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Development and validation of novel tools to assess reproductive traits and improve beef cattle reproductive efficiency

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Abstract

There are significant challenges in recording reproductive performance in northern beef cattle production systems. This project explored how emerging automated remote monitoring tools might be used to record fertility traits. The work used proximity loggers, RFID readers located at watering points, automated vision recognition and walk-over-weighing to determine age of puberty, date of calving and oestrus events. Proximity loggers were most accurate in recording individual oestrus events but need further technology development to make them a practical tool. Combining Kamars and automated vision recognition software showed potential as an accurate and practical tool to determine age of puberty in young heifers. An RFID reader showed some promise to measure association patterns between bulls and cows coming to water to be used as a proxy for determine oestrus events. Combining RFID readers and walk-over-weighing showed great promise in automatically recording date of calving in 90% of cows to enable a simple tool to determine days to calving.

Executive summary

Background

Reproductive performance is the single most important factor related to profitability of northern beef breeding enterprises. Reproductive performance is influenced by the age of puberty, the length of the post-partum anoestrus interval (PPAI; length of time from calving to next oestrus) and the total lifetime productivity or total weight of calves weaned per cow (Mukasa-Mugerwa 1989; Burns *et al.* 2010). The extensive nature of the northern Australian beef industry hinders data collection on these parameters when compared with beef produced on smaller and more intensive production systems in temperate environments, thus northern businesses are operating without pivotal information to allow them to benchmark and improve future herds.

Northern Australia typically experiences much lower pregnancy rates and weaning rates, especially in first calf heifers, than temperate zones (McGowan *et al.* 2014). The harsh environments create a significant challenge for breeding cows. Identifying cows that have high reproductive efficiency and building on their superior genetics has the potential to increase reproductive rates in Northern Australia, however, there is a lack of fertility parameter recording. More detailed recording of reproductive performance will lead to robust genetic evaluations and more accurate estimated breeding values (EBV's), which should then lead to greater uptake of those genetics by the commercial industry.

In addition to the issues of performance recording and obtaining knowledge on individual cattle performance, some producers report calf losses between 10-15% from positive pregnancy test diagnosis through to weaning. This translates into $100s of millions in lost production annually on a national scale (McGowan 2014), thus signifying the economic and animal welfare significance of this issue. thus signifying the economic and animal welfare significance of this issue. There are many reasons why calf loss can occur, such as disease, predation, calving difficulty, but due to the extensive environment recording this information is extremely difficult.

Automated livestock management systems (ALMS) present an opportunity to improve individual animal monitoring and management strategies while delivering labour, economic and production benefits. Location telemetry has been used to provide information related to bull/cow (O'Neill *et al.* 2014) and cow/calf interactions (Swain and Bishop-Hurley 2007). These social interaction data are related to biological effects such as age of puberty and length of postpartum anoestrus. In addition, when combining the social information with data from a Walk-Over-Weighing (WoW) system there is the potential to determine maternal parentage, date of birth and estimated birth weight. There have been a number of studies that have demonstrated that spatial monitoring of social interactions between cattle can be used to determine oestrus and maternal behaviour (Swain and Bishop-Hurley 2007; O'Neill *et al.* 2014). This project aims to integrate ALMS technologies and determine how emerging precision livestock management can be used within the seedstock industry. The focus is on delivering more accurate quantitative measures of reproductive performance.

Objectives and Aims

The overall aim of the project is to use a range of ALMS technologies to identify various stages of the reproductive cycle in an extensive beef breeding operation, by monitoring both adult cows and pre-pubertal heifers. Reproductive measures include the onset of puberty, oestrus and mating activity, date of calving, calf and cow weights, maternal parentage, cow/calf interactions signifying mothering ability, calving interval and postpartum anoestrus. The measures will be recorded using a combination of technologies including: walk over weighing systems, proximity loggers, accelerometers and visual recognition software.

Results

The range of technology that has been used in this project can be combined to provide almost a complete picture of the heifer's development and determine both the age of puberty and date of conception.

Identifying age of puberty

The proximity sensor data was analysed to identify the formation of small sub groups of cattle in oestrus, known as a sexually active group (SAG), by comparing the confirmed time of oestrus with changes in regular social associations for those heifers, as per the social network analyses in Handcock et al. (2009). The sequence that animals traverse a WoW platform has been linked to maternal parentage (Menzies *et al.* 2018) and oestrus events (Corbet *et al.* 2018), thus the WoW sequential data was analysed for patterns reflected in the proximity data to determine if first oestrus, and hence puberty, can be determined using WoW data alone. This can be cross-referenced with images of activated Heatmount detectors that were taken as their RFID tags were read as they entered the water compound.

Identifying date of conception

Recording mating information was not an initial objective of the project, however, this information was readily recorded using the range of technology used in this project and further demonstrates the technologies usefulness for commercial application. An estimate of foetal age was recorded at each ultrasound, which can be compared with peaks in heifer-bull contacts recorded by proximity sensors to indicate date of conception, as reported by O'Neill et al. (2014). Independently, the sequences in the RFID data can be compared at similar time points to determine if the bull and heifer in oestrus cross the RFID reader together to provide an estimate of oestrus and date of conception, similar to Corbet et al. (2018).

Outcomes for industry

The use of paddock based automated data capture is still relatively new technology. This project is the first time that it has been used to attempt to identify age of puberty in cattle. Each new application and new group of cattle provides new challenges but also helps provide some new learnings that will ensure the technology progresses to deliver practical applied solutions for industry.

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1. Background

1.1. Project overview

Reproductive performance is the single most important factor related to profitability of northern beef breeding enterprises. Reproductive performance is influenced by the age of puberty, the length of the post-partum anoestrus interval (PPAI; length of time from calving to next oestrus) and the total lifetime productivity or total weight of calves weaned per cow (Mukasa-Mugerwa 1989; Burns *et al.* 2010). The extensive nature of the northern Australian beef industry hinders data collection on these parameters when compared with beef produced on smaller and more intensive cattle production system in temperate environments, thus northern businesses are operating without pivotal information to allow them to benchmark and improve in future herds.

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The overall aim of the project is to use a range of ALMS technologies to identify various stages of the reproductive cycle in an extensive beef breeding operation, by monitoring both adult cows and pre-pubertal heifers. Details of the current issues faced by industry relating to reproductive recording, as well as potential technological solutions, are described in the following sections.

1.2. Overall lifetime reproductive performance

Lifetime reproductive performance is generally described and measured as the calving and weaning rate in beef cattle herds. Optimal reproductive performance would aim for a cow to wean a calf each annual cycle. Selection to improve weaning rates has been challenged by the low heritability of the trait (Mackinnon *et al.* 1990). Reproduction is a complex trait and a product of many components such as the attainment of puberty, successful fertilisation, gestation, parturition, lactation and re-conception. Recent research conducted by the Beef CRC identified that some components of reproduction are moderately to highly heritable, genetically correlated with weaning rate and therefore warrant further investigation for genetic improvement (Johnston *et al.* 2014). Two traits in particular, age at puberty and first post-partum anoestrus interval, were considered important as they could be measured early in the breeding life of a female and were indicators of lifetime reproductive performance.

In addition to the issues of performance recording and obtaining knowledge on individual cattle performance, some producers report calf losses between 10-15% from positive pregnancy test diagnosis through to weaning. This translates into $100s of millions in lost production annually on a national scale (McGowan 2014), thus signifying the economic and animal welfare significance of this issue. There are many reasons why calf loss can occur, such as disease, predation, calving difficulty, but due to the extensive environment recording this information is extremely difficult. The factors associated with lifetime reproductive performance, namely age at puberty, PPAI and calf loss are described in more detail in the sections below.

1.2.1. Age of puberty

Attainment of puberty is the first vital step in the breeding timeline of all livestock species. The aim is for heifers to be pubertal prior to their first exposure to the bull, which in northern Australia generally occurs at 2 years of age. Age and weight at puberty are highly heritable and correlated with lifetime reproductive performance (Johnston *et al.* 2009), as heifers that reach puberty early are more likely to conceive a calf earlier in the first and consecutive years (Johnston *et al.* 2014). The Beef CRC research also demonstrated considerable sire variation in the age at puberty of their daughters, particularly in Brahman cattle, indicating that targeting sires with early maturing daughters could provide an opportunity to lift overall reproduction. Puberty is attained with the first behavioural oestrus that is accompanied by ovulation and development of a corpus luteum with a typical lifespan. Since oestrus is associated with distinctive behavioural patterns, investigation using on-animal sensors to detect these behavioural patterns and provide a remotely monitored system to record the onset of oestrus behaviour is warranted.

1.2.2. Post partum anoestrus interval

Post-partum anoestrus interval (PPAI) is the length of time from calving to a cow's next oestrus event. The average length of PPAI affects a herds overall lifetime reproductive efficiency, as the success of a cow conceiving a calf to produce in the following calving season is highly dependent on when she returns to oestrus. Before oestrus can resume following parturition, the reproductive tract must go through a period of recovery, which can take between 20 to 40 days (Short *et al.* 1990). Following the reproductive tract returning to normal, the resumption of oestrus can be affected by various factors, such as investment in the calf in terms of suckling and nutrition and the cow's nutrition, age, parity and genetics. The PPAI is reported to have a moderate to high genetic heritability (Johnston *et al.* 2014), thus selecting for cows that return to oestrus sooner will influence the overall productivity of the herd.

The period of oestrus occurs when gonadotropic hormones elicit a surge in luteinising hormones causing the dominant ovarian follicle to ovulate. A corpus luteum (CL) develops on the ovary at the sight of ovulation and begins secretion of progesterone to maintain the pregnancy if fertilization occurs. The onset of oestrus is characterised by changes in behaviour often displayed as mounting other cows and eventually allowing herself to be mounted by others, a behaviour called standing oestrus, which lasts for 6 to 24 hours. Ovulation occurs 24 to 32 hours after the onset of standing oestrus, enabling the cow to conceive a pregnancy if inseminated during standing oestrus (Fortune 1994). There is also evidence that sub-groups are formed when more than three female cattle exhibit oestrus at the same time and form a close proximity group (Sveberg *et al.* 2013). This specific sexually active group formation is thought to serve as a visual signal to increase mating opportunities.

The behavioural changes that occur around oestrus are used by intensive cattle industries (e.g. dairy cattle producers) to identify PPAI and can be used to determine when cattle are ready to be mated, as part of artificial insemination programs. Identifying oestrus in extensively managed beef cattle herds is difficult and time consuming, as cattle are not regularly observed to identify indicators of oestrus, and techniques used in more intensive industries, such as oestrus detection markers, are not practical. The industry are therefore lacking information on valuable herd reproduction related data. Due to the large genetic component, knowledge on individual and herd level PPAI provides an opportunity to both record and improve overall reproductive efficiency. Using technology to record behavioural changes indicative of oestrus provides a novel and efficient way to remotely record reproduction data, however, the application of technology to record oestrus is limited and further research is required.

1.2.3. Calf loss

Losses from pregnancy diagnosis to weaning are the major cause of reproductive inefficiency in northern Australia. The reasons for calf loss are not well understood but studies conducted by (Holroyd 1987) and more recently by Brown et al. (2003) have clearly demonstrated that greatest calf loss is around the time of calving. Many factors can affect calf viability in the first couple of weeks after birth. Dystocia is a well-recognised cause of neonatal loss and although calves maybe born alive they may be slow or fail to suckle due to cerebral anoxia which occurs during prolonged parturition. Although the prevalence of dystocia in *Bos indicus* cattle is generally lower than in *Bos taurus* cattle (Rowan 1990), Brown et al. (2003) observed that the prevalence of dystocia was 4% in maiden Brahman heifers mated to Charbray bulls. Also, Fordyce et al. (2009) reported a mortality rate of 5-10% due to dystocia in Brahman cross females calving at 2 years of age.

Bunter *et al.* (2013) studied data from 9296 calves born to 2078 dams over 9 years across five sites to investigate factors associated with calf mortality for tropically adapted breeds (Brahman and Tropical Composite) recorded in extensive production systems. The average calf mortality pre-weaning was 9.5% of calves born, varying from 1.5% to 41% across all sites and years. In total, 67% of calves that died did so within a week of their birth, with the cause of death most frequently recorded as unknown. Observations to record reasons for calf mortality is not practical in extensive production systems and devices used to automatically and remotely monitor calving events could help improve calf survival.

1.3. Automated livestock monitoring systems

Obtaining accurate data on lifetime reproductive performance traits provides producers, both seedstock and commercial breeders, with essential information to benchmark their performance and identify areas for improvement. Recording this type of information, however, primarily relies upon repeated records of ovarian activity to ascertain oestrus events and pregnancy status as well as continual surveillance to monitor calf health and survival. Such intensity of measurement would not be practical for most commercial beef producing enterprises. Moreover, adoption of genetic evaluation technologies by beef producers is slow and a major barrier to adoption is the perceived challenge of collecting accurate pedigree and performance data (Agricultural Business Research Institute 2015). Developing automated methods of recording to achieve precise measures of reproductive events (e.g. oestrus, conception, calving, re-conception) in livestock populations may help increase adoption of genetic technologies by beef producers.

The section below details technology that is available to record animal reproduction data in order of technologies that are research specific devices, due to their application method, data processing and cost, to commercially available products, that producers can currently purchase ‘off the shelf’. This project allows a valid comparison of technologies that have the potential to collect reproduction data so the most effective and accurate method can be determined, either singly or in combination. The outcomes will identify future avenues for commercial applications so that producers can increase productivity and profitability through obtaining greater knowledge on their breeding cattle.

1.3.1. Proximity loggers

The social associations of cattle within a group provides important information on the health and well-being of the individuals involved. Remote monitoring technologies called 'proximity loggers' enable researchers to measure in great detail how cattle interact, where a ‘contact’ is defined when two individuals wearing proximity logging collars come within close proximity of each other, regardless of their behaviour (Figure 1). Social behaviour encompasses all affiliative/positive behaviours, with the strongest of all social behaviours being the bond between a mother and her offspring. Reproductive behaviours, such as maternal investment, mating events and oestrus behaviour, all occur within close proximity of one individual with another and are therefore perfectly suited to be identified in proximity logger data.

Proximity loggers use UHF radio signals to detect other devices within a pre-defined range to record the duration and frequency of all close proximity encounters. An encounter distance of <4 m represents approximately two body lengths of a cow, however, due to refraction, reflection and absorption of radio waves, the actual detection distance cannot be precisely determined and is instead provided as a range. The continuous recording capability of the sensors allows data to be recorded ‘24/7’ in the animal’s natural environment, without the disturbance by observers. While the sensors are currently not equipped to wirelessly transmit data, it is foreseen that this will be a possibility in the future, allowing real time data capture and monitoring.

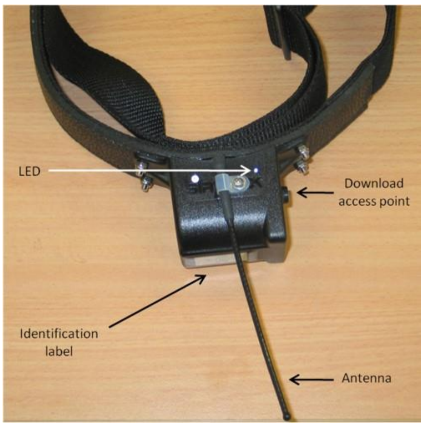

Figure 1. Left: The external components of a proximity logger collar, Right: cattle fitted with proximity logging collars

Proximity loggers have been used extensively over the past 10 years to record reproduction data on cattle. Proximity loggers were first applied to a commercial cattle herd by Swain and Bishop-Hurley (2007) to investigate maternal affiliations between beef cows and their calves, with cows associating more with their own calf than any other cow or calf. Proximity loggers have also been validated to identify oestrus and date of conception in cattle (O'Neill *et al.* 2014), as well as identify changes in association patterns as cows approach calving before changing their association patterns to reflect maternal status (Swain *et al.* 2015).

