Final report

Calf 48h – better detection of calving events for improved productivity

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Abstract

The objective of the Calf 48h project has been to identify a system capable of facilitating the diagnosis of the causes of calf loss in remote, extensive grazing systems. This report provides detailed results from several studies exploring the potential for sensors systems to detect parturition and associated maternal behaviours in extensively grazed cattle.

In the main field trial on a Barkly Tablelands station, the Calf Alert intravaginal system did not enable the real time detection of parturition events at scale. The Smart Paddock GNSS collar system initially failed to deliver the data required to facilitate the real time location of cattle at the expected temporal resolution. Although problematic in this deployment, we believe this system has value with further refinement of the technology

Despite the major failure of these systems, two case studies of individual animals where data was successfully collected are presented. These show that the concept of integrating data from the calf alert system and tracking collars could provide the information being sought as the objective of this project.

Ultimately, the project was terminated due to the failure of the technologies to provide reliable data across the entire herd with significant refinements needed from the developers of the technologies before we can recommend further investment in these particular systems.

Executive summary

Background

Calf mortality is a significant source of lost income for the Northern Beef Industry, estimates vary, but most consider the financial losses to be in excess of $100m per year. Before interventions can be proposed and implemented by producers, research is required to determine exactly where, how, and why calves are being lost. Gathering this data remains a significant challenge in extensive grazing landscapes, large paddock sizes coupled with infrequent opportunities to monitor animals limits the identification and investigation of calf loss events. This project sought to develop and evaluate tools and systems that will provide this critical missing information.

Aims/objectives

The objective of the Calf 48h project was to identify a system capable of facilitating the diagnosis of the causes of calf loss in remote, extensive grazing systems.

Methodology

A range of sensor systems were considered. A desktop review and preliminary field testing was conducted and selected sensors systems were progressed for evaluation at a commercial scale. A large scale field trial was conducted on a Barkly Tablelands Station located west of Camooweal, in collaboration with researchers from the Northern Territory Department of Industry, Tourism, and Trade (NT DITT) from September to December 2021. A total of 284 breeders, housed in two adjacent 5,428 ha and 5,622 ha paddocks, were utilised for this trial. Smart Paddock GNSS collars (n = 196) were deployed, alongside Calf Alert intravaginal sensors (n = 196). Four radio towers were constructed to facilitate real time data transfer from the Smart Paddock and Calf Alert sensors. Because of the challenges with sensor systems and restrictions on field observations caused by COVID, the analysis primarily focusses on exploring the potential causes of system failures. Where a small amount of data was successfully collected, two case studies are presented showing how these sensor systems can be integrated to achieve the original objective.

Results and key findings

In the main field trial on a Barkly Tablelands station, the Calf Alert system did not enable the real time detection of parturition events at scale. There appear to be several possible causes for this failure including: the early expulsion of sensors, misinterpretation of the attenuation of the radio signal while the sensor was in situ, gradual failure of the chipset over time, and variation in antenna reception.

The Smart Paddock collar system initially failed to deliver the data required to facilitate the real time location of cattle at the expected temporal resolution. The key issue was identified to be the initial set up of the devices, where the developer failed to properly initialise the devices prior to deployment. Limited connectivity on the Barkly Tablelands Station exacerbated this problem and limited the remote reconfiguration of the collars. Although problematic in this deployment we believe this system has value with further refinement of the technology

Although the systems that were deployment experienced major failures, two case studies of individual animals where data was successfully collected are presented. These show that the concept of integrating data from the calf alert system and tracking collars could provide the information being sought as the objective of this project.

Recommendations

There remains a need for a system that can provide researchers and producers with the key information to enable the diagnosis of the causes of calf loss in Northern Australia. While the Calf Alert system appeared to hold some promise for this, a significant redesign of the retention system, electronics, and data analysis protocols would need to be considered before we recommend further application of this device in mature cows in extensive and remote environments. The Smart Paddock system needs further refinement but may provide the required data with the development of behavioural algorithms to identify parturition from GNSS and accelerometer. Research investment should be focussed on systems that can be translated from initial high-cost R&D tools into commercial affordable systems for producers. This will mean that the outcomes of research can be ultimately applied by producers on their own properties to enable diagnosis of the specific causes of calf loss they are experiencing. While the commercial developers of sensor technology will continue to push in this direction, a coordinated effort across these technology companies and research providers would see faster benefits for the industry and prevent the failures demonstrated in the project from impacting eventual adoption.

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1. Background

Calf mortality is a significant source of lost income for the Northern Beef Industry, estimates vary, but most consider the financial losses to be in excess of $100m per year. Before interventions can be proposed and implemented by producers, research is required to determine exactly where, how, and why calves are being lost. Gathering this data remains a significant challenge in extensive grazing landscapes, large paddock sizes coupled with infrequent opportunities to monitor animals limits the identification and investigation of calf loss events. This project sought to develop and evaluate tools and systems that will provide this critical missing information.

Several key technologies have been previously developed that could provide the information required by researchers seeking to understand calf loss. Previous research had developed a research device (Calf Alert) to report the time and location of parturition with an accuracy of 70%. This project aimed to integrate the current Calf Alert device with a range of on- and off-animal sensors to further improve this accuracy. One of the key issues with current implantable parturition detection systems is their inability to accurately locate the device and therefore calving site. This project aimed to explore how on-animal sensor systems (e.g. collar or ear tag) might provide this missing data. The data from real-time GNSS tracking systems was to be integrated with signals from the Calf Alert device to provide researchers with ability to accurately locate the calving site. The sensor data collected by these on-animal sensor systems was also to be used to quantify behavioural attributes of cows around the time of parturition which may be linked to causal factors of calf mortality.

2. Objectives

The objective of the Calf 48h project was to identify a system capable of identifying the parturition event that could facilitate the diagnosis of the causes of calf loss in remote, extensive grazing systems.

This report will describe the evaluation of two separate sensor systems: firstly the Calf Alert intravaginal device designed to alert to calving events; and secondly the Smart Paddock system designed to provide data on the location and behaviour of cows.

A key objective of this project was to explore how integrating these systems could provide the key data to enable the detection and diagnosis of calf loss in extensive grazing systems.

3. Methodology

A field trial was conducted on a Barkly Tablelands station, located approximately 70 km west of Camooweal, in collaboration with researchers from the Northern Territory Department of Industry, Tourism, and Trade (NT DITT) from September to December 2021. A total of 284 multiparous cows (average age = 5.95 years ± 0.82 SD), expected to calve between mid-September to late November, were recruited to the experimental group. These animals were placed in one of two adjacent 5,428 ha and 5,622 ha paddocks. Smart Paddock collars (n = 196) were deployed, alongside Calf Alert intravaginal sensors (n = 196), which were previously been validated in a number of MLA projects (Stephen et al., 2018). Additionally, cattle were fitted with store-on-board iGotU GNSS collars (n = 284). Four radio towers were constructed to facilitate real time data transfer from the Smart Paddock and Calf Alert sensors. These towers were equipped with high gain directional LTE antennas (Yagi 698-3800MHz) connected with the Camooweal Telstra tower for 3G connectivity to facilitate real time data transfer from the Smart Paddock and Calf Alert sensors. Each tower had a Teltonika RUT240 Modem connected to the Calf Alert receiver and Smart Paddock gateway. These systems were powered by 12V batteries recharged via solar panels.

Researchers from CQU and the NT DITT conducted routine monitoring of the animals to identify the presence and status of new calves during a number of field visits. During this period, observations were also collected confirming the maternal state of the cow, teat/udder scores, maternal bond, body condition score, calf vigour, and where possible, evidence of congenital defects. This observation process was significantly hampered by COVID-19 travel restrictions with staff from both CQUniversity and NT DITT unable to travel to the station when required on several occasions.

4. Project outcomes

This project sought to evaluate the potential for integrating two information streams from the Calf Alert intravaginal device and the Smart Paddock using real time GNSS time stamps to indicate the approximate time and location of calving. Numerous challenges were encountered with both individual platforms, which significantly limited the success of this proposed system. These limitations will be detailed further in the following sections.

4.1 Performance of Calf Alert devices during full scale deployment

Prior to full scale deployment, all devices were tested to ensure functionality and durability. A receiver, which was later deployed on the radio tower on the Station, was set up to verify the reception of transmissions and ensure that the tags were functioning in the expected manner. The devices were tested in the laboratory by systematically inserting the devices into the applicator to test the durability of the form factor. Of the 234 Calf Alert devices that were tested, 5% (n = 11) resulted in broken components and were not progressed for deployment (Figure 1). Concerns around the size of the applicator (diameter of 40mm) were discussed with researchers from Charles Sturt University (CSU) that were involved in the system development. A smaller diameter applicator (32mm) was designed and approved by CSU for use in this trial.

Figure 1. Calf Alert device depicting a broken “spider”as a a result of initial testing form factor failures.

A total of 196 Calf Alert intravaginal devices were deployed on 11 September 2021 on the Station. These devices were nominally programmed to generate a radio signal at 5 min intervals. The Calf Alert devices internal timing mechanism meant that variation was present in the programmed sampling frequency with an expected range of between 4.5 and 5.5 min. Delays in equipment and field staff availability meant that the radio receiver towers were not deployed until 29 September 2021, with the experimental period defined as occurring between 30 September and 15 December 2021.

Of the 196 devices deployed, six did not transmit during the experimental period and were considered to have failed due to unknown hardware compromise (Table 1). Of the remaining 190 Calf Alert devices, 71.6% (n = 136) began transmitting within 2 days of the commencement of the trial. Only nine devices (4.7%) transmitted for the entire experimental period and five devices (2.6%) transmitted for less than 1 day (Figure 2).

This variation in transmission characteristics across the group of devices has proven problematic as it has made detection of expulsion events difficult as discussed in later sections.

Table 1. Descriptive details of Calf Alert failure and transmission statistics.

