Final report

Investigating the causes of calf losses in extensive pastoral systems - Calf watch

Project code: G.GBP.0027

Prepared by:
Tim Schatz^, Kieren McCosker^, Jack Wheeler^, Eleanor Fordyce^, Georgia Glasson^, Melissa Wooderson^ and Raoul Boughton*
^Northern Territory Department of Industry Tourism and Trade, *University of Florida

Date published: 03 February 2022

PUBLISHED BY
Meat & Livestock Australia Limited
PO Box 1961
NORTH SYDNEY NSW 2059

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

Investigating calf loss in northern Australia has been difficult using traditional methods as calving females and calf carcases are difficult to find in large paddocks, and close observation during calving alters behaviour. The ability to remotely monitor calving would greatly improve research into calf loss. The CalfWatch project developed a system to remotely monitor calving under extensive conditions in northern Australia and used it to investigate calf loss over two calving seasons at Manbulloo station near Katherine (NT).

Northern Territory Dept. Industry, Tourism and Trade (NT DITT) staff worked with University of Florida researchers to modify existing birth sensors to increase the range and enable use in locations where mobile phone coverage was limited. Tracking of cows using GPS was necessary to find calving cows after an alert was received and DITT researchers worked with Smart Paddock Pty Ltd to develop a suitable tracking system for extensive systems.

The “CalfWatch” system was effective for monitoring calving when all components worked properly, although the performance of the birth sensors and GPS collars was variable over the two calving seasons. The project gained insights into the causes of calf loss in extensive northern herds and has been another step forward in addressing the problem of calf loss in northern Australia.

Executive summary

Investigating calf loss in northern Australia has been difficult using traditional methods as calving females and calf carcases are difficult to find in large paddocks, and close observation during calving alters behaviour. The ability to remotely monitor calving in extensive situations would enable collection of data that previously was not possible and assist research to investigate and reduce calf loss. The CalfWatch project aimed to develop such a system and to use it to investigate the causes of calf loss.

The objectives of this project were to:

1) Review the remote calf loss monitoring systems used by University of Florida researchers and developed ways to modify them so that they are suitable for use in northern Australian conditions (eg. in large areas with limited mobile phone coverage).

2) Develop and test systems that:

   a. remotely record calving time and location and;

   b. remotely monitor calves so that deaths can be detected and carcases located in extensive conditions in northern Australia.

3) Use the systems developed in objectives 1 and 2 to investigate the causes of calf loss on a NT DITT research site near Katherine, NT.

Northern Territory Dept. Industry, Tourism and Trade (NT DITT) staff worked with University of Florida researchers to modify existing birth sensors to increase the range and enable use in locations where mobile phone coverage was limited. The system used intra-vaginal birthing sensors that emitted a UHF signal when a rapid temperature change was detected (when expelled during calving). The signals were received by antennas in a low-power wireless-area network (LPWAN) and transferred by a gateway, via the internet to servers owned by the sensor manufacturer. Calving alerts were transmitted in real time to a supporting website. A pilot phase demonstrated that GPS tracking was required to locate cows when a calving alert was received. As a result, suitable GPS tracking collars were sourced that recorded location every 15 min. This enabled calving sites and cows to be located for observation around the time of birth and later. The CalfWatch system (birth sensors and GPS tracking collars) was subsequently used to investigate the causes of calf loss over two calving seasons at Manbulloo station near Katherine (NT) in a 2,215 ha uncleared paddock of native pasture. Four gateways with external antennas mounted on 12 m high towers gave adequate coverage of the paddock to pick up signals from expelled birth sensors. About 200 cows per year were fitted with birthing sensors and GPS tracking collars in August in 2019 and 2020. Observations were recorded during calving from October to early January. Post-mortems were conducted on any calf carcases that were found in time for this to be done (within 12 h).

Sufficient data/observations were collected to be able to determine the calving outcomes of 208 pregnancies during the 2019 calving season and 192 pregnancies during the 2019 calving season. Birth sensors gave calving alerts from 85% of cows in 2019 and 51% of cows in 2020. The GPS tracking collar system enabled cows to be found easily, despite issues with reliability. When a calving alert was received and the cow had a working GPS collar, the system allowed calving observations to be recorded. If a cow did not have a working GPS collar then in most cases it was not possible to

locate them. In 2019, the GPS collars were working on 51% of cows that an alert was received from, so overall both the birth sensor and GPS tracking systems functioned properly on 43% of cows at calving. In 2020 the GPS collar was working properly on 82% of cows that an alert was received from, so overall 42% of cows had correctly functioning birth sensor and GPS tracking systems when they calved. Despite these shortcomings with the technology it was possible to record calving outcomes for most cows by a combination of the technology and visual observation, as the cows congregated around the only water point in the paddock during the day due to the dry conditions during the calving seasons.

