final report

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Remote calving alert for beef cattle – Technology Development (Phase 3)

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Abstract

The Calf Alert device developed in MLA project B.NBP.0666 was upgraded to improve signal transmission and reception. The technical upgrade involved utilising A31 PCB's, in contrast to the A21 PCB's used in earlier devices. The cargo pod was modified to rectify factors affecting reliability- stronger, water-resistant pod and increased cargo space for the new PCB's. A static field test comparing A21 and A31 devices demonstrated improved signal clarity, good reception in the presence of tall vegetation, and improved precision and accuracy. Devices were tested in 80 mid-to-late gestation cows at Rockhampton and Longreach properties. The devices were monitored over 150 days for reception and location data utilising Taggle terrestrial receivers. Parturition events and locations were recorded by daily visual surveillance of calving paddocks. A31 devices functioned better without interruption throughout the trial period. The modifications resulted in a spike in reception data concurring with the calving date in 66% of cows, while calving location was derived for 64% of cows. A slight drop in location precision was observed but was adequate to locate calving sites. Reception number and location precision was inversely proportional to distance to the receiver. Variability was attributed to occasional PCB failure and malfunctioning of receivers; all of which have solutions.

Executive summary

This project was carried out to further improve and field test the intravaginal device developed in B.NBP.0666 for use in calf loss research in pregnant cows to quantify and categorise calf loss from pregnancy diagnosis to weaning.

Project objectives:

1. Investigate and report the long-term retention rate of Calf Alert devices in 40 pluriparous cows throughout gestation; investigate receiver antenna function to ensure maximum signal reception; investigate and report on increasing the signal strength of the current Calf Alert prototype; and investigate and report on modifying the receiver to fit into an unmanned aerial vehicle.

2. Investigate on Phase 2 recommendations to improve signal reception by modifying the Calf Alert pod and upgrading the PCB from A21 to A31, and report on the success via a static field testing.

3. Deploy and test the modified and upgraded Calf Alert device (with A 31 PCB) in pregnant cattle to monitor improvements in signal reception, location detection, and identification of date and timing of calving.

Based on Phase 2 results and after consultation with Taggle technical experts, some of the key points identified to improve transmission included the priority of waterproofing the cargo pod; upgrading the chip within the device from the A21 to the A31 version; and increasing the height of the receiver towers to improve signal reception. Discussion with Taggle's technical experts made it clear that affordable unmanned aerial vehicle (UAV) technology was not available to carry a 7 kg Taggle receiver as payload and was not pursued.

Increased protection of the Taggle chip within the Calf Alert device was achieved by increasing the internal diameter of the Calf Alert pod so that Taggle chip fits with less lateral force. Polycarbonate was used as it is stronger than the original acrylic, allowing a thinner, but stronger wall.

Prevention of moisture condensation was achieved by redesigning the cargo pod with only one opening. Polycarbonate also enabled the use of ultrasonic welding to effect a robust seal in contrast to glue used in the two joins of the Phase 2 acrylic device. Pressure testing of the modified device under water at a pressure of 100 Psi (approximately 7 Bar) for 12 hours resulted in no water leaks.

Improved signal reception was achieved by using A31 PCB's instead of the A21's to improve signal: noise ratio. Subsequent static field testing using the A31 PCB in the modified Calf Alert device resulted in a higher number of receptions, higher degree of accuracy and greater precision compared to the A21 device.

40 mid-to-late gestation Belmont Red cows were enrolled 18 with A31 PCB's and 22 cows with A21 PCB's. At Longreach, 40 mid-to-late gestation cows were enrolled - Brangus (11 with A21 devices and 9 with A31 devices) and Santa Gertrudis (9 with A21 devices and 11 with A31 devices). Taggle networks were established at both trial sites each with four Taggle receivers. The Taggle network at Belmont covered an area of approximately 149.5 ha, whereas the network at Longreach was 975.6 ha. At Belmont, cows were rotated between two paddocks (47 ha) within the Taggle network while at Longreach all cows grazed in a single paddock (376 ha) throughout the experimental period.

The coordinates of the Taggle receivers and the paddock boundaries were imported into Google Earth and the centre point derived. Cows were checked daily throughout the calving season in either motor vehicles or motor bikes

Two types of files, which relate to the receptions and locations generated by each Taggle device, were imported from the Taggle System Pty Ltd server to a CQUniversity server. The reception data was analysed to determine the number of receptions per day from each of the four receivers at each trial site.

Over the 150 days of data collection there were 114,293 receptions at Longreach and 383,960 receptions at Belmont. 66/80 (82.5%) of the inserted devices provided locations throughout the experimental period with 51/80 (63.8%) devices providing locations past the point of calving. Reduced distance between the calving paddocks and receivers at Belmont provided significantly better reception and location data The reduced height of the antenna (12 m versus 15 m) appeared to have no effect on its ability to receive transmissions.

Conclusion and recommendations

More stringent quality control in the manufacture of the Calf Alert device and the availability of a reliable network with uninterrupted transmission will make it suitable for use in commercial and research beef operations to monitor calving and calf loss.

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1 Background

It has been estimated that about four to eight percent of calves die between parturition and weaning and about 90% of the loss happens during the first week postpartum (Kasari, 1989). Although dystocia is considered one possible cause, there are many other potential reasons that may result in calf-losses such as mis-mothering, poor nutrition, predation and disease. Lack of methods to gain accurate statistics has been an impediment to monitor and manage calf losses in extensive grazing systems. It was proposed that access to a device that could telemetrically detect parturition events and allow autopsies of dead calves and timely recording of calving related data would be useful to derive scientifically based conclusions. This project was carried out to refine the design and further field test a previously developed intravaginal device in pregnant cows (B.NBP.066).

The first phase of this project (B.NBP.0545) reviewed and investigated the feasibility of designing a range of prototype calf alert design options for development and testing. Initial steps involved reviewing the literature to investigate; physiological and behavioural changes at parturition; pre-existing technology (for example the detection of oestrus) which may be adapted to the detection of calving; the risks associated with long-term application of intravaginal devices; and patents or commercial birth-alert systems currently available. It also identified an industry partner (Taggle) with existing technology that could be incorporated into a telemetric calf-alert device. From the initial report, three prototypes were designed to provide a telemetric calving alert device that could identify the time and location of a calving event. These prototypes required further development and testing, leading to Phase 2 of the project.

Phase 2 of this project (B.NBP.0666) involved integrating Taggle electronic technology into intravaginal prototypes developed in Phase 1. The final prototype was deployed and tested for its ability to remain in-situ during gestation, and detect time and location of calving. The selected prototype from Phase 1 was modified and re-manufactured using a plastic injection moulding technique. This was initially trialled for four weeks in five non-pregnant cows, with 100% retention and no adverse effects. Later it was inserted into 20 early (2 to 3 months) pregnant cows, with 20 contemporary controls. A Taggle ear tag was used to detect parturition related movement behaviour. The cows were monitored monthly using an intravaginal endoscope and full blood counts together with assessment of acute phase proteins were carried out to detect any inflammatory response. Device retention was 75% until calving and there were no adverse effects on long term device retention on cow health or pregnancy. The location signals could be detected only from 3 out of 20 devices which on further investigation were attributed to moisture condensation within the Calf Alert pod and signal detection interference due to tall vegetation. These issues led to Phase 3 of the study which comprises further refinement of the Calf Alert device.

2 Project objectives

The objectives of this project were to address the issues that affected reliability of Calf Alert device trialled in Phase 2 by way of modification and upgrade of the device.

By October 2016

- Investigate and report on the retention rate of the calf alert device throughout gestation in approximately 40 pluriparous animals
- Investigate and report on increasing the signal strength, and/or the ping rate of the current calf alert prototype. If expense, or technological challenges are too great to modify the current Taggle technology, then alternative technological options will be investigated and where possible, effected

• Receiver antenna function investigated to ensure maximum signal reception and success documented
• Investigate and report on modifying the receiver to fit into an unmanned aerial vehicle and success of application

By April 2017:

• Confirm as a valid option within the October milestone, purchase and modify three unmanned aerial vehicles to carry a receiver.
• Transmitter signal-strengths and/or ping rates field tested utilising static devices located throughout the grazing paddock. Signal reception via land-based antennae and the unmanned aerial vehicle receiver will be monitored.
• Determine reliable signal reception strength from static devices located in an extensive-grazing environment. Stop/Go point for project progression.
• Incorporate modified electronic components into the intravaginal device module
• Complete investigation into ear tag design to improve retention rate

By February 2018:

• Complete trial to insert an updated intravaginal device plus attach ear tag to 20 heifers, with equivalent control animals: record calving date and time plus detailed movement behaviours at calving utilising land antennae and UAV
• Assess if the calf alert device coupled with cow movement behaviour at calving can meet the minimum specification of detecting the time of calving within 12 h with location of calving within 50m.

3 Methodology

3.1.1.1 Structural modification of the Calf Alert device:

Phase 2 recommendations to improve signal reception by modifying the Calf Alert pod were investigated. A meeting was held between the project team and Taggle engineers. The improvements that were suggested were to increase the size of the pod, construct it out of polycarbonate instead of acrylic and weld the seams to ensure they are water tight. The PCB would also be changed from A21 to A31 to increase signal strength while maintaining battery capacity.

3.1.1.2 Laboratory testing of the modified device

The pod would then be tested in the laboratory under water at 100 PSI and also be stress tested to see that it will handle external pressure. Finally it will undergo static field testing to see it can be strategically located in known positions.

If the devise passes all the laboratory testing, it will then be field tested at both Belmont Research Station (Belmont) in Central Queensland and Longreach Pastoral College (Longreach) in western Queensland during 2017/18. Two types of Calf Alert devices, differing only in PCB's circuitry (A21 & A31) will be trialled at each trial site.

3.1.1.3 Field testing of device and receivers

A total of 40 mid-to-late gestation Belmont Red cows with Calf Alert devices containing A31 and A21 PCB's will be tested at Belmont research Station. At Longreach, another 40 mid-to-late gestation cows comprising of Brangus and Santa Gertrudis will be implanted with both A21 and A31 devices. Taggle networks will be established at both trial sites with each site having four Taggle receivers. The Taggle network at Belmont will cover an area of approximately 149.5 ha, whereas the network at Longreach will cover 975.6 ha. At each trial site three of the four receivers will have their antennas mounted on 15 m masts and one on a 12 m mast. At Belmont, cows will be rotated between two paddocks (47 ha) within the Taggle network while at Longreach all cows will be grazed in a single paddock (376 ha) throughout the experimental period.

To determine the approximate distance the Calf Alert device transmissions has to travel to reach each receiver the distance from a point, claimed as the centre of the paddock, to each receiver will be calculated. The coordinates of the Taggle receivers and the paddock boundaries will be imported into Google Earth and the centre point derived. The process used to derive the centre point in the paddock is to find where the half-way point on the paddock boundaries intersect. The Google Earth ruler is then used to measure the distance from the centre point to each receiver.

Cows are to be checked daily throughout the calving season to record the calving date of each cow. This will involve staff to drive around the calving paddocks in either motor vehicles or motor bikes and observe cows for signs of a recent parturition event such as a new born calf, obvious calving site, and presence of after birth etc. The cow's identity and calving date are to be recorded as well as udder and teat structure, calf details and location of the calving site (if identified). When a calf is located it will be captured, the mother and calf identified and this information will be used to assign the calving date for each cow. On the final ultrasound assessment, hair samples will be collected from cows and calves for DNA analysis to confirm that the cow was the mother of the tagged calf and hence the calving date was correct. The DNA samples will be analysed by the Animal Genetics Laboratory at the University of Queensland using 21 microsatellite markers, which is a recommendation of the International Society for Animal Genetics (ISAG 2012).

3.1.1.4 Data entry

Two types of files, which relate to the receptions and locations generated by each Taggle device, will be imported from the Taggle System Pty Ltd server to a CQUniversity server. Code will be written in R Foundation for Statistical Computing software to import the CSV files. The reception and location files will be accumulated for the experimental period (150 days). The reception data will be analysed to determine the number of receptions per day from each of the four receivers at each trial site. To assess whether a peak in receptions from a Calf Alert device can indicate the date of calving, the total receptions for each device from each of the four receivers at each trial site will be summed and the total receptions per device per day graphed. The graphs will be visually assessed to determine whether a peak in the number of receptions will fall within ± 24 hours of the observed calving date and therefore can provide accurate information on the date of calving. The location data will be analysed in a similar fashion to the reception data to compare the number of locations provided per device type and per trial site. The date of the last location from each device will be compared with the calving date to assess whether the locations were provided at and after the point of calving.

