10/2023 | 22 | 8 |
| Hey Mickey Denario | 29/11/2018 | Pregnant | *i 10/10/2023 | 13 | 17 |
| Ideal Alice | 22/09/2010 | Pregnant | *i 14/11/2023 | 0 | 30 |
| La Soiree | 12/11/2007 | Pregnant | *i 28/12/2023 | 0 | 30 |
| Stars Delight | 09/11/2012 | Pregnant | *i 10/10/2023 | 30 | 0 |
| Supremacy | 07/11/2006 | Pregnant | *i 04/10/2023 | 23 | 7 |
| Cyclone Emily | 07/10/2011 | Dry | N/A | 29 | 1 |
| Glenferrie EJ | 07/11/2009 | Dry | N/A | 23 | 7 |
| Lee Girl | 13/11/2014 | Dry | N/A | 23 | 7 |
| Super change | 07/12/2014 | Dry | N/A | 23 | 7 |
| Taylor Kate | 07/11/2008 | Dry | N/A | 23 | 7 |
| Trigirl Brigade | 21/11/2004 | Dry | N/A | 23 | 7 |
| Yankee dream | 04/12/2006 | Dry | N/A | 23 | 7 |

*i : Insemination date


**Figure 2.1 (A&B)**. Spatial layout of paddocks 1 and 2 (A) allocated to pregnant mares and paddocks 3, 4, and 5 (B) allocated to dry mares, including positions of paddocks, gates and water troughs.

### *2.3.2 Pasture Management*

The animals used in this study were familiar with the paddocks as it was their normal grazing rotational routine. Each rotation placed mares into allocated paddocks for forage availability to ensure consistency in feed access, nutrient intake, and grazing conditions across the study period. The mares were moved within their management groups. The paddocks provided sufficient space to facilitate natural movement, social interaction, and expression of herd dynamics. Silage was spread on the ground to reduce competition and prevent overcrowding at feeding sites. Rotational grazing was implemented to support normal equine grazing behaviour, which is characterised by repeated grazing bouts interspersed with periods of rest and social interaction under pasture-based conditions (Duncan, 1992).

### *2.3.3 Handling frequency*

Mares were typically brought into the stables or handling yards once per month when required for essential husbandry procedures. These included farrier appointments, routine vaccinations administered at set points throughout gestation, as well as drenching for parasite control. This limited handling approach reduced potential stress associated with frequent human–animal interactions while maintaining necessary health standards.

## 2.4 Wearable sensor system

### *2.4.1 Sensor design and GPS technology*

Movement and behaviour of mares within paddocks was monitored using sensors incorporated into a wearable mask built by HorseSafe (HorseSafe, n.d.). The sensors incorporate triaxial accelerometers to record movement patterns and a GPS unit to capture the spatial position of the mare. The device enabled continuous monitoring of movement, activity patterns and spatial use of pasture. The HorseSafe device is a commercially developed tool with a unique monitoring system, developed by the New Zealand company HorseSafe, a division of IoT Ventures, designed to provide continuous, remote insight into a horse's activity, location, and welfare status. The system comprises a compact sensor device that is securely placed in a purpose-built face mask worn by the horse, and a wireless connection that connects the device to a cloud-based platform using long-range, low-power technology (HorseSafe, n.d.). Location and motion detecting sensors embedded in the mask continuously record parameters such as local time (Coordinated Universal Time; UTC), and activity. The sensor collected real-time data on movement patterns which included: standing, lying, walking, trotting, cantering, charging, rearing, lip curl, cast, steps and transmit this information into the HorseSafe proprietary cloud. Through the app, users can access continuous behavioural metrics, receive alerts for potential health or safety concerns (e.g., colic, injury, casting, or escape), and review historical activity from any internet-connected device (HorseSafe, n.d.).

### *2.4.2 Triaxial accelerometers*

The device has incorporated a 3D accelerometer capable of capturing linear acceleration across the X (lateral axis providing side to side movement), Y (vertical axis providing upward and downward movement), and Z (longitudinal axis providing forward and backward movement) axes, along with an onboard machine learning core (MLC) capable of running activity-recognition models directly on retrieving device. Although the mask included a gyroscope, its data was not utilised at this stage of analysis. Accelerometer data enabled behavioural categorisation by identifying head position and movement patterns of mares while wearing the sensor equipped mask (Turner et al., 2023).

### *2.4.3 Sensor data processing*

The mask has a built-in solar panel (Figure 2.2) that charged the batteries in the mask. The accelerometer data was further processed in the HorseSafe propriety system to classify behaviours. Data was recorded continuously by the sensor without a fixed sampling interval. Measurements were then stored internally on the device and later downloaded via the HorseSafe software interface. Data from the device was transmitted wirelessly over a long-range, low-power network (LoRaWAN) via a gateway to the cloud. This enabled real-time monitoring without the need for cellular or Wifi coverage on rural properties.

Once data reached cloud storage, they were processed using proprietary in-house algorithms, and the analysed outputs were then communicated to the user via the HorseSafe mobile application. Users could view their horse's activity and also receive notifications in the occurrence of potential issues detected, such as, prolonged inactivity or behaviour suggesting distress. The application supported multiple horses per account, presented data separately for each animal and allowed more horses to be monitored from the same dashboard.