Calf loss rates were 17% in both 2019 and 2020. Over the two years the technology enabled 11 calf-carcases to be found for autopsy. There were numerous minor causes of calf loss (1% or less) during the 2019 and 2020 calving seasons including early abortion, dystocia, neonatal septicaemia, pneumonia, deformity and wild dog attack, however "unknown causes" were the biggest cause of loss in both years due to variable performance of the birthing sensors and GPS collars. A portion of these losses due to unknown causes are likely to have been due to poor mothering (cows abandoning calves) but could not be quantified. Efforts were made to not disturb cows that appeared agitated and some cows were not observed at all after calving due to equipment failure. A number of cows that lost their calves were observed to have bottle teats post calving, but several weeks later udders appeared normal and so they would not be identified as having bottle teats at a muster several months later. If this is typical of northern herds then it is likely that bottle teats are a bigger problem than previously thought.

The project has increased the understanding of the causes of calf loss, although there were still a significant proportion of losses due to unknown causes. Efforts are ongoing to further develop devices that will identify calving from accelerometer data in real time and transmit calving alerts. If this can be done, it would enable birth date to be recorded remotely in extensive areas without the need for birth sensors. Further investment in the development of devices that transmit calving alerts and enable cows to be found in extensive situations is recommended.

Table of contents

1. Background

Calf loss has been identified as a major issue in northern Australian beef production systems and it is seen as an area in which it should be possible to make large improvements. Foetal and calf loss on northern Australian cattle properties can be extremely variable with reports ranging from 4% to 60% (Holroyd 1977). The reason for the large variability is that there are many factors which can contribute to it including predation, disease, nutritional deficiency, heat, dystocia, bottle teats and poor mothering ability of heifers (Entwistle 1983). The effects of these factors are cumulative in determining total foetal and calf loss and, depending on the circumstances, any of these factors can cause a large increase in calf loss. Examples of this are that leptospirosis outbreaks have been reported to cause abortions in 50% of cows (Knott and Dadswell 1970) and vitamin A deficiency associated with drought in north western Queensland has been reported to cause calf losses of up to 40% (Holroyd *et al.* 2005; Hill *et al.* 2009).

Holroyd (1987) reported that acceptable levels of foetal and calf loss (from confirmed pregnancy to weaning) in well managed herds in northern Australia with low exposure to reproductive diseases are around 12%. However the Cash Cow project found that losses exceeded 19% in a quarter of heifer mobs and 15% in a quarter of cow mobs in both the Northern Downs and Northern Forrest regions (McGowan *et al.* 2014). Schatz and Hearnden (2008) found that calf loss averaged 22% in first calving heifers on 14 commercial properties in the Northern Territory and was as high as 39%.

While there have been numerous reports of high calf loss in northern Australia, most previous studies reported that the causes of calf loss remain unknown in many cases (Holroyd 1987, Brown *et al.* 2003, Burns *et al.* 2010). This shows that there is a need for further research into the causes of calf loss and that there is potential for large improvements. Reducing calf loss will provide significant benefits to northern beef producers. Lane *et al.* (2015) estimated that neonatal calf loss due to unknown causes costs north Australian cattle producers $53.9M annually (this does not include the cost of losses due to known causes such as dystocia, BVDV, vibriosis and calf scours). Reducing calf loss rates by 10% in heifers and 5% in mature cows is likely to be more achievable than increasing pregnancy rates by these amounts.

Despite the problem of calf loss being well known, it has been difficult to research the causes of calf loss and develop interventions to improve it as calf carcases are difficult to find for post mortems and observation of calving females on extensive properties in northern Australia is often not possible due to the large size of paddocks and difficulty of access during the wet season. Holroyd (1987) noted the difficulty of finding calf carcases on extensive properties in northern Australia and in a review of 12 years data from Swans Lagoon Beef Cattle Research Station in north Queensland reported that most calf losses were from unknown causes since in the majority of cases it was not possible to locate a calf carcase. Also when observation of calving females is conducted, animal behaviour is affected by the observation and this can exacerbate the problem. Therefore there is a need to be able to monitor calving remotely and locate calf carcases for research in extensive situations. This will be a “game changer” for research into calf loss in northern Australia. It will be especially useful for research into the effect of paddock size on calf loss, as it is suspected that the incidence of calf loss is increased when calving occurs a long way from water points in large paddocks and that reducing paddock size may reduce calf loss rates. However there is currently no scientific evidence for this, and it is difficult to spend the large amount of money required on infrastructure without evidence to base the decisions on.

This project aimed to develop a system that would revolutionise research into calf loss in northern Australia. The aim was to develop a system that would enable the time and location of calving to be recorded remotely and alerts sent when calving commenced so that researchers could respond and record observations and be able to locate dead calves quickly to conduct autopsies. The ability to do this in extensive situations would greatly improve the ability to investigate the causes of calf loss and come up with solutions that are relevant to north Australian cattle properties. Reducing calf loss would greatly improve the productivity and profitability of northern cattle properties.

2. Objectives

1) Have reviewed the remote calf loss monitoring systems used by University of Florida researchers and developed ways to modify them so that they are suitable for use in northern Australian conditions (eg. in large areas with limited mobile phone coverage).

Objective 1 : The remote calf loss monitoring systems used by University of Florida were modified for use in extensive northern Australian situations.

2) Have developed and tested systems that:
   a. remotely record calving time and location and;
   b. remotely monitor calves so that deaths can be detected and carcases located in extensive conditions in northern