In the current project, the data recorded by proximity sensors will be compared with validated data, such as oestrus confirmed by ultrasound detection of a corpus luteum or activated oestrus detectors, to identify changes in social patterns related to these events that could indicate when behavioural patterns change in response to physiological or environmental stressors.

1.3.2. Taggle technology

Taggle is a fixed antenna positional system that relies on triangulation of a radio signal from a mobile node (i.e. ear tag) to a minimum of three static base stations to calculate an approximate location. Taggle was initially developed to locate animals on a property and identify stock that had been illegally removed from the property.

The use of Taggle radiolocation devices to provide animal interactions based on spatial proximity has been documented in a small number of trials conducted over varying areas and topographies. Within a small scale (5 ha) static trial, Taggle radiolocation devices (ear tag) provided a spatial precision of approximately ±22m (Menzies *et al.* 2016). Taggle accuracy has also been tested in a recent MLA project (Project B.NBP.1619) aimed at developing a remote calving alert device using a similar form of Taggle device tested statically. The taggle technology within the Calf Alert apparatus provided less precision than the static tests when tested in an area more representative of industry grazing areas. Testing the Calf Alert devices at both Rockhampton (149.5 ha) and Longreach (975.6 ha) showed that the device provided spatial precision of approximately 115m and 218m, respectively (Stephen *et al.* 2018). It was therefore concluded that the Taggle device would not provide insufficient precision to reliably provide location to determine animal associations such as bull/cow interactions associated with a mating event. However, there have been some recent developments in the printed circuit board of the Taggle radiolocation device that result in an improved signal: noise ratio. The improvement would result in the device transmission being received by the land-based receivers at approximately 5dB less than the previously tested devices. This enhancement should result in greater receptions over a larger area and, therefore, potentially increased precision and warrants further investigation. Thus, due to the variation around the accuracy of Taggle for fine scaled behavioural trials in combination with current restrictions on manufacturing Taggle ear tags, the tags were not used in the current study.

1.3.3. Visual imagery

Visually observing individuals regularly is not practical on extensive beef operations, where animals may only be sighted once or twice a year in remote locations. This is in stark contrast to cattle in more intensified industries that are observed a minimum twice per day. Recording visual images of cattle on a daily basis provides an opportunity to remotely monitor their well-being. For example, real-time automatic cameras have been developed in the dairy industry to analyse cattle movement as an indicator of lameness (Viazzi *et al.* 2013). In relation to reproduction, there is the potential to use automatically recorded images to identify specific reproduction based attributes, such as oestrus. Oestrus detection devices, such as Kamars and Estrotect heat detectors, are frequently used in the dairy industry to indicate that a cow has displayed oestrus behaviour based on her willingness to stand to be mounted by others, thereby activating the oestrus detection device to change colour from white to red. This project is the first to investigate the use of visual imagery to remotely detect oestrus in extensively managed beef cattle.

1.3.4. Walk-over-weighing

Recording weight data on an animal can provide important insights into its growth and health. Walk-over-weighing (WoW) systems provide an automatic method of recording individual animal weights as they enter a compound, usually surrounding an attractive enticement, such as water or supplement. A weigh platform connected to an electronic recording system is placed in between two fence panels to create an entrance into the compound. As the animal enters the compound, its National Livestock Identification System (NLIS) ear tag is detected by a Radio Frequency Identification (RFID) reader and the animal's identity and weight is stored on a local processor. The CQU developed system then sends the animal's weight data over a 3G connection to a central server.

Walk-over-weighing systems have recently been proven to determine important reproduction data in extensive beef production, namely maternal parentage and date of calving. Identifying maternal parentage is an essential component of genetic recording, yet manually recording this information is difficult, as cows often calve in the absence of producers, matching cows to calves in yards can be erroneous and DNA testing is costly. Menzies et al (2016) developed an algorithm to identify greater than 90% of cow-calf pairs based on the temporal sequence that they entered a WoW system, providing confidence that automatic RFID sequencing can be used to identify genetic relationships. Recording calving date is also an essential component of genetic recording, however, it is subject to the same recording difficulties as assigning parentage. Calf birth date is often approximated based on their size when first yarded, which can vary depending on differing breeds, genetics and maternal investment. Recently, Menzies et al (2017b) used the WoW weight profile to identify a change in weight associated with calving to accurately assign a birth date to ~80% of calves. These recent advances highlight the additional applications that can be gained from a remote WoW system to record essential herd information, saving time and labour required to collect this information. There is the potential for WoW sequencing to be applied to other areas of reproduction, such as date of conception and oestrus behaviour, to provide a greater range of applications of reproduction data recording.

1.3.5. RFID

The National Livestock Identification System (NLIS) was introduced in Australia in 1999 to meet the requirements of some export red-meat markets and enable individual animals to be traced for the purpose of food safety. The system became mandatory in most states by 2005 and the radio frequency identification (RFID) technology that came with the NLIS system has increased the precision of livestock management. RFID-tag readers incorporated in Walk-over-Weighing (WoW) systems, for example, have enabled automated collection of daily weights and RFID sequential data as cattle access water. The temporal sequence of individuals accessing a watering point in a rangeland grazing system has been shown by Menzies *et al.* (2018) to determine maternal parentage with 97% accuracy and has the potential to provide knowledge of other key aspects of reproductive behaviour in cattle. The mandatory requirement for all cattle to be fitted with NLIS tags provides an industry relevant method to record individual animal data without requiring additional identification or on-animal sensors.

1.4. Summary

The previous section highlighted the current issues relating to recording reproduction parameters and provided context of their importance for moving the industry forward in terms of genetic improvement. Automatic recording techniques have the potential to increase not only the amount but also the accuracy of quantitative measures of reproductive performance. This project aims to integrate ALMS technologies and determine how emerging precision livestock management can be used within the seed stock industry with a focus on two of the main indicators of lifetime reproduction efficiency, being identifying oestrus to determine PPAI and age of puberty. Additional reproductive parameters can be determined once these parameters have been determined, such as bull libido, date of conception, and maternal parentage and investment.

2. Project objectives

1. The net benefit will be delivered through automated measures that can be used to derive improved knowledge on reproductive efficiency in northern breeder herds. This information will allow more rapid genetic gain and potentially more widespread use of EBVs.
2. Northern seedstock producers will be able to automatically record key reproductive information such as maternal parentage, age at puberty, calving interval, post-partum anoestrus interval, birth date and birth weight. These measures will mean a greater supply of EBV-recorded bulls focussed on reproductive efficiency with the potential to increase profitability, which will help address current issues of poor profitability and high debt levels

of northern producers. Increased profitability will have flow on effects in the wider community and make employment in rural areas more attractive.

3. The industry is looking for practical solutions to manage their production systems and is interested in the use of technology to improve current monitoring practices. Although technologies have been available and proven to derive information such as parentage, the cost of the technologies has limited uptake. The emergence of tracking technology such as Taggle and WoW is providing potential economic benefits. Measuring parentage and other traits such as mothering ability, bull libido, onset of puberty and post-partum anoestrus has the potential to lead to targeted genetic selection.
4. The extensive environment of the northern beef industry has always been both an advantage and a disadvantage. The use of on-animal telemetry systems has the potential to enable producers a higher level of control and increased husbandry monitoring. The greatest output from the investment will be data and a demonstrated system that has been trialled under commercial conditions. The project will provide data to demonstrate how producers can make more informed decisions based on factors such as whether a cow is raising a calf, what her inter-calving interval is, how many matings each bull is having and the age heifers are reaching sexual maturity.

To respond to these objectives, the following hierarchy of technology requirements for collecting data on animal behaviour and location was proposed Figure 2. Ideally, generating data on oestrus and date of calving requires complete knowledge of where an animal is and what it is doing 100% of the time; such information provides the most accurate description of an animal that is comparable to human visual observations. An example of technology within this tier are GPS collars and ear tags and Taggle ear tags. The second tier considers technologies that focus on temporal rather than spatial accuracy but still with continuous recording, such as a 'contact' recorded by proximity loggers when two animals come together in time, irrespective of their spatial location. The third tier relates to technologies that can deliver temporal associations at a fixed location, such as RFID readers located at a water trough. The ability of technology to deliver accurate and continuous spatial and behavioural data becomes less refined with increasing hierarchy level.

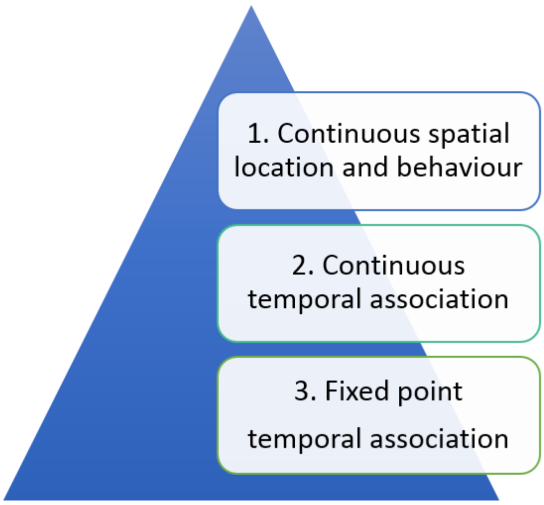

Figure 2. A hierarchy of technology requirements to record accurate cattle location and behaviour

This hierarchy was used to theoretically evaluate the technologies used in the current project for their accuracy to derive location and behavioural information, including proximity loggers, Taggle locating ear tags, RFID sequencing and identifying activated oestrus detectors using visual imagery. Figure 3 summarises the predicted accuracies from each of the technologies on their own and also in combination. Thus, the use of these technologies to record oestrus activity and date of calving, were the focus of the current project, noting that Taggle were eventually not used in the project due to inaccuracies with the technology reported subsequent to project commencement.

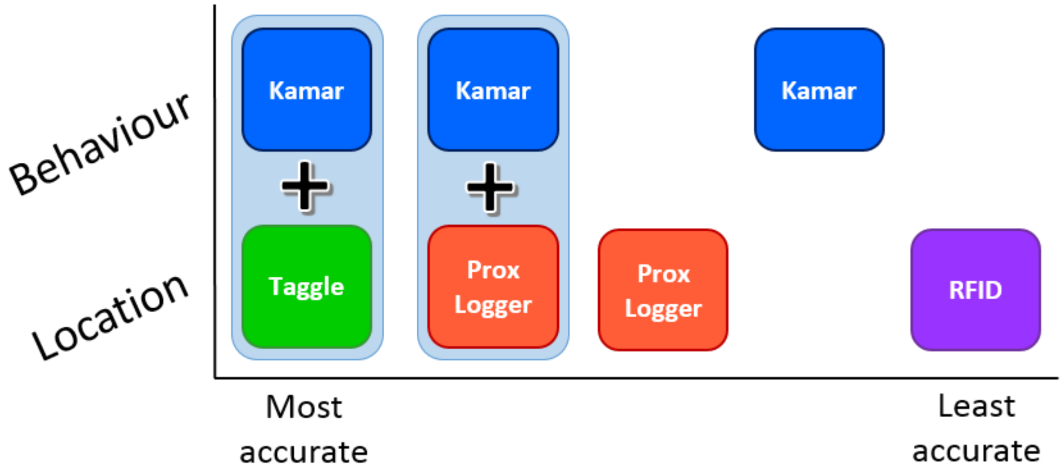

Figure 3. A representation of the accuracy of the technologies used in this project to record cattle behaviour and location, either singly or in combination. RFID refers to the integration of automated electronic identification via walk-over-weighing systems to record sequential patterns of individual animals.

3. Methodology

Two separate studies were conducted to investigate the use of ALMS to record reproduction data in adult breeding cattle, namely to identify oestrus in adult cattle and onset of puberty in pre-pubertal heifers. In addition one of the ALMS were used to estimate date of calving to infer PPAI, these were compared with manually recorded date of calving using daily visual checks. The same ALMS's were established in each of the two studies with the details described below.

3.1. Animals and data collection

The study was conducted at Belmont Research Station, referred to as 'Belmont', located approximately 26 km north of Rockhampton, in Central Queensland (150° 23' E, 23 ° 13' S). All procedures used in the study were approved by the CQUniversity Animal ethics committee (approval number 20244).

3.1.1. Adult cows

Year 1 - Date of calving and oestrus behaviour

Eighty multiparous pregnant cattle were selected for the trial in August 2016 based on confirmed pregnancy status. One group comprised 40 Belmont Red cattle (*Bos taurus x Bos indicus*), with a mean weight (±s.d.) of 513 (±54.1) kg and the other group comprised 40 Brahman (*Bos indicus*) cattle with a mean weight (±s.d.) of 527 (±43.4) kg. The two different breeds were chosen to provide an industry relevant comparison based on their different reproductive characteristics. The cattle were born between 2008 and 2014, with the majority born in either 2010, 2011 or 2012. The groups were maintained separately throughout the study and located in separate paddocks on Belmont.

The Belmont Red cattle were located in one of two paddocks with an ALMS surrounding a trough located in between the two paddocks. Paddock 66 was 28 ha and paddock 35 was 22 ha. This design allowed the cattle to be located in either paddock depending on forage availability, whilst still accessing the same ALMS. The Brahman cattle were located in a single 65 ha paddock of undulating open woodland with one ALMS. These cattle were not rotated through other paddocks, as the paddock size was much larger and there was sufficient forage throughout the study period. A mineral lick supplement was supplied when the pasture growth was low and cattle were in the late stages of gestation.

Calving began in the Brahman group on the 21st September and the last cow calved on the 30th December 2016. Belmont Red cows commenced calving on the 3rd October 2016, and all cows had calved by 2nd January 2017. Each cows' calving date was recorded daily by manually observing the cows from a motor vehicle. Calves born in the previous 24 hours were weighed and identified with an ear tag and NLIS tag.

Cows were mustered to the yards several times during the study, with cow body condition score (BCS), weight and lactation status recorded at each yarding. Cows were scanned for post-partum ovarian activity in mid-December when three Brahman and seven Belmont Red cows were still to calve. On 22nd December a bull was introduced into each group and remained with the groups for 11 weeks, allowing three oestrus cycles for each cow to conceive. A second bull was placed with Brahman cows in late January. The cows were scanned for ovarian and pregnancy status in early February, 7 weeks after the bulls were introduced, which coincided with branding of the calves. The cows were also scanned for pregnancy/ovarian activity in early March when the bulls were removed, and again on the 4th May, 8 weeks after bull removal which coincided with weaning.

Oestrus behaviour was monitored from February onwards using a range of recording methods, additional to the data recorded from the RFID sequence, WoW, digital image and water consumption that was recorded each time a cow entered the watering compound. Proximity logging collars were fitted to 15 cow-calf pairs and the bulls from each group, Kamar heat detectors were applied to all cows, and ovarian activity was monitored at the February, March and May ultrasound scans. Static weights were also recorded monthly when the cattle were mustered to the yards. In addition to recording oestrus behaviour the ALMS was also used to record date of calving.

Year 2 - Maternal parentage

Two cow herds at Belmont Research Station were assessed to determine the accuracy of Walk-over-Weighing data to derive maternal parentage. The experiment was conducted at Belmont (150°13'E, 23°8'S), approximately 26 km north of Rockhampton, Qld, Australia. The cattle had ad libitum access to pasture and water within their paddocks.