3.1.1.5 Decisions on unachievable objectives.

The objective of using a UAV (unmanned aerial vehicle) to carry the receiver will not be pursued as early discussions with Taggle's technical experts made it clear that UAV technology was not yet advanced enough to carry a 7 kg Taggle receiver as payload. Hence the focus will be mainly directed towards improving the terrestrial receivers. Another objective to investigate ear-tag design to improve retention rate will also not be pursued as Taggle Systems have not been focussing on ear tags in recent years due to a major shift of their focus to water meters.

4 Results

4.1.1.1 Structural modification of the Calf Alert device:

A meeting was held involving Taggle Systems, Central Queensland University and Charles Sturt University to review previous results of the device deployment and to identify methods of improving reliability. Based on technical advice (Taggle Systems) and field evidence of moisture condensation within the first-generation pods, the most likely reason for device failure was moisture damage within the Calf Alert pod leading to one or more of PCB damage, signal attenuation, or battery dysfunction.
Discussions with an industrial design specialist (Cube Designs), informed the following stages of device modification:

Stage 1 – Capsule and Cap design (Fig. 1 and Fig. 2)

The capsule was redesigned to incorporate an opening suitable for holding an ultrasonic welding fixture. In contrast to the two openings in the original design, the second generation design has just one opening to seal.

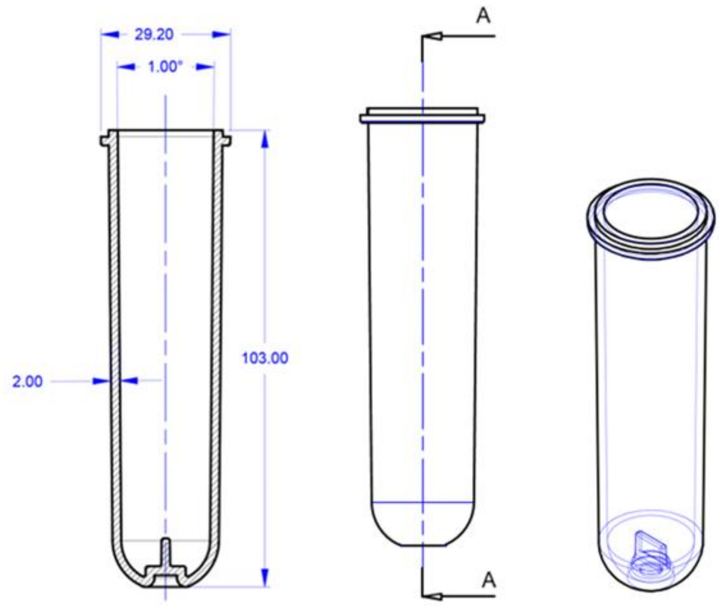
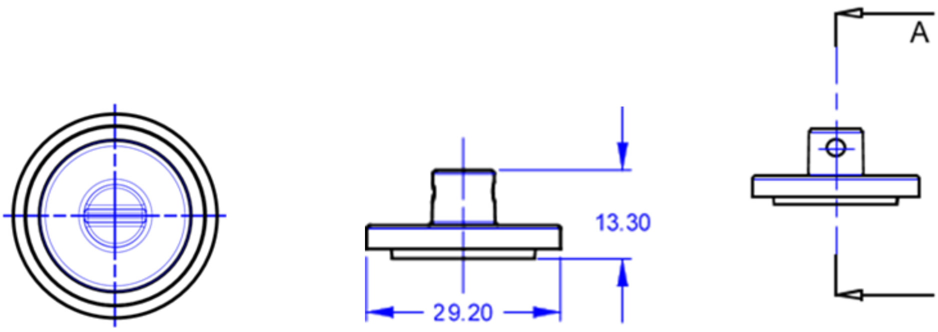


Fig. 1 - New design of the modified Calf Alert tube



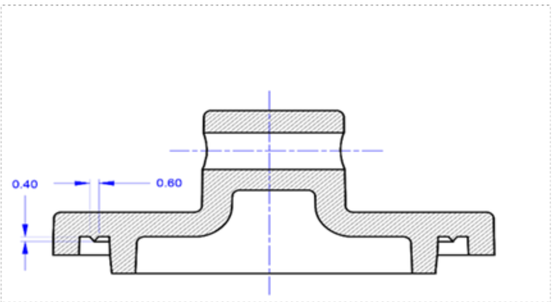


Fig. 2 - New design of the modified Calf Alert cap allowing for the ultrasonic seal

Stage 2 – Tool making
A new second-generation mould set was developed for injection moulding the capsule components from clear polycarbonate. Polycarbonate is stronger than the Phase 1 acrylic compound, allowing thinner, but stronger walls. Thinner walls allow more room in the cargo pod to house the PCB without lateral stress. Tooling and moulding was completed in China.

Stage 3 – Part manufacture
Manufacture included production of 200 moulded capsule parts to allow for weld and pressure testing, and parts for a production run.

Stage 4 – Ultrasonic welding
There was a need to custom design and manufacture a welding-horn fixture to hold the capsule parts during ultrasonic welding.

Stage 5 – Pressure/ Leak test
Seven capsule assemblies were pressure tested under water to 7 Bar for 12 hours to assess the integrity of the ultrasonic weld. Tensile testing to 20 kg has also been performed, without failure.

Stage 6 – PCB production
This included fitting 50 of the new Calf Alert devices with A21 PCB's and another 50 devices with A31 PCB's, desoldering old batteries and installing new batteries that could run an activated device for approximately 2-3 years. Activation starts when the battery is soldered to the PCB. All PCB's are tested for signal strength.

Stage 7 – Assembly (Fig. 3)
This included the assembly and welding of 100 Calf Alert devices with attachment of the nylon anchor spider.

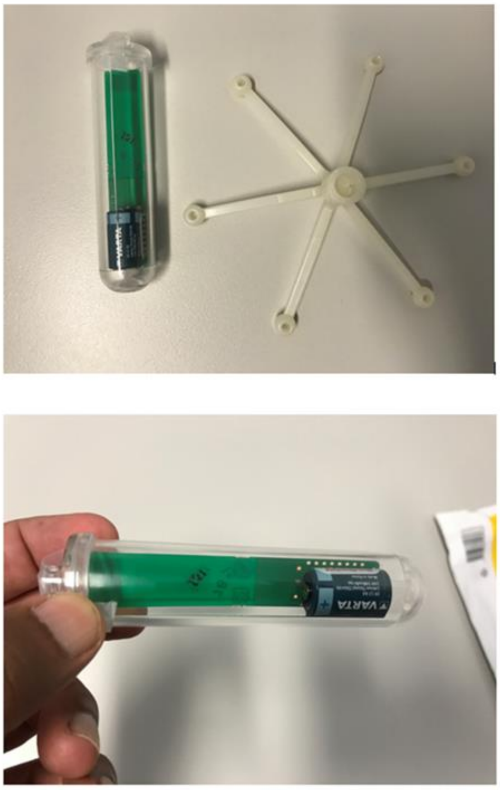


Fig. 3 – Modified Calf Alert device. Shorter than version one, but with more cargo space

To improve the reliability of the device, the following modifications were adopted:

1. **To increase the protection of the Taggle chip within the Calf Alert device**

To increase the protection of the Taggle chip (PCB), the internal diameter of the Calf Alert pod was increased so that the current (A21) and new (A31) Taggle chip fits with less lateral force. Lateral force on the chip was identified as a possible cause of electronic failure. The increased cargo space of the Calf Alert pod was made possible by utilising polycarbonate as the new construction compound. Polycarbonate is stronger than the original acrylic.

2. **To prevent moisture condensation**

To prevent internal moisture condensation, the cargo pod was redesigned with only one opening. The pod was also moulded utilising polycarbonate instead of acrylic. This new material is stronger, allowing the thinner wall (see point 1 above). Polycarbonate also enabled the use of ultrasonic welding to effect a robust seal in contrast to glue used in the two joins of the Phase 1 acrylic device.

3. **To improve signal reception**

50 Calf Alert pods have been manufactured containing Taggle A31 PCB’s. A31 PCB’s have the same signal strength as the A21's (and so a comparable battery life), but the important variation is that they have an improved signal: noise ratio. This means that the signal will be able to be identified at the receiver tower at a signal strength of approximately 5dB less than if it was an A21. In summary, the signal strength is the same, but the signal is clearer, meaning improved reception. Unfortunately, manufacture and delivery of these improved PCB’s was delayed, meaning they could not be fitted into the Calf Alert pods in time for the static field testing. However, they will be available for *in vivo*

testing in September. Calculations predict that the incorporation of the A31 PCB into the Calf Alert device will provide a 30% improvement in signal reception compared to the A21 PCB.

4. **To test signal reception**

To test signal reception, static field tests were conducted comparing the A21 PCB's fitted in the new moisture resistant Calf Alert pods, with the A31 PCB's previously utilised in Taggle water meter devices.

4.1.1.2 Tests for structural strength and leakage

CUBE Industrial designs conducted ultrasonic welding tests with and without the Taggle PCB inside the device. Achieving the optimal welding seal incorporated changing the parameters of ultrasound wave intensity and duration, plus clamp pressure. The original welding horn (the device that transduces the ultrasonic energy to the plastic joint) designed by CUBE Designs could create a watertight weld but was not suitable to completely close the taper/interference fit of the components to the required specifications to ensure watertightness at high pressure. The original welding horn was not able to supply sufficient energy and pressure without rupturing the cargo pod. Therefore, the original welding horn resulted in only two welded lines in the joint instead of the intended three. Work to rectify this deficit resulted in a new ultrasonic horn being customised from a specialist company (Consonics).

Utilising the first of the second-generation pods, pressure testing under water at a pressure of 100 Psi (approximately 7 Bar) for 12 hours has resulted in no water leaks. Tensile testing to 20 kg has seen the weld maintain integrity. Lateral toughness of the device was tested using manual hammer blows, with no failure.

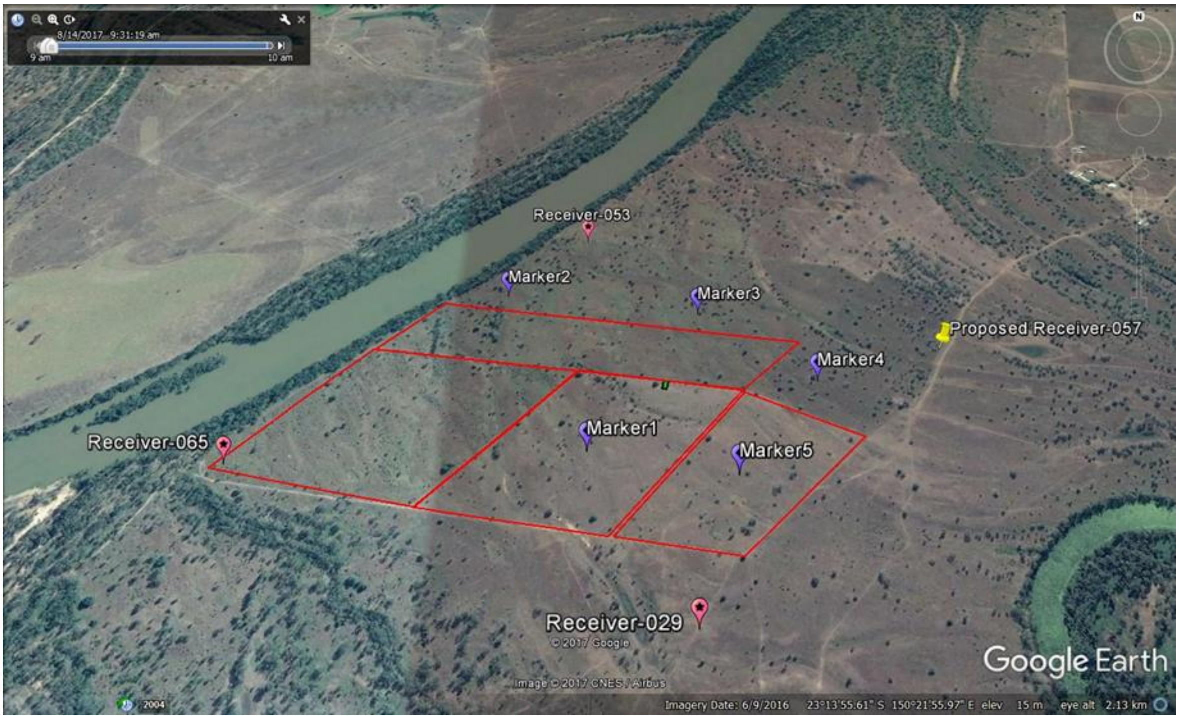


Fig. 4 – Google earth image of the paddocks showing location of the markers and the Taggle receiver towers.