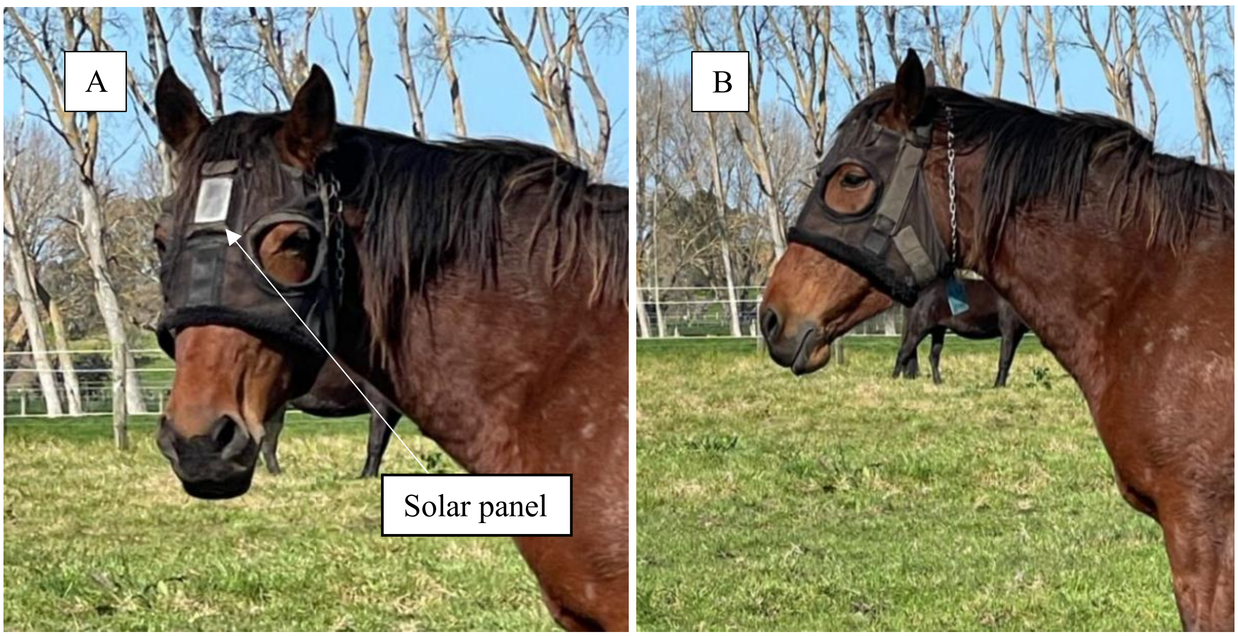


**Figure 2.2 (A&B).** HorseSafe mask positioned on a mare; ventral (A) and lateral (B) view at Alabar Farms (Photograph taken by the author in June 2024). Solar panel was positioned on the upper anterior portion of the mask, as labelled.

## 2.5 Behaviour observations using HorseSafe sensor

Behavioural classifications were developed prior to this study by HorseSafe using continuous video footage provided through the HorseSafe cloud-based monitoring platform (HorseSafe, n.d.).

### *2.5.1 Treatment animals and monitoring protocol*

Subsample of study mares per paddock (n = 7 dry; n = 8 pregnant) were equipped with masks for the purposes of this study. Mares with the mask were monitored continuously throughout the study period while remaining within their respective paddock groups. Group sizes within paddocks fluctuated over the course of the study due to routine farm management events. Mares were generally in groups, however, were housed alone if in need of extra care due to low body condition score (Table 2.2). Despite these changes, the study aimed to maintain continuity of data collection from the same mares throughout the observation period.

### *2.5.2 Behaviour categorisation*

Behavioural categorisation in this study do not represent standardised or universally accepted classifications within equine behaviour research. Instead, they are proprietary labels assigned by the technology provider to describe certain movements that was detected by the system. Categories were developed by sensor manufacturers to align with the relevance of behaviours performed on the farm to monitor management and welfare, rather than to replicate traditional ethological behaviour categories. The terminology used in this thesis reflects behaviour patterns embedded within the device’s analytical framework and should be interpreted accordingly. The mask used in this study was a beta-version system at the time of data collection. This version was still undergoing advancements, validation and refinement to hardware performance and behavioural classification algorithms.

**Table 2.3** Ethogram showing the description of mare behaviours labelled by the HorseSafe manufacture.

| Behaviour | Description |
|---|---|
| Standing | Mare is upright with all four limbs supporting body weight and no forward locomotion (recorded as "still"). If standing was recorded as 0 in the dataset, this indicated a device malfunction requiring reboot, typically caused by excessive battery drain associated with GPS activation. |
| Lying | Mare is positioned on her side with limbs extended and spine parallel to the ground (lateral recumbency). |
| Walking | Mare moves forward with at least one hoof in contact with the ground at all times. Approximately 100 steps had to be taken for a recording of one minute walking. |
| Trotting | Mare performs two-beat, diagonal gait where diagonal limbs move forward simultaneously. |
| Cantering | Mare performs a three-beat, asymmetrical gait. |
| Charging | Accelerated forward head movement. |
| Rearing | Accelerated vertical head movement along the horizontal axis. |
| Lipcurl | Raised head with extended neck, often curving it slightly. |
| Cast | Mare is positioned upside down. An automated alert was sent to the owner approximately one minute after detection. |
| Steps | Mare is in locomotion at a normal pace. Step detection used a debounce threshold of 10, meaning activity was recorded only after the mare completed ≥10 consecutive steps. |

Behaviour categories have continued to be refined since the study period (September 2024), with advancements made to the behavioural classification descriptions following data collection. However, during the study period, only step count data was validated, consequently, this thesis primarily focused on the same (Guichard, 2024).

## 2.6 Weather data

Daily weather data were downloaded from NIWA weather station near Pukekohe EWS (37.09415° S, 174.77598° E). Data included daily rain precipitation (mm), air temperature (C°) and relative humidity (%). Temperature humidity index (THI) was calculated using equation (Mader et al., 2006):

Temperature humidity index (THI) equation:

$$\mathrm{THI} = 0.8 \times T + \mathrm{RH} \times (T - 14.4) + 46.4$$

Where T is temperature in °C, RH is relative humidity expressed as a proportion.

## 2.7 Statistical analysis

Raw data for the study period was retrieved from the HorseSafe cloud base system and provided for the purpose of this research. Mares were first stratified according to physiological status (pregnant or dry). Additional variables extracted from the provided dataset included step count, GPS location data, and timestamps, which allowed the integration of hourly weather information and spatial location data. Mares were also categorised according to housing condition, group housed or individually housed to evaluate potential management effects on behaviour. Behavioural analysis were carried out using Minitab statistical software (Minitab LLC, Pennsylvania, USA). Movement data recorded by the triaxial accelerometers within the masks were initially processed using custom macros developed in Microsoft Excel (Neyeloff et al., 2012). The processed main dataset was then used for subsequent statistical analyses.

### *2.7.1 Weather data analysis*

Hourly weather data was retrieved for the study period from the NIWA database. Weather data was aligned with the timestamped behavioural dataset to allow interpretation of activity patterns in relation to prevailing environmental conditions.

*2.7.2 Spatial analysis*

Spatial analyses were conducted using GPS location data obtained from the mask. Location coordinates were imported into ArcGIS Pro (ArcGIS Pro version 2.2.4; Esri, Pennsylvania, USA, 2018) for spatial processing and mapping. An optimized hot spot analysis (z-score) was conducted using ArcGIS to identify statistically significant spatial clustering of mare GPS location fixes. An area of higher concentration of mare locations compared to the expected number given a random distribution of mares is known as a hotspot. On the other hand, a cold spot was defined as an area that had a lower concentration of mare locations compared to the expected number given a random distribution of mares.