Number of devices deployed	196
Number of devices without any transmissions	6
Average transmission length	34.2 days
Minimum transmission length	< 1 day
Maximum transmission length	76 days

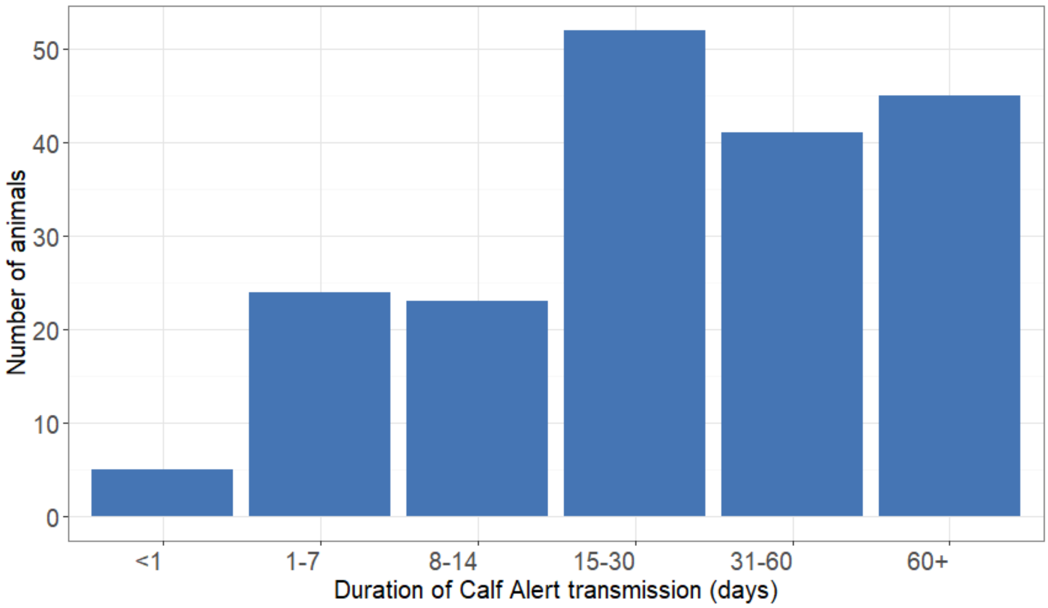

Figure 2. Distribution of duration of Calf Alert signals across the 190 units that transmitted during the experimental period.

The operation of the Calf Alert system did not conform with expectations. Instructions from researchers experienced with the use of the system suggested that the radio signal would be largely attenuated by the tissues surrounding it in the vaginal cavity (Stephen et al., 2019). A dramatic increase in radio signal at the time of expulsion was expected to be associated with calving to enable real time alert to this event (Stephen et al., 2018).

A key issue occurred at the commencement of the trial period as Taggle (developers of the Calf-Alert system chipset) experienced problems with data backhaul due to changes made by Telstra. As such, the alerting software to be used with the Calf Alert system (established by CQUniversity), which was reliant on the Taggle API, failed and real time analysis of the data became problematic. A temporary solution was developed, which relied on the technology providers periodically emailing the data to the CQUniversity and NT DITT researchers, however, this also failed to enable the potential identification of expulsion events in real time. A critical issue was identified in that support from Taggle for this project was delayed as they prioritised their other markets.

Following sensor deployment and radio tower installation, a total of 22,215 transmissions were detected on 30 September and 1 October (experimental days 1 and 2) from 122 cattle (Figure 3). Most of these sensors were only reporting a small number of signal receptions. This large number, however, initially created confusion as the modelling protocol developed erroneously indicated that a large number of expulsion events had occurred on or before 1 October 2021 for these animals. While this coincides with the numbers expected based on estimated calving date from foetal aging (n = 109), field observation of the cattle suggested that these alerts were not associated with genuine calving events as only a small number of cows were observed in a maternal state (estimated at approximately 40 animals).

In response to the apparently erroneous data being generated by the Calf Alert system, a new analytical model was developed during the trial period in an attempt to identify true expulsion events. This model identified instances where transmission was received from two or more radio towers at the exact same timestamp. Figure 3 shows the number of calving alerts generated using the developed multi-tower model, and the estimated calving date. The alerts provided by this model more closely aligned with the observations made in the field of approximately 40 animals having calved, however, the model failed to show many expulsion alerts later in the deployment as would have been expected from estimated calving dates and the observations made in the field. While this model also likely failed to correctly identify all expulsion events, it did enable the research team to accurately locate several expelled devices and validate that these events occurred well after the initial phase of the study.

In general, it has proven difficult to interpret the results obtained from the Calf Alert system. Three possible causes of error were hypothesised:

1. The Calf Alert devices had been expelled prior to the parturition events.
2. The Calf Alert devices were emitting a radio signal that was not being attenuated or being variably attenuated according to distance to tower and/or animal position.
3. The devices experienced technical failures over time and although retained did not emit a signal at parturition.

The evidence for these three possibilities and the actions we undertook in response are detailed below.

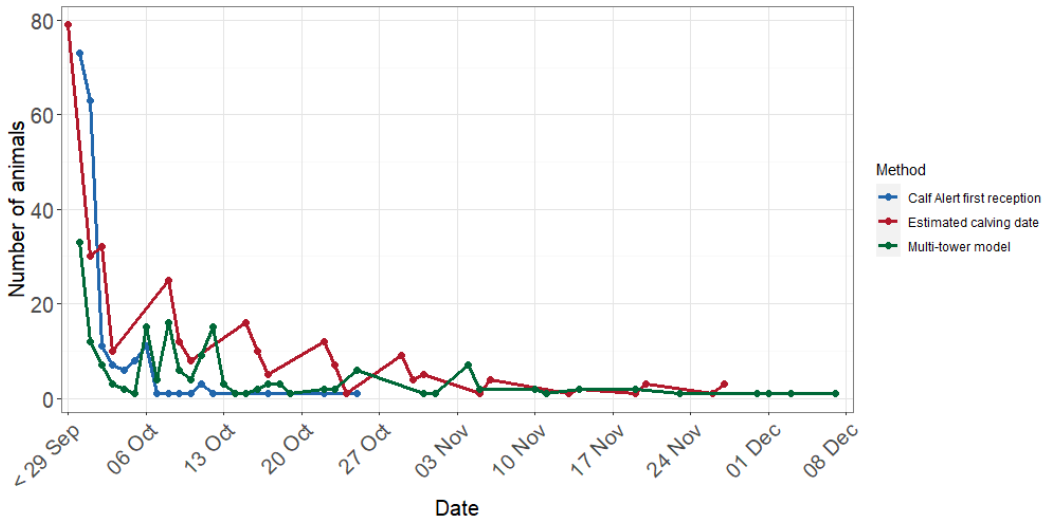

Figure 3. Three models were developed to identify the expulsion of the Calf Alert device. The Calf Alert first reception model attributed the first reception of a signal as the date of expulsion. A multi-tower model was developed, which described the simultaneous transmission of data to two or more towers. The estimated calving date was generated from foetal aging (foetal aging is known to have an error of 20 days (Laven, 2016)).

Early expulsion as a cause of increased alerts at trial commencement

In a paper made available after trial commencement, the Calf Alert device was found to have an early expulsion rate of 25% in mature cows (Stephen and Norman, 2021). As such, it is expected that a proportion of devices are likely to have been expelled prior to the calving event. It is unclear how many devices might have been pre-emptively expelled, as cows that were expected to calve before 30 September 2021 (n = 79) did not appear to align with the field observations made during the first week (estimated at approximately 40 animals). If early expulsion is higher than expected, one possible cause might be the variation in applicator used in this study. While no conclusive results can be drawn at this stage, it is likely that a proportion of devices were lost by the animals prior to an actual parturition event.

Failure of radio signal to be attenuated by the animal

One cause of confusion in interpreting the results from the Calf Alert device was the higher than anticipated rate of radio signals passing through the animal’s body tissue and being detected by a radio tower. Some radio signal receptions were to be expected while the device was within the animal, however, the elevated rates initially created some confusion. To confirm that signals were indeed being received from within the animal, we explored how signal count varied with distance to tower. In some case study animals, a proportional relationship was observed between the number of transmissions received and the proximity to the radio tower. Integrating the data from the Calf Alert and Smart Paddock devices reveals that an increasing number of transmissions are captured when cattle are at a closer proximity to the radio tower (Figure 3). This confirms that for some animals, the radio signal was not being attenuated by the body tissue. There are several possible reasons why this was the case – the transmitting power of the device was higher than previously used (this would have been a setting configured by the developers), the radio antenna quality or placement may have impacted by improving the reception of the signals, and finally, the device may have migrated within the animal, such that it was closer to the vaginal entry, providing it with less body tissue to attenuate the signal. None of these possible causes could be validated and remain a probable cause of some of the error experienced.

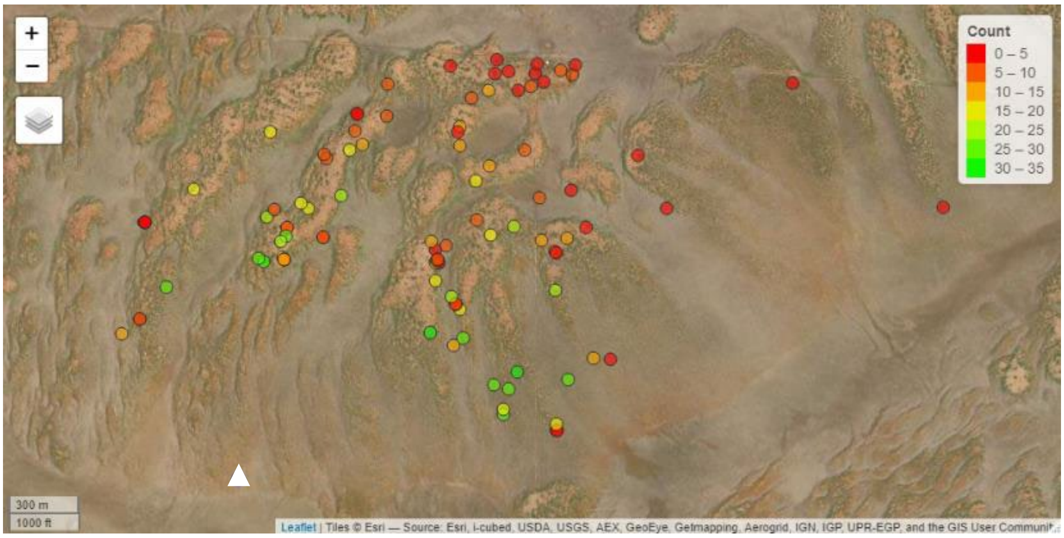

Figure 4. The number of Calf Alert radio signals received per hour from different locations in the paddock. The Smart Paddock data was used to geolocate the animal. A trend appears to show that more signals are received when the animal is closer to the tower. This confirms that for some animals, the radio signals were not being attenuated whilst being carried within the animal. The white triangle denotes the location of the radio tower.

Gradual degradation of Calf Alert devices over time

Further investigation of the data from the Calf Alert tags, in conjunction with spatial data from the Smart Paddock devices, was undertaken. Several challenges that impacted on the ability to accurately discern when device expulsion had occurred were identified. The relationship between transmission count and expulsion was multi-factorial and likely impacted by diurnal changes and temperature and the animal's proximity to the radio tower.