Static Test design; To test and compare the signal strength and/or transmission rates of A21 and A31 PCB's, a static field test was conducted at Belmont Research Station (Rockhampton). Five markers (tomato stakes hammered into the ground) were placed within the boundary of the Taggle receivers, which included the four paddocks in which the experimental cows graze (Fig. 4).

Markers are numbered from 1 to 5 and the receivers are numbered 029, 053, 057 and 065 (after the completion of the static test Receiver-057 was moved to the proposed location)

Due to manufacturing delays beyond the control of project management, it was not possible to get the A31 PCB's fitted within the modified Calf Alert device prior to commencement of the static test. The A31 Calf Alert devices were received only by 12th of Sept 2017 and hence a brief static testing was conducted from 13th to 15th Sept (details provided in section 4.5). In place of Calf Alerts fitted with the A31 PCB's, Taggle Systems provided used water meters containing the same A31 PCB to be used in the modified Calf Alert device. Factors beyond the control of this study were battery quality in the used devices and variation in signal attenuation from the Calf Alert.

For the static test, five modified Calf Alert devices fitted with A21 PCB's (Fig.3) and 10 Taggle water meters fitted with A31 PCB's (Fig. 5) were deployed. The bottom of each marker (stake) was taped with one Calf Alert device with A21 PCB and two water meters with the A31 PCB. The locations where markers were placed had varied quantities of forage due to floods and varied grazing. Markers 2 and 3 were in an area where the forage was 60 and 85 cm tall when compared to others which were less than 15cm. Three land-based receiver antennae's (Fig. 4 – Receiver # 029, 053 and 065) were located between 630 and 1,128m from the centre of the paddocks with the fourth receiver (# 057) approximately 6,370m away on the top of a hill.

Fig. 5 – Taggle Water Meter with A31 PCB used in the static test (Image courtesy - http://www.taggle.com.au)

4.1.1.3 Data collection and statistical analysis:

Data were collected over two test periods (9th to 14th Aug 2017 and 14th to 21st Aug 2017) and included information on device receptions, locations, accuracy and precision. After the initial period, A31 devices at each marker had their orientation changed to a more favourable position to test whether this increased receptions/locations.

Code was written in R Foundation for Statistical Computing software (R version 3.1.1) to perform all statistical analysis. To monitor the number of receptions at each receiver, a histogram was generated of the number of receptions per device. Additionally, the receptions per day over the data collection period were graphed. The data showed that there was no difference in the receptions from the A31 device based on the two orientations trialled and therefore data was pooled into one data collection period for all statistical analysis.

For the location data, a histogram was generated of the number of locations for each device. The average number of locations for each device type over the data collection period was also calculated. The longitude and latitude coordinates provided by Taggle Systems were converted to Universal Transverse Mercator (UTM) Cartesian coordinates which reference the Australian Geodetic Datum (GDA94) (Zone 56) and graphed per device to show the scatter of coordinates compared to the marker location.

Statistics were calculated on both the precision and accuracy of the devices. The precision provided a measure of variance whereas the accuracy provided a measure of the closeness to the true location generated from the handheld GPS unit.

4.1.1.4 Final Field Testing at Belmont and Longreach

4.1.1.4.1 Animal Ethics

All procedures used in the study were approved by the CQUniversity Animal Ethics Committee (approval number 20664).

4.1.1.4.2 Animals and data collection

The aim of this field trial was to test the performance of an updated Calf Alert device-pod containing either A31 printed circuit boards (PCB's) or A21 PCB's in pregnant cattle, coupled with sensor ear tags to record date and time of calving, and further assess if combined output from these devices could detect calving within 12 hours of actual calving and within 50 meters of actual calving locations. The planned application of Taggle radiolocation ear tags to simultaneously monitor movement behaviour was not fulfilled due to supply failure.

This study was conducted at both Belmont Research Station (Belmont) (150° 23' E, 23 ° 13' S), approximately 26 km north of Rockhampton, in Central Queensland and Longreach Pastoral College (Longreach) (144° 13' E, 23 ° 28' S), approximately 15 km south of Longreach, in western Queensland. Two types of Calf Alert devices, differing only in PCB's circuitry (A21 & A31) were tested at each trial site. The A21 devices have been used in all previous Calf Alert experimental work. The two device types operate at the same signal strength so have comparable battery life. The A31 boards have an improved signal: noise ratio. This means that the signal is received by the Taggle receivers at a signal strength of ~ 5dB less than if it was an A21. This should result in the A31 devices achieving more receptions and locations than the A21. In addition, due to the perceived failure of the Calf Alert device in a previous trial due to condensation on the PCB, all devices were hermetically sealed and pressured tested to ensure water ingression could not occur.

Forty-three cows from an existing herd at Belmont were mustered on the 15th September 2017 for Calf Alert device insertion. The cows were born between 2008 and 2014 with the majority born in either 2010, 2011 or 2012. A block design was chosen to divide cows into blocks based on their year of birth (T1). The website Random.org was used to randomly allocate device types within blocks. As each cow entered the crush to have their device inserted, based on their sequence number and block, they were allocated the device type. Only 40 of the 43 cows had devices inserted with the reason for excluding cows including not being pregnant or having poor temperament. There were 22 cows allocated the A21 device and 18 cows allocated the A31 device.

Table 1: Block design for the breakup of cows into different age groups

Block	Year Drop	Count
1	2008 – 2009	9
2	2010 – 2012	25
3	2013 – 2014	9

In order to have 40 cows that would calve within the desired timeframe at Longreach, a group of Brangus cows were trucked from another Queensland Agricultural Training Colleges property ("Berrigurra") and added to an existing herd of 20 Santa Gertrudis cows. The 20 Santa Gertrudis cows had their devices inserted on the 6th October 2017. Again, the Random.org website was used to randomly allocate the device types to each cow, however, as the cow ages were not known prior to insertion and dentition was not assessed, the year of birth was not considered. Therefore, based on the sequence number of the cow through the crush, they were randomly assigned either an A21 or an A31 device. There were eleven A21 devices and nine A31 devices inserted.

The second group of cows at Longreach had their devices inserted on the 17th October. There was a total of 24 Brangus cows to choose from, with three removed due to not calving in the desired window and one due to low body condition (the cow was mouthed and found to have no teeth). The device types were allocated using the same procedure as employed for the previous Longreach mob on 6th October 2017. There were nine A21 devices and eleven A31 devices inserted.

Taggle networks were established at both trial sites with each site having four Taggle receivers. The Taggle network at Belmont covered an area of approximately 149.5 ha whereas the network at Longreach was 975.6 ha. At each trial site three of the four receivers had their antennas mounted on 15 m masts, whereas the antennas at receiver Taggle-057 at Belmont and receiver Taggle-320 at Longreach were only mounted on 12 m masts. At Belmont, cows were rotated between two paddocks (47 ha) within the Taggle network while at Longreach all cows grazed in a single paddock (376 ha) throughout the experimental period. Images of the two trial sites and the paddocks used throughout the experimental period are shown in Fig.6.

To determine the approximate distance the Calf Alert device transmissions had to travel to reach each receiver the distance from a point, claimed as the centre of the paddock, to each receiver was calculated. The coordinates of the Taggle receivers and the paddock boundaries were imported into Google Earth and the centre point derived. The process used to derive the centre point in the paddock was to find where the half-way point on the paddock boundaries intersected. The Google Earth ruler was then used to measure the distance from the centre point to each receiver.

Due to some hardware issues the Taggle network at Longreach was not fully operational until the 17th October. One cow calved on the 14th October when only 2 receivers were operational and was therefore excluded from the data analysis.

Fig.6- Trial sites at a) Belmont and b) Longreach with the boundaries of the paddocks used throughout the experimental period shown in red.

Cows began calving at Belmont on the 13th October 2017 and at Longreach on the 14th October 2017. The last cow calved on the 22nd December 2017 at Belmont and the 4th January 2018 at Longreach. Cows were checked daily throughout the calving season to record the calving date of each cow. This involved staff driving around the calving paddocks in either motor vehicles or motor bikes and observing cows for signs of a recent parturition event such as a new born calf, obvious calving site, and presence of after birth etc. The cow's identity and calving date were recorded as well as udder and teat structure, calf details and location of the calving site (if identified).There were two Santa Gertrudis cows and 3 Brangus cows at Longreach in which the calving date was not recorded. It is unknown whether these cows calved successfully as no calves were found and therefore all 5 cows were removed from the data analysis that considered how closely the peak in receptions coincided with the observed calving date and whether the calving location could be ascertained. When excluding the cow that calved prior to when the Taggle network was fully operational, and those cows without calving dates, there were 34 cows included in the data analysis at Longreach. All 40 cows at Belmont had a calving date recorded and were therefore included in the analysis.

4.1.1.5 Data processing and analysis

Code was written in R Foundation for Statistical Computing software (R version 3.1.1) (R Core Team 2014) to import the CSV files, generate graphs and perform the analysis to monitor the receptions and locations provided by the 41 devices (which included a replacement device). Data were accumulated for the 180 days from the time of device insertion until the end of the calving period (the data collection period). However, to check that all devices were functioning prior to insertion a Pearson's correlation coefficient was performed to compare the time before insertion with the number of transmission. Data was extracted from 8:32am on the day of insertion, when the first receptions where noted, until the last cow had the device inserted at 12:13pm.

To monitor the number of receptions at each receiver on a daily basis, a webpage was developed using the Shiny R package (Chang et al. 2016). The webpage generated a bar chart with separate bins for each hour of the day on the x-axis and the count of receptions on the y-axis, with a separate graph for each of the four receivers. Once a device provided receptions it was checked to see if a location was being provided and if the cow had calved, based on the daily calving observations. If the device provided a location the GPS coordinates were used to attempt to find the device and if found the location was staked, photographed and GPS coordinates derived using a Garmin Oregon 550 (Garmin International, Inc. Olathe, Kansas, USA) handheld GPS unit.

The reception data was initially analysed to determine the number of receptions from each of the four receivers. This was achieved by calculating the total receptions for each receiver and then graphing the number of receptions per day per receiver over the duration of data collection.

Any failure of the Calf Alert devices was calculated by determining the date of the final reception for each device. The cumulative decrease in device survival was calculated over the experimental period. This was achieved by calculating the total number of devices having receptions at the day of device insertion and then subtracting the sum of all devices that had failed within that and all previous 30 day periods, until the end of the experiment.

Peak in receptions from Calf Alert devices as an indicator of calving date

To assess whether a peak in receptions could indicate date of calving, the receptions for all receivers were combined and the total receptions per device per day graphed. The observed calving date was inserted as a red vertical line on the graph. The ability to visually distinguish the time of calving, based on a peak in the number of receptions coinciding with the observed calving date, was assessed for all Calf Alert devices.

4.1.1.6 Locations from Calf Alert devices to derive the calving site

The GPS coordinates for all devices that provided locations were accumulated over the data collection period and averaged for each Calf Alert device. Using Google Earth to reference Belmont Research Station, the locations of the Calf Alert devices and the Taggle receivers were mapped.

The precision of the derived locations for each found Calf Alert was assessed by comparing all locations for each device with the mean location. The longitude and latitude coordinates provided by Taggle were converted to Universal Transverse Mercator (UTM) Cartesian coordinates which reference the Australian Geodetic Datum (GDA94) (Zone 56). The Euclidean distance (d) from the mean Calf Alert derived location to each individual location were assessed to calculate precision using:

$$d = \sqrt{(x_a - x_b)^2 + (y_a - y_b)^2}$$

Where x_a is mean Calf Alert easting location, x_b is the individual Calf Alert easting location, y_a is the mean Calf Alert northing location and y_b is the individual Calf Alert northing location. Once the Euclidean distance from each individual location to the mean location was calculated, all the values for each individual device were averaged to provide the mean precision for each Calf Alert device.

The accuracy of the found Calf Alert devices was measured by comparing the Calf Alert averaged locations with the handheld GPS coordinates. The Euclidean distance formula (above) was again used but instead of x_b and y_b being the individual Calf Alert easting and northing coordinates they were the GPS easting and northing coordinates. The distance between the mean Calf Alert coordinates and the GPS coordinates provided the accuracy for each Calf Alert device.

Two types of files, which relate to the receptions and locations generated by each Taggle device, were imported from the Taggle System Pty Ltd server to a CQUniversity server. Code was written in R Foundation for Statistical Computing software to import the CSV files. The reception and location files were accumulated for the experimental period starting at 1pm on the 15th September 2017 until 1pm on the 12th February 2018 (150 days). The reception files listed the device transmissions received by each receiver (tag number, date and time, Taggle receiver number and received signal strength indicator) and the location files listed the tags that had a location derived from each Taggle network (date and time, tag number, longitude and latitude).