*2.7.3 Step count analysis*

Mare step count was derived from accelerometer data that was used as a primary indicator of locomotor activity. Among the variables recorded, step count was considered the most robust indicator of activity and was therefore prioritised for analysis. Other behavioural outputs generated by the mask were excluded due to the early developmental stage of the sensor system and activities not being able to be attributed to behaviours accurately. Prior to analysis, step count (group and alone) data were checked for normality using the Kolmogorov-Smirnov test. Extreme values exceeding 2000 steps within a sampling interval were treated as outliers and removed from the dataset to reduce the influence of potential sensor errors. The removal of extreme values is a common practice in behavioural and accelerometer-based studies to minimise bias introduced by outliers (Barnett and Lewis, 1994). Normality tests were found to be normal. Data from dry mares housed individually were excluded from selected analyses due to the insufficient number of observations which limited the ability to support meaningful statistical inference.

Linear mixed-effects models were used, as they accommodate repeated measures and hierarchical data structures while accounting for non-independence among observations within individual mares. Mares were included as a random effect to account for random observations from the same individuals across the study period. One-way ANOVA was carried out within the pregnant mares that were housed in groups or alone. The inclusion of housing condition allowed assessment of management-related effects on mare activity by examining if locomotor activity different between pregnant mares housed within social groups and those managed individually.

# Chapter 3. Results

## 3.1 Weather

The study period occurred during September 2024 and was characterised by mild, transitional spring weather conditions with moderate day-to-day variability. Maximum daily temperatures ranged from 14.2°C (20/09/2024) to 20.7°C (22/09/2024) (Figure 3.1). Minimum daily temperatures ranged from 4°C (12/09/2024) to 12.2°C (07/09/2024). This demonstrated a general pattern of initial stability, a mid-month decline, and a gradual increase toward the end of the period. The lowest temperature occurred on 12/09/2024, while higher values were recorded during the first and final weeks of the month. Temperature Heat Index (THI) were consistently low to moderate ranging from 50 (12/09/2024) to 59 (01/09/2024 & 07/09/2024). Data indicates moderate variability in temperature and THI, consistent with typical early spring transitional conditions. Notably, a marked decrease in THI occurred between 12/09/2024 and 18/09/2024, corresponding with the cooler minimum temperatures during this period.

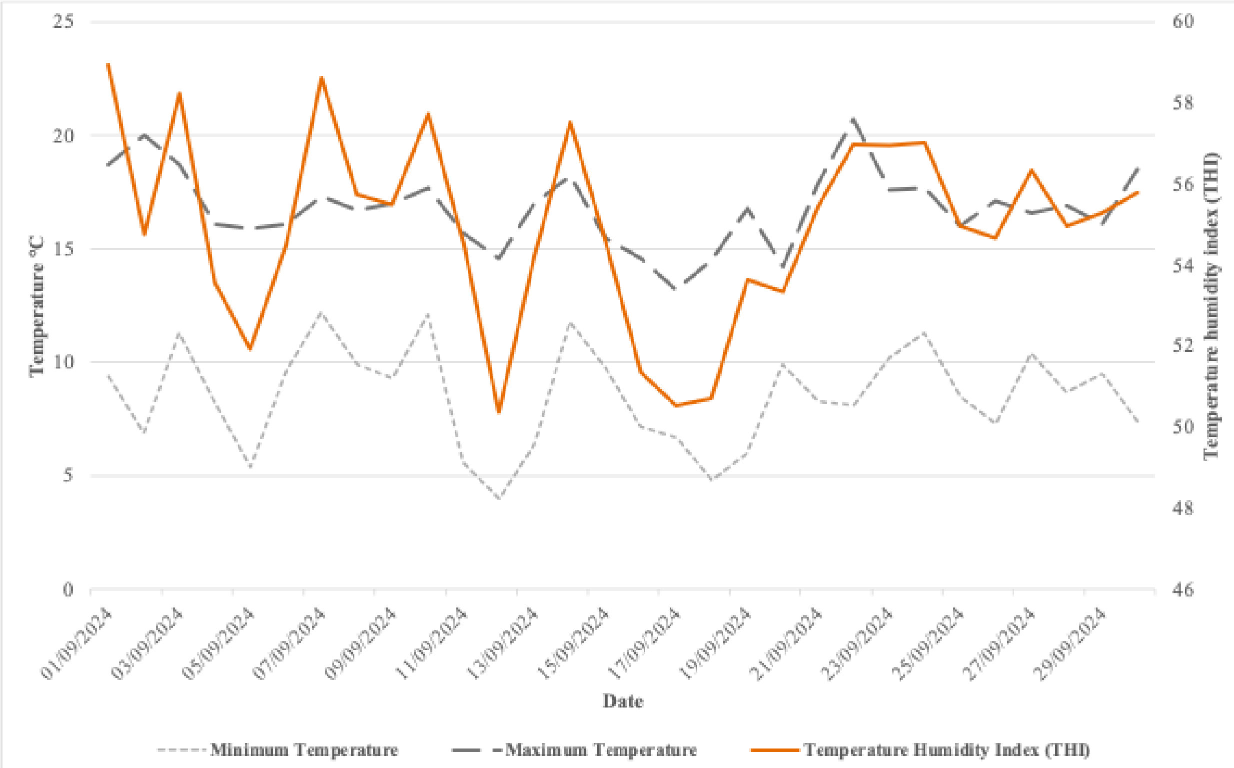


**Figure 3.1** Daily minimum temperature (°C), maximum temperature (°C) and temperature-humidity index (THI) recorded during September 2024.

Rainfall was intermittent, with a few isolated high-precipitation events and relative humidity fluctuated throughout the month, approximately 66-94%. Daily rainfall during the study period ranged from 0.2 to 27.6 mm, with the highest precipitation recorded on 20/09/2024 (Figure 3.2). Rainfall remained low throughout September, with most days receiving 0–0.3 mm and only isolated events exceeding this range. The most notable rainfall occurred on 20/09/2024 (27 mm), with smaller peaks on the 14th, 15th, 16th, and 17th days of the month. Relative humidity peaked on 20/09/2024, indicating considerable day-to-day variability in climatic conditions. Higher humidity values typically coincided with cooler or wetter days, as observed on 12/09/2024 and 20/09/2024. Conversely, lower humidity levels, such as the minimum recorded on 25/09/2024, aligned with drier and slightly warmer conditions.