A total of eight static Calf Alert devices were deployed around the experimental site. These reported a deteriorating number of transmissions over time (Figure 5). A diurnal effect also appeared to be present whereby the number of transmissions captured decreased between 7:00am and 2:00pm (Figure 6). In the later stages of the trial, the number of transmissions ceases completely in the middle part of the day (Figure 6). This could be attributed to hardware failure due to extreme temperatures or other diurnal effects at the experimental site.

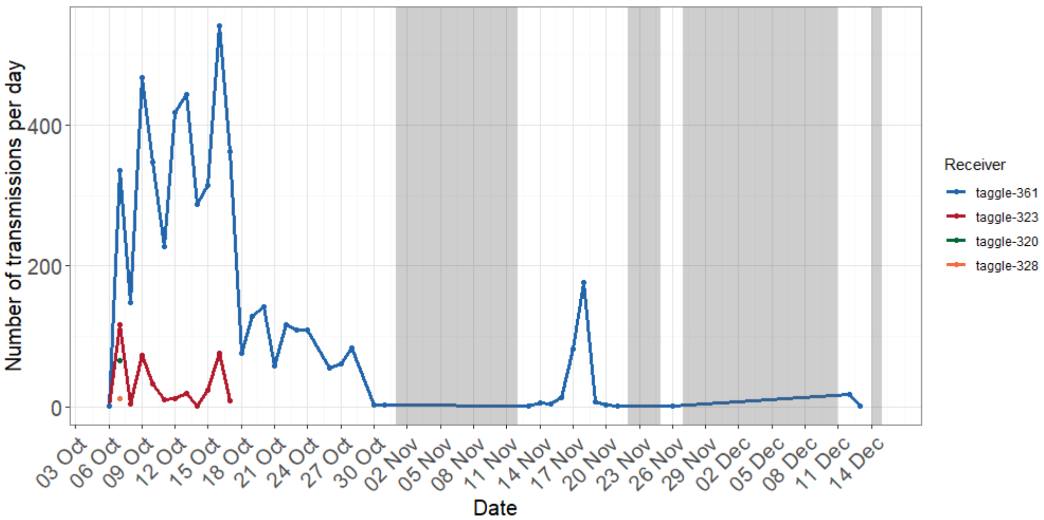

Figure 5. Results from one static Calf Alert device, deployed to validate signal receptions. The radio signals are primarily received by radio tower taggle-361 (the tower closest to this device) initially but deteriorate over time. The next closest radio tower, taggle-323, receives several transmissions for the first 11 days. The two remaining radio towers, taggle-320 and taggle-328, only report receptions on one day. The shaded areas represent periods of time when no transmissions were captured from the radio towers.

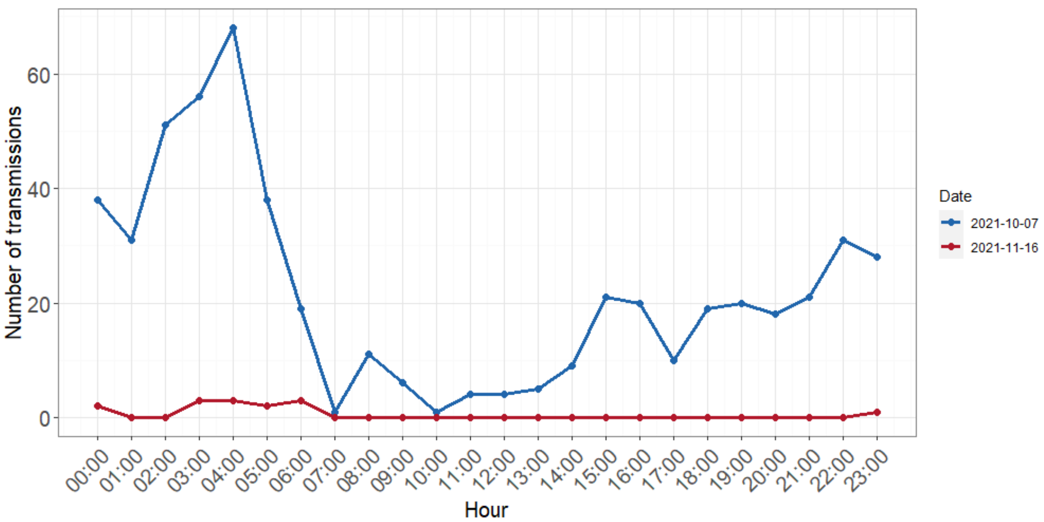

Figure 6. Number of transmissions for each hour across the day from one static Calf Alert device. The number of transmissions followed a broad diurnal pattern, with a higher number of transmissions observed in the early morning, followed by a decrease between 7:00am and 2:00pm. In the initial weeks of the trial, this trend was more apparent, however, in the later stages of the trial, the overall number of transmissions decreased and ceased completely during the middle of the day.

Exploring Radio Signal Strength Indicator (RSSI)

During the experimental period, it became apparent that the signal strength of the radio transmission made by each Calf Alert device might provide information to enable refinement of alerts. This feature has not been explored in previous research using the Calf Alert device. The signal strength of each transmission is measured by the antenna and reported as the Received Signal Strength Indicator (RSSI). These are mostly reported as negative numbers and stronger signals are associated with negative values closer to zero.

Similar trends were observed in RSSI decreasing over time in the static tag (Figure 7), experiencing a diurnal effect (Figure 8), and increasing in value with increasing proximity to radio towers (Figure 9). Additionally, preliminary analysis of the Calf Alert data revealed differences in baseline RSSI ranges between individual radio towers (Figure 10).

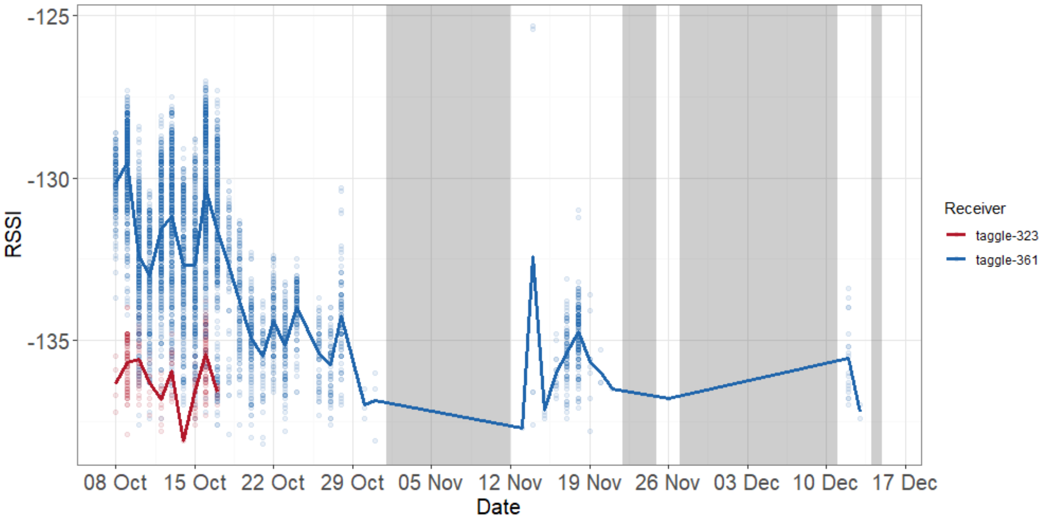

Figure 7. The RSSI from one static Calf Alert device showed a progressive decline in strength over time. The shaded areas represent periods of time when no transmissions were captured from the radio towers.

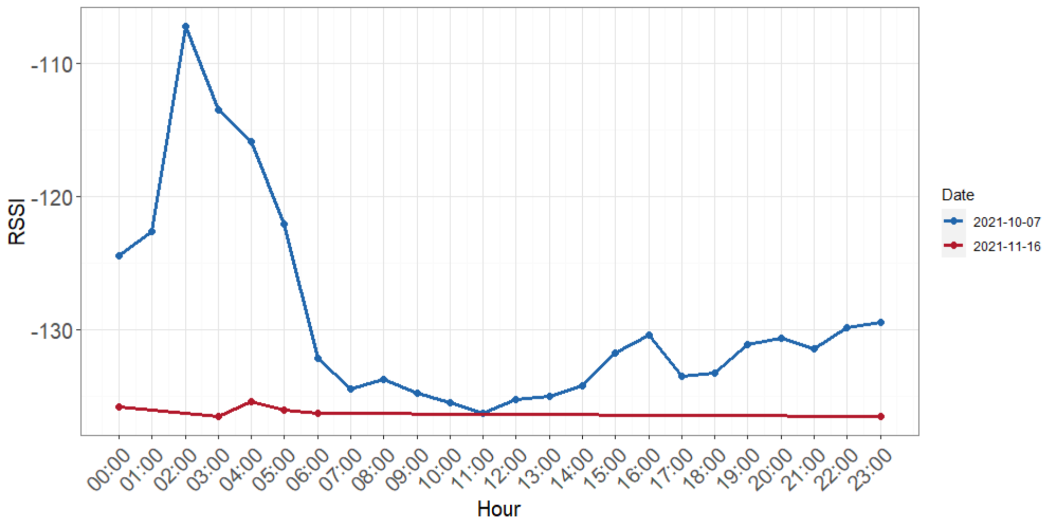

Figure 8. RSSI for each hour across the day for one static Calf Alert device. The RSSI showed a diurnal pattern, with a decrease in RSSI observed commencing from approximately 6:00am to 2:00pm each day and a gradual increase experienced in the afternoon and evening. The number of data points contributing to the apparent diurnal effect is greater in the earlier stages of the trial and reduced in the latter part of the trial.

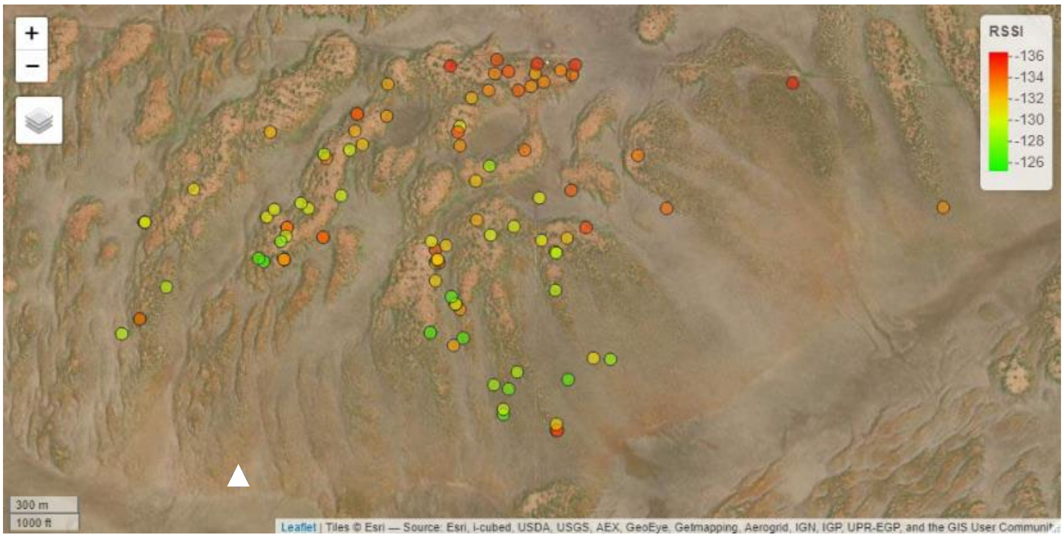

Figure 9. The mean RSSI per hour from the Calf Alert devices across different locations, generated using the Smart Paddock data, in the paddock. A trend appears to indicate that an RSSI value closer to 0 was generated at a closer proximity to the radio tower. The white triangle denotes the location of the radio tower.