The first group contained 39 Belmont Red (adapted *Bos taurus*) cows and their calves grazing within a 50-ha paddock (paddock 66). The second group contained 39 Brahman cows (*Bos indicus*) and their progeny grazing within a 65-ha paddock (paddock 17). The Belmont Red and Brahman herds calved from 13 October 2017 until 22 December 2017 and from 10 September 2017 until 22 January 2018, respectively.

Throughout the calving season daily observations were conducted to locate and recorded the birthdate, birth weight, maternal parentage and sex of all newborn calves. Each calf had an RFID and management ear tag fitted when captured. It is estimated that greatest period between the time of a calf being born and the time when it was tagged was 48 hours. Each herd had 39 newborn calves tagged and recorded.

On 9 March 2018, both herds were mustered to a set of cattle yards with Belmont Red (n=39) and Brahman (n=39) calves being branded and vaccinated, male calves castrated and those with horns being dehorned. Two Belmont Red calves were not sighted after branding with no data recorded in the dataset.

Weaning occurred on 24 May 2018 for the 37 Belmont Red calves and 21 May 2018 for 39 Brahman calves. The last date that WoW data was recorded was the weaning date for each herd. The calves had access to the WoW system from birth to weaning with data being recorded when calves walked on the weight platform in order to go to the watering point.

The cattle accessed the WoW unit through a race, walking over the weight platform, having their RFID tag read and weight recorded simultaneously. The cattle then passed through a one-way spear gate to access the water trough and exited the compound through a separate spear gate (Menzies *et al.* 2017). The WoW system at paddock 66 comprised an Aleis RFID reader (Aleis 8051, Aleis, Capalaba, Qld, Australia) to record the RFID number and a Tru-Test WoW platform and WoW2 indicator (Tru-Test Limited, Auckland, New-Zealand) to record the weight. The only difference with the WoW system at paddock 17 was that it used a Tru-Test XRP2 RFID reader.

The two cow herds had previously been conditioned to use the WoW system with access since March 2015 and February 2016 for Belmont Red and Brahman cows, respectively. The calves, however, were not given any training prior to or during the data collection period.

3.1.2. Pre pubertal heifers

A group of 40 pre-pubertal Belmont Red heifers, weaned in June 2016, were monitored over a 7 month period to identify the onset of puberty. The heifers were introduced to the study in August 2017 when they were rising 2 year olds and weighed an average (±s.d.) 366 (±35.3)kg with an average body condition score of 3.0 (±0.2; on the 5 point scale). The heifers were located in either paddock 19 (30 ha) or paddock 20 (32 ha), with a central watering compound shared between the paddocks so the ALMS could continuously monitor the animals independent of their paddock location.

Oestrus behaviour indicating puberty was monitored from August onwards using a range of recording methods, additional to the data recorded from the RFID sequence, WoW, digital image and water consumption that was recorded each time a heifer entered the watering compound. RFID sequence was used to calculate an average of time between cows and the bull moving through the WoW system as described for the adult cows. Proximity logging collars were fitted to all 40 heifers throughout the 7 month trial, Kamar heatmount detectors or Estrotect heat detectors were applied to all heifers, static weights were recorded monthly and each heifer was scanned fortnightly via ultrasonography for ovarian activity and P8 fat depth. In addition to recording oestrus behaviour, the ALMS was used to record date of conception.

A bull was introduced on the 19th December 2017. The bull was fitted with a proximity logger, however, this collar came off during the deployment and was not found. A new collar was fitted at the next yarding, thus, contact data with the bull was recorded for 21 days from the 2nd to the 23rd February 2018. Monitoring ceased in February 2018 when all but one heifer had recorded a corpus luteum and 30 heifers were confirmed to be pregnant following the final ultrasound, ranging from 4 weeks to 11 weeks pregnant.

3.2. Data processing and analysis

The manually and automatically collected data was processed to determine when oestrus was identified within the different data sources. These data points were then compared to determine the correlation between methods, which could then be used to rank each method on its accuracy in identifying the time of oestrus, either singly or in combination with other sources. Once oestrus behaviour had been identified, other reproduction events were investigated, such as calculating PPAI as the amount of days from partition to next oestrus. The date of conception was determined based on either a peak in the number of proximity logger contacts recorded between a cow/heifer and the bull, or in the case of no proximity logger data with the bull, assessing the sequence that the bull and cow/heifer crossed the RFID reader. The date of conception was cross checked with visual images of the animals entering the watering compound and estimated foetal age via ultrasonography. Age of puberty was calculated by reporting each individual’s age (in days) at the time of first recorded oestrus. The data processing for each data source is presented below.

3.2.1. Manually recorded data

Ovarian activity and P8 fat depth were determined using ultrasound imaging with a Honda HS-2000V (Honda Electronics, Toyohashi, Japan) scanning machine and a 7.5 MHz linear array transducer. The data were manually entered into a TSi animal management system (Gallagher, Hamilton, New Zealand) at the time of data collection, while static weights were directly recorded onto the TSi from the weigh scales. The data from each session was downloaded via USB as a .csv file and processed using Excel to summarise the data.

3.2.2. Automatically recorded data

Social associations between cows, heifers and bulls

The proximity logger data were downloaded as a .csv file using a USB interface (Sirtrack administration tool v1.1.06, Sirtrack, Havelock North, New Zealand). The data was processed using R statistics (R Core Team 2017), using the compression method described by Hamede et al (2009) to remove any overlap recorded between two loggers; not all contacts are exactly reciprocated between loggers, thus the data are processed to condense the data by eliminating any overlapping data between a pair of loggers and compiling into a single file. The data recorded on the day of fitting collars were not used in the analysis to account for non-paddock behaviour, such as movement from the cattle handling facilities and being within close proximity when held in the yards. Similarly, the data collected on the last day of each deployment was also not used in the analysis. Additionally, 1 second contacts can erroneously occur when near the edge of the detection range (Prange *et al.* 2006) and can falsely bias the data, thus they were not included in the analysis. Summary statistics were calculated for each animal to determine association peaks that could indicate oestrus. Daily cow-bull contacts were plotted over time and significant differences between peak daily contacts of cows exhibiting oestrus during the study period and peak daily contacts of anoestrous cows were determined using the two-sample t-test of sample means and standard deviations. Due to the majority of heifers already having displayed oestrus prior to the proximity logger recorded by the bull, a statistical comparison was not appropriate due to the small sample size of non-oestrus heifers (n=2), instead records were investigated for peaks in bull contacts as well as peaks in heifer-heifer contacts to assess the presence of sexually active groups.

Remote data acquisition

RFID data files and digital images were streamed wirelessly via the Telstra Next G™ telecommunications network directly to a server for downloading to a personal computer. The visual images recorded as each animal's RFID tag was read as it entered the watering compound was visually inspected to assess if Kamars or Estrotect Heatmount detectors had been ruptured, indicating oestrus. The data recorded in this study were used to develop an algorithm to automatically detect colour changes in Kamars. This algorithm is being further tested to determine if it can use real-time images to detect oestrus in cattle.

The Automated Livestock Management System (ALMS) combines a walk-over-weighing unit with an RFID reader to automatically identify and record the weight of cattle as they access water. The ALMS uses a small microcomputer to control data recording and also to provide an automated system for downloading the data and transferring it to a cloud data storage device. Two files are separately recorded one records the electronic identification (EID) NLIS number and the date and time, the second records the EID NLIS number, the date and time and the weight of the cattle. The EID only file provide a more complete record of the date and time each cow, calf and bull comes to water. The files are downloading every 10 minutes and the data is finally written to daily csv file.

Data processing involves reading in all individual files and identifying any rows that have erroneous data such as incomplete RFID number or weight files that have rows missing either RFID files or weights missing. When cattle cross the weigh platform sometimes they have a cow following closely behind them, this can cause incorrect weight records with two animals being weighed at the same time. Weekly averaging allows erroneous records to be identified and removed from the data set.

The EID data is used to construct detailed association measures between all individuals within the herd. These measures are based on the time difference between cattle as they cross the weigh platform and have their EID tag read. These data processing use the EID only file as it has a more complete record of animals crossing the weigh platform. RFID sequence was used to calculate an average of time between cows and the bull moving through the WoW system. Code was written in R v3.2.3 (R Core Team 2017) to develop an algorithm which initially compared the time that individual cows and bulls passed the RFID reader and identified the shortest time interval between the bull and each individual cow on each day. A moving average of the shortest time interval was then calculated over three days using data from either side of a central daily value. The moving average aimed to reduce the impact of short-term fluctuations and identify periods when a bull and cow consistently (over a three day period) accessed water in close proximity. The sensitivity and specificity of time to bull (TTB) as a test for cows in oestrus were calculated as the true positive rate, and the true negative rate respectively.

Date of calving

Estimating the date of calving relies on identifying changes in the live weight of cattle that is indicative of a birth event. The current approach uses a heuristic (a set of logical rules) method that aims to filter the ALMS data to identify the period, and then with further filtering rules to identify the date of calving. Initially the weekly average data sequentially tests the mean and standard deviations of the all weights from any given week, if the standard deviation falls outside of 15 kg the largest outlier is removed and the data are retested. Data are only retained and allocated to a weekly average if the standard deviation falls below 15 kg and there are least four weights for any given week. Once the weekly average is calculated the difference in weight between weeks is calculated. All weeks that have a drop in weight of more than 25 kg are assigned as potential weeks of calving. The daily data is then used to assign the day of calving. It is recognised that future analyses might benefit from a more rigorous multivariate statistical approach, however, current data sets restrict the ability to construct and validate a statistical model. Heuristic methods not only help develop and test initial models, they also provide important knowledge on the possible parameters that might be useful in a more detailed statistical model. Future approaches are considered in the discussion.

Maternal parentage

All data were processed and analysed using R Foundation for Statistical Computing (R Core Team 2017). Typically within northern Australia calves are first brought to a set of cattle yards at the branding round and then reprocessed at weaning. In order to keep the experimental protocol relevant to existing management practices, the dataset for each paddock was reduced to only the periods between the branding and weaning dates.

There were some periods with no WoW records. For the Belmont Red herd, the internal memory in the XR3000 indicator was exhausted resulting in no data being collected between 12 and 16 April 2018. Due to the accumulation of surface water in paddock 17, cattle were removed on 1 February 2018 and only returned on the 4 April 2018 when an electric fence was established around the creek to encourage cattle to drink from the water source within the WoW compound.

To identify the cows and calves from the WoW dataset, CSV files were imported for each paddock that listed the RFID, class (cow or calf) and paddock for all cows and calves in the two paddocks. Daily WoW data files were imported for the period between branding and weaning for each paddock and rows of data containing RFID’s not associated with the cows and calves were removed from the dataset.

The half-weight index measure of temporal associations, which scores all cow and calf combinations between 0 and 1, was used to assign maternal pairs (Menzies *et al.* 2018). R code was written to calculate the association between each cow and calf within each paddock using a 5 minute period between RFID reads. Once each calf was assigned an association with each cow the cow/calf pair with the strongest association (highest HWI) was assigned as a maternal pair and removed from the dataset and the code was run again to determine the next strongest association and continued to iterate through the dataset until each calf was assigned a cow. At this point the cow/calf maternal pairs were compared with the associations determined by daily observations throughout the calving season and the total of correct associations determined as a percentage per paddock.

4. Results

4.1. Adult cows

4.1.1. Oestrus detection

Ultrasound scanning

Ultrasonography of the cows' reproductive tracts Figure 4 identified the presence of an ovarian CL in six of the Brahman cows and nine of the Belmont Red cows, indicating that these 15 cows had ovulated during the 29-day observation period. The remaining 15 cows either had not returned to cyclic oestrus activity postpartum or had a CL and an early pregnancy, so had cycled and conceived before the start of the study period and, hence, did not ovulate during the study period. For the purpose of definition in the present study, the cows that did not ovulate were termed 'anoestrus' or 'acyclic'. Oestrus or cyclic cows were defined as those that ovulated during the study period and were determined by a combination of CL presence, a peak in daily contact with the bull and an activated heat-mount detector. Fetal aging indicated that of the 15 cows that had ovulated, 13 had also conceived during the study period.

Figure 4. Cow being scanned for ovarian activity (left); an image from the ultra-sound scanning machine showing ovarian corpus luteum *with a central fluid filled cavity (right) indicating incidence of ovulation.*

Proximity loggers and heat-mount detectors

In the Brahman group, activation of heat-mount detectors Figure 5 coincided with the peak in cow–bull daily contact of all six cows exhibiting oestrus. In the Belmont Red group, activated heat-mount detectors aligned with peaks in daily bull contact for seven of the nine cyclic cows. One detector was not fully activated and a second was not seen activated but noticed missing just after the peak in bull contact. Across the groups, the activated heat-mount detectors reliably aligned with peaks in cow–bull contact in 87% of individuals.

Figure 5. A cow with activated heat-mount detector is closely followed through a WoW system by a bull.

In each breed group, peaks in daily cow–bull contact were greater ($P < 0.001$) for the cows in oestrous than for anoestrous cows. Peak daily contact with the bull at the time of oestrus for the six cyclic Brahman cows averaged (±s.d.) 174 (±58.2) contacts per day, while the nine acyclic Brahman cows averaged a maximum of 57 (±18.9) daily contacts during the study period. Peak daily contact in the nine cyclic and the six acyclic Belmont Red cows averaged 104 (±35.6) and 44 (±19.8) respectively. For two of the Brahman cows, daily bull contact peaked twice during the 29-day study period, indicating that they each had two oestrus events 18 or 19 days apart. Figure 6 shows the number of daily contacts of a cow with the bull (bar plot), with peaks 19 days apart indicating two oestrus periods. Fetal aging confirmed that this cow conceived at the time of the second oestrus event.

RFID sequence (time to bull)

Average time to bull (TTB) following cows in oestrus was typically less than 240 s, with an average (±s.d.) of 115 (±74.7) seconds in the Brahman group and 178 (±126.2) seconds in the Belmont Red group. When cows were not in oestrus, TTB was longer ($P < 0.01$) and averaged 2988 (±2734.5) seconds in the Brahman group and 2413 (±1758.6) seconds in the Belmont Red group. The line plot in Figure 6 gives an example of TTB dropping to below 240 s during oestrus events, signified by peaks in daily bull contact (Figure 6).