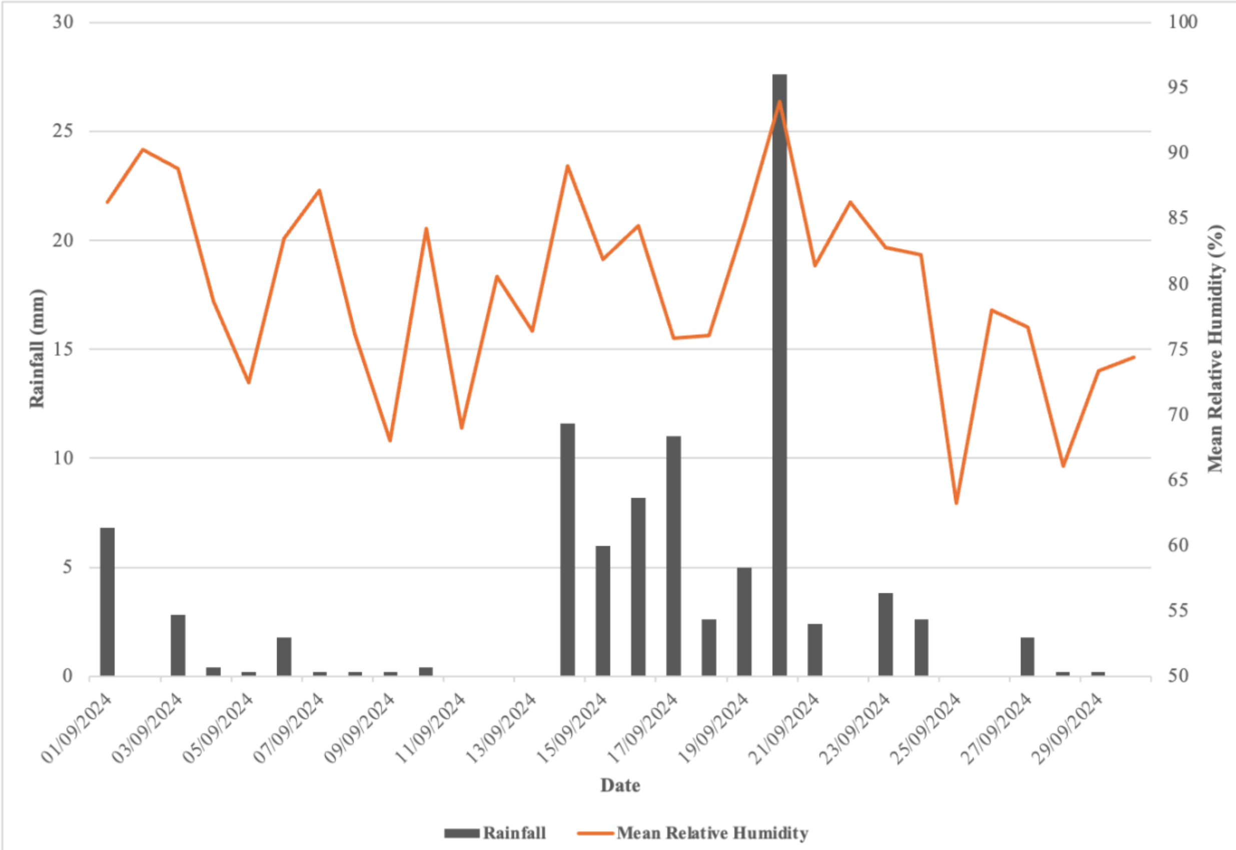


**Figure 3.2** Daily accumulative rainfall (mm), mean relative humidity (%) recorded during September 2024.

## 3.2 Animal density and spatial distribution

Paddocks 1 and 2 (Figure 3.3 A) housed the pregnant mares whereas, paddocks 3, 4, and 5 (Figure 3.3 B) housed the dry mares. Red areas represent high mare density of recorded GPS fixes and blue areas represent low GPS density locations. These clusters represent zones where mares spent more time than expected under a random spatial distribution analysis identifies hotspots, while areas with fewer recorded fixes represent cold spots indicating less time in that area. In paddock 1, a strong hotspot was identified in the south-west and south portions of the paddock. Paddock 2 displayed multiple scattered hotspots across the paddock, particularly in the south-west region. Smaller cold spots were seen in the north-west region. In paddock 3, hotspot activity concentrated on circular clusters in the central, south and west regions of the paddock. Surrounding this area were cold spots, particularly towards the paddock boundaries. Paddock 4 displayed relatively fewer clusters compared with other paddocks. Small hotspot areas were present within the central and northern sections, while cold spot areas were distributed around the paddock perimeter. A hotspot was located centrally, near the water trough. In paddock 5*,* several small hotspot clusters were detected throughout the paddock, particularly near the central-eastern area around the water troughs.


**Figure 3.3 (A&B).** Map showing the spatial distribution (magnitude per unit area) of mares in paddocks 1 and 2 (A) housing pregnant mares and paddocks 3, 4 and 5 (B) housing dry mares, using optimized hot spot analysis at the study site. Paddocks are identified with a red border. The blue areas represent low mare density while the red areas depict high mare density. Hotspot (dark red areas) indicate significant (P<0.01) spatial clusters of high values (larger positive z-score), cold spot (dark blue areas) indicate significant (P<0.01) spatial clusters of low values (smaller negative z-score), while white indicates random distribution with no spatial clustering.

## 3.3 Step count analysis

### *3.3.1 Effect of day on step activity of broodmares*

Day influenced broodmare (dry and pregnant) step behaviour (F = 15.92, P < 0.001) over the month of September 2024. Step behaviour fluctuated throughout the month with no clear pattern. Dry mares took consistently more steps per day (5,230 steps/mare/day) compared to pregnant mares (3,547 steps/mare/day). An exception was recorded on 21/09/2024 when pregnant mares took slightly more steps than dry mares (Figure 3.6).