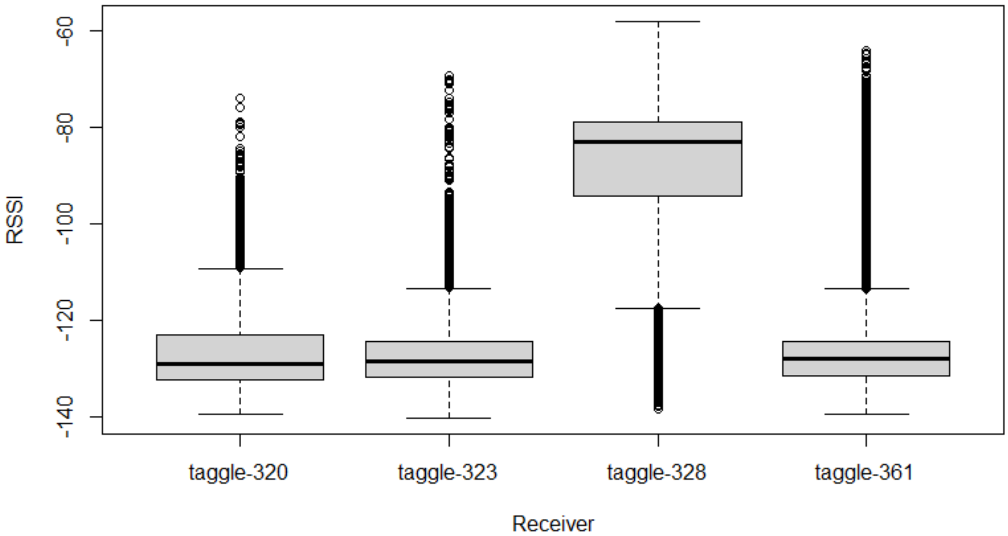

Figure 10. An inherent difference in RSSI range appears to occur between the four radio towers, which impacted on the detection of Calf Alert expulsion.

The ability to accurately identify the time of calving is a critical component to the success of this project and it was anticipated that the Calf Alert devices would be able to facilitate this data collection. The devices, however, failed to work as expected and as such, unsupervised and semi-supervised machine learning approaches were explored to autonomously identify patterns in the data that could be indicative of an expulsion event. Section 4.3 will explore two case studies of confirmed expulsion events. These case studies will be used to advise potential features that could be developed for machine learning.

Key findings, recommendations, and future actions

- The Calf Alert system failed to deliver the service it was implemented to provide and did not enable the real time detection of parturition events.
- There appear to be several possible causes for this failure, including: the early expulsion of sensors, misinterpretation of the attenuation of the radio signal while the sensor was in situ, gradual failure of the chipset over time, and variation in antenna reception. No single causal factor could be identified.
- A redesign of the retention system, electronics, and data analysis protocols would need to be considered before we recommend further application of the Calf Allert device in mature cows in extensive and remote environments

4.2 Performance of Smart Paddock devices during full scale deployment

Based on the preliminary testing undertaken during the trial period (reported in Williams *et al*. 2022 – see Appendix 1), the Smart Paddock collar was deemed suitable for progression to full scale deployment on the station. Real time data was visualised on the Smart Paddock dashboard (https://app.smartpaddock.com/) and users were able to visualise historical location information for the previous week (Figure 11). The technology providers also routinely shared the raw geolocation data as csv files via email.

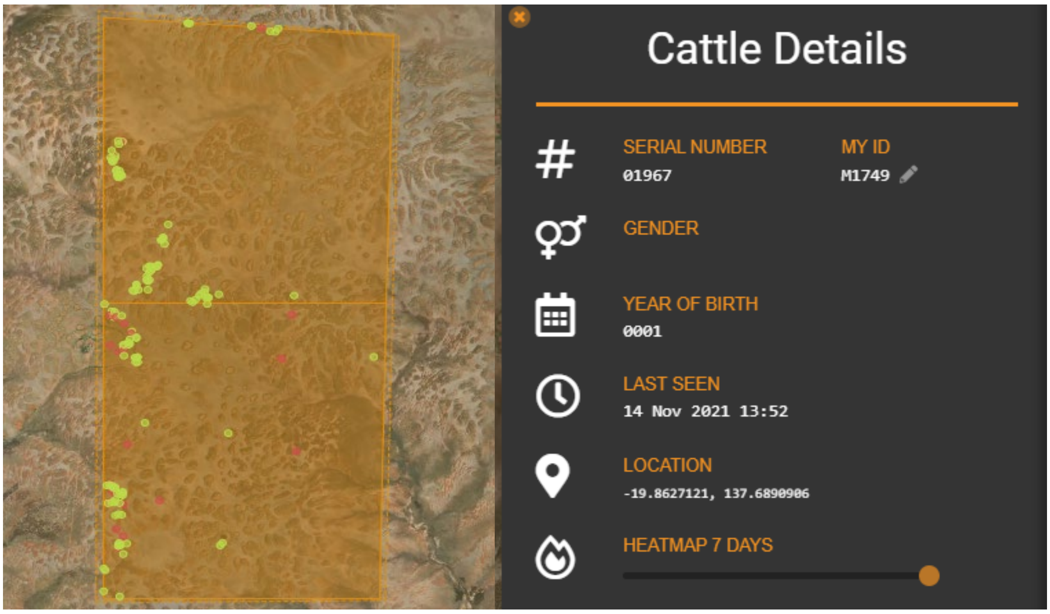

Figure 11. Real time Smart Paddock data could be visualised on the dashboard. Users had the option to either view the data for all animals (left) or the historical data (up to 7 days prior) for a single animal.

A total of 196 Smart Paddock collars were deployed on 11 September 2021 at the research site.

A total of 822,947 data points were generated from 191 individuals (Table 2). Five devices did not transmit any data during the experimental period, and the datasets from a further 12 animals did not capture any spatial data (latitude and longitude values were 0). Throughout the trial, a small number of animals lost their collars (n = 5), however, the devices could be retrieved during the observation campaigns as many provided location data to enable them to be found.

One key issue that impacted significantly on the performance of the Smart Paddock collars in the study was the failure of this system to update the sample interval of data when deployed. The devices are shipped in a low temporal resolution sample interval so that battery power is not wasted. The developer's intent was to have the device update from the 2 hour sample interval to 10 min upon deployment. Due to limitations in radio bandwidth, however, they were unable to achieve this as a batch for all devices and had to progressively update them. The sampling rate and amount of data captured per day from the Smart Paddock collars remained low until 15 October 2021, when the technology provider developed a solution to increase the sampling rate across more devices (Figure 12, Figure 13).

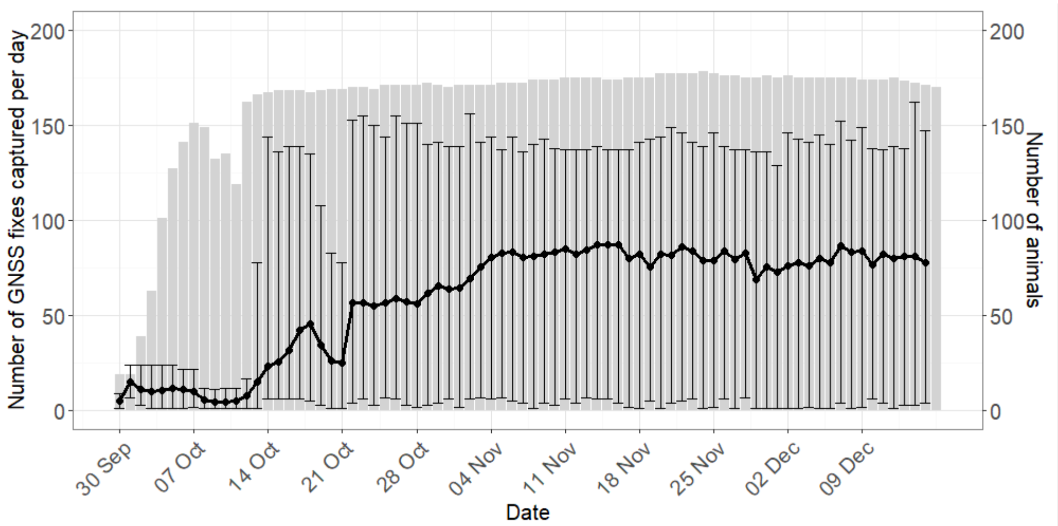

Figure 12. Mean number of GNSS fixes captured per day by the Smart Paddock devices. Error bars indicate the minimum and maximum number of GNSS fixes captured on one day by any of the experimental animals. The grey bars represent the number of animals with Smart Paddock data that contributed to the trendline.