The reception data was initially analysed to compare the number of receptions per device type, per trial site and per Taggle receiver. The reception data was further analysed to determine the number of receptions per day from each of the four receivers at each trial site in order to determine if each receiver functioned continually. This was achieved by calculating the total receptions for each receiver and then graphing the number of receptions per day per receiver over the experimental period.

To assess whether a peak in receptions from a Calf Alert device could indicate the date of calving, the total receptions for each device from each of the four receivers at each trial site were summed and the total receptions per device per day graphed. At Belmont especially, presumably due to the smaller area covered by the Taggle network, and to a lesser degree at Longreach, device transmissions were attained by the Taggle receivers while devices were still in the vagina. This meant that in many cases a low number of receptions were accumulated before the parturition event. Within the graphs showing receptions per day for each device, the date of the observed calving event was displayed as a red vertical line. The graphs were visually assessed to determine whether a peak in the number of receptions was within ± 24 hours of the observed calving date and therefore could provide accurate information on the date of calving.

The location data was analysed in a similar fashion to the reception data to compare the number of locations provided per device type and per trial site. In order for the technology to provide information on the causes of perinatal loss, the device needs to provide a location at the point of calving. If it is provided prior to calving and/or not after calving it may indicate that the device has been expelled from the vagina prior to calving or that the device has malfunctioned. Therefore, the date of the last location from each device was compared with the calving date to assess whether the locations were provided at and after the point of calving. Devices were also assessed for the precision of the generated location, which provides an indication of the variance by comparing the mean location for each device with the distance to all its locations. There were two devices at Longreach that were not included in the precision analysis due to them being moved from the location in which they were found.

Data from the day of insertion showed that all devices were transmitting prior to being inserted. When comparing the number of receptions from each device with the time of insertion, there was a significantly correlated ($P<0.001$) Pearson's coefficient of 0.99.

Based on the monthly ultrasound observations, there were 7 devices expelled before the cows calved, with only one of the devices replaced. This provided a device retention rate of 83% (34 of 41 devices remained in situ). In addition, after all cows had calved and coinciding with the final ultrasonic assessment, one cow was noted to still have a device present, with DNA analysis confirming that she was the mother of the assigned calf.

Over the 180 days of data collection there were 79,298 receptions for the 4 Taggle receivers, with large variations in the number of transmissions received (Fig. 7). The total receptions were 19,020, 24,879, 420 and 34,979 for receivers Taggle-029, Taggle-053, Taggle-057 and Taggle-065, respectively.

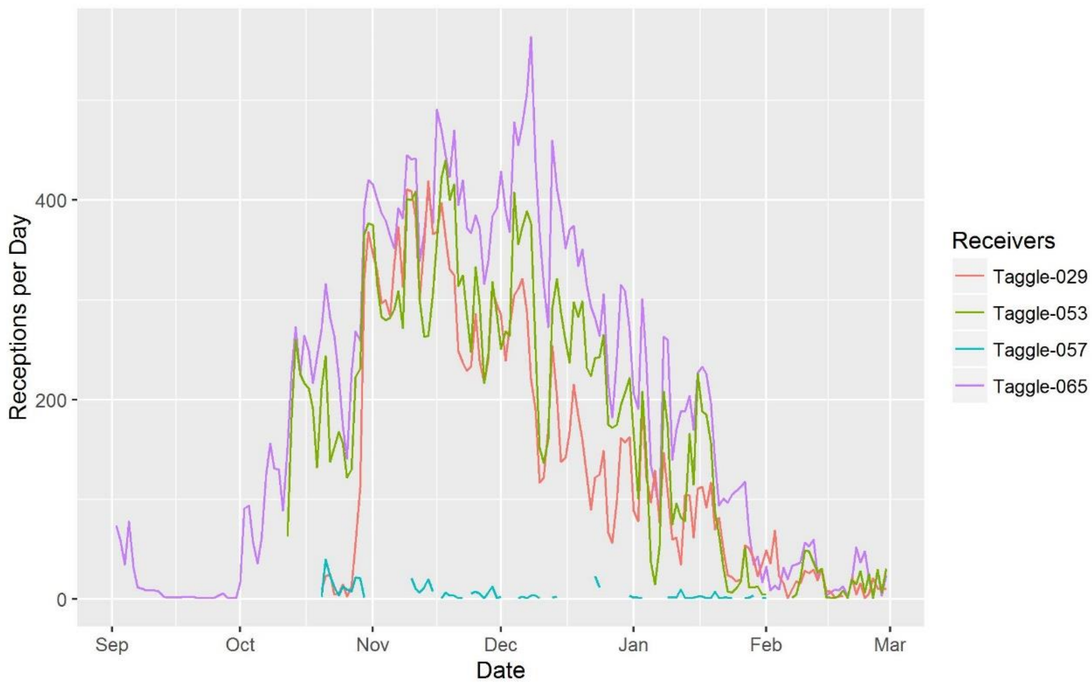


Figure 7- Transmissions received by each of the four Taggle receiver towers over the data collection period

When comparing the receptions from each Calf Alert device the results showed that some devices were not detected by any receivers. Thirty-four of the 41 devices provided receptions throughout the data collection period, however seven had no signal picked up by any of the receivers. Of the 34 devices that transmitted after insertion only 13 had receptions post calving, two of which were excluded as they were noted to have been expelled at the ultrasonic assessment prior to calving. Of the 21 devices that transmitted post insertion but not continuing until calving, the majority (all but 5 devices) only registered transmission in September well before calving. There were two cows that did not get a recorded calving date but since their Calf Alert devices stopped transmitting only 3 days after insertion, which is well before calving started, they were still included in the group that did not transmit post calving.

The Calf Alert device failure throughout the data collection period, shown as the month in which the devices registered their last reception, was as follows: September = 23; October = 3; November = 2; December = 4; January = 3 and February = 6. The cumulative decrease in survival, shown as those devices that were transmitting at the end of the each 30 day period, illustrates the stark decline from the 41 devices operating on the day of insertion to only 18 devices working after 30 days. There was then a linear decline in survival over the next 150 days with only two devices transmitting to up to the last day of data collection (Fig. 8).

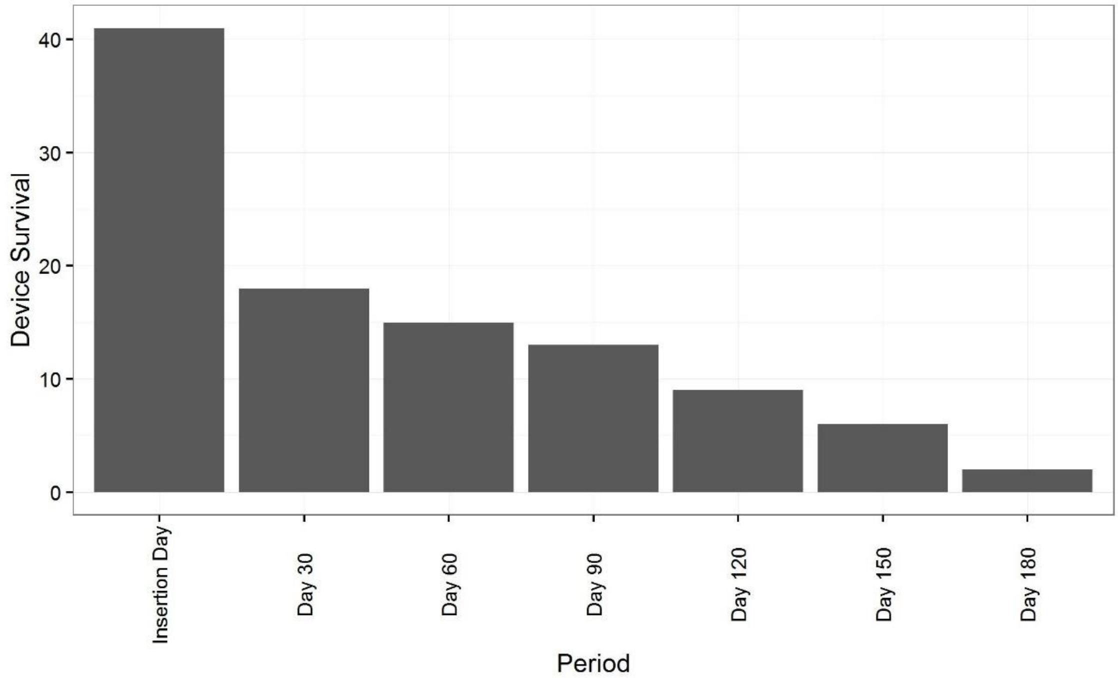


Figure 8 - Cumulative decrease in Calf Alert device survival over the experimental period showing all 41 devices operating prior to insertion, then a stark decline after 30 days and a gradual drop off over the rest of the period.

4.1.1.7 Peak in receptions from Calf Alert devices as an indicator of calving date

Of the 11 devices that provided receptions past the point of calving, the visual assessment of their transmissions showed peaks in receptions as follows: three devices were within 24 hours of calving, four devices were 2 days prior to calving, three devices were 3 to 7 days prior to calving and one device was 15 days prior to calving. The peak in receptions was on average four days prior to the calving date. The best and worst indicators of calving, based on the peak in receptions, are shown in Fig. 9.

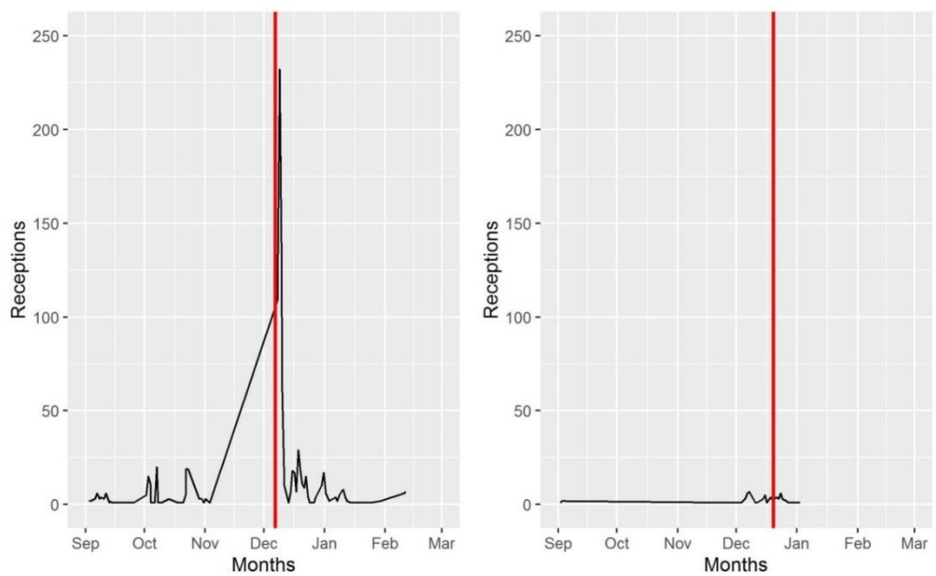


Figure 9 - Graph of the device receptions showing the best indicator of calving with the peak in receptions corresponding with the calving date (left window) and a very poor indicator of calving with the peak in receptions 15 days prior to calving (right window)

4.1.1.8 Locations from Calf Alert devices to derive the calving site

There were 12 devices that provided locations, the number of location logs varied from two to 1211 per device, with a total of 4002 data points (T2). The devices from three cows were recorded as having fallen out at an ultrasound scanning prior to them calving and two of the devices provided locations well before the cows calved. These two cows were noted as having their device protruding from their vulva greater than 30 days prior to calving. All three devices are therefore excluded from those devices that provided a location possibly associated with calving. Two other devices (3301 & 3126) were included in those providing receptions post calving but did not derive a location.

Table 2. Count of the number of location logs provided per Calf Alert device over the experimental period.

Calf Alert device	Count
3096	1101
3286	205
3300	1080
3378	153
3379	5
3386	187
3398	2
3403	4
3411	41
3418	1211
3421	6
3860	7

One device provided a location three days before calving, three devices were on the day of calving or the day after, two devices were between 4 and 11 days after calving and three devices were between 12 and 27 days after calving. The average time from calving to providing a location was 8 days.

The locations of the 9 devices, the three closest Taggle receivers and paddock boundary are shown in Fig. 10. The derived locations for devices 3421 and 3379 were not within the area that the cattle grazed and can be seen as the pins to the west of the paddock within the river.

Figure 10 - Google earth image (16m above sea level) of the calving paddock with the white line showing the perimeter and the green teardrops showing the derived locations for the 9 Calf Alert devices. Also shown, as pink teardrops, are three of the four Taggle receiver towers.