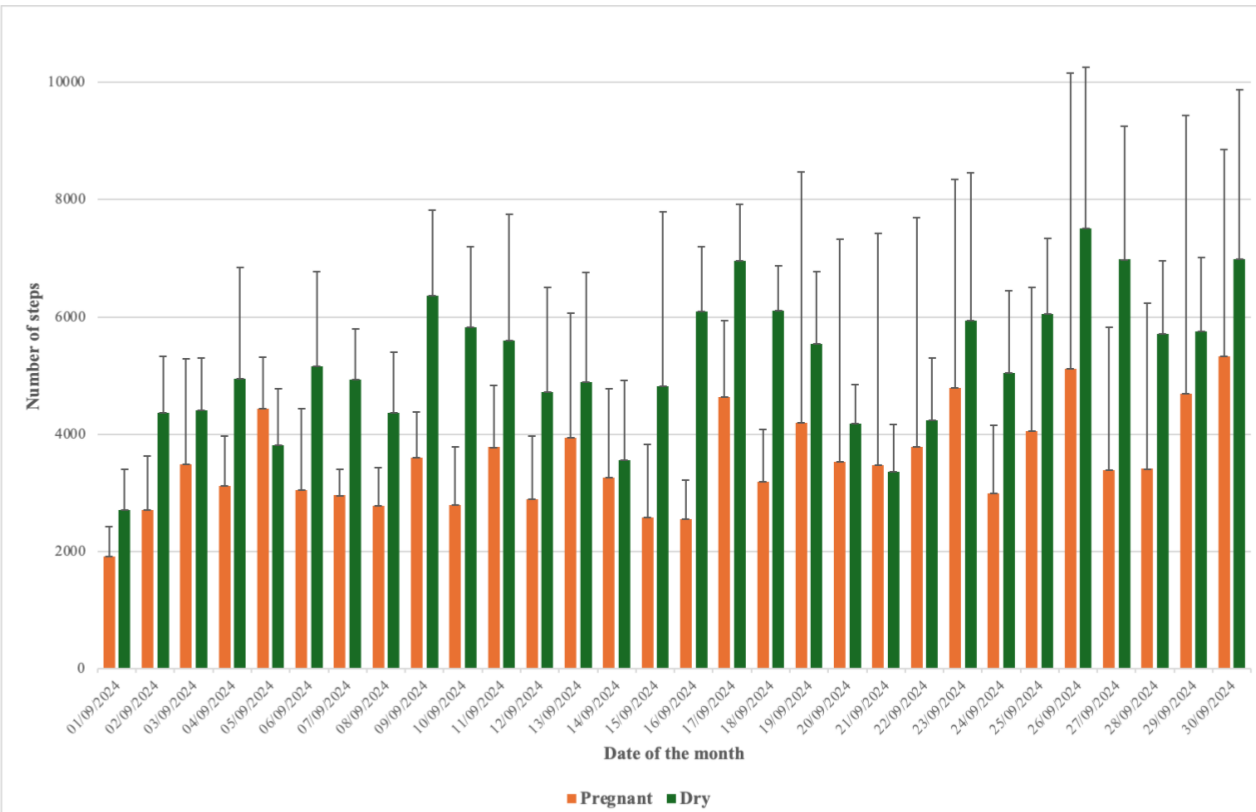


**Figure 3.4** Graph representing mean number of steps per day (±standard deviation (SD)) over the 30-day study period for pregnant and dry mares.

### *3.3.2 Effect of physiological state on step activity within each hour of the day*

All mares were used for this analysis, irrespective of their housing condition (group or alone). Dry mares were observed to take approximately 18.99 steps more (mean ± SD; 58.22 ± 9.3) per hour compared to pregnant mares (39.23±10.9) ($F = 14.93$, $P = 0.002$) (Figure 3.4). Effect of hour was significant ($F = 34.48$, $P < 0.001$). Both groups of mares had a peak of step activity at 08:00 with a smaller peak between 17:00 and 19:00.

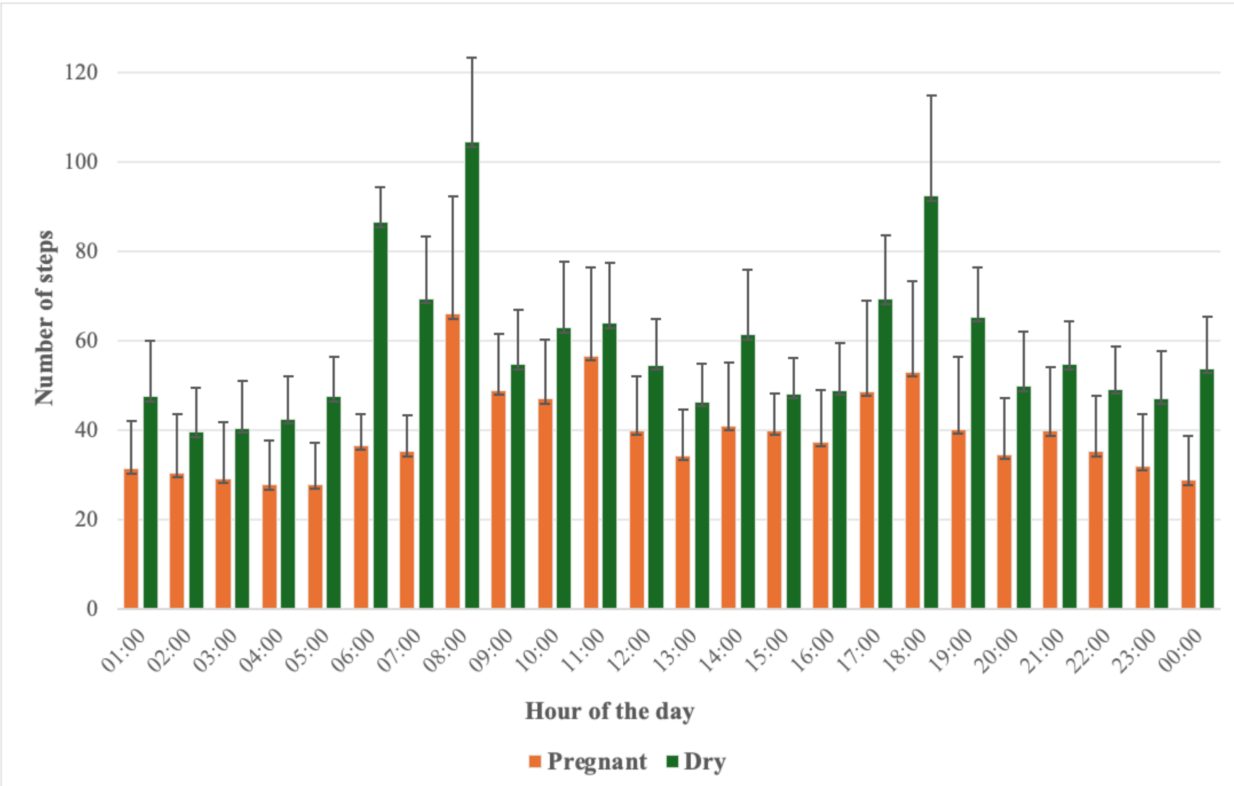


**Figure 3.5** Graph representing mean number of steps per hour, per mare (±standard deviation (SD)) over the 24-hour study period for all pregnant and dry mares.