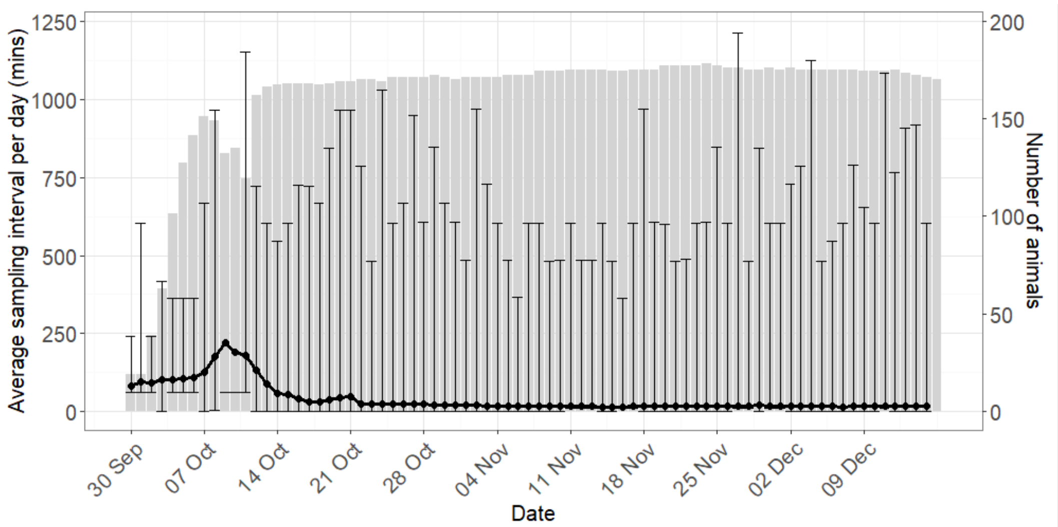

Figure 13. Average sampling interval captured per day by the Smart Paddock devices. Error bars indicate the minimum and maximum sampling interval recorded by any of the experimental animals. The grey bars represent the number of animals with Smart Paddock data that contributed to the trendline

Prior to 15 October 2021, the average sampling interval per day was 155.73 min and following reprogramming of the sampling interval, the average sampling interval per day decreased to 67.88 min (Table 2, Figure 14, Figure 15). A total of 28 animals achieved an average sampling interval of 30 minutes or less for the entire experimental period. This performance was far below our expectations, as the original intent was to use the GNSS data at 10 minute intervals to enable the location of the animals after the Calf Alert device had been expelled. An attempt was made during the trial period to utilise the GNSS tracking data to model parturition events directly, however, the low temporal resolution meant that this could not be achieved. The poor performance of the Smart Paddock device was disappointing, particularly given its successful performance in test deployments at Belmont Research Station (see Appendix 1).

Table 2. Descriptive statistics of Smart Paddock transmission performance.

Number of data points	822,947
Number of data points following cleaning using speed and distance metrics	789,951
Number of data points without spatial data	31,120
Number of incorrect fixes following cleaning using speed and distance metrics	1,876
Number of devices deployed	196
Number of animals with sufficient data	177
Number of animals without any transmission	5
Number of animals with no location data	12
Number of animals with datasets with incorrect fixes	2
Average sampling interval per day (before 15 October 2021)	155.73 min
Minimum sampling interval per day (before 15 October 2021)	10.0 min
Maximum sampling interval per day (before 15 October 2021)	1,326.53 min
Average sampling interval per day (after 15 October 2021)	67.88 min
Minimum sampling interval per day (after 15 October 2021)	8.88 min
Maximum sampling interval per day (after 15 October 2021)	1,124.95 min

Although the data collected by the real time GNSS units were more limited than expected, it still provided valuable insights into animal behaviour and location that has enabled specific targeted field observations, some of which will be reported in the case studies in section 4.3. A basic summary of the data collected over the trial period is reported below.

The raw data was processed and speed and distance features were calculated to remove datapoints that were considered inaccurate, namely where speed or distance was greater than what was biologically possible for a cow (Heglund and Taylor, 1988). Additionally, all latitude and longitude values that were 0 were also removed (Table 2). Following processing, a total of 789,951 data points from 177 individual animals were captured (Table 2).

The average distance travelled by animals across the experimental period was 5.2km/day (Table 3). It should be noted, however, that the distance travelled is calculated by determining the distance between successive GNSS fixes. Therefore, animals with more frequent sampling intervals will often be observed covering greater distances compared to those with a less frequent sampling interval. As such, the total distance travelled per day for animals with sampling intervals of 30 minutes or less was 6.5km/day (Table 3).

Table 3. Descriptive statistics pertaining to animal behaviour across the experimental period, as measured using the Smart Paddock devices.

Average distance travelled (all animals)	5.2km/day
Average distance travelled (<30 min)	6.5km/day

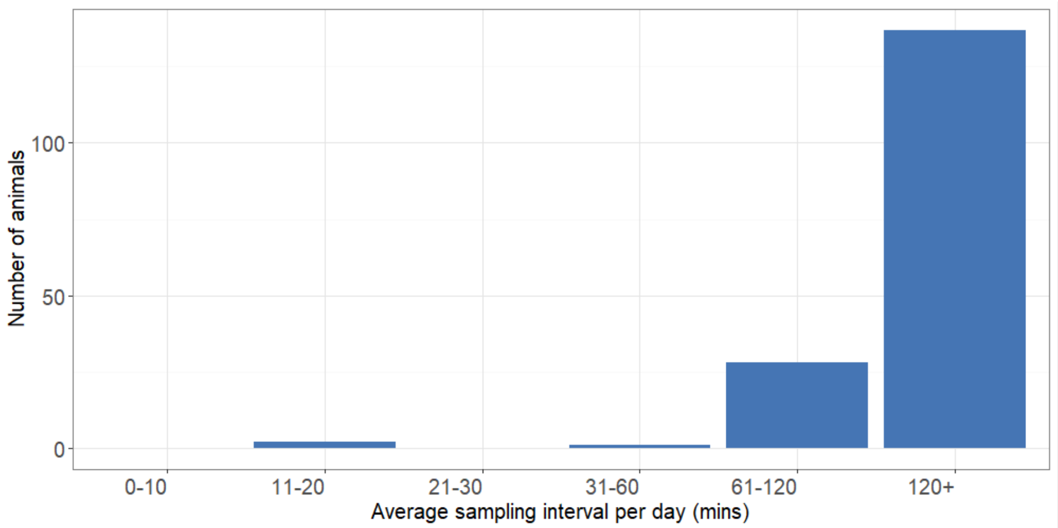

Figure 14. The average sampling interval per day prior to the technology provider increasing the sampling rate on 15 October 2021.

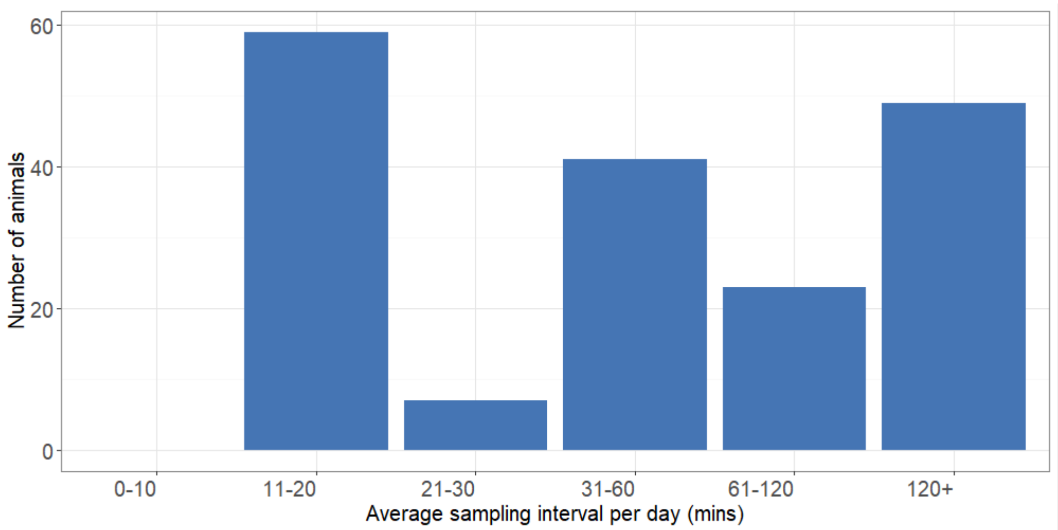

Figure 15. The average sampling interval per day following the technology provider increasing the sampling rate on 15 October 2021.

The variation in sampling interval across the experimental period made it difficult to draw comparable conclusion between the experimental days, particularly as it was anticipated that the majority of animals had calved prior to 15 October 2021 when the sampling rate was still low. The infrequent sampling rates also limited the ability of field staff to locate calving sites, as predicted by the Calf Alert devices.

Key findings, recommendations, and future actions

- The Smart Paddock collar system initially failed to deliver the data required to facilitate the real time location of cattle at the expected temporal resolution.
- The key issue was identified to be the initial set up of the devices where the developer failed to advise the researchers of the requirements for initialising the devices prior to deployment. Limited connectivity at the Station exacerbated this problem.
- The Smart Paddock system will continue to be recommended for use, however, clearer directions around the set up of the system and requirements for connectivity will need to be provided in the future.

4.3 Case study results of successful sensor deployment and data analysis

Although the sensor systems experienced significant problems, on the limited number of occasions when data could be collected, it was found to be of value. Two case studies are presented below that demonstrate the benefits of integrating these sensor systems. These case studies show that the information that was sought as the objective of this project can be gleaned from this strategy if the sensors system could be deployed successfully.

Case study 1 – Exploring the potential for this system to detect dystocia and cow mortality events

On 19 October 2021, researchers were notified of a cow that had died whilst calving. A “downed” alert was not generated for this animal on the Smart Paddock dashboard, however, the last recorded location on 13 October 2021 was used to find the animal 824m away from the actual coordinates (Figure 16). The Calf Alert device was found expelled under the tail of the cow and the Smart Paddock collar was found underneath the cow’s neck. We were informed by the developers that a “downed” alert is generated when a number of static locations are captured. Communication with the Smart Paddock device ceased on 13 October 2021, and as such, it was theorised that the cow had died on this day on top of the Smart Paddock collar, preventing it from transmitting and preventing the generation of a “downed” alert.

This outcome enabled an investigation of the potential for both the Calf Alert and Smart Paddock devices to provide key data on dystocia and mortality events. Calf Alert data could be analysed for changes in transmission count and RSSI. The first transmission was captured on 1 October 2021 and all other transmissions prior to expulsion were inconsistent, with no data observed for multiple days (Figure 17). On the day of expulsion, the number of transmissions captured increased substantially (Figure 17). Decreasing transmission counts were then observed in the following days before cessation on 16 October 2021 (Figure 17). Similar trends were also observed in RSSI, with a slight increase from baseline levels observed on the day of expulsion followed by a decreasing RSSI range in the days thereafter (Figure 18). This result suggests that the Calf Alert system operated as it was initially expected for this particular cow.