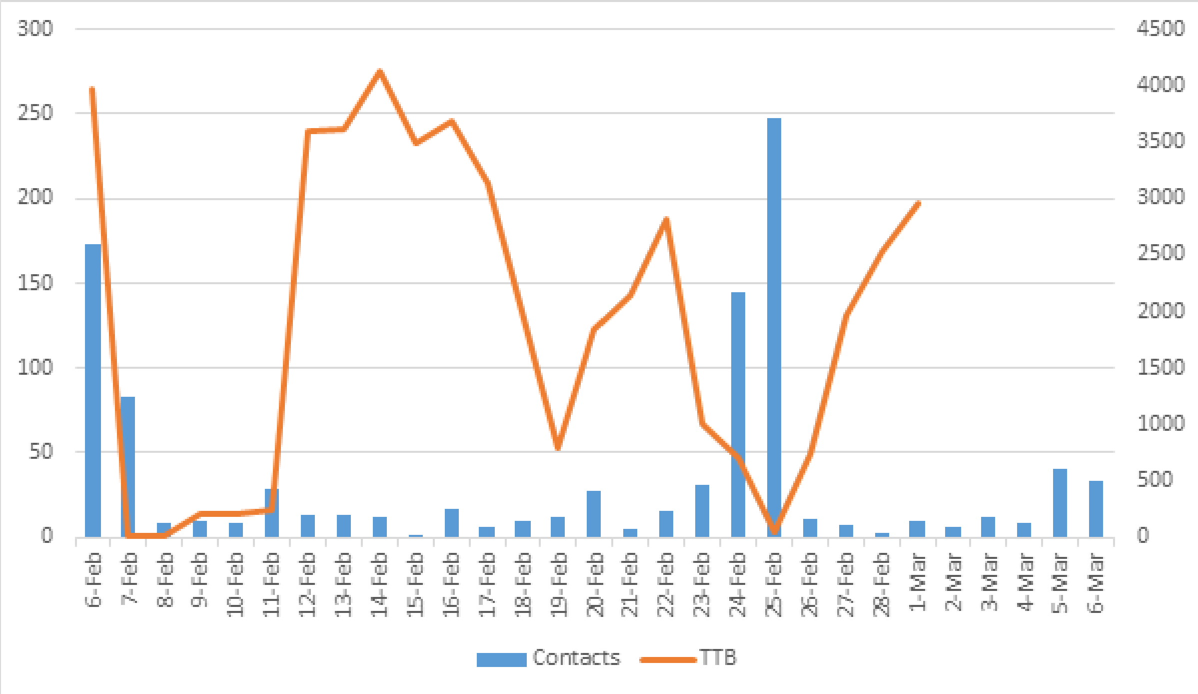

Figure 6. Graph showing typical distribution of daily contacts (bar plot; left y axis) of a cow in oestrus with the bull and a rolling average of time (line plot in seconds; right y axis) to the bull following her through a WoW system.

The number of oestrus events and the number of true positive and falsely predicted oestrus events across cow groups is presented in

Table 1. Sensitivity was 0.65 and represents the probability that TTB was short (<240 s) when the cow was in oestrus (true positive rate). Specificity was 0.60 and represents the probability that TTB was longer (>240 s) when cows were not in oestrus (true negative rate).

Table 1. Number of true positive and true negative oestrus events detected by the shortest interval of time from cow to bull accessing a watering point (TTB).

Test (TTB)	Oestrus event		Total
	Present	Absent	
Positive (short TTB)	11	6	17
Negative (long TTB)	6	9	15
Total	17	15	

Sensitivity: 0.65 (95% CI – 0.38 to 0.86)
Specificity: 0.60 (95% CI – 0.32 to 0.84)

Short TTB reliably predicted oestrus in six of the eight (75%) oestrus events observed in the Brahman cows and in five of the nine (56%) oestrus events in the Belmont Red group. Two bulls were used in the Brahman group, which is likely to have added to the sensitivity of RFID sequence to determine cows in oestrus in that group. It was observed that while the more dominant bull was engaging with cows away from the WoW compound, his subordinate followed oestrus cows as they accessed the watering point.

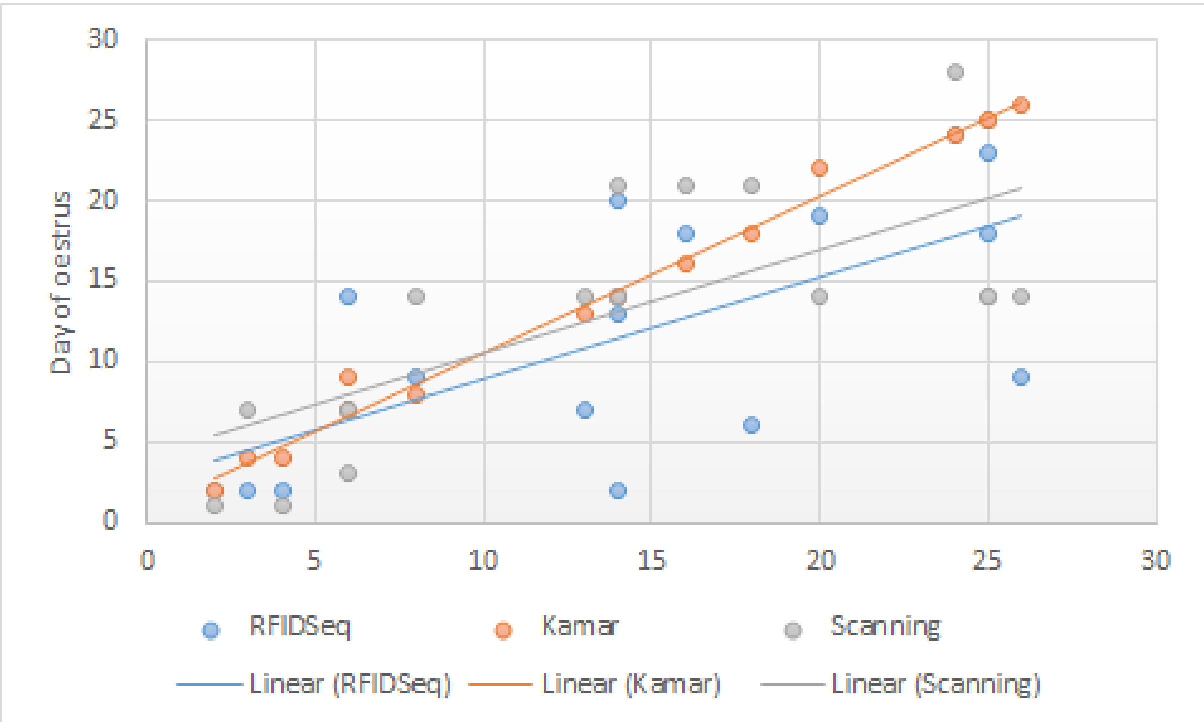

Figure 7. Plot of day of oestrus as determined by the peak in cow-bull contact (x-axis) compared with that determined by either RFID sequence through a WoW, activated Kamar or estimated from ultra-sound scanned CL presence (y-axis).

Figure 7 shows a plot of the day that oestrus occurred within the 30 day study period as determined by the 4 technologies. The comparison indicated that using the peak in cow-bull contact as a benchmark for determining time of oestrus, the correlation with the other devices was 0.67 with RFID sequence, 0.71 with ultrasound scans and 0.99 with activated Kamars.

4.1.2. Date of calving

Using the combination of weekly average weights and associated weight changes between weeks alongside the full daily data the algorithm initially estimated an interval where the change in weight could be attributed to a calving event. This interval was then refined using the daily weight records from within the interval to estimate date of birth. The date of birth estimates were compared with the independently recorded data Figure 8.

There were two cows that didn't have a visual date of birth record and one cow that didn't have any ALMS records. Of the remaining 37 cows there were three that had estimated dates of birth that were greater than two weeks outside the visually recorded dates of birth. These dates were for two cows that were 51 days outside the calving date and one that was 121 days. An example of these cows ALMS records are presented but they have been removed from the overall summary.

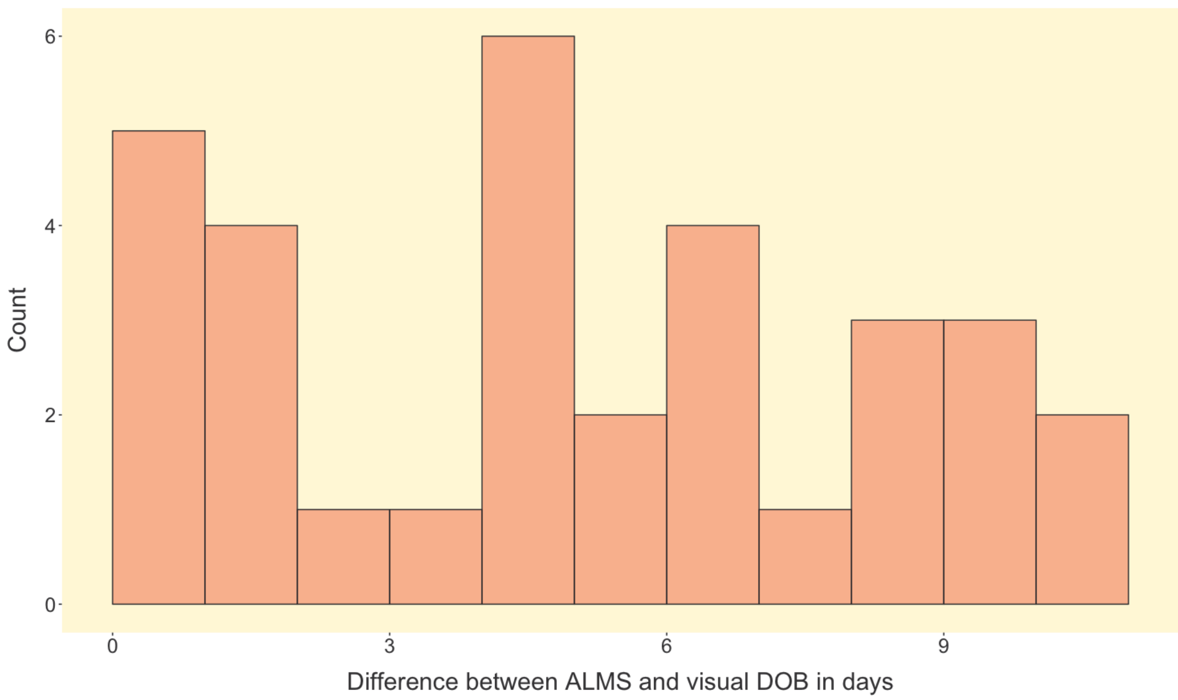

Figure 8. Distribution of accuracy (difference) between observed and predicted dates of birth.

The ALMS data analytics was able to predict 92% of the cattle within two weeks of calving. From this 92% of cattle the average number of days between observed and predicted was 4, with a maximum of 14 days and five cattle that had the same day prediction for calving.

The individual data graphics provide good examples of the challenges in deriving accurate dates for calving events. The predictions fall into three categories, highly accurate, moderately accurate and inaccurate. Figure 7 to 12 provide examples of the weekly average weight differences and daily data to demonstrate the profiles of data that were used and includes the initial prediction of the calving window (green bar) the predicted birth date (red hatched line) and the visual assessment of the birth date (grey solid line).

It is worth noting that while the cattle were checked on a daily basis and the visual recording is considered the actual date it is possible that some cattle birth events might have been initially missed and recorded a few days after the actual birth dates. Figure 9 provides a good example where both the daily and the weekly average data strongly suggest that the birth date was on the 6th November 2017, however, the official visual recording occurred a day later on the 7th November 2017.

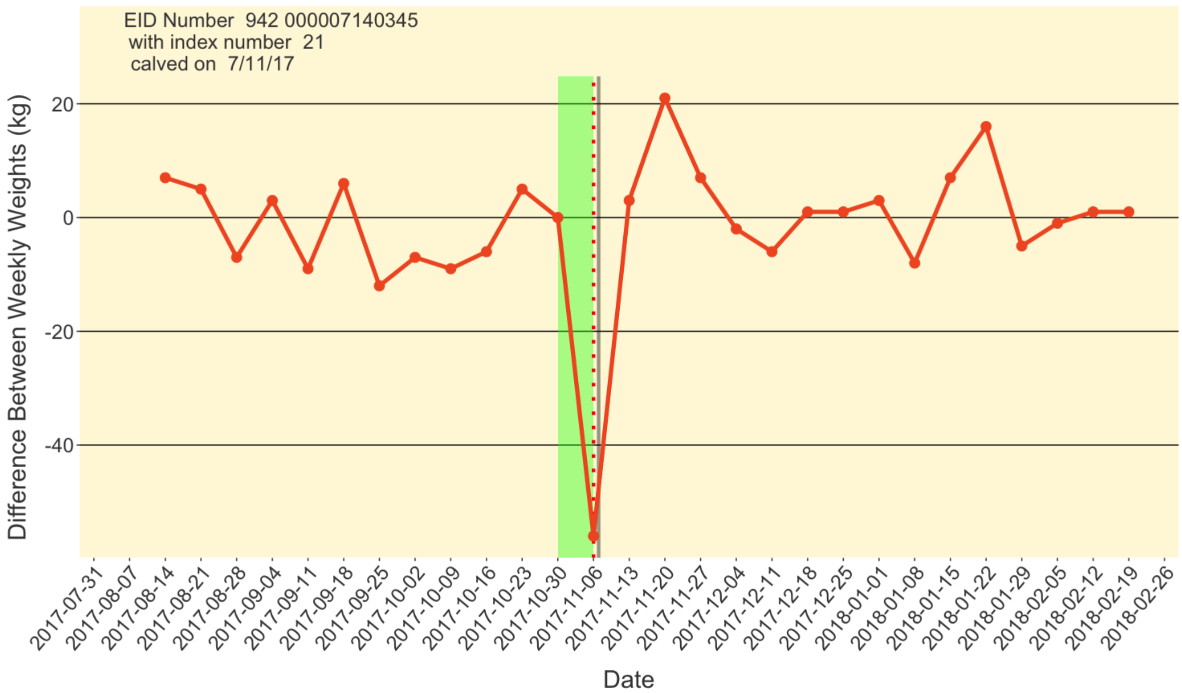

Figure 9. The weekly average weight differences the green bar represents the estimated period after the initial filter for week of calving based on a weight change difference greater than 25kg.

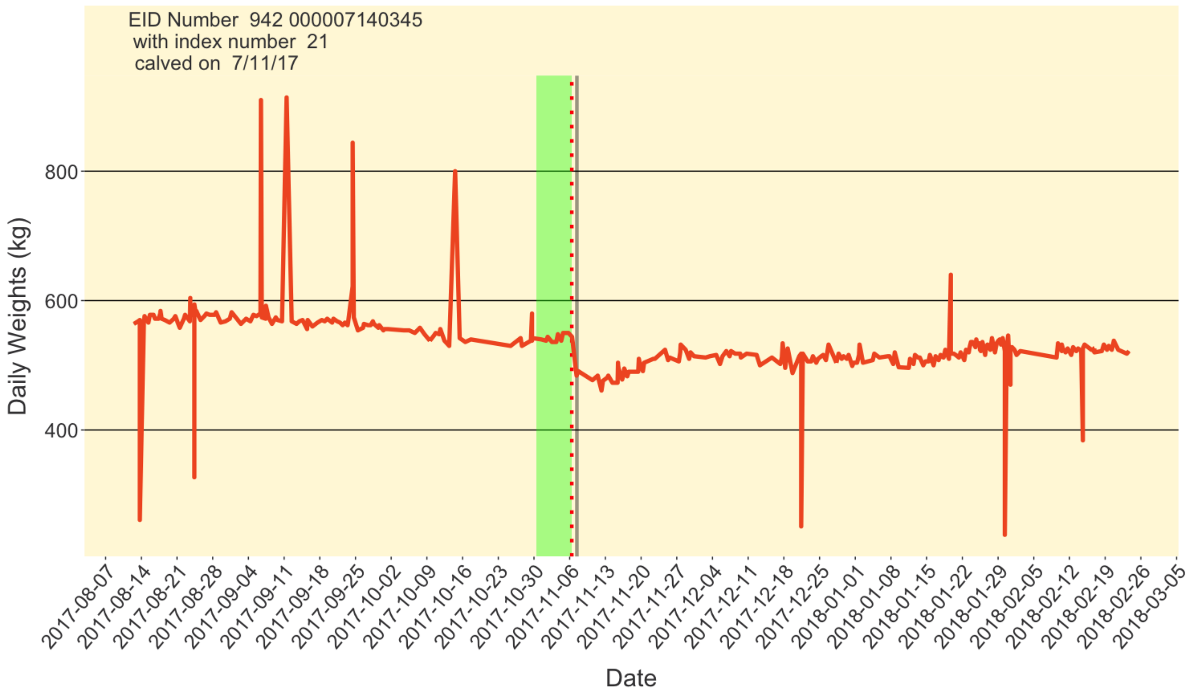

Figure 10. The daily weights records with the overlay of the weekly window for a potential calving event showing how the daily change in weight can be used to predict date of calving.