Four devices that provided locations were located in the calving paddock. Two of the four devices were within or close to the precision described by (Menzies *et al.* 2016) who recorded precision values of ±22 m in a static array of Taggle devices. Device 3300 was less precise than was expected and device 3421 had a large variation in the derived locations as evidenced by it being located within the river in Fig. 10. The location accuracy showed the same trend as precision with two of the four found Calf Alert devices being less than ±6 m and the third device was less than ±22 m. It was only device 3421 that provided an inaccurate location, which was consistent with the device's precision (T3).

Table 3. The precision and accuracy of the derived locations for each found Calf Alert devices. Precision is measured as the Euclidean distance between the averaged and individual locations where as accuracy is the Euclidean distance between the average location and the GPS derived locations.

Devices	Precision (m)	Accuracy (m)
3286	18.73	5.98
3300	69.96	21.38
3418	23.68	0.40
3421	607.08	489.35

Cow 4944, which had device 3421, calved on the 21 October and the three locations derived on that day were all well away from the site where the device was found. The three locations provided on the 10 and 11 November were much more tightly grouped around the location where the device was found but the other locations distorted the average. The other device that provided a location outside the paddock boundary, device 3379, had five derived locations and all were within the river and as the device was not found, there is no way of assessing how precise or accurate the locations were.

There were two other devices found in the calving paddock with neither generating any locations even though they appeared to be ideally situated. This contrasts device 3300 that provided the third greatest number of locations but was found in an area with numerous seedling and sapling trees (Fig.

11). In addition, one of the devices found without providing locations had condensation on the inside of the Calf Alert housing.

Figure 11 - Images of Calf Alert device 3300, which provided 1199 locations in a less than ideal setting and Calf Alert device 3327, in a seemingly ideal locality but provided zero locations

There was a trend towards less locations being provided as the calving season extended. Of the 38 cows that had calving dates recorded the percentage that provided a location decreased from 55% in October almost linearly to 0% in February (T4).

Table 4. The number of cows calving, the number of Calf Alert devices providing locations and the locations provided as a percentage of cows calved in each month of the calving season.

Calving month	Number of cows calved	Number of locations	Percentage
October	9	5	56%
November	9	2	22%
December	13	4	31%
January	5	1	20%
February	2	0	0%

4.1.1.9 Report on scoping to improve transmission and reception and report on whether the receiver can be miniaturized to optimize for use in a UAV

Taggle has upgraded the Calf Alert chip from an A21 to an A31. This translates into a 30% increase in transmission signal strength compared to the A21 chip used in the study reported in this document. It was also calculated that there will be a 30% improvement in signal reception with every doubling of the height of the receiver tower. Taggle estimate will cost approximately $10,000 to get tooling done to create A31 PCB's to fit the calf alert device. Once tooling is complete, each PCB will cost about $5. Taggle also advised that a multiple input receiver (MI), will help with signal detection.

One problem noted in the current trial was that many of the devices contained moisture condensation within them when found after expulsion from the cow. Technical advice from Taggle was that any moisture within the device would adversely affect the PCB and the transmitting antenna. This condensation problem would explain all of the device transmission failures in the current trial. Options to prevent moisture entering the device include:

- Putting a conformal lacquer coating over the PCB and/or the complete Calf Alert cargo pod to prevent moisture damage
- Placing moisture absorbent material within the calf alert device
- Potting the electrics (that is filling the Calf Alert cargo pod up with resin) to completely protect the electrics within the device
- Filling the Calf Alert cargo pod with expanding foam

Additionally, there is a plan to increase the internal diameter of the Calf Alert device so that the Taggle chip fits with less force. Currently, there is a very slight bend in the circuit board to allow it to fit within the internal diameter of the Calf Alert cargo pod. This slight flexion of the circuit board may result in damage to soldered connections during deployment.

4.1.1.10 Update on the use of behavioral algorithms as a calving predictor

Results from current and previous studies are showing that at calving, cows become more agitated, spend periods of time moving between standing and lying, and isolate themselves. A number of telemetry technologies provide the opportunity to monitor and identify behavioural signals that are indicative of the onset of parturition. The use of proximity loggers in earlier reported studies has shown that the temporal changes in social behaviour is a good indicator of date of calving and may time the event to within 12 hours.

Calving events are indicated by reduced movement over a 24 to 48 hour period. The ability to determine an accurate calving event using the Taggle system requires accurate and reliable location information. Preliminary data from earlier studies showed that Taggle ear tags may have had the potential to identify calving events based on the movement of the cows. However, this study has demonstrated that the current Taggle tags are not able to provide sufficient location accuracy to accurately determine a calving event. Further work is being conducted to determine whether the upgraded Taggle tags, coupled with optimally tuned receiver towers will be able to provide more reliable location information.

4.1.1.11 Results on static test at Belmont Research Station using the modified Calf Alert Device with A21 PCB and Taggle Water Meters with A31 PCB

When comparing the receptions from the A21 **Calf Alert** and A31 **Water Meter** devices, there was a marked difference in the performance of the two devices. The average receptions per day for the two devices were 265.5 for the A21 devices as opposed to 51.6 for the A31's. In order to compare the receptions per day across the data collection period the data was restricted from the 10th to the 20th August to get complete 24 hour periods. The graph of receptions per day (Fig. 12) showed reasonably consistent receptions for each device and each device type (A21's v's A31's) and that the change in orientation of the five A31's had no influence on the reception number. One A31 device provided no receptions during the data collection period.

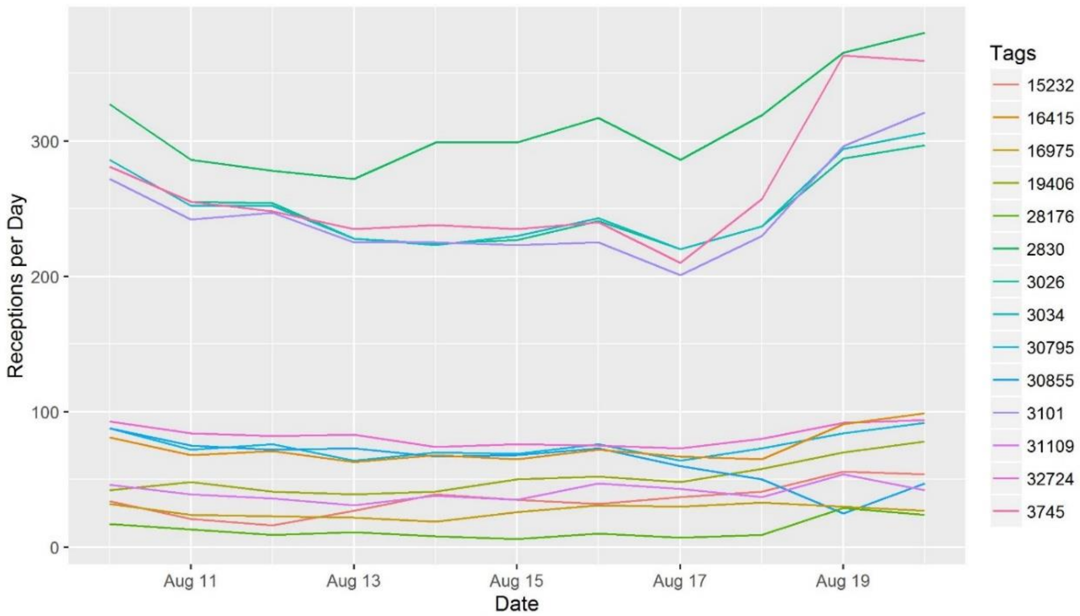


Fig. 12 – Receptions per day per device over the data collection period. The A21 devices (4-digit Tags) had approximately five times the number of receptions per day than the A31's (5-digit Tags).

When analysing the location data, it was apparent that only 13 of the 15 devices provided locations, with two devices not providing any location data being A31's. The location data followed the same trend as the reception data with the A21 Calf Alert devices attaining far greater locations than the A31 water meter devices (70.4 V's 11.1, respectively). All functioning devices (13/15) provided an adequate number of locations irrespective of the amount of forage in which they were placed.

A summary of the locations provided over the 11 days of the static data collection is shown in the figures below (Fig. 13 to 17):

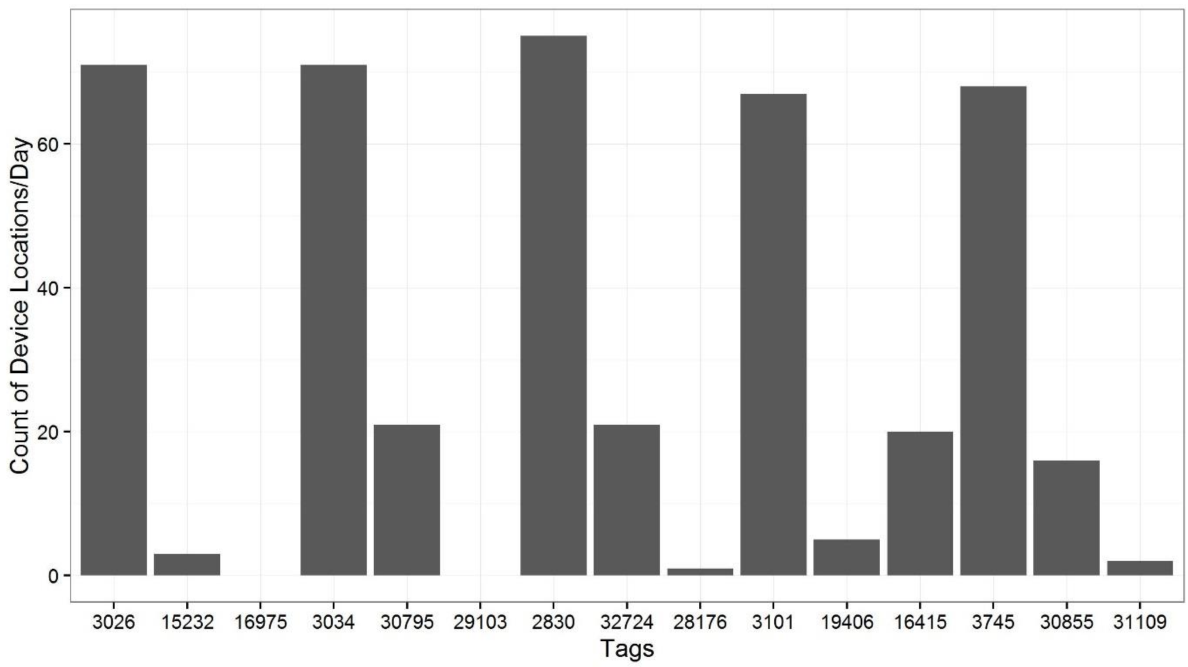


Fig. 13 - Locations provided over the static test (9th to 21st Aug 2017) – On the horizontal axis, four-digit identifiers represent the modified Calf Alert device with A21 PCB's while five-digit identifiers represent the used Taggle Water Meter with A31 PCB's.

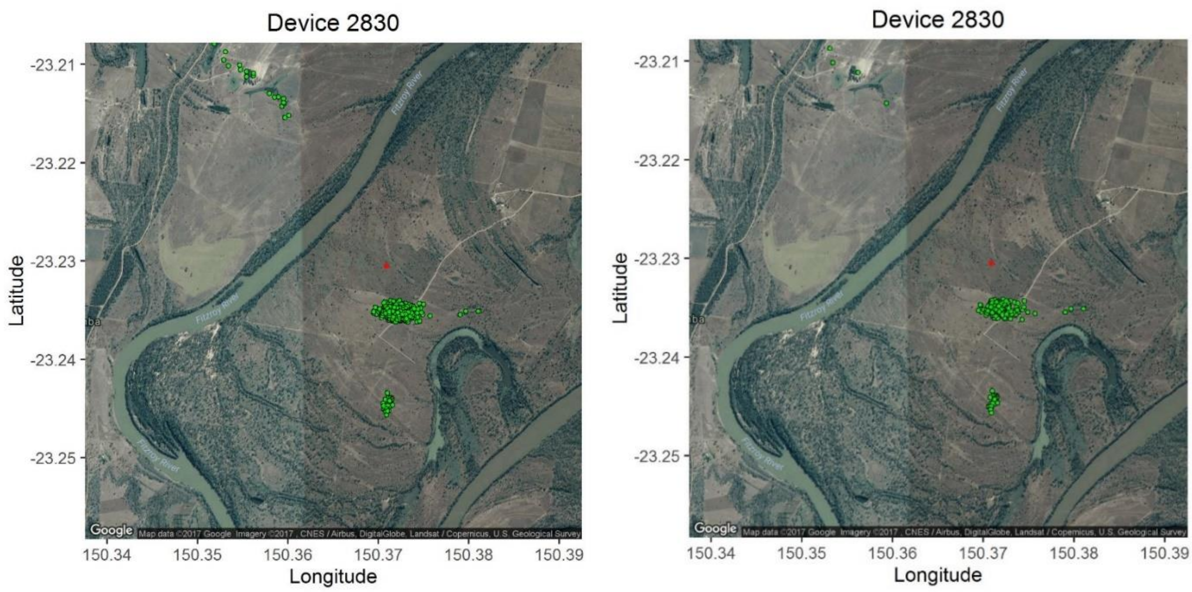


Fig. 14- A21 Calf Alert device with the highest number of derived locations (green dots represent the derived locations and red dot represents the marker/stake). Left image is Trial one; Right image is Trial two.