When step count was examined within physiological state, hour of the day remained a significant factor influencing mare movement activity across the 24-hour period however, the dry mares had slightly different periods when activity was lowest compared to pregnant mares. Dry mares exhibited pronounced peaks in step count at 08:00 and 18:00, while the lowest levels of activity were observed at 03:00 and 23:00 ($F = 23.70$, $P < 0.001$). In pregnant mares, hour of the day remained significant ($F = 15.71$, $P < 0.001$) with greater step counts at 08:00 and 18:00 and reduced activity was observed overnight at 00:00 and 03:00.

*3.3.3 Comparison of step activity between physiological states within grouping management*

Mares used for this data analysis were pregnant and dry mares housed in paddocks in groups and not from those that were housed alone. Dry mares housed in a group, took more steps per hour (61.8 ± 7.1) overall compared to pregnant mares in a group (39.8 ± 5.35) ($F = 6.15$, $P < 0.05$) (Figure 3.5). The two groups exhibited diurnal variation in activity with step counts generally increasing during daylight hours and declining overnight. Peaks in step activity were observed during early morning and late afternoons period; 06:00 – 08:00 and 17:00 – 18:00 respectively.

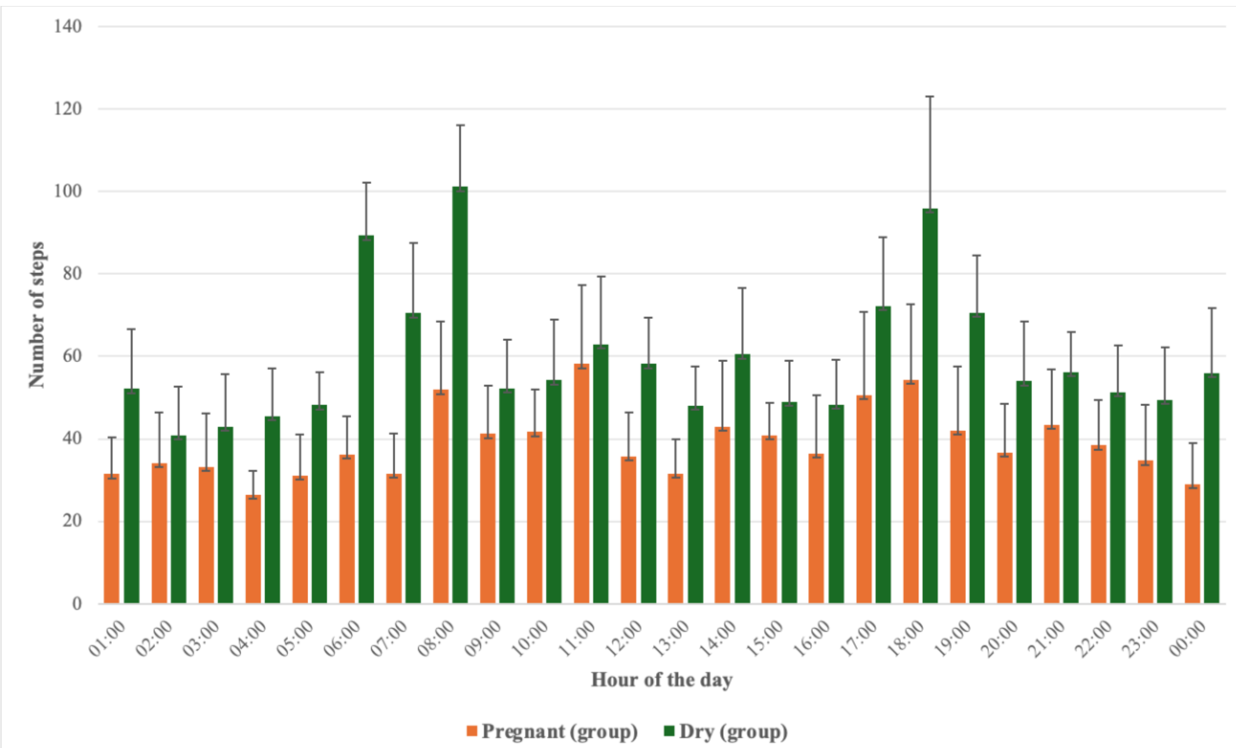


**Figure 3.6** Graph representing mean number of steps per hour per mare (± standard deviation (SD)) over the 24-hour study period for pregnant (n = 6) and dry (n = 7) mares which are housed in their respective groups.

*3.3.4 Effects of group management on the step behaviour of pregnant mares*

Comparison of pregnant mares, housed in groups with those in a paddock by themselves, had no difference in step activity ($F = 0.52$, $P = 0.473$), indicating that housing status did not significantly influence locomotor activity within pregnant mares. Data for dry mares housed individually was insufficient for analysis so, the effect of group management was not analysed for dry mares.

# Chapter 4. Discussion

This research aimed to investigate behavioural patterns of broodmares managed in a pasture-based system, with a particular focus on the influence of physiological state, weather conditions and management practices. Behavioural patterns were compared between pregnant and dry mares to determine whether reproductive state influenced hourly and daily activity and movement. Spatial analyses were used to characterise patterns of paddock use, providing further insight into how paddock characteristics influence mare behaviour.

## 4.1. Assess the influence of weather conditions, paddock and grouping characteristics on the behaviour of broodmares.

### *4.1.1 Effect of weather on step count*

In horses, according to Morgan et al., (2002), behavioural adjustments to thermal stress have been reported when THI values exceed approximately 72-75, with animals experiencing heat stress showing reduced movement patterns. Zähner et al. (2004) also noted that grazing livestock modify activity patterns in cooler or wetter conditions including changes in grazing and resting behaviour. Fluctuating weather conditions in early spring are variable factors that can influence pasture availability, mare movement and activity budgets (McIlwraith et al., 2017; Rutter, 2010; Mejdell et al., 2020). Despite fluctuations, humidity levels did not appear to exert a strong influence on THI and the moderate but variable temperatures and the THI values suggest generally low heat stress risk for the mares in this study. Collectively, these temporal conditions indicate that mares were exposed to environmental variability but non-challenging weather throughout the study period.