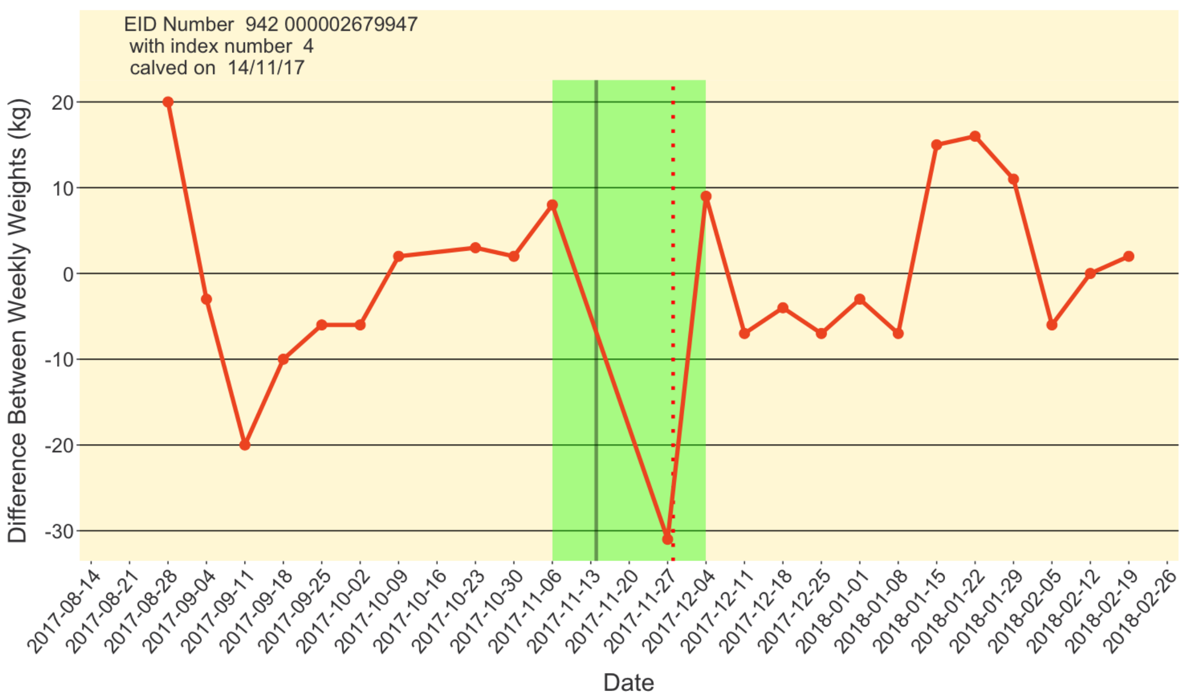

Figure 11. The figure represents a predicted calving date two weeks later than the actual calving date. The larger green bar representing the initial estimated period for a calving event reflects the lack of data available to calculate a reliable weekly average used to determine weight change per week.

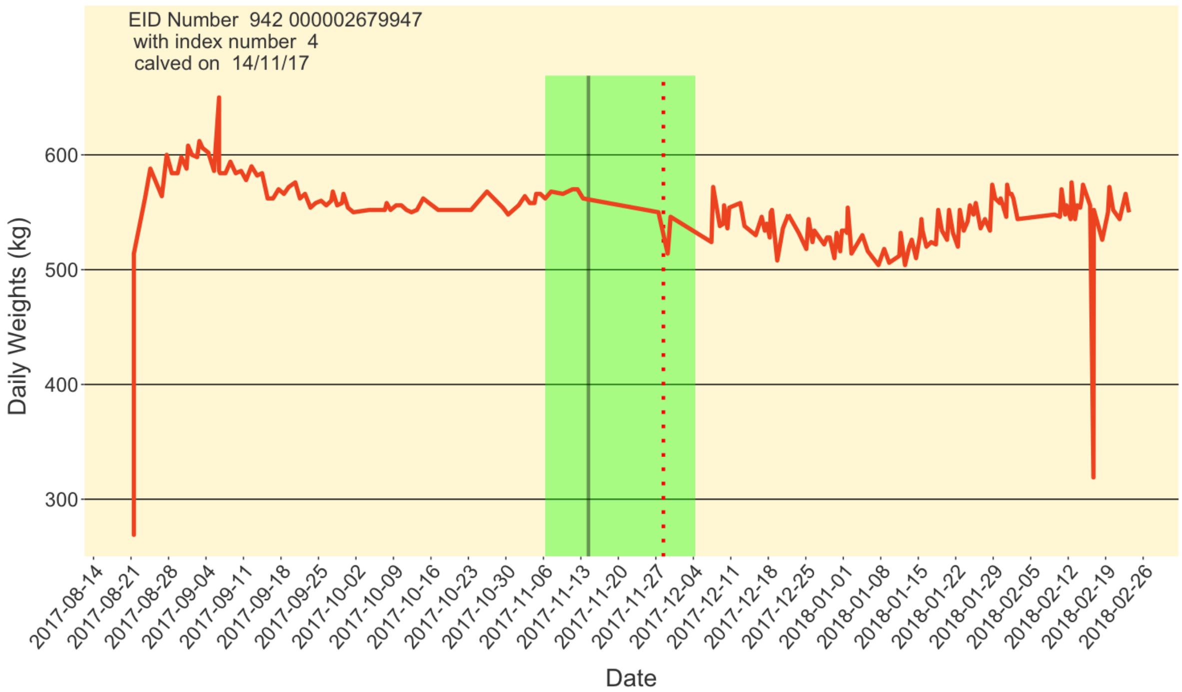

Figure 12. The lack of weekly data available to estimate the calving period in Figure 11 is shown to be due to lack of daily weights in the calving period. The actual date of calving corresponds to a small drop in the daily weight of the cow.

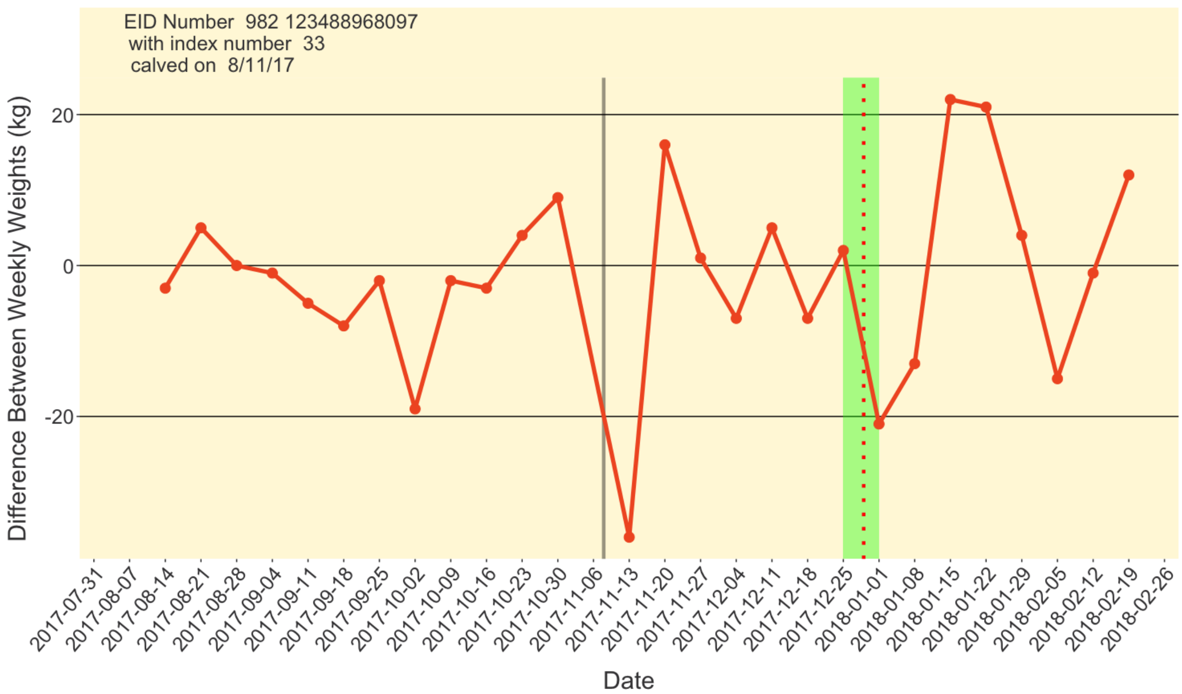

Figure 13. The estimated period and final date of calving (green box and orange hatched line) are over 7 weeks from the actual date of calving. The lack of data and averaging on a per week basis reduced the predictive power of the decline in weights in early November.

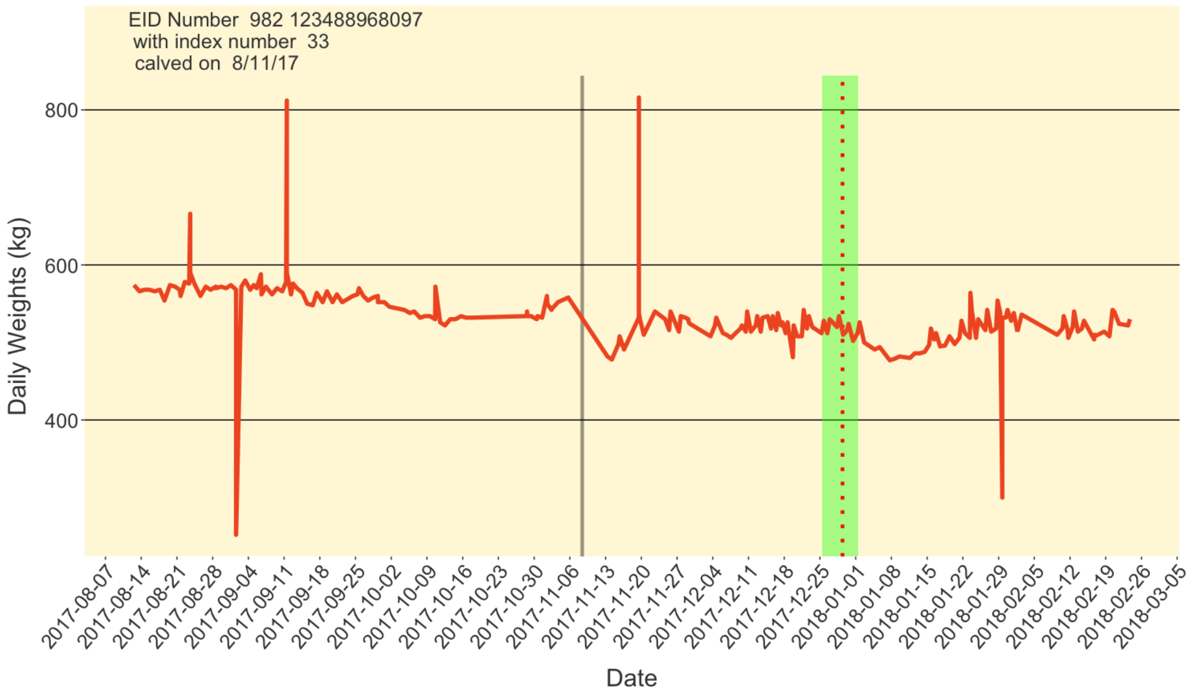

Figure 14. The daily data shows a lack of daily data around the calving event. The predictive ability of the ALMS can be challenged by cows that stay off water as they get close to calving and the data shows greater variance in weights post calving, it is not clear what is causing this result.

The graphs presented represents examples of the data that is used to predict date of calving. These graphs demonstrate how the ALMS can accurately predict calving events but also some of the challenges and inaccuracies that can occur. Overall the algorithm was able to provide reasonable (within 10 days of actual calving) accuracy for over 90% of the calving events. Of the 37 calving events that had data only three calving events were completely miss identified. The predicted calving events were most accurate in the periods where cows more regularly visited water and crossed the ALMS to enable more accurate weekly averages.

The detailed daily graph data shows that for all cows there are outliers. The Tru-Test walk-over-weighing unit aims to avoid erroneous data, however, if two cattle cross the weigh platform in close proximity this can cause discrepancies in the weight data.

4.1.3. Maternal relationships

Maternal parentage - RFID sequencing

In paddock 66, although there were 2645 data records for the cows and calves, 7 (19%) of the Belmont Red calves had no data recorded from branding to weaning with these calves ranging in age from 78 to 147 days at branding. The period between branding and weaning was 76 days. The daily usage of the WoW system showed a degree of variability between classes of cattle with approximately 53% of the cows and 17% of the calves utilising the system daily (Figure 15a), excluding the period when no data was recorded. Of the 30 calves utilising the WoW system the number of times their RFID tags were read varied from a minimum of 1 to a maximum of 38 times over the period with a mean of 15.0 ± 11.9 s.d. Using the HWI, the correct maternal parentage on the 30 calves was derived for 56.7% (17) of calves. The HWI values ranged from 0.26 to zero with a mean of 0.099.

In paddock 17, there was a very similar number of data records (2648) compared to paddock 66. No data was recorded on 12 (31%) Brahman calves from branding to weaning with these calves ranging in age from 70 to 165 days at branding. The period between branding and weaning was 73 days, however calves only had access to the WoW system for 47 days. The daily usage of the WoW system showed similar variability between classes of cattle to that in paddock 66 with approximately 64% of the cows and 23% of calves utilising the system daily (Figure 15b) excluding the period when no data was recorded. Of the 27 calves utilising the WoW system the number of times there RFID tags were read varied from a minimum of 1 to a maximum of 37 times over the period with a mean of 15.5 ± 11.4 s.d. Although there were 39 cows in the paddock only 34 had their RFID's recorded with the other 5 cows presumably watering from the creek. Using the HWI the correct maternal parentage on the 27 calves was derived in 44.4% (12) of calves. The HWI values ranged from 0.23 to 0.02 with a mean of 0.097.

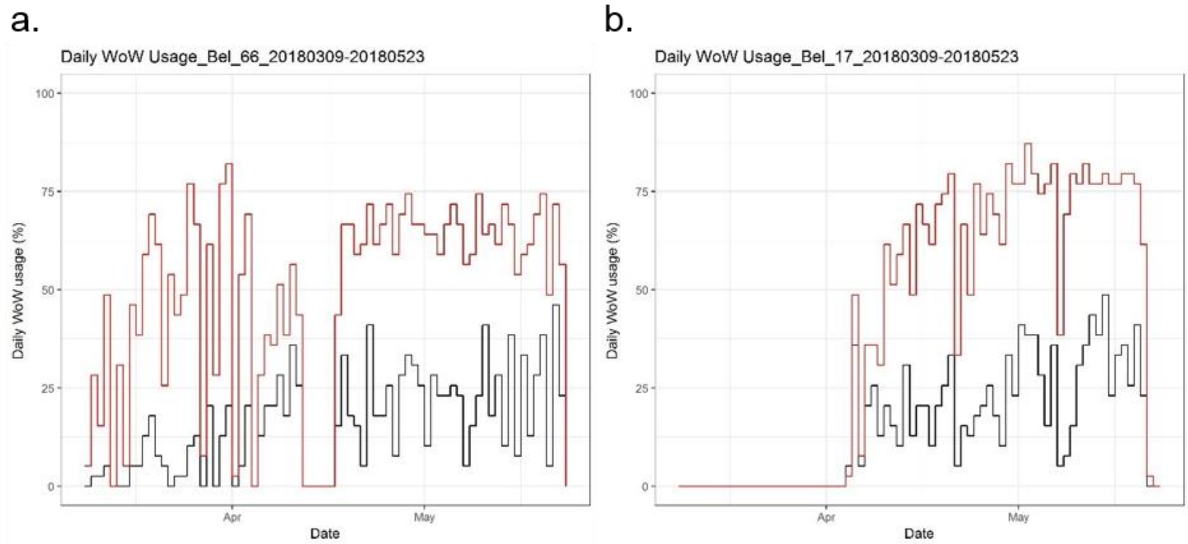

Figure 15. Daily WoW usage as a percentage of animals in each class (cows in red and calves in black) for (a) Belmont Red cattle in paddock 66 and (b) Brahman cattle in paddock 17.