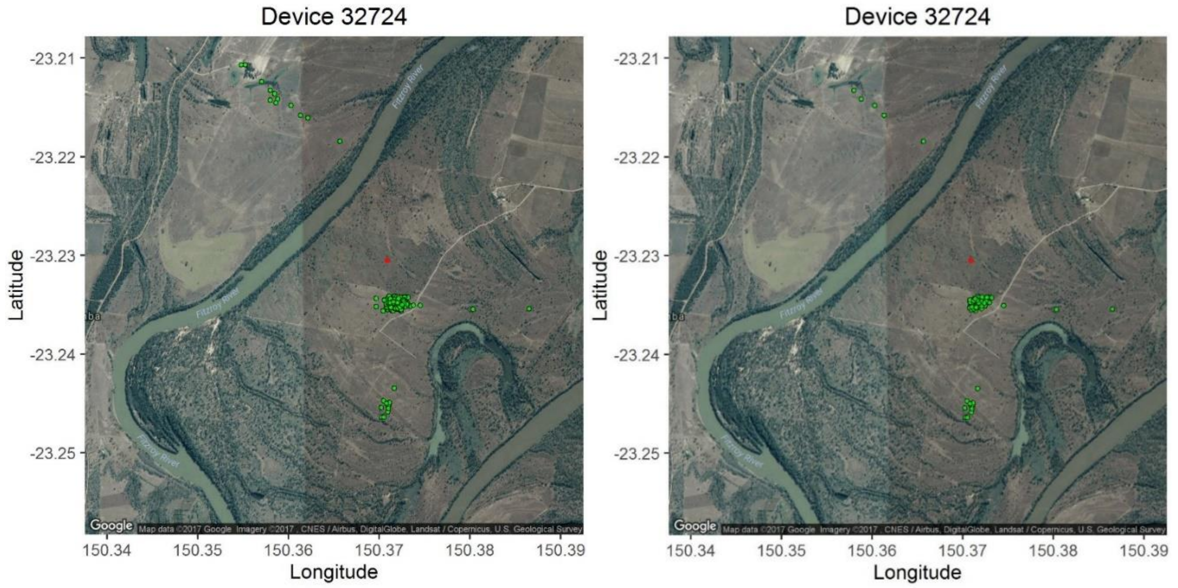


Fig. 15- A31 Water Meter with the highest number of derived locations (green dots represent the derived locations and red dot represents the marker/stake). Left image is Trial one; Right image is Trial two.

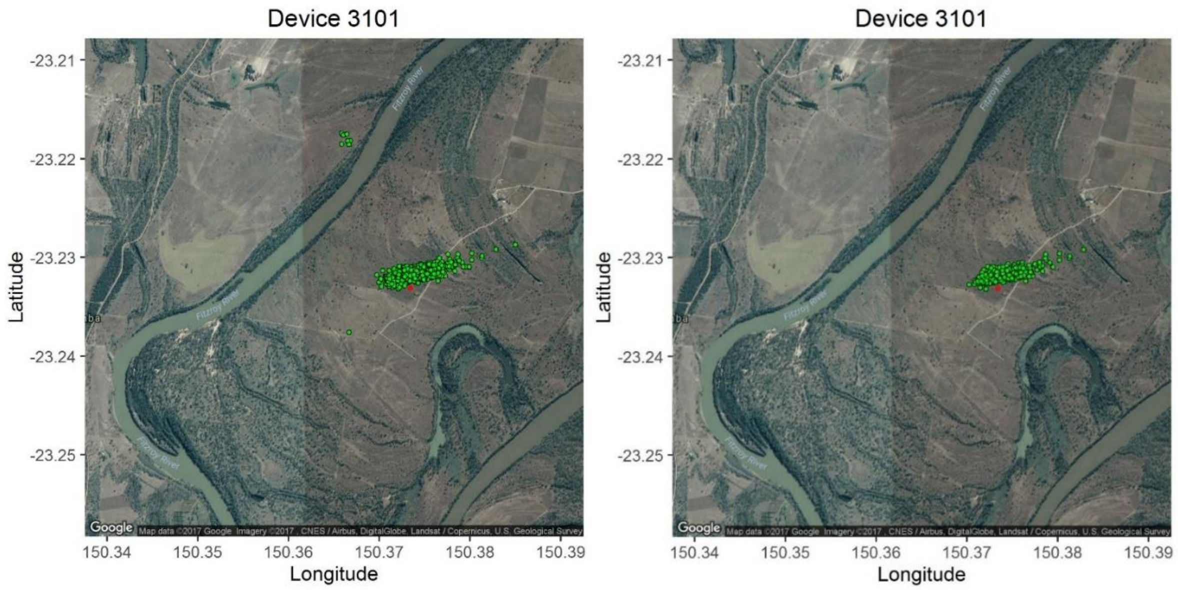


Fig. 16 - A21 Calf Alert device with the least number of derived locations (green dots represent the derived locations and red dot represents the marker/stake). Left image is Trial one; Right image is Trial two.

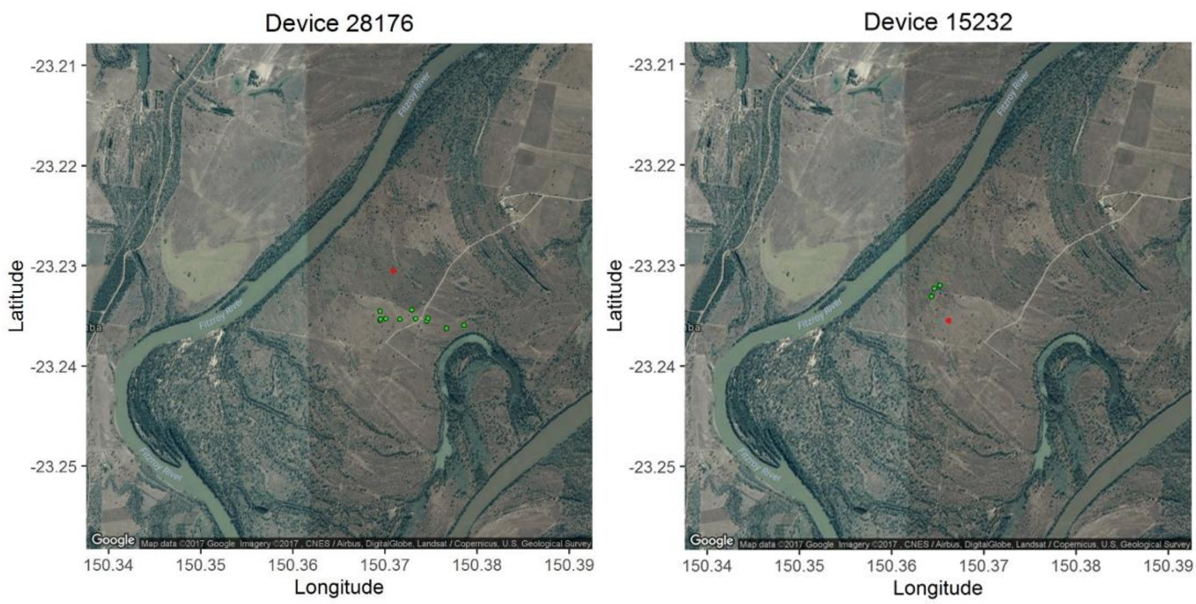


Fig. 17 - A31 Water Meters with the least number of derived locations (green dots represent the derived locations and red dot represents the marker/stake).

The overall precision of the various devices ranged from 51.4 m to 371.8 m with a mean precision of 198.4 m. The different device types also influenced precision with Calf Alert A21's having a mean of 150.2 m, (minimum = 59.8 m and maximum = 263.8 m) whereas the Water Meter A31's had a mean of 228.4 m, (minimum = 51.4 m and maximum = 371.8 m).

The accuracy of the devices ranged from 243.7 to 889.8 m with a mean accuracy of 576.2 m. There was little difference between the two device types with the Calf Alert A21's having a slightly better (shorter) mean accuracy compared to the A31's (560.1 V's 586.2m respectively).

4.1.1.12 Complete investigation into ear tag design to improve retention rate

This objective could not be pursued since Taggle Systems has not been focussing on ear tags in recent times due to a major shift of their focus on water meters. In order to progress with the ear tag design, we might have to do it as a separate project with Taggle.

4.1.1.13 Results upgraded calf alert in pregnant cattle

Over the 150 days of data collection there were 114,293 receptions at Longreach and 383,960 receptions at Belmont. The reception data showed variance between both the device types and the trial sites with the A31 devices having twice as many receptions at Belmont and approximately 22% less receptions at Longreach than the A21 devices (T5).

Table 5: Device receptions at each trial site and for each device type.

Trial Site	Type	Count	Mean	Minimum	Maximum	SD
Belmont	A21	22	6371.6	2	31171	7175.6
Belmont	A31	18	13543.6	349	32058	9903.6
Longreach	A21	20	3215.9	144	14398	4225.9
Longreach	A31	20	2498.7	304	7295	1935.7

The number of receptions per receiver also varied markedly within and between trial sites (T6). The reduced height of the antenna on receiver Taggle-057 appeared to have no effect on its ability to receive transmissions with it attaining the most receptions at Belmont.

Table 6: Device receptions per receiver for each trial site.

Trial Site	Receiver	Distance from Paddock Centre (m)	Count of Receptions
Belmont	Taggle-029	658	98004
Belmont	Taggle-053	802	67695
Belmont	Taggle-057	840	124054
Belmont	Taggle-065	1198	94207
Longreach	Taggle-320	2152	6214
Longreach	Taggle-323	2930	33531
Longreach	Taggle-328	2970	7107
Longreach	Taggle-361	1531	67441

In terms of the number of transmissions being received by each Taggle receiver, the data at Longreach showed large variability between receivers with the receiver closest (Taggle-361) to the calving paddock achieving the most receptions (Fig.18 & T6). The daily reception data at Longreach highlighted that receiver Taggle-328 failed around the 17th November 2017 and therefore only received data for 36 days of the experimental period. In addition, Taggle-320 operated sporadically. The sporadic receptions for Taggle-320 may relate to the malfunctioning of the receiver rather than the height. The reception data for each of the receivers at Belmont was less variable than Longreach with most receivers attaining a reasonably equal number of receptions per day. However, again it appears that one receiver (Taggle-053) operated sporadically throughout the experimental period (Fig.19) with data not collected on 84 of the 150 days of the experiment.

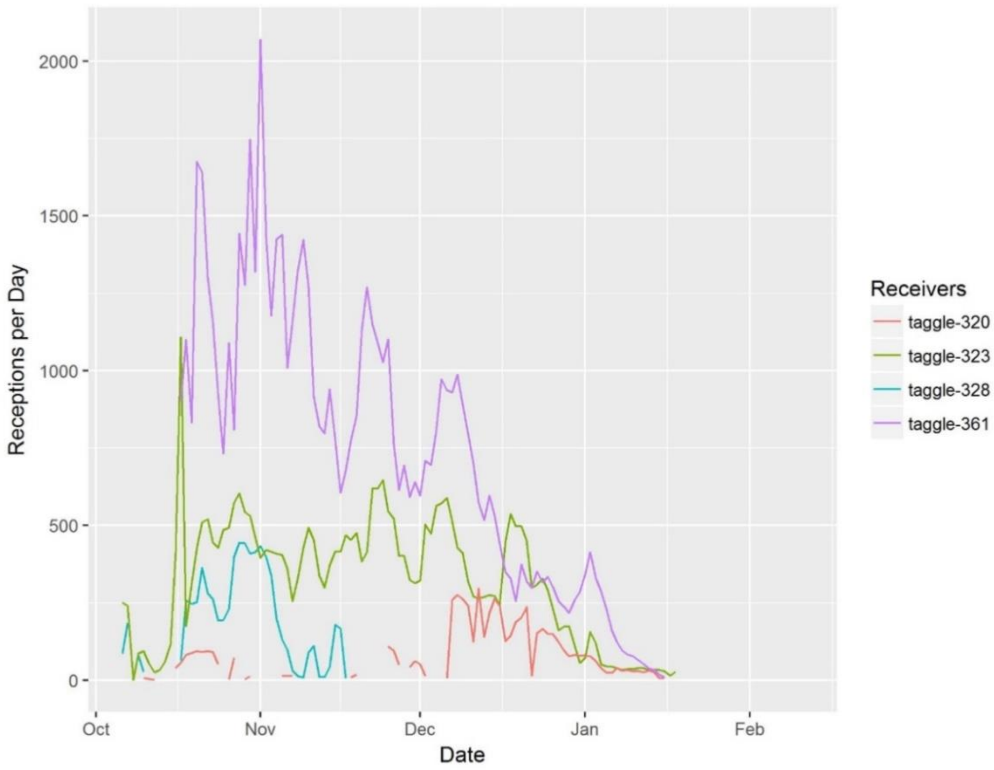


Fig.18 - Daily receptions attained by each of the Taggle receivers at Longreach for the experimental period.