Step count varied across the study period with lower values observed at the beginning of the month (01/09/2024) and again during the mid-month period (12/09/2024 and 15/09/2024 to 16/09/2024). During these periods, cooler temperatures and rainfall may have influenced behavioural patterns, as the daily step count was reduced. For example, on the first day of the study period (01/09/2024), 7mm of rainfall was recorded (Figure 3.2), and this day had the lowest step count observed for pregnant mares housed in a group (Figure 3.6). Colder and wet days have been associated with reduced nocturnal grazing and increased shelter-seeking behaviour among horses (Morgan et al., 2002; Zähner et al., 2004). During the daytime, horses may also modify their activity budgets by reducing grazing time, increasing standing or resting behaviour, and remaining closer to sheltered areas to reduce exposure to precipitation and wind. These behavioural adjustments are considered adaptive responses that help conserve energy and maintain thermal balance during extreme weather conditions which can in turn influence movement patterns and paddock utilisation (Mejdell et al., 2020; Rutter, 2010).

Higher humidity, particularly when combined with mild temperatures, can reduce evaporative cooling efficiency, potentially affecting thermoregulation during periods of increased activity (McCutcheon & Geor, 1998; Morgan, 1998). When compared with the step count data, there is consistency with diurnal activity rhythms rather than any disruptions from heat stress or weather. Horses generally maintain stable physiological function within a thermoneutral zone of approximately 5–25°C, within which metabolic heat production remains relatively constant with minimal thermal regulation (Morgan, 1998; Mejdell et al., 2020). Similarly, low THI values observed during the study period were unlikely to have imposed meaningful cold stress on the mares. Horses can tolerate temperatures below the thermoneutral range due to physiological and behavioural adaptations such as increased metabolic heat production and increased movement (Cymbaluk, 1994; Morgan, 1998).

### *4.1.2 Spatial analysis interpretation*

Spatial analysis indicated that mares did not use paddock space uniformly, with clear zones of high and low activity reflecting non-random patterns of area utilisation. Areas of high mare density (hotspots) were associated with paddock features such as shelter belts, water troughs and gates. They act as focal points for congregation and repeated movement. Horses being grazers frequently concentrate activity near water sources, shade or access points due to repeated visitation and social interactions, leading to consistent spatial fixes (Bailey et al., 1996; Dumont and Hill, 2004). For example, in a study of GPS-tracked cattle in arid rangeland pastures, animals used showed consistent spatial occupancy patterns, selecting areas that consisted sufficient forage and favoured dry patches over less suitable terrain. This indicated the uneven use of landscape spatially rather than uniform distribution (Larson et.al, 2017). Harmse & Niekerk (2023) found that, hotspots were places where animal clustered and grazed more thus being closely aligned with environmental distribution. In contrast, areas of low density (cold spots) were used less frequently and likely reflected influences like terrain, distance from resources or variations in pasture availability. Cold spots tend to occur where vegetation was less attractive (Harmse and Niekerk, 2023). Resource distribution and environmental features shape movement patterns and aggregation behaviour in pasture-based systems (Arnold and Dudzinski, 1978; Bailey et al., 1996; Sigurjonsdottir et al., 2003).

Overall, the spatial hotspot analysis provides valuable context for understanding broodmare behaviour under pasture-based management. By identifying consistent areas of congregation and avoidance, this approach complements temporal activity analyses and enhances interpretation of movement data derived from wearable sensors. From a management perspective, recognising spatial patterns of paddock use may inform decisions related to pasture allocation, infrastructure placement, and welfare monitoring, ultimately supporting more efficient and welfare-oriented broodmare management systems (Bailey and Provenza, 2008; Sigurjonsdottir et al., 2003).

## 4.2. Compare step count for 24-hour time budgets between pregnant and dry mares.

### *4.2.1 Temporal effect on step count*

Pregnant and dry mares demonstrated diurnal patterns, consistent with findings reported in the literature and with the typical grazing-rest cycles observed in pasture-based horses. Periods of increased locomotion correspond with peak grazing times, while lower activity levels occurred during rest cycles. Mares typically exhibit two main daily peaks of activity associated with grazing, occurring during the early morning and late afternoon, while reduce locomotor activity occurs overnight and during resting periods in the middle of the day (Arnold & Dudzinski, 1978; Berger et al., 1999). According to Duncan, (1980) and Mayes and Duncan, (1986), mares spend 10-17 hours per day grazing, with grazing bouts concentrated around dusk and dawn, which would correspond to periods of increased movement patterns across pasture observed in this study.

### *4.2.2 Effect of day on step counts*

Day-to-day variation in step count for the study period was observed between pregnant and dry mares, with dry mares taking more steps per day than pregnant mares. In one instance, dry mares recorded lower step count during 21/09/2024, a day after significant rainfall (Figure 3.2) Weather events such as rainfall can influence movement patterns and grazing distribution. Wet ground conditions may reduce movement as animals avoid muddy areas or seek shelter (Arnold & Dudzinski, 1978). Additionally, wind exposure and shelter belts can influence paddock utilisation and activity budgets (Mejdell et al., 2020; Morgan, 1998; Van Dierendonck et al., 2011).

### *4.2.3 Comparison between physiological states*

Dry mares were found to have higher overall step count than pregnant mares, indicating that pregnancy may be associated with reduced locomotor activity. While both groups maintained similar overall behavioural patterns, dry mares took approximately 19-20 steps more per hour than pregnant mares. From a study conducted by Piccione et al. (2015), movement patterns were monitored in mares and it reported significant decrease in activity during late gestation indicating behavioural adjustments associated with physiological changes during pregnancy. The reduction in number of steps in pregnant broodmares in this study is likely related to physiological adjustments during late gestation, including energy conservation and altered behavioural priorities (NRC, 2007). Physiological and endocrine changes caused by pregnancy are known to progressively influence locomotor behaviour, with reduced voluntary movement and increased resting, particularly during late gestation. These reductions in activity are considered biologically appropriate and support foetal development by limiting unnecessary energetic expenditure (Arnold & Dudzinski, 1978; Sigurjonsdottir et al., 2003).