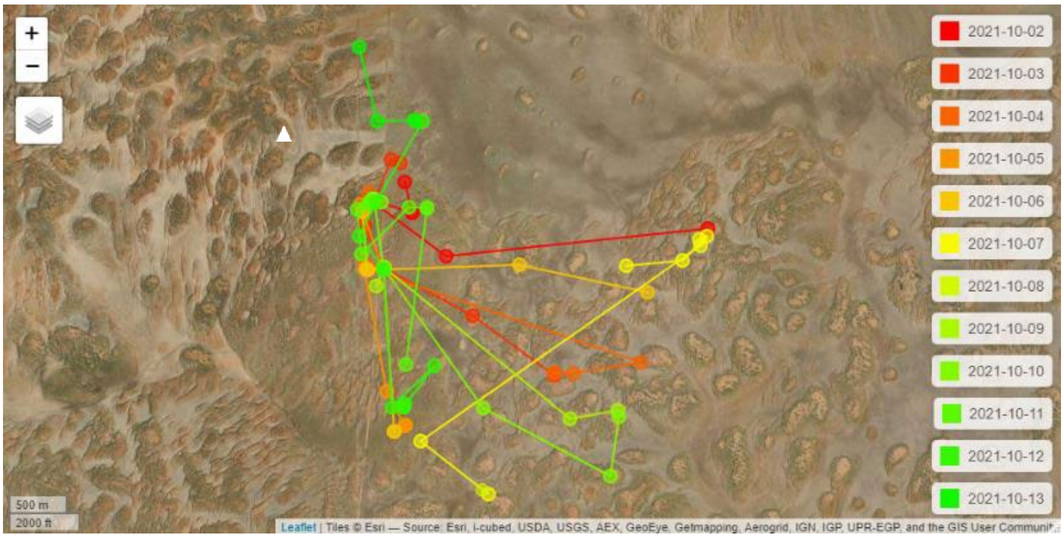

Figure 16. Spatial utilisation, as captured using the Smart Paddock tags, for the focal animal. The white triangle represents the location where the cow was found deceased.

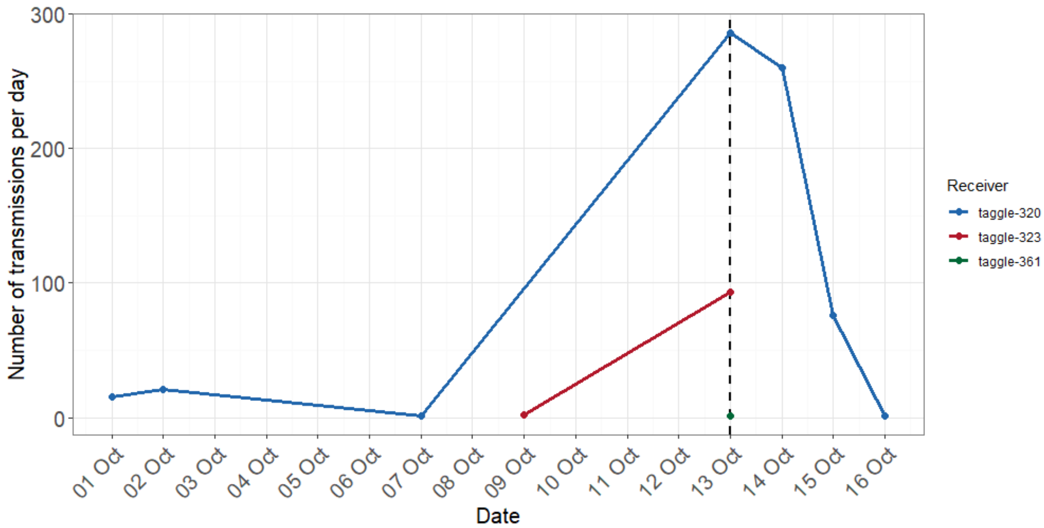

Figure 17. The number of transmissions captured per day from the Calf Alert across the experimental period for the focal animal. On the proposed day of expulsion (dashed line), the number of transmission increased and were captured from three radio towers. Following the proposed expulsion, transmissions were recorded on a daily basis.

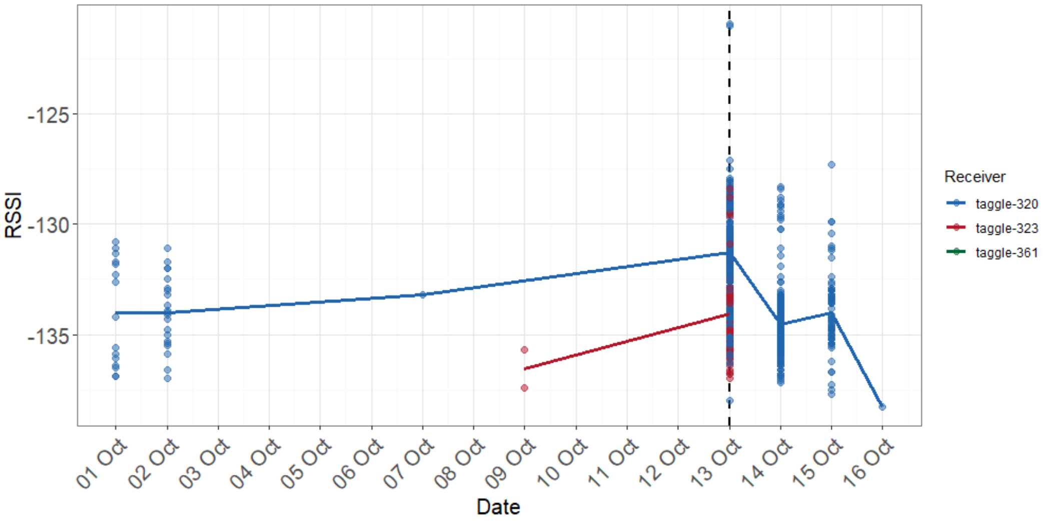

Figure 18. The RSSI transmitted by the Calf Alert for the focal cow. An increase in RSSI range was identified on the proposed day of expulsion (dashed line), with a progressive decline until the device ceased transmitting on 16 October 2021. Following the proposed expulsion, transmissions were recorded on a daily basis.

The Smart Paddock sampling interval for this animal prior to expulsion was on average 145.3 min, with substantial variability between days (Figure 19). The lack of data and variability in sampling interval made it impossible to draw accurate comparisons between the days and no further spatial analysis was undertaken.

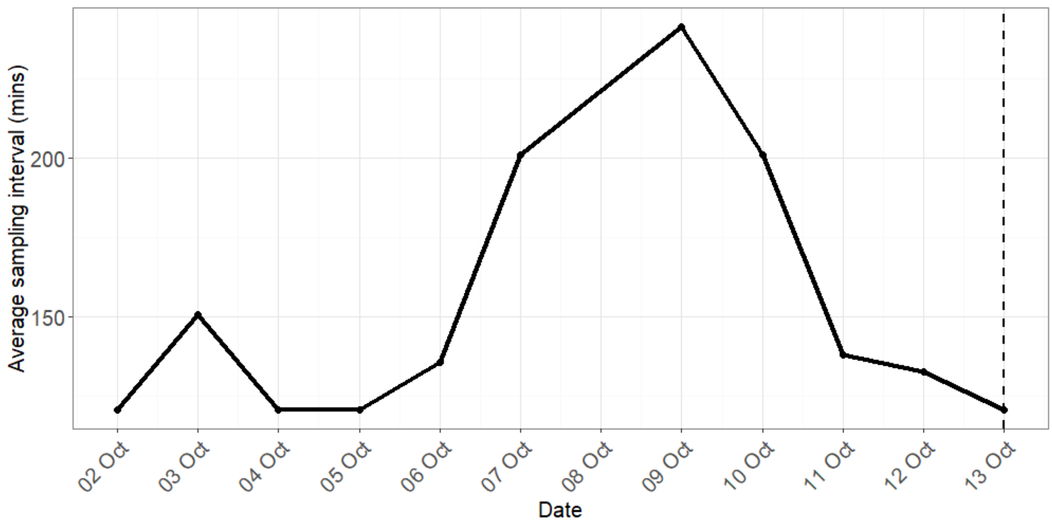

Figure 19. The average sampling interval per day across the experimental period showed a great deal of variation and as such, results could not be accurately compared between days.

Key findings, recommendations, and future actions

- In this case study, the Calf Alert system provided a clear indication of expulsion related to parturition.
- The Smart Paddock system did not provide a "downed animal" alert, however, the coarse temporal resolution of the data allowed the location of the animal.

- If the Smart Paddock system had been operating at its intended frequency, it would most likely have enabled the transmission of a downed alert and the rapid location of the deceased animal.
- This case study suggests that if both the Calf Alert and Smart Paddock systems could be optimised and integrated, they would provide an excellent approach for detecting adverse parturition events.

Case study 2 – Successively detecting parturition and preliminary exploration of maternal behaviour around calving

On 10 October 2021, a cow was observed with a calf with its navel cord still intact, indicating that calving had recently occurred. Analysis of the Calf Alert data using knowledge gained from the analysis presented earlier indicates that the date of expulsion was on 9 October 2021, where an increase in the number of transmissions and RSSI was observed (Figure 20).The use of a simple threshold (nominally 100 signal receptions per day) would have suggested that this animal had expelled the device prior to 9 October 2021, on the 4 October or 5 October 2021 (Figure 20). This highlights the variability in data reported by the Calf Alert system, which made interpretation difficult.

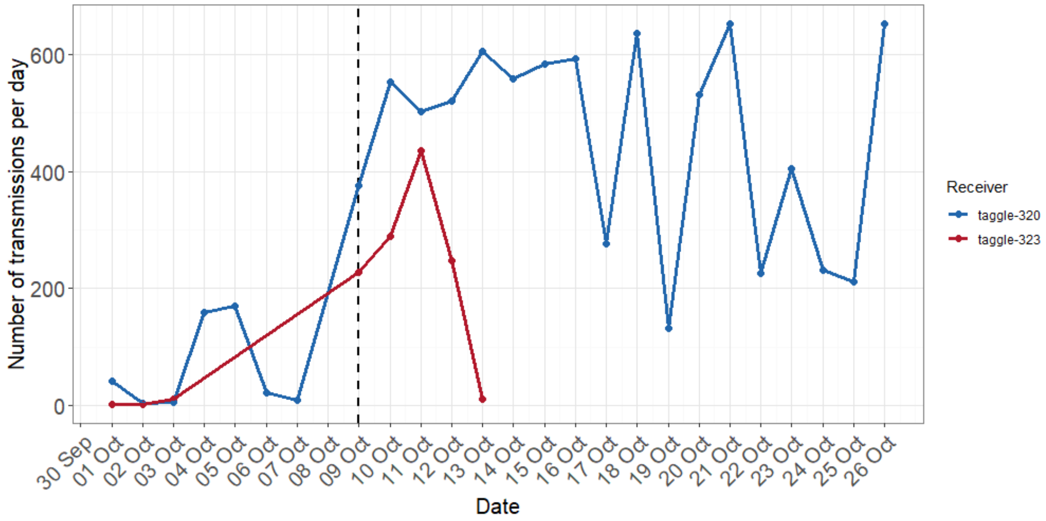

Figure 20. The number of transmissions captured per day from the Calf Alert tags. All transmissions were captured from two radio towers. On the proposed day of expulsion (dashed line), the number of transmissions increases.