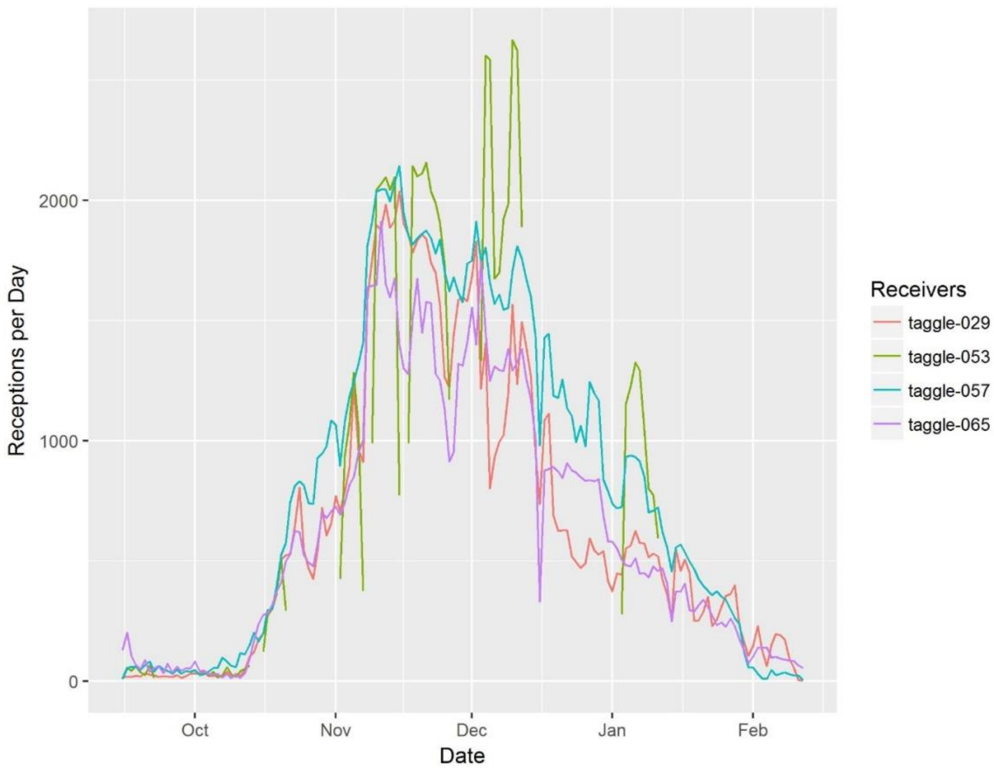
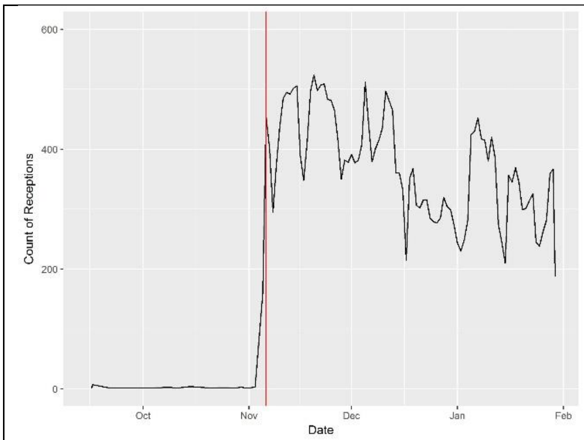
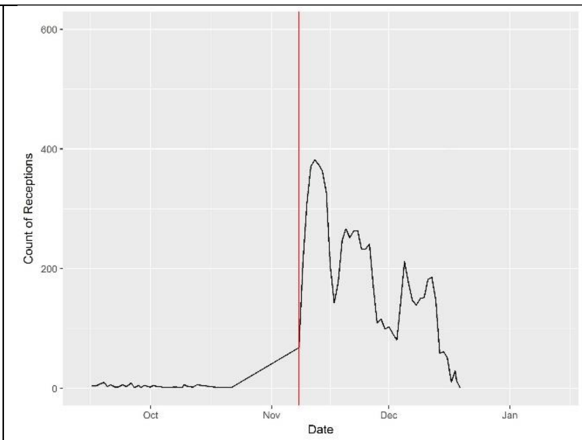


Fig.19- Daily receptions attained by each of the Taggle receivers at Belmont for the experimental period.

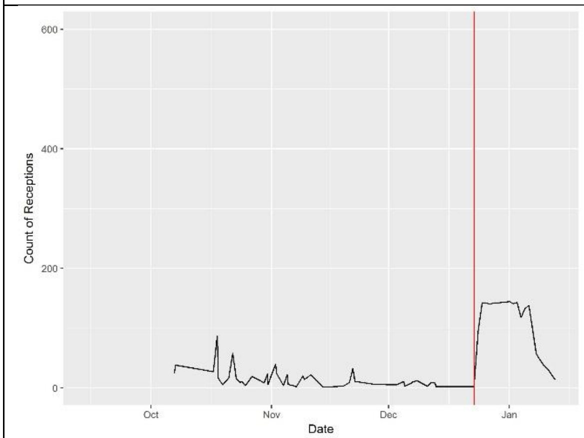
The data on whether a peak in receptions for each Calf Alert device could be used to derive the calving date again showed a degree of variability. Of the 74 cows that had confirmed calving dates and calved after the Taggle network was operational, in approximately 66% of animals the observed calving date concurred with a spike in reception data. The results for Belmont were considerably better than Longreach with 72.5% of calving dates concurring with a spike in the reception data as opposed to 58.8% at Longreach. The results for the different device types were reasonably similar with 63.4% the A21 devices having a spike in receptions concurring with the calving date as opposed to 69.7% for the A31 devices. Examples of the spike in receptions for the two device types and the two trial sites are shown in Fig.20.



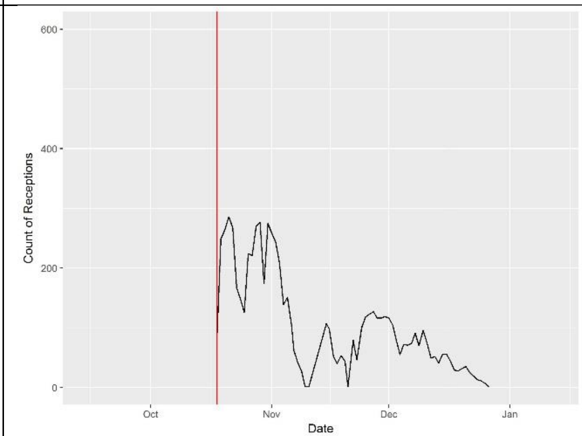
Cow 12-068 at Belmont with an A31 device



Cow 13-336 at Belmont with an A21 device



Cow 4158 at Longreach with an A31 device



Cow H38 at Longreach with an A21 device

Fig.20 - Reception examples for two trial sites and two devices types, a) Belmont cow with and A31 device, b) Belmont cow with an A21 device, c) Longreach cow with an A31 device and d) Longreach cow with an A21 device.

When considering the location data again there was considerable variability between trial sites and device types. Of the 80 devices inserted and over the 150 days of data collection there were 80,319 locations provided. This equated to 6696 locations at Longreach and 73623 locations provided at Belmont. The smaller area covered by the Taggle network at Belmont may have been a factor in more locations being derived at that site (see T7) with a total of 14 devices at Longreach not providing any locations. However, the sporadic operation of receivers Taggle-320 and Taggle-328 could well have impacted on the ability to triangulate locations based on receptions from three receivers. The nonfunctioning devices were spread evenly between A21 and A31 devices with 8 of the A21's and 6 of the A31's not providing locations at Longreach. In summary, there were 66 of the 80 (82.5%) inserted devices that provided locations throughout the experimental period.

Table 7: Device locations at each trial site and for each device type.

Trial Site	Type	Count	Mean	Minimum	Maximum	SD
Belmont	A21	22	1010.9	15	5992	1417.8
Belmont	A31	18	2854.6	17	7633	2394.5
Longreach	A21	20	235.8	0	2056	532.4
Longreach	A31	20	99	0	1086	267.8

The location data from Belmont showed that six devices did not provide a location past the observed calving date, with the last location provided for these devices being a mean of 61 days prior to their recorded calving date. The six devices comprised five A21 and one A31 device types. This meant that 34 of the 40 devices (85%) provided a location after the calving date.

The location data from Longreach showed an inferior result possibly due to the large area covered by the Taggle network and the unreliable performance of the receivers. Of the 34 cows included in the data analysis, 17 devices (50%) provided locations after calving. There were five devices that did not provide locations past the observed calving date with the mean last location for these devices provided 46 days prior. The remaining 12 devices were those that did not provide any location data (the two additional devices not providing a location were from cows that did not get a calving date recorded).

It is possible that if a device was providing receptions past the point of calving and that if all Taggle receivers were operating throughout the experimental period, that more locations would have been provided. Of the six devices at Belmont that did not provide a location to the point of calving only two devices provided receptions past calving. Similarly, of the five devices at Longreach that did not provide a location to the point of calving only two provided receptions past calving. Therefore, the majority of the devices that did not provide locations also failed to provide reception data.

The precision of the derived location was calculated for each trial site and each device type and it would appear that the larger area covered by the Taggle network at Longreach has resulted in less precise locations being provided (T8). Note that the minimum value of zero is a result of a device providing exactly the same coordinates for all locations. When comparing the trial sites, both device types performed with less precision (approximately twice the variance) when the network area increased from that at Belmont to Longreach. The A31 devices provided more precise locations when used in the smaller area at Belmont but they exhibited slightly less precision with the larger network area at Longreach.

Table 8: The device precision (m) at each trial site and for each device type.

Trial Site	Type	Count	Mean	Minimum	Maximum	SD
Belmont	A21	22	125.1	0	429.8	124.5
Belmont	A31	18	102.8	0	609.2	133.2
Longreach	A21	12	217.0	0	1217.6	379.4
Longreach	A31	14	219.2	0	1193.5	328.3

Shown in Fig.21 are examples of the locations provided by the two device types at the two experimental sites. Calf Alert device 3249, an A21 device used at Longreach, provided a location precision of 73.8 m from 758 data points and device 120020, an A31 device used at Belmont, provided a location precision of 61.4 m from 2447 data points.

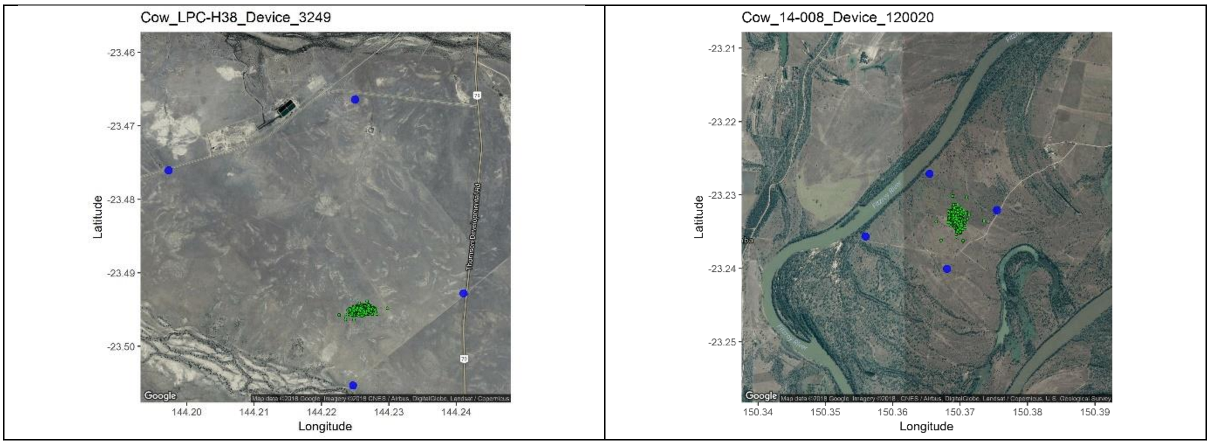


Fig.21- Examples of the locations provided at a) Longreach using an A21 device and b) Belmont using an A31 device

5 Discussion

The aim of this trial was to investigate the long-term retention of Calf Alert device in pluriparous pregnant cows. This was achieved by utilising the calf alert device in 40 pregnant females. This trial confirmed approximately an 85% retention rate is achievable with no adverse effects in extensively managed beef breeders. Discussions with Taggle technical experts identified specific points to improve transmission, including the priority of waterproofing the cargo pod of the device; providing a waterproof conforming lacquer to the chip within the device; upgrading the chip within the device from the A21 to the A31 version. Feasibility of utilising an unmanned aerial vehicle (UAV) was also discussed with Taggle technical experts and they advised that at 7 kg receiver will be too heavy for an affordable, unmanned aerial vehicle. Hence the focus changed towards improving terrestrial receiver towers.