Diurnal rhythms in dry mares exhibited more pronounced activity peaks while pregnant mares showed a similar rhythm but with lower overall activity levels. The pronounced peaks in activity during early morning and late afternoon align with crepuscular grazing tendencies commonly reported in equids, under pasture-based management (Piccione et al., 2015). However, pregnant mares exhibited reduced activity compared to dry mares, even during the peak periods at dawn and dusk.

### *4.2.4 Comparison between physiological states in housing practices*

There was little variation between step behaviour in pregnant mares kept in group or alone. This further indicates that for a pregnant mare being with other horses or being the sole occupant of a paddock did not influence locomotor activity. Group-housed mares can have increased activity levels associated with social or group interactions but this has been observed to not influence movement patterns when horses have adequate space and access to resources in pasture-based systems (Sigurjonsdottir et al., 2003; Hartmann et al., 2012).

## 4.3. Practical application of mask derived behavioural data to help improve broodmare management, early detection of health concerns and support reproductive success.

The results from the sensor demonstrate the potential value of wearable sensor technologies for improving broodmare management in pasture-based systems because they allow continuous, objective monitoring of mare activity without the need for direct human observation. Continuous behavioural and location data can provide early indications of changes in activity patterns that could signal health issues, stress, or altered physiological status (Halachmi and Guarino, 2016; Neethirajan, 2017). Accelerometer-based sensor technologies have been widely validated in livestock systems and can thus, achieve high behavioural classification accuracy (Parsons et.al, 2024). By enabling the technology to monitor individual animals rather than group-level observations, such technologies can support early detection of behavioural deviations associated with illness, lameness, or reproductive issues. This approach can therefore contribute to improved welfare, early detection of health concerns and better reproductive outcomes within commercial breeding operations

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## 4.4 Limitations of this research

Despite the strengths of this study, the following limitations were noted:

1. The use of accelerometer driven mask technology is effective for capturing general movement patterns, however, they may not fully distinguish between specific behaviours such as grazing, lying, standing or social interactions. As a result, some behaviours may have been grouped or interpreted indirectly through movement proxies rather than directly observed behaviours. The results highlight that further refinement of the HorseSafe mask is necessary to fully achieve the objective of comprehensively defining broodmare behaviour for management purposes. Further development and calibration of the accelerometer sensors, combined with validation against behavioural observations would strengthen the accuracy of the technology.

2. Sample size used for this study was relatively small, which may have limited the statistical power of the findings. Behavioural variation between individual horses can be considerable; therefore a larger sample size across multiple groups would provide broader and stronger confidence that the observed patterns are representative of the broodmare population.

3. As per the environmental conditions during the study period, data collection occurred during relatively moderate and non-challenging weather conditions. Therefore, the study may not have fully captured how broodmare behaviour and activity patterns changed under extreme environmental conditions. Weather extremes, such as heavy rainfall, heat or extreme cold, represent a wider range of climatic conditions that would help determine if the behavioural patterns observed here remain consistent under environmental stress.

4. In addition, the study was conducted on a commercial farm setting, which introduced both advantages and limitations to this research. While the commercial farm setting provided the practical relevance and real-world applicability of the findings, it also reduced the level

of experimental control compared to controlled research designs. Factors such as paddock rotation schedules, pasture quality, and natural variations in the coastal environment could not be standardised and may have influenced mare behaviour.

## 4.5 Scope for future research

While the present study provides valuable insights into broodmare behaviour movement patterns and spatial distribution using wearable sensor technology, there is scope to expand and refine this research. Future studies should consider longer monitoring periods, larger sample sizes and measure additional physiological and environmental variables to further improve understanding of broodmare behaviour in pasture-based systems.

Firstly, extending the duration of monitoring across multiple seasons would provide a more comprehensive understanding of how environmental factors influence broodmare activity. The present study was conducted over a single month during early spring, when thermal conditions was not challenging on the mares. Therefore, monitoring across summer and winter periods would allow for the assessment of behavioural responses to a broader range of weather conditions.

Secondly, increasing the number of animals monitored would improve statistical power and allow for a more detailed examination of individual behavioural variation within mare populations. Larger datasets allow future studies to explore how various factors like age, reproductive stage and temperament influence movement patterns.

Future research could examine behavioural changes across different stages of the gestation period. Monitoring mares throughout pregnancy and early lactation may help identify behavioural indicators associated with foaling. The influence of paddock design and resource distribution on mare movement patterns could also produce some interesting findings.

Finally, advancements made in sensor technology and data presentation present opportunities to develop automated monitoring systems for commercial breeding operations. Continued development and application of sensor technologies will enhance the understanding of broodmare behaviour thus providing valuable tools to improve welfare and decision making in commercial breeding systems.

## 4.6 Conclusion

This study demonstrated that broodmare movement behaviour is influenced by a combination of environmental conditions, paddock characteristics and physiological state. Environmental conditions during the study period remained within moderate weather conditions, resulting in minimal influence on movement patterns. However, spatial analysis revealed that movement patterns were not uniform in the paddocks; suggesting that mares congregated around key environmental features such as shelter belts, water troughs and gateways. These findings highlight the importance of paddock design and resource distribution thus, influencing movement and spatial behaviour.

Pregnant mares exhibited lower overall step counts compared to dry mares, reflecting behavioural adaptations that are associated with physiological demands of gestation and energy conservation during late pregnancy. Despite these differences, both physiological states maintained similar diurnal activity rhythms that are characterised by increased movement patterns during daylight hours and reduced movement overnight, consistent with established grazing patterns in pasture-based horses. Understanding how activity varies across the day and between physiological states provides valuable insight into broodmare behaviour and has implications for optimising pasture allocation, reproductive management, and welfare monitoring in extensive breeding systems. This variability reflects intermittent bouts of locomotion interspersed with periods of relative inactivity. The overall pattern indicates sustained differences in activity levels between physiological groups throughout the day.

The practical application of wearable sensor technologies provided valuable insights into broodmare behaviour that would be difficult to obtain through traditional observational methods. Continuous monitoring of movement and spatial activity offers considerable potential for improving broodmare management within pasture-based systems and provides high resolution monitoring in order to capture temporal patterns in activity that may not be detectable through short-duration visual observations.

To conclude, the findings demonstrate that putting together behavioural sensor data with environmental and spatial analysis provides a powerful approach for understanding and managing behaviour and management in commercial equine production systems.

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