4.2. Pre pubertal heifers

4.2.1. Oestrus detection

Ultrasonography

Throughout the 7 month trial, all but one heifer recorded the presence of a CL as identified by ultrasound. It was expected that the heifers would have reached puberty prior to the bull being introduced in December, however this did not occur, and it is thought their nutrition and body condition was responsible for the delay. Two heifers exhibited the presence of their first CL in December, 27 in January and eight in February. The average weight of the heifers reaching puberty was 438±28kg with an average P8 fat measurement of 2.3±0.9mm. While this weight is well above the reported average pubertal weight for Belmont Red heifers of 330 kg (Johnston et al., 2009), the fat cover was below 3mm required for puberty as reported by Johnston et al. (2009). Thus, while the heifers frame and weight would indicate they should have reached puberty, they maintained a relatively low fat cover, which may have contributed to their delay in showing pubertal oestrus compared to reported averages for this breed.

Fetal aging indicated that of the 39 heifers that reached puberty and ovulated, 34 of those had also conceived during the study period. Interestingly, two heifers reached puberty and were recorded pregnant in February but yet were confirmed non-pregnant in May, indicating early embryonic loss. Ultrasound results were correlated with a peak in daily contacts with the bull and peak in daily contacts with other heifers, and the sequence that the bull followed a heifer past an RFID reader. Unfortunately, many of the Estrotect^{TM} heat-mount detectors did not remain adhered to the heifer's tailbone post-application and images recorded from the remote camera could not accurately validate mounting activity against the ultrasound scanning results or the ALMS technologies (Figure 16).

Figure 16. Left: Inactivated Estrotect^{TM} heatmount detector partially lifted off from the heifer's skin. Right: Activated Estrotect^{TM}

Peaks in female-male proximity contacts

During the 21 day period when bull-heifer contacts were recorded, 22 heifers displayed oestrus as confirmed by ovarian scanning. Four heifers did not record any contact with the bull, either due to nil contact or issues with proximity loggers, and two of these did not conceive a pregnancy during the trial.

Records were examined for heifers that were recorded to have a CL present during the data collection period. CL presence indicated that oestrus occurred at least 2-3 days and up to 17 days prior to scanning. A descending CL (CA; *corpus albicans*), indicated that oestrus would occur within the next 1-2 days. Correlating ultrasound data with the peak in contacts recorded between the bull and heifers identified oestrus within 7 days in the 17 heifers that met the specific criteria (Figure 17). The correlation between the two methods, however, was low (r = 0.23), confirming that peaks in proximity logger contacts with the bull was not a good predictor of oestrus based on ultrasound scanning estimated date of conception in this group of heifers. In the single case where the proximity peak occurred 21 days after the predicted oestrus, the heifer recorded a CL via ultrasound it is likely the heifer displayed a consecutive oestrus cycle resulting in greater contacts with the bull, possibly as the majority of heifers had conceived and the bull could spend more time with a single heifer.

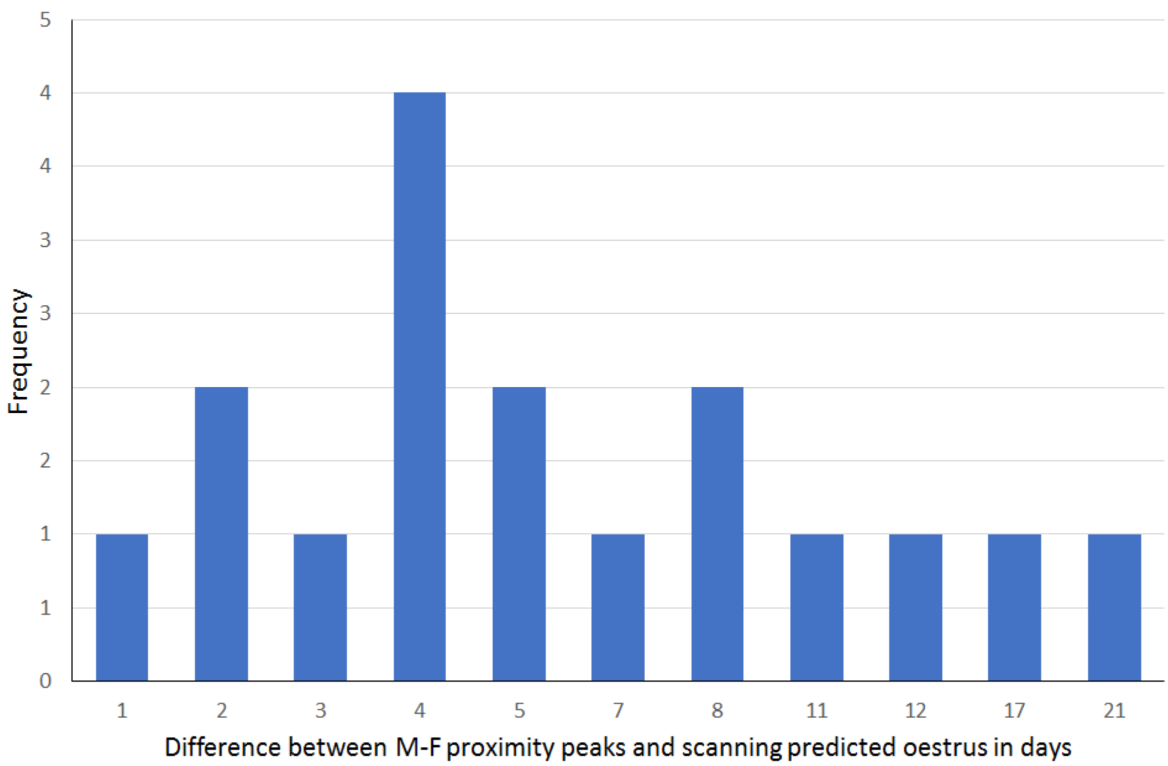

Figure 17. The frequency distribution of day's difference between peaks in PL contacts between a heifer and the bull compared with the estimated date of oestrus determined by ultrasound.

Two heifers reached puberty during the data recording period, as evidenced by the first detected CL using ultrasonography. These two animals showed the greatest correlation between CL detected date and peak in contacts between the heifer and the bull recorded by proximity loggers (Figure 18), both within 1 day accuracy.

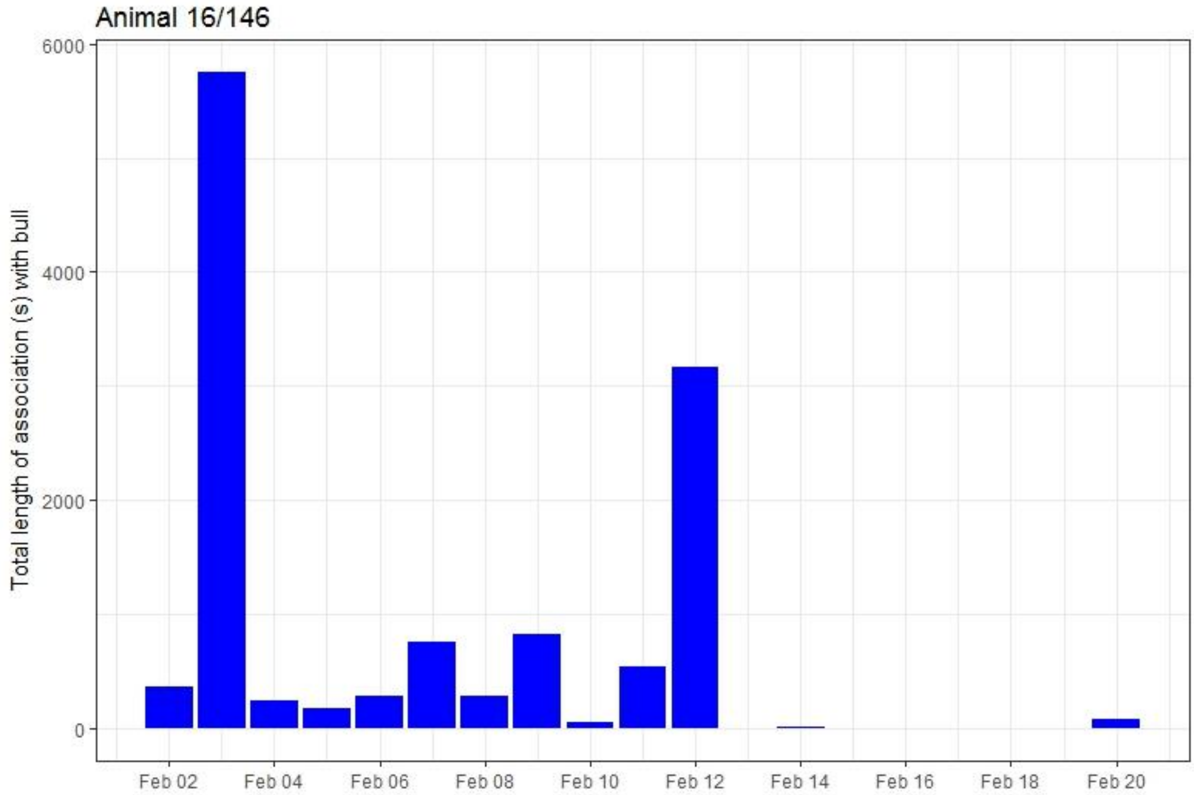

Figure 18. A clear peak in contacts between the bull and when a heifer reached puberty, as evidenced by the presence of a corpus luteum via ultrasound.

Female to female contacts

When comparing contacts between heifers, irrespective of bull-heifer contacts, 36 heifers recorded contacts with other heifers. The average daily contact length and number of contacts per day was 45.73±16.70 s and 389.29±236.38 contacts, respectively, while the peak contacts between heifers ranged from 107s to 8547s with an average of 3472 s (equivalent to 57 minutes), and the number of maximum contacts between heifers ranged from 1 to 108 contacts with an average of 31 contacts.

Aligning peaks in proximity contacts with estimated conception date resulted in 22% being within 1 week and 47% being within 2 weeks of the actual ovulation date (Figure 19). While this is not as precise as aligning female-male contacts to within a few days of oestrus events, these peaks may suggest the formation of sexual active groups around the time of oestrus and hence puberty in pre-pubertal heifers. A detailed example of a particular heifer is shown in Figure 20, where the peak in average daily contacts aligns with the estimated date of ovulation followed by peak in contacts with the bull.

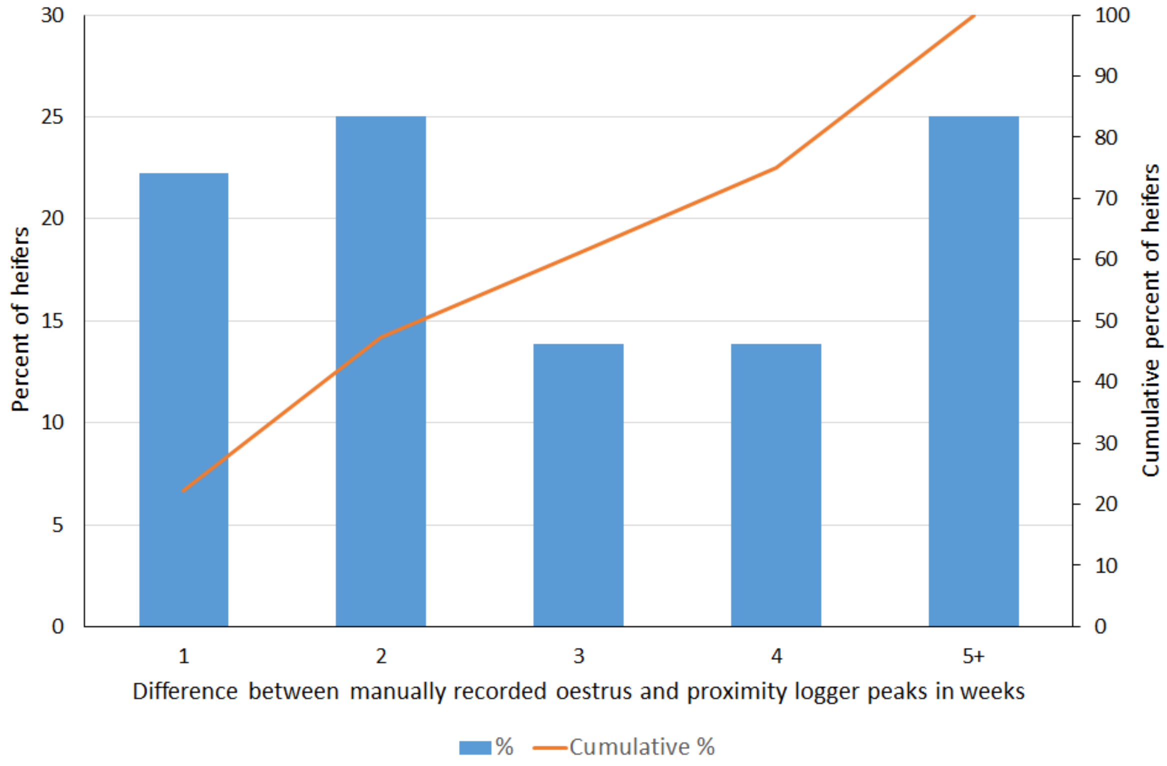

Figure 19. The difference between manually recorded oestrus events and peaks in female-female contacts recorded by proximity loggers showing the percent of heifers for each week as well as the cumulative percent of heifers

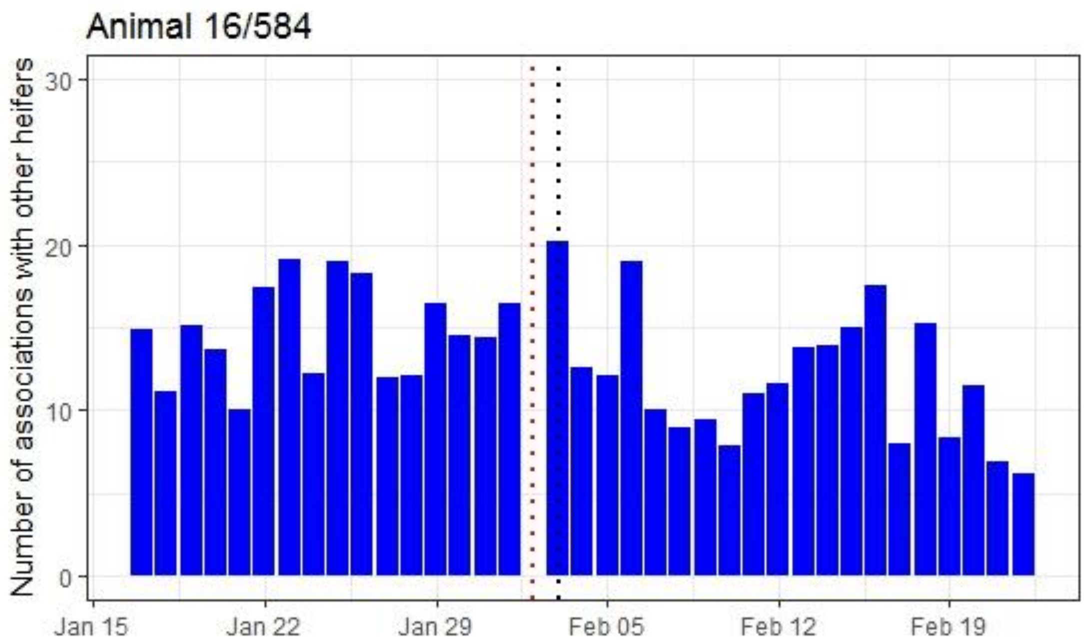

Figure 20. Heifer-heifer contact example trace for AnimalID 16/584 showing the average number of associations with other heifers. The red dotted line indicates where her first corpus luteum was detected via ovarian ultrasound. The black dotted line indicates the day of maximum contacts with the bull, later confirmed to be within 4 days of the estimated date of conception via fetal aging.