In this case study, it appears that the rate of transmission following expulsion does not decrease over time in the same manner observed earlier in the report in the static Calf Alert tag. Again, this highlights the variability in signal provided by the Calf Alert devices, with some apparently deteriorating while others are able to maintain a signal for some time. A gradual decrease in RSSI is, however, observed following expulsion (Figure 22). It should be noted that this animal had a higher baseline transmission frequency and RSSI compared to the animal described in section 4.1. This could be due to the proximity of this cow to the radio tower.

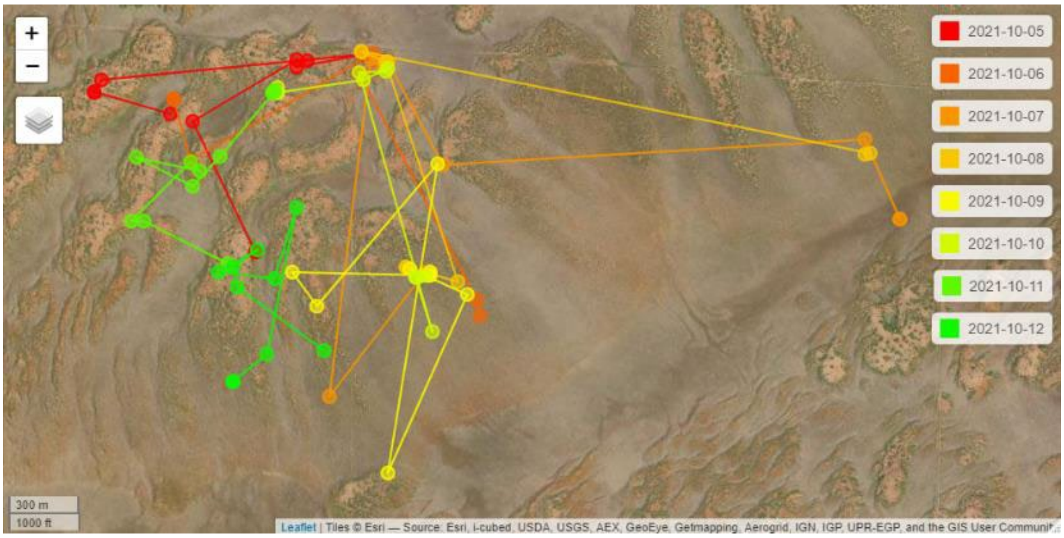

Figure 21. The spatial utilisation of the focal cow, as captured using the Smart Paddock collars, on the days prior to and following calving on 9 October 2021 (yellow dots/lines).

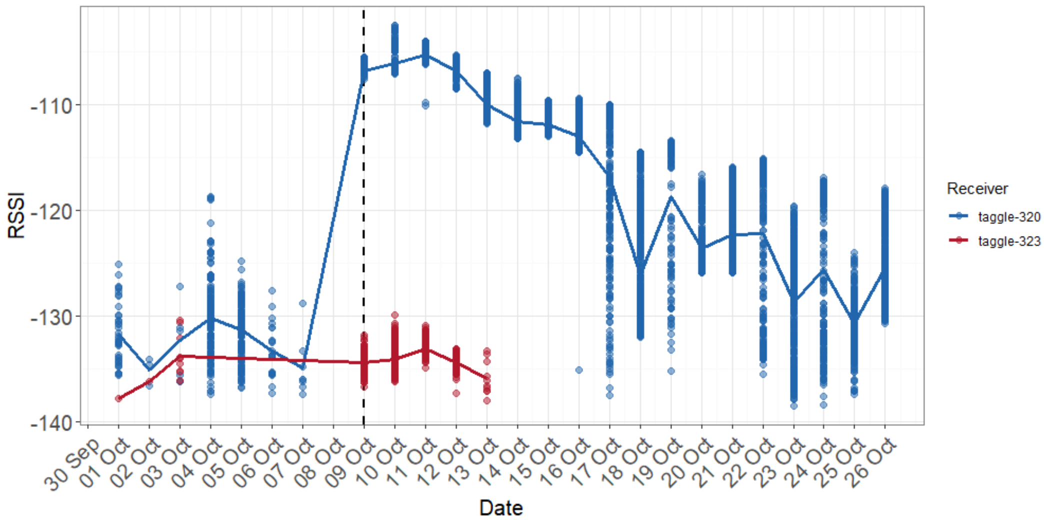

Figure 22. The RSSI of the Calf Alert device of the focal animal during the experimental period. On the proposed day of expulsion (dashed line), the RSSI increases, before gradually decreasing in the following days until the receiver ceased transmitting on 26 October 2021.

Prior to 12 October 2021, the average sampling interval of the Smart Paddock devices was 134.8 min, before sampling rate increased (Figure 23). A relatively consistent sampling interval was observed between 5 October and 12 October 2021, ranging from 120.6 min to 150.7 min per day (Figure 23). This coincided with the pre- and postpartum period. As such, further data analysis was conducted using the data from this time frame.

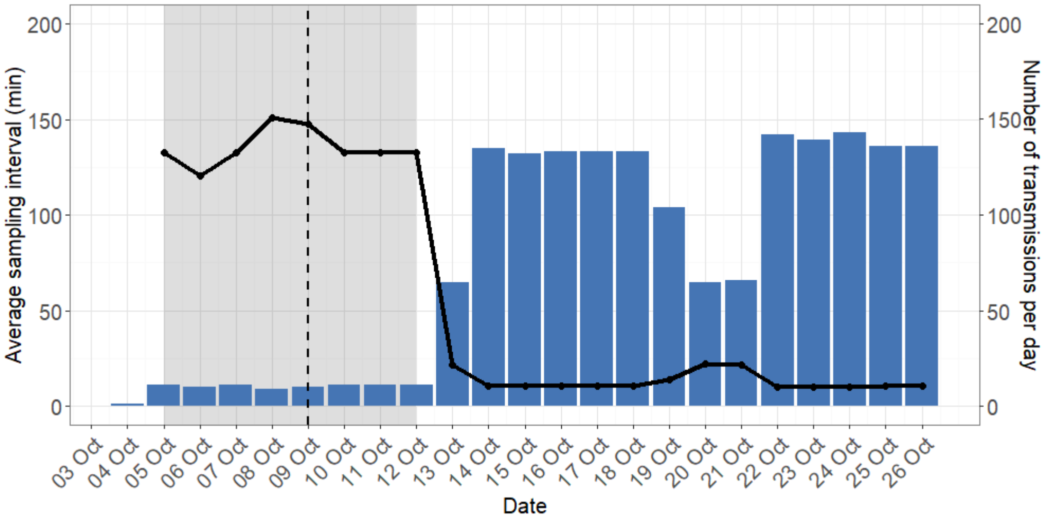

Figure 23. The average sampling interval (line) and number of transmissions captured per day (bars) across the experimental period. In the initial weeks of the trial (shaded area), the average sampling interval and number of transmissions captured per day were comparable, before the sampling rate was increased on 13 October 2021. The proposed calving date (dashed line) occurred during this period.

The minimum convex polygon (MCP) using 90% of the data closest to the centroid of the data points was calculated. This metric relates to the spatial utilisation of the animal across each day. Prior to calving, the MCP averaged 103.3 ha and following calving, MCP averaged 16.7 ha (Figure 24, Figure 25). On the day of calving, MCP declined and remained suppressed for 3 days following calving (Figure 24, Figure 25). This same decrease in MCP has been observed in studies in other species, including sheep (Fogarty et al., 2020) and moose (Melin et al., 2019), as well as in cattle, as seen in the results reported for the Belmont Research Station project (Williams *et al.* 2022).

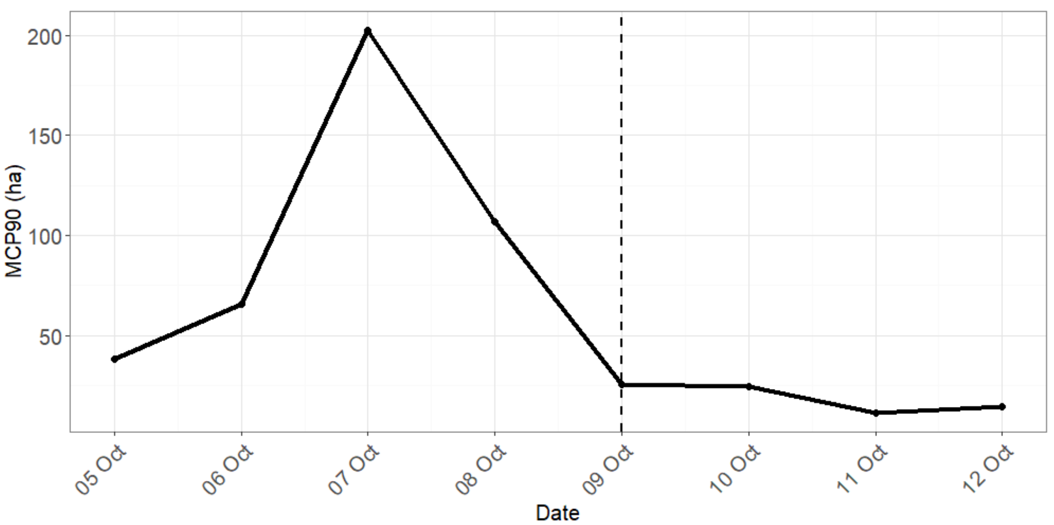

Figure 24. The minimum convex polygon, excluding the outer 10% of data, as calculated using the Smart Paddock devices, in the pre- and postpartum period for the focal cow. On the day of calving (dashed line), the MCP decreases and remains suppressed in the following days.

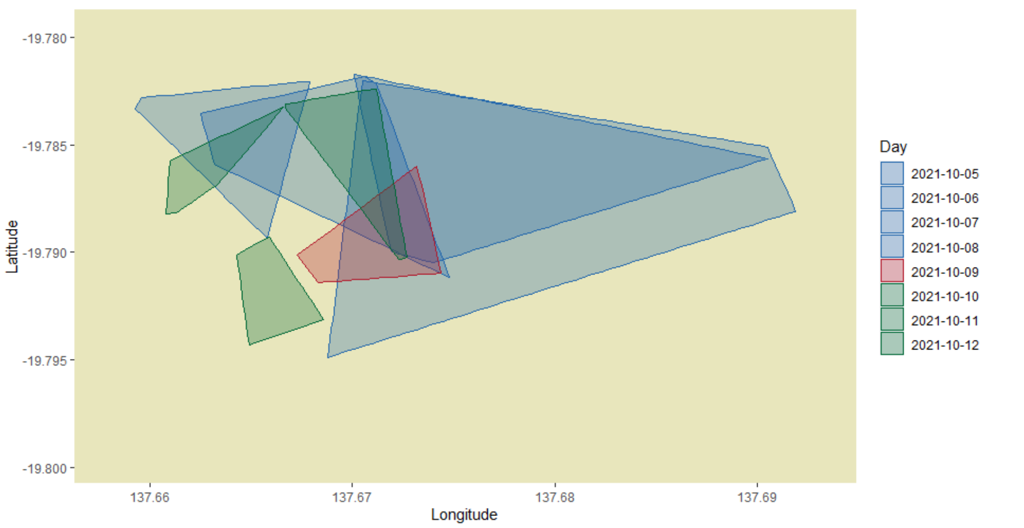

Figure 25. The minimum convex polygon, excluding the outer 10% of data, as calculated using the Smart Paddock devices in the pre- (blue polygons) and postpartum (green polygons) period for the focal cow. The day of calving is denoted by the red polygon. The MCP decreases on the day of calving and remains reduced in the postpartum period.