Initial concerns regarding transmission and reception failures of the Calf Alert device in project B.NBP.0666 were that technological deficits associated with the Calf Alert printed circuit board (PCB) and the receiver towers were the main cause of failure. However, progressive recovery and investigation of failed Calf Alert devices from project B.NBP.0666 identified moisture condensation within the Calf Alert pod as the primary cause of failure. Redesign of the Calf Alert pod included reducing two joins to just one; replacing the acrylic construction material with stronger polycarbonate; replacing glue as a joint sealant with the more effective ultrasonic sealing technique; and widening the cargo pod to reduce material fatigue on the PCB. Additionally, the use of an upgraded PCB was investigated for inclusion into the device.

Initial static field testing confirmed that with these modifications, and utilising the original A21 PCB, the Calf Alert device provided between 200 and 400 receptions per day in vegetation up to 85 cm in height. Importantly, some of the highest numbers of daily receptions were recorded from paddocks with more vegetation. This level of reception quality was achieved with four receivers placed between 630 m and 6.3 km from the trial site. Based on this data, there is confidence that the second-generation Calf Alert device containing the A21 PCB can provide accurate time and date data on calving events. Further static field testing using the A31 PCB in the modified Calf Alert device resulted in a higher number of receptions, higher degree of accuracy and greater precision. The outcomes after modification of the device seem to be very promising for the next phase of the in vivo trial at Belmont and Longreach.

The initial location data was disappointing considering the high number of signal receptions. The accuracy and precision of the location data was much poorer than the 15 m to 22 m respectively, reported in project B.NBP.0666. Further discussions with Taggle technicians revealed that a software error associated with identifying the receiver antennae was responsible for these poor precision and accuracy results. The precision and accuracy results have improved significantly after the software error was addressed, with further optimisation possible as more data is collected.

The delay in acquiring A31 PCB's in time for inclusion into the second-generation Calf Alert device prior to the initial static field-trial was disappointing. Having to use A31 PCB's designed for use in water meters added an extra variable to the trial, making comparison of the two PCBs difficult. However, we were able to receive the modified Calf Alert device with A31 PCB's in September and can now verify its higher degree of performance as advised by Taggle Systems. The in vivo field trial could now utilise 40 pieces of Calf Alert with A31 PCB's and another 40 pieces with A21 PCB's.

The aim of this field trial was to test the performance of an updated Calf Alert device-pod containing either A31 PCB's or A21 PCB's in pregnant cattle, coupled with sensor ear tags to record date and time of calving, and further assess if combined output from these devices could detect calving within 12 hours of actual calving and within 50 m of actual calving locations. A static test conducted as part of Milestone 3 had previously confirmed improved performance of the modified version of the Calf Alert device for both reception and location data.

The results from the field trials conducted at the two locations were encouraging with some variations between trial sites. The results from Belmont were a good reflection of the anticipated outcomes from the modified version of the devices in a well-managed environment, with an overall increase in the number of receptions and location data. There was a clear indication of A31 devices outperforming A21 devices as evidenced by double the number of receptions from A31 devices. This was mainly attributed to the performance of the modified device, and uninterrupted functioning of the Taggle receivers which enabled accurate flow and recording of data. The results from Longreach had some variability possibly due to the following reasons:

- Failure of functionality of a few of the Calf Alert devices and hence no data
- Loss of data due to some cows calving before the receivers became operational

- Sporadic recording of data due to intermittent malfunctioning of Taggle receivers
- Devices providing fewer/no locations due to technical problems with Taggle receivers
- Relatively larger sized paddocks at Longreach when compared to Belmont

An explanation of the above points follows:

Over the data collection period, the total number of receptions at Longreach was less than one third of receptions recorded at Belmont. This significant difference is explained by the fact that there were 14 devices at Longreach that did not provide any location data, thus skewing the results. At Belmont, 100% (40/40) of the devices provided location data, which reflects the efficiency of the system in a well-managed environment. Additionally, there was more agreement between the actual recorded calving date and the observed spike in the number of receptions (72.5% vs 58.8%) at Belmont. Although not significantly different, Calf Alert devices with the A31 PCB's showed more agreement in this regard when compared to A21 PCB's (69.7% vs 63.4%). The height of the tower (15-meter vs 12 metre) did not appear to have any significant effect on receptions or locations. Although the number of receptions was less for receiver Taggle-320 at Longreach (6214), it was most likely due to malfunctioning of the receiver rather than the height, or its distance from the paddock. This conclusion is justified by the fact that the 12 m receiver (Taggle-057) at Belmont had the maximum number of receptions recorded in comparison to all other receivers across both trial sites. There was a drop in mean precision in comparison to the initial experimental work using a Taggle ear tag array and previous Calf Alert projects. This was most likely due to a drop in the number of locations recorded in the current trial. Although we could not achieve the required precision of 50 m, it is suggested that the precision would be adequate to locate calving sites. This precision would be improved by optimising the Taggle software to ensure maximum data flow without interruptions, and having improved receiver function associated with commercial installation protocols.

Some of the original objectives were not achieved in this trial for various reasons, however this did not have any significant impact on the expected outcomes, especially when looking at the overall results. The cow movement behaviour around time of calving could not be assessed due to non-availability of sensor ear tags. This was mainly due to a major shift of Taggle Systems focus from ear tags to water meters. Detection of time of calving utilised ± 24 hours rather than 12 hours from the observed calving date to suit the management practices of the trial sites. This increased the likelihood of recording a calving within 24 hours of actual calving. Use of a UAV to monitor calving location, date and time of calving was not an option due to non-availability of a market ready UAV capable of carrying a 7 kg Taggle receiver. This was previously documented in the Milestone 4 report.

6 Conclusions/recommendations

Phase 3 of the Calf Alert project documented tangible improvements, making this technology very promising to monitor calf loss. The initial field trial utilising the Calf Alert devices with A21 PCB's concluded that the retention rate of the device within the pregnant cow was stable at around 85%. This level of retention is compatible with the device being suitable for research into calf loss. Some of the expelled Calf Alert devices were found to have condensation on the inside of the apparatus leading to the conclusion that water ingression had caused electrical failure of a large percentage of devices, resulting in poor transmission and location detection. The recommendation was to directly seal the chip with a conforming, waterproof layer and to improve the seal of the cargo pod following discussions with Cube designs. Another recommendation was to improve the transmission from the Calf Alert device by upgrading the PCB from A21 to the new A31. This would provide up to 30% improvement in receptions and further improve detection and location accuracy. Further discussion with Taggle's technical experts made it clear that unmanned aerial vehicle technology was not yet advanced enough to take a 7 kg Taggle receiver as payload. Their recommendation was not to pursue the use of unmanned aerial vehicles as receivers but to continue improving the terrestrial receivers.

Initial studies into the use of behavioural algorithms provided firm evidence that they could predict the time of calving to within approximately a 12 hour period. It is recommended to pursue that line of research, as it provides a model for developing many telemetrically monitored behavioural algorithms that could assist with monitoring reproductive parameters across the beef cattle production cycle. The usefulness of behavioural algorithms improves as the accuracy of the location and proximity data improves. Currently, GPS collars are providing this accuracy, while the accuracy from Taggle ear tags needs to be improved. It was recommended to use GPS collars as the standard for improving behavioural algorithms, while utilising Taggle tags side-by-side with the collars in an effort to improve the accuracy of this cheaper ear-tag technology. Later it was realised that this objective could not be pursued due to a major shift of Taggle systems focus from manufacturing ear tags to water meters. In order to progress with the ear tag design, we might have to do it as a separate project with Taggle.

The successful outcomes of pressure and leak tests, following the modifications to the Calf Alert device, have had a positive effect on Calf Alert durability and signal transmission. The static field test using the modified Calf Alert device with A21 and A31 PCB's produced excellent results consistent with accurate date and time stamping of a calving event. The fact that the second-generation Calf Alert device produced good signal in the presence of tall forage indicated that the lack of reception and location data noted during the earlier trial was mainly due to water ingress and not signal attenuation associated with vegetation. The poor precision and accuracy of location data derived initially in the static field-trial was due to a software error which was later rectified by Taggle Systems and had led to a significant improvement in accuracy and precision of locations.

The final field trial in Phase 3 confirmed that 82.5% of the inserted devices provided locations throughout the data collection period and 63.8% of devices providing locations past the point of calving. Results also confirmed a higher long-term retention rate of the modified Calf Alert device in pregnant cows without any adverse effects. The precision of calving location in this trial was adequate to locate calving sites. The ability to detect calving within 24 hours of observed calving date would enable the maximum number of calves to be monitored in the first 24 hours of their life thereby increasing the opportunity to identify, investigate and address any calf losses occurring in that time frame.

The current device transmits every 15 minutes and can potentially transmit to receivers up to 7km away (potentially covering 15,000 ha), however our trials have only operated in areas just greater than 1000 hectares and have not had the opportunity fine-tune large-scale receiver function. To allow the Calf Alert device to achieve its maximum potential, there will need to be investment in developing robust systems to optimise receiver technology, location and reliability. This is a necessary approach to take this research to its logical next step of wider industry implementation.

In addition to progressively improving reception and location data, we would also like to integrate the Calf Alert device with other sensors such as:

- Accelerometers to measure the duration of parturition and assess cow positioning during parturition. This would highlight whether the cow experienced a difficult birth i.e. dystocia.
- Radiolocation ear tags to measure the distance to water from the calving site, time spent at the calving site post birth, whether the cow returns to the calving site to find the calf.
- Use of the device in heifers.
- Build algorithms to provide alerts based on a peak in receptions and following up with intensive recording of the date/time of birth and the accurate location of the calving site.

- Link the results from the calf alert data with date of birth derived from published results using automated livestock monitoring systems (ALMS) that are based on walk-over-weighing. The ALMS will enable more producers to be able to benchmark date of birth and track calf growth and identify calf losses from mobs of cattle.
- Incorporating a thermometer within the Calf Alert pod

Overall, the use of the modified version of Calf Alert device containing the A31 PCB, has shown greater reliability to detect location, date and time of calving within a 24-hour period. More stringent quality control in the manufacture of the Calf Alert device and the availability of a reliable network with uninterrupted transmission will make it suitable for use in commercial and research beef operations to monitor calving and calf loss.

7 Key messages

The current experiment has demonstrated considerable progress towards a research tool that will provide date and location of the calving within the peri-natal period in rangeland production systems.

The device has been trialled in pregnant cows for up to 7 months without any adverse effects and high retention rate - this is an 'Australian first' with most other intravaginal devices only being in situ for a couple of weeks. The Calf Alert device is active from the time of intravaginal insertion sending attenuated signals (in contrast to the spike in reception at calving) and hence any failure in the device during the course of gestation can be detected early. The intravaginal Calf Alert device does not require mobile phone signalling or GPS and hence requires a small battery that may last for up to 2 years. This makes it suitable for inserting in pregnant cows at an early stage of gestation, thus avoiding mustering late-pregnant cows, especially in northern wet season.

The ability to detect calving within 24 hours of observed calving date will enable the maximum number of calves to be monitored in the first 24 hours of their life thereby increasing the opportunity to identify, investigate and address any calf losses occurring in that time frame. For example, providing the date and time could be used to highlight how climatic effects result in calf loss such as extremes in the temperature humidity index. Similarly by deriving the location of the calving site new calves can be observed for abnormalities such as congenital defects, or other causes of ill thrift. Additionally cows can be assessed for problems resulting from calving difficulty, poor mothering, distance to water, low body condition resulting in reduce milk production and therefore dehydration of the calf, or effects from the environment such as predation, temperature/humidity etc.

The retention of the device in mature cows is adequate; the modifications to the device has resulted in a spike in receptions data concurring with the calving date in 66% of cows and 64% of the cows had a location derived after calving. With greater quality control in the manufacture of the devices and monitoring of the Taggle network to ensure all receivers are operational, the technology has great potential to unlock the causes of calf loss.

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