RFID sequence (time to bull)

During the 21 day period when bull-heifer contacts were recorded, only heifers that had not yet conceived as of the 12/01/2018 were included in the RFID time to bull sequence analysis; the TTB, proximity peaks with bull and estimated conception from USS were compared for these 17 heifers.

Time to bull was categorised as being within 60 seconds, 200 seconds, 300 seconds or greater than 300 sec. Sequences above this range were considered to occur more by chance than a relationships between oestrus related behaviour. There were 46 TTB dates recorded for the 17 heifers (Figure 21). There were no correlations between TTB with proximity logger recorded peaks (r=-0.38, p=0.12) or ultrasound predicted conception dates (r=-0.32, p=0.20) (Figure 22).

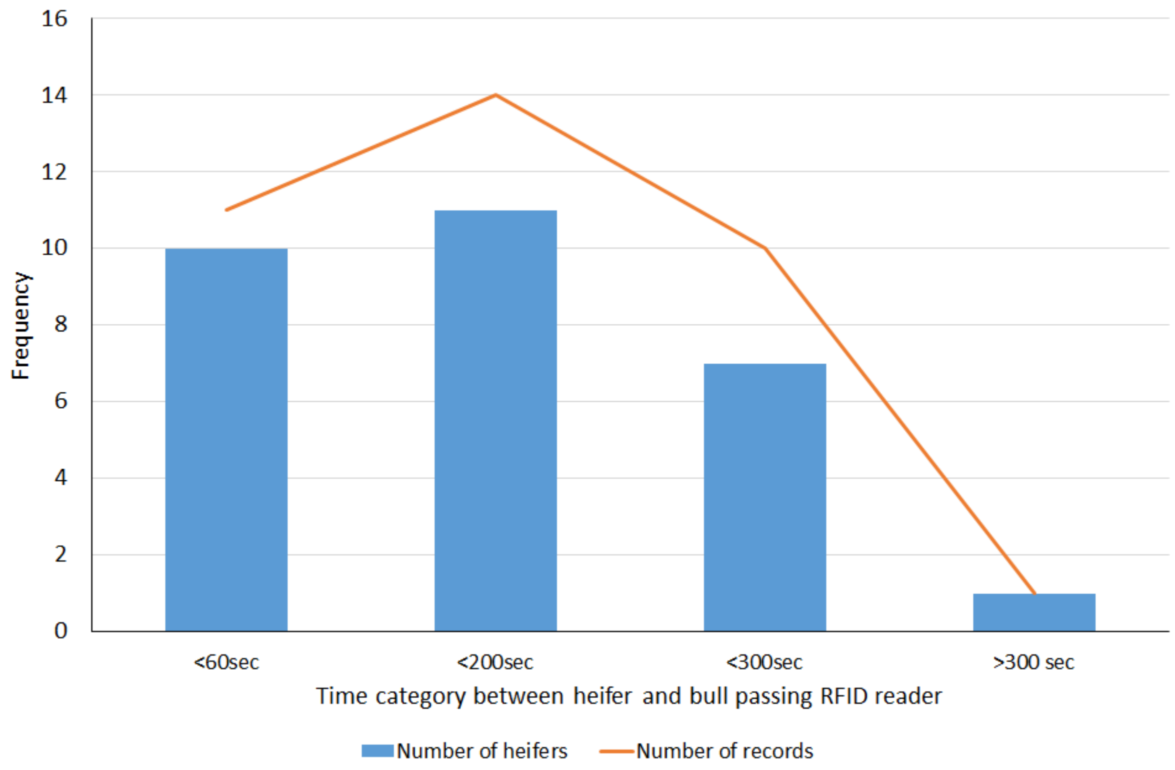

Figure 21. Frequency of data points used to analyse the sequence of the bull following heifers past the RFID reader to predict day of oestrus.

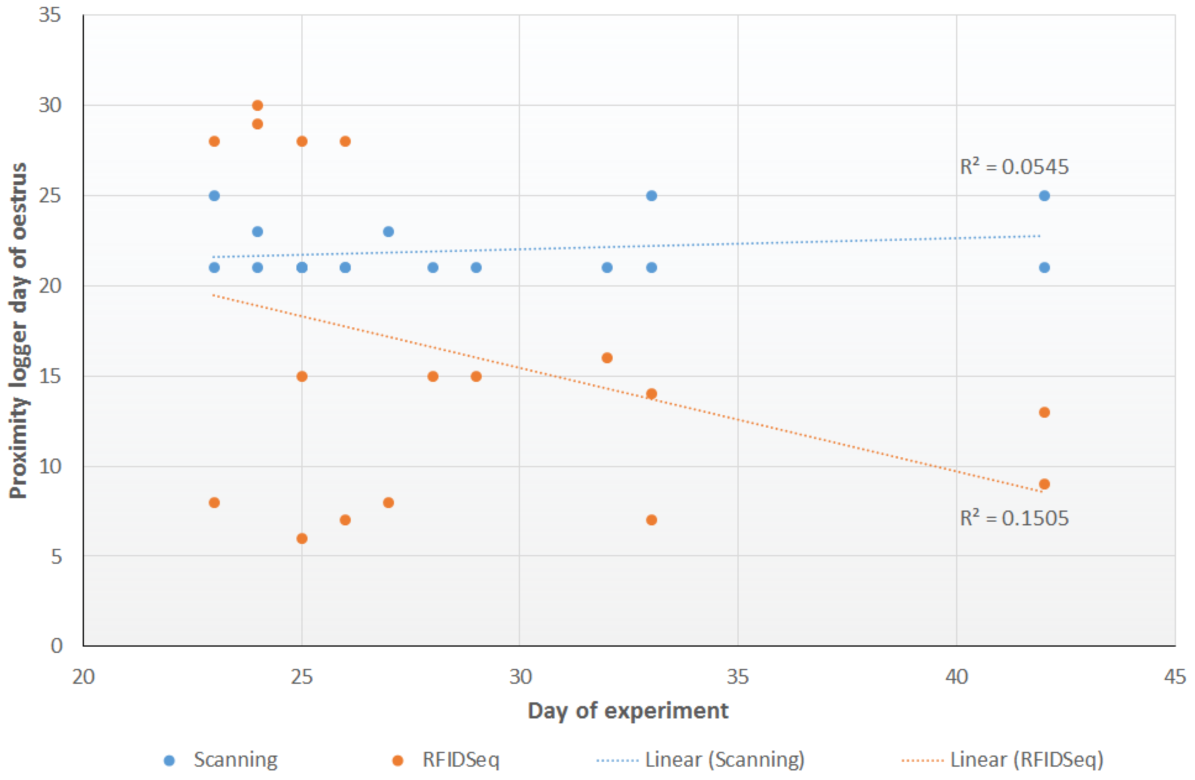

Figure 22. A comparison of estimated day of oestrus for ultrasound scanning and RFID sequencing methods compared with peaks in proximity logger contacts between the bull and heifers.

5. Discussion

Reproductive performance is a key driver of profitability in the northern beef industry. The MLA funded CashCow project demonstrated there are a significant number of properties that have the potential to increase reproductive performance (calves weaned). Whether commercial or seedstock cattle, the ability to influence the drivers of reproductive performance requires accurate and cost effective measures to benchmark individual cattle. The reproductive measures of PPAI and age at puberty are reported to be the main indicators of lifetime reproduction efficiency (Johnston *et al.* 2013), however, recording these measures on-farm is difficult in extensive environments using traditional manual methods, thus their use has been limited in breeding programs. The use of automated data collection provides a means to collect reproduction data without the expense of labour and time, hence, the aim of this project was to investigate a range of technologies suitable for recording reproduction measures and determine their accuracy and efficiency on-farm. It is proposed that using automatically derived reproduction measures, specifically oestrus activity and days to calving, to inform management decisions in current breeding programs would result in a rapid increase in herd fertility and production over just a few breeding seasons. Such an increase would prove the usefulness of informed breeding decisions, leading to a greater uptake within the industry

The use of paddock based automated data capture is still relatively new technology. This project is the first time that it has been used to attempt to identify oestrus and age of puberty in cattle. Each new application and new group of cattle provides new challenges but also helps provide some new learnings that will ensure the technology progresses to deliver practical applied solutions for industry. The application of Automated Livestock Management Systems using a walk-over-weighing platform combined with a range of other sensors has been developed and refined in this project. The following sections consider how this study progressed the technology to address reproductive measures, provide some insight into the practical implications of the technology, addresses the success in meeting the milestones and identifies some of the data collection challenges. Technology to derive age of puberty and oestrous measures

The project considered a number of technologies including walk-over-weighing and temporal sequencing to derive cattle association measures. In addition vision recognition and proximity loggers were used. An evaluation of these technologies to derive reproductive measures is summarised in Table 2.

The use of the Automated Livestock Management System provides a practical and well developed system. The system was used to measure weight changes of cattle to identify the date of calving. The biggest challenge with the ALMS weight recordings was to identify and remove outliers. Previous published work (Menzies *et al.* 2017b) has used weight change as an indicator of date of calving. This study has extended the previous research and the data sets demonstrate the potential for this technology to automatically identify the date of calving.

Oestrus events to derive both age of puberty and post-partum anoestrus interval used a combination of technologies. Earlier work (O'Neill *et al.* 2014) demonstrated the potential for proximity logging devices to determine oestrus events. This study showed that proximity loggers are the most reliable method to determine oestrus events, however, proximity loggers are not very practical and require regular downloads. The transceiver technology that underpins the proximity logger could be developed to have an automated download.

Table 2. An evaluation of the technologies used to determine oestrus, age of puberty and date of calving in the current project.
[1]Probability refers to the probability of the method being able to detect the specific reproduction measure, either low, medium or high.

Reproduction measure	Method	Scale of measurement	Strengths	Limitations	Probability[1] (L, M, H)	Accuracy (average)
Oestrus	Proximity loggers	Fine	Temporal association; continuous	No spatial reference; No live data	High	~ 1 day
	RFID	Coarse	Temporal association at a specific spatial location; live data	Requires animals to pass reader to access trough	Medium	~ 2 days
	Kamar detection via image analysis	Medium	Temporal association at a specific spatial location; live data	Requires animals to pass reader to access trough; not automated - analysis is currently manual; oestrus detectors require manual attachment	High-medium	~ 2 days
	Ultrasound	Medium	Allows for human interpretation, industry standard	Labour intensive; Requires specialist technician; commercially impractical to perform monthly scans	Medium-low	~ 1 week
Age of Puberty	Proximity loggers	Medium	As above	Peaks in female-female contacts not as obvious as bull-female peaks, requires further investigation	Low	~ 2 weeks
	RFID	Coarse		Requires presence of a bull	Low	*undefined*
	Kamar detection via image analysis	Medium		Issues with detectors remaining stuck, Kamars outperformed Heatmount detectors	Low	*undefined*
	Ultrasound	Medium		As above	Medium	~ 1 week

Reproduction measure	Method	Scale of measurement	Strengths	Limitations	Probability[1] (L, M, H)	Accuracy (average)
Date of calving	Walk-over-weigh	High	Automatically record weight in paddock; avoids disturbing or mustering cattle; live data transmitted and analysed via DataMuster™	Incomplete data if cattle can access surface water; requires installation and training	High	~ 4 days
	Proximity loggers	High	Temporal association; continuous; detect change in association patterns post-calving	No spatial reference; no live data	Medium	~ 1 week
	RFID	Coarse	Temporal association at a specific spatial location; live data	Only applicable if calf is tagged at birth; calf may not cross WoW platform for several weeks post birth	Low	*undefined*
	Daily calf catching	Medium	Allows for visual interpretation and manual procedures, such as tagging or assistance with the birth if required; can assess health of cow and calf	Labour intensive; usually conducted once per day, thus births can go undetected in between observations	High	~ 1 day

The temporal sequence data from the ALMS was used to identify oestrus using the data to derive an association with the bull. These data proved to be easy to remotely and automatically collect. While the results did show some variability they also showed promise. The current algorithm uses a heuristic method based on biological reasoning. The amount of data that was available in this trial does not provide sufficient data to derive a statistical model. Further work so extend the data would help facilitate more robust estimates of oestrus events.

The automated data image capture used to identify ruptured Kamars proved to be a reliable and technically practical method for identifying oestrus events. The results highlighted that using automated data images combined with vision recognition that the Kamars were more reliable than Heatmount detectors. The current system used off-line image processing, if vision recognition is going to be a practical system then it requires the image processing to be incorporated as part of the local ALMS. There are also some practical considerations associated with fitting and maintaining heat mount detectors.

5.1. Success in meeting project objectives

A short summary of how each of the project objectives have been met is detailed below:

Objective 1. The net benefit will be delivered through automated measures that can be used to derive improved knowledge on reproductive efficiency in northern breeder herds. This information will allow more rapid genetic gain and potentially more widespread use of EBVs.

The project utilised a range of technologies that were able to record information on reproduction parameters, namely oestrus and date of calving. Recording these measures on-farm is difficult in extensive environments using traditional manual methods, thus their use has been limited in breeding programs. As PPAI and age at puberty are reported to be the main indicators of lifetime reproduction efficiency (Johnston *et al.* 2013), it is proposed that using this information as a selection tool in current breeding programs would result in a rapid increase in herd fertility and production over just a few breeding seasons. Such an increase would prove the usefulness of informed breeding decisions, leading to a greater uptake within the industry. Based on the results of this study, implementing walk over weighing technology provides a means to record both bull-cow activity and date of calving, with the accuracy of identifying oestrus activity increasing with the use of proximity loggers. Such a system on-farm requires appropriate software that can analyse and process the raw data into an interpretable form, where producers can have access to the information they require, which may be a brief summary or in-depth analysis of individual animal performance, depending on the purpose. DataMuster™ is a unique application that can assimilate this information and more, and is one way that on-farm technology can accurately and seamlessly be translated into individual animal performance data.

Objective 2. Northern seedstock producers will be able to automatically record key reproductive information such as maternal parentage, age at puberty, calving interval, post-partum anoestrus interval, birth date and birth weight. These measures will mean a greater supply of EBV-recorded bulls focussed on reproductive efficiency with the potential to increase profitability, which will help address current issues of poor profitability and high debt levels of northern producers.