The total distance travelled per day prior to calving was on average 3.5km and following calving, the total distance travelled per day averaged 2.1km and remained suppressed for 3 days postpartum (Figure 26). This is consistent with other studies (Pearson et al., 2020).

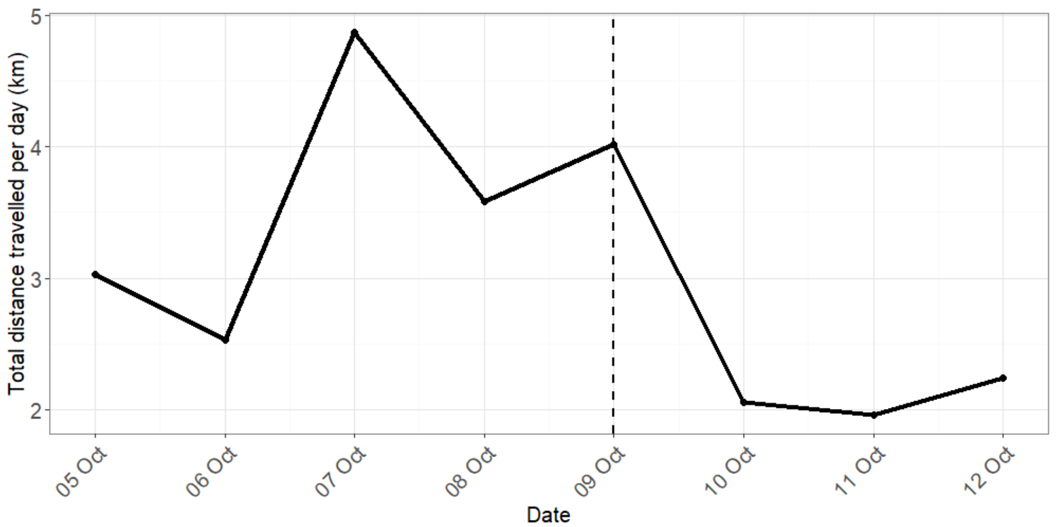

Figure 26. The total distance travelled in the pre- and postpartum period, as captured using the Smart Paddock devices, of a cow that was proposed to have calved on 9 October 2021 (dashed line). In the days following calving, the total distance travelled is further reduced.

One key novel behaviour of interest in terms of detecting parturition and also understanding maternal behaviour is the cow's use of water points. Prior to calving, this case study cow visited a watering point at least once a day, however, on the day of calving, no visits were recorded at the watering point. The first instance of postpartum water utilisation occurred on the day following calving, however, no visits to water were recorded on day 2 or 3 postpartum (Figure 27). This cow utilised the same watering point, which was in the closest proximity, often in the morning or the afternoon. This lack of visitation data may actually be more representative of short times spent at water points, as the large sample interval may have masked the animal's movement to and from the water trough between location fixes. This feature will be explored more extensively when the high resolution GNSS data is collected from the iGotU devices.

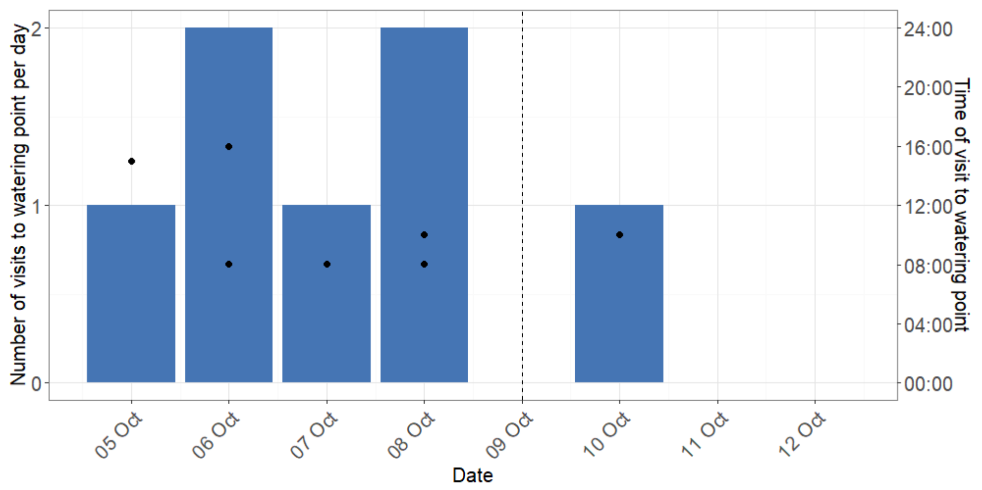

Figure 27. Total number of visits within a 100m radius of a watering point (bars) and the time in which the cow visited the watering point (dot point), measured using Smart Paddock. Prior to calving, the cow visited water at least once per day, however, on the day of calving, as indicated by the dashed line, the cow did not visit water. In the postpartum period, overall water usage decreased with days reporting no visits potentially an artifact of sample interval.

This animal was selected for preliminary analysis as sufficient Smart Paddock data was available for broad behavioural trends to be identified. The majority of the experimental animals, however, did not have sufficient data for detailed behavioural analysis to be conducted. Furthermore, variability in sampling interval across the experimental period greatly limited the ability to draw accurate conclusions between days. A number of metrics, particularly those pertaining to social behaviours, such as isolation, and behavioural changes compared to the remainder of the herd, also could not be generated due the lack of Smart Paddock data.

Key findings, recommendations, and future actions

- The Calf Alert device initially appeared to provide a false positive when utilising a simple threshold, however, closer inspection of the data (particularly RSSI) demonstrates that a more accurate algorithm could be developed.
- Even with the coarse Smart Paddock temporal resolution (~2 hour sampling interval) several indicators of parturition and maternal behaviours were discernible.
- Water visitation shows some promise in providing an indicator of parturition and will likely be an important component of maternal behaviour.

5. Conclusion

The objective of the Calf 48h project was to identify a system capable of facilitating the diagnosis of the causes of calf loss in remote, extensive grazing systems.

In the main field trial on a Barkly Tablelands station, the Calf Alert system did not enable the real time detection of parturition events at scale. There appear to be several possible causes for this failure, including: the early expulsion of sensors, misinterpretation of the attenuation of the radio signal while the sensor was in situ, gradual failure of the chipset over time, and variation in antenna reception.

The Smart Paddock collar system initially failed to deliver the data required for real time location of cattle at the expected temporal resolution. The key issue was identified to be the initial set up of the devices, where the developer failed to properly initialise the devices prior to deployment. Limited connectivity on the Barkly Tablelands Station exacerbated this problem. Although problematic in this deployment we believe this system has value with further refinement of the technology

Although the systems that were deployed experienced major failures two case studies of individual animals where data was successfully collected are presented. These show that the concept of integrating data from the calf alert system and tracking collars could provide the information being sought as the objective of this project.

Ultimately, the project was terminated due to the failure of the technologies to provide reliable data across the entire herd with further refinements needed form the developers of the technologies before we can recommend further investment in these particular systems.

Future research into systems that provide this data is essential if the industry is to understand the impact and then find solutions to the problem of calf mortality across Northern Australia.

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Appendix I

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ANIMAL PRODUCTION SCIENCE

Sensor-based detection of parturition in beef cattle grazing in an extensive landscape: a case study using a commercial GNSS collar

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ABSTRACT

Context. Neonate management remains a key issue in extensive beef production systems where producers are faced with substantial environmental and management challenges that limit their ability to monitor and manage livestock in a timely manner. Parturition is a critical event and can affect the calf health and survival, particularly in the perinatal period (up to 48 h after birth). As such, monitoring parturition using precision livestock technologies may provide producers with additional tools to manage their cattle and mitigate the impacts of neonatal mortality in extensive beef systems. **Aims.** The purpose of this study was to determine whether data from a global navigation satellite system (GNSS) collar could be used to detect parturition events in extensively grazed beef cattle. **Methods.** Forty-eight *Bos taurus* cows (583.5 kg body weight ± 9.25 s.e.m.) were allocated to a 28 ha paddock between 8 January 2021 and 6 March 2021 during the calving season. Thirty of the animals were fitted with GNSS-equipped collars (Smart Paddock, Vic., Australia) that captured data at 10 min intervals. Parturition events were recorded daily by visual observation. Collected data were used to calculate key predictive features related to calving behaviour. Derived features were compared and assessed for changes in the period surrounding parturition. **Key results.** Increases were observed in distance to nearest neighbour and to herd aggregate features, and decreases were observed in paddock utilisation and distance travelled features in the lead-up to calving ($P < 0.05$). Furthermore, the number of animals within a 20 m radius decreased significantly ($P < 0.05$) in the lead up to parturition, supporting known isolation behaviours. **Conclusions.** With further development of predictive algorithms, on-animal sensors may be valuable in the prediction of calving events in extensive beef production systems. **Implications.** Remote management and monitoring with on-animal sensor technologies, such as GNSS collars and tags, will provide producers with an additional means of monitoring their animals, while overcoming many of the management challenges associated with extensive grazing operations.

Keywords: birth events, calf loss, calving, on-animal sensors, precision technology, rangelands, smart-tags, welfare implications.

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Introduction

Reproductive efficiency is a key driver of profitability in extensive livestock systems (McCosker *et al.* 2020). Losses can occur at any phase during gestation, but mortality at calving represents the greatest at-risk period for the red meat industry in extensive grazing systems (Chang *et al.* 2020*a*). With the advent of on-animal sensor technologies, there are opportunities to monitor and manage livestock in extensive livestock systems at resolutions far greater than previously possible (Williams *et al.* 2021). These technologies could support the remote detection of behaviours and capture data for individual animals in remote and rugged areas, such as those in more extensive landscapes, where parturition events often go unnoticed, and the causes of calf loss remain a mystery on many properties (Chang *et al.* 2020*b*). Technologies, such as