Increased profitability will have flow on effects in the wider community and make employment in rural areas more attractive.

The project attempted for the first time to automatically record individual animal reproductive information. In all measures the project had varying degrees of success in automatically recording the fertility information. The project was unable to derive an automated measure of birth weight.

Using technology to remotely record reproduction data results in a greater quantity of data collected than previously acquired, providing not only reproduction data but a whole systems approach that can be used to monitor individual animal productivity and performance. With appropriate data management systems, individual animal information can be traced back over generations and breeding performance reports generated, allowing producers to make informed decisions when selecting breeding stock or real time monitoring of performance.

The implications of greater individual animal recording over generations can significantly improve the accuracy and reliability of EBV's. There is the potential for increased accuracy in EBV's to result from a greater number of breeding systems using ALMS to continuously record production data that is then contributed to BREEDPLAN, which would be relevant across various production systems and environments. Greater confidence would be gained in the EBV system as producers using ALMS would be able to align their own reproduction reports with those produced by BREEDPLAN. The results show that proximity loggers were the most accurate technology to detect oestrus in the presence of a bull, and hence, confirm date of conception, while the use of walk-over-weighing technology proved to be an accurate method of automatically recording date of calving.

Issues have been raised about the labour, time and expense required to contribute data to BREEDPLAN (Agricultural Business Research Institute 2015). These issues could be overcome if ALMS infrastructure was already installed for producers own purposes. Additionally, future data management systems could be modified to produce BREEDPLAN approved reports to further decrease the input required from the property submitting information. This presents many advantages, including standardising the accuracy of data submitted to BREEDPLAN due to the data being recorded using a single system, thereby negating any human recording errors or discrepancies across measurements.

Objective 3. The industry is looking for practical solutions to manage their production systems and is interested in the use of technology to improve current monitoring practices. Although technologies have been available and proven to derive information such as parentage, the cost of the technologies has limited uptake. The emergence of tracking technology such as Taggle and WoW is providing potential economic benefits. Measuring parentage and other traits such as mothering ability, bull libido, onset of puberty and post-partum anoestrus has the potential to lead to targeted genetic selection.

The project has demonstrated a trade-off between practicality and accuracy, where the greatest accuracy in recording individual reproductive traits comes at a cost of decreased practicality compared with traditional methods, for example, ultrasound scanning for pregnancy diagnosis requires less infrastructure and establishment than installing a walk-over-weigh system (see Table 3 for a summary).

The use of ultrasound scanning in isolation from other technologies is a common practice used across the industry, and as such, the advantages and disadvantages are widely accepted. The cost of a respectable ultrasound machine is around $16,000, as well as the wages to hire a skilled contractor to perform the diagnosis, ranging from approximately $4 to $5 per animal, or a contract rate of $1,000 per day, whichever is higher. Pregnancies can be detected to 3 weeks and foetal aging can be performed with high precision from 4 to 12 weeks. The greatest accuracy at determining oestrus and conception, however, requires frequent scanning during an oestrus cycle, up to two scans 5-10 days apart. This intense frequency, and even performing monthly scans, are not a commercial reality, however, a single scan at around 600 days (when roughly 50% of heifers a pubertal) is a proxy being used to identify sires with more daughters pubertal by that age. Additionally, mustering costs and practicalities need to be considered, with cattle being made to walk tens of kilometres to the yards and kept off pasture for over a day, which has undefined implications on cattle productivity.

Walk-over-Weighing systems comprise the equivalent structure and technologies to a static weighing system, that is, the system includes liveweight scales (loadbars) and a liveweight indicator; a platform which may or may not be built into a weigh box; RFID antenna and reader; solar panel, battery and solar regulator and other technology components related to the transmission of data using either a 3G modem or satellite connection. Prices vary between approximately $16,000 and $26,000 including delivery.

Walk-over-Weighing typically uses water as an inducement and therefore a paddock with a single water point, that encourages all cattle to cross the WoW system to access water, is the ideal situation. If other water points can be shut off or fenced off it would ensure all animals are being recorded. The alternative is to only record a percentage of the mob but still gain information on their growth path. It is possible that other attractants such as supplementation may encourage animals to use the water point which contains the WoW system but this is still to be researched.

For cattle to utilise a WoW system they need to be trained. Typically this takes approximately 15 days but is quite variable and would depend on the temperament of cattle, their experience with cattle handling facilities such as spear gates and the ability to manage and apply pressure to cattle to entice them to utilise the system. Well trained animals that have experience utilising spear gates or walking through cattle yards will have a shorter period to be conditioned to use WoW. Depending on the size of the compound surrounding the water point, systems can generally be set up or moved between watering points in approximately 4 hours with two labour units.

Currently proximity loggers are primarily a research device, yet demonstrate the benefits of collecting social interaction data. A proximity logging collar without automatic data transfer retails for approximately $800 and requires the entire herd under study to be collared to provide complete and meaningful data. Application requires all cattle to be mustered to the yards for collars to be fitted and checked for sizing. New models have wireless download capabilities, however, older models require animals to again be mustered to have collars removed and data downloaded manually. The data also requires further processing to identify animals, their social groups and reproduction behaviour from the social interaction patterns. The advantages extend to continuous ‘24/7’ data collection, low battery requirements and a general acceptance of cattle wearing collars. In the past 10 years of proximity logger research at CQU, there have been no instances of cattle reacting badly to a collar that has required the collar to be removed, nor has a collar ever become entrapped on an object, such as a tree or fence. The results of this research have confirmed the proximity logger data to be an accurate reference point to identify oestrus and mating, thereby validating the usefulness of the technology.

Table 3. A comparison of cost and practicalities of the technologies evaluated to record cattle reproduction data

Technology	Cost	Advantages	Disadvantages
Ultrasound scanning	$4/head	Pregnancy diagnosis within 3 weeks	Labour intensive
RFID/Walk over weighing	$15k plus ear tags depending on set-up can run ~500 head	Labour saving Uses NLIS ear tags Easy to operate Very accurate data Saves mustering cattle Remote automated data collection	Requires cattle to be trained Rainfall and surface water can reduce cattle access to the system Requires new cattle management techniques Installation may require technical assistance
Proximity logger	$800/head	Continuous social interaction data recording, including mating and oestrus behaviour to within 1 day	Low practicality; Older models require collars to be removed to download data Potential for collars to come off, cause rubbing or get caught on objects such as trees

This project has shown the potential for ALMS technologies to accurately and reliably report individual animal reproductive data. While the usefulness of the data has been demonstrated, further research is required to enable fail-safe communication between the technologies and base stations/Data Muster software, which will be a challenge for parts of Queensland where there are issues with mobile coverage. Developments are underway to improve the walk-over-weighing infrastructure to make installation less labour intensive by minimising components. Advances in proximity loggers are leading towards ear tag applications with automatic download capabilities, which would enable a greater uptake by moving away from collars that require fitting and removing; such an attachment is suitable for research environments but is not as practicable for commercial applications as an ear tag.

Objective 4. The extensive environment of the northern beef industry has always been both an advantage and a disadvantage. The use of on-animal telemetry systems has the potential to enable producers a higher level of control and increased husbandry monitoring. The greatest output from the investment will be data and a demonstrated system that has been trialled under commercial conditions. The project will provide data to demonstrate how producers can make more informed decisions based on factors such as whether a cow is raising a calf, what her inter-calving interval is, how many matings each bull is having and the age heifers are reaching sexual maturity.

This project has demonstrated the usefulness of various technologies, with proximity loggers determined to be the most accurate to record oestrus and date of conception and walk-over-weighing with RFID sequencing recommended as the most beneficial to record date of calving. Successfully implementing these technologies on-farm hinges on the use of an appropriate data management system that can record, synthesise and report on production relevant information. DataMuster™ is a data management system developed by CQUniversity to receive and present production relevant data from ALMS, and thus is currently the only system capable of dealing with such information. DataMuster™ is in the initial stages of commercial trials and it is envisioned that it will be commercially available in the near future.

5.2. Data collection challenges

While the project has successfully met the stated objectives, there were challenges that impacted on the amount of data collected being less than initially planned. The details of these are detailed below relating to both the adult cows and pre-pubertal heifer components of the project.

Adult cows

Following ex-Tropical cyclone Debbie in March 2017, the Rockhampton region experienced major flooding. Belmont Research Station recorded in excess of 600mm of rain for March and all paddocks were inundated with surface water. The walk-over-weighing technology and associated electronics were removed from the paddocks in preparation for major flooding of the river which can affect two of the 3 WoW systems currently installed, hence there was no data recording during this time. This meant a loss of EID and weight data from mid-March to early-May. Although the loss of data did not affect the experimentation reported here, surface water and flooding events continue to be a challenge to continuous monitoring of cattle accessing WoW at watering troughs. Solutions to the challenges being tested include provision of loose-lick protein inside the WoW as an inducement and development of a portable WoW system that can be easily packed up and moved with the cattle as they change paddocks.

Pre-pubertal heifers

There was a delay in the heifers reaching puberty prior to the bull being introduced. While this hasn't impacted the project outcomes, the heifers were expected to reach puberty prior to bull exposure. The possible reasons for the pubertal delay is attributed to the heifers maintaining a low fat cover from their initial acquisition in August 2017 until late October 2017 following significant rainfall events and supplementation. The results show that the majority of heifers conceived a pregnancy within the mating period, thus, the delayed onset of puberty has not affected their reproductive potential. It would be interesting to follow these animals in future years to determine if reaching puberty late has consequences on lifetime reproduction performance, as reported by others (e.g. Johnston *et al.* 2013).

New products are entering the market that assist in automatic detection of oestrus, which may lead to a greater detection of oestrus with improved accuracy and timeliness. An advancement on Kamar devices is the development of FlashMate™ by Gallagher. The device adheres to the cow's rump as per a Kamar application, but the device contains sensor technology that records the frequency and intensity of mounting behaviour and will only light up once the interaction patterns indicate accurate oestrus. The device is also designed to remain on the same cow during the breeding season to indicate consecutive oestrus events or the likelihood of pregnancy, signalled by different colours. This feature is an improvement on Kamars and Heatmount detectors that are required to be removed and replaced once activated. Another device in development is a remote sensing Kamar device called 'HeatWatch II® estrus detection system' manufactured by CowChips LLC in the United States, which sends a digital radio signal to a computer or smart phone via a base station once a beacon has been activated via pressure from mounting. The data is then processed through complex algorithms to report on the mounting behaviour and probability of 'true oestrus' out of all mounting events, similar to FlashMate. While both devices are aimed at the intensive dairy industry, these developments have far reaching applications to obtain greater information on individual beef cow reproductive performance that can be used to analyse the efficiency of an entire herd and where improvements could be implemented.

Determining maternal parentage

The use of WoW and the HWI to derive maternal parentage has previously been studied by Menzies *et al.* (2017a) within a very similar setting at Belmont Research Station. The result on that occasion was that over a 27 day period correct maternal parentage was able to be derived on 97% of the calves compared to DNA analysis. When comparing the daily usage of the WoW the results from Menzies *et al.* (2017a) showed that approximately 90% of the cows and 61% of calves utilised the system daily. Along with a lower daily usage, this year's study also resulted in a lower mean number of records per calf. The data from 2015 showed that the calves were recorded on average 26.42 ± 5.66 s.d. over a much shorter data collection period (27 days versus 76 days (paddock 66) and 47 days (paddock 17) respectively) compared with approximately 15.0 ± 11 s.d. in 2018. Therefore it is assumed that the lower frequency of calves crossing the WoW system has resulted in the much lower percentage of maternal parentage derived from WoW.

Over the previously 3 years of trialling WoW at Belmont the research has repeatedly shown that once animals are conditioned to use a WoW system, even if they have had a period away from the system, they will readily use the system once back in a paddock with the WoW system. When the maternal parentage trial was initially conducted in 2015 it was the first installation of WoW at Belmont and both cows and calves were conditioned to access water by crossing the WoW system over a 21 day training period. Both cow herds used in the current experiment had been using a WoW system for between 2 and 3 years, however, the calves did not receive any training. The current research highlights that by conditioning calves to utilise the WoW system higher percentages of maternal parentage can be achieved. Although currently not demonstrated, it is suggested that training the calves to cross the WoW system when they are returned to the paddock following branding and possibly for a couple of days after that, could result in much higher daily usage.

6. Conclusions/recommendations

This project has demonstrated that remote automated monitoring tools have significant potential for accurate recording of fertility traits. Fertility can be determined using a number of different measures including date of calving, oestrus activity and age of puberty. The project has evaluated a number of technologies that can provide indirect measures of behaviours associated with reproductive activity. The project has demonstrated that there are technologies that can be used to automatically measure all aspects of reproductive performance. However, the challenge for cattle producers it to identify practical tools that are most accurate and can map to traits that can be used to impose the greatest selection pressure when trying to lift reproductive performance. Date of birth using RFID and walk-over-weighing provides a technology that is both practical and accurate and although if used in conjunction with recording date of joining could provide a measure for days to calving. This reproductive performance trait is used in Breedplan and is proven to have value for reproductive performance. Age of puberty is more difficult to record and the use of Kamars associated with vision recognition was less practical but showed some promise. Individual oestrus events using RFID sequence data was the least accurate, however, using oestrus detection as a measure of fertility is highly heritable and provides the most accurate tool to lift reproductive performance. The results from this study show that association patterns between bulls and cows and cows that form part of a SAG has potential to be used as an indicator of oestrus activity. The recommendation is that behavioural patterns that form part of existing measures of cattle accessing water have enough value to warrant further research. For industry to have confidence and be able to access the remote automated monitoring technologies, more work needs to be done on better understanding the drivers behind cattle coming to water. In particular ensuring a management design that requires cattle to use the ALMS at least five time per week.

6.1. Future direction

This project as demonstrated the usefulness and potential value of remotely recording reproduction-related behaviours and activity. The development of data management platform, Data Muster™, provides a way for raw data to be assimilated into meaningful production data on farm. The current research has conducted under commercial conditions on a research property; future applications require installation on a larger range of commercial properties to evaluate the on-farm benefits, economic analyses and identify solutions to challenges faced during this phase, including communication and network limitations, and ensuring cattle access the walk over weighing system at least 5 times per week.

As the applications of the technology are widened, it is foreseen that technology advancements will occur at a similar pace, thus, it may not be too far into the future where proximity loggers are available at a feasible cost to apply to an entire herd in a commercially relevant application, such as an ear tag. Along with technology developments and wider applications, will also be the collection of large data sets that will allow heuristic models to be validated with statistical comparisons, allowing the development and further refinements of algorithms and statistical models.

Getting producers to see the value in the technology will be another challenge to face, and will require extension efforts to demonstrate the on-farm benefits; one approach with the potential to return great benefits is that of producer led-research, where there is two-way communication between researchers and producers. This way forward presents a bright future for the successful implementation of technology on farm with benefits for both research and commercial sectors.

6.2. Disclaimer

This project used ALMS systems to monitor the cattle behaviour, these systems form part of the commercialisation of DataMuster™. The algorithms that formed part of this project were not developed in this project. This project provided data that was used to test and validate algorithms for date of birth, cattle weights, temporal sequencing and associated links with mothering up and identifying oestrus events. The vision recognition data that formed the basis for the algorithm used to automatically identify colour changes in a Kamar associated with oestrus and age of puberty was collected in this project. Commercialisation of the vision recognition software needs to be discussed with MLA. DataMuster™ is seeking to extend the results from this project and deliver as commercial services to allow cattle producers to access the benefits of the learnings from this project.

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8. Appendix

8.1. Map of trial paddocks on Belmont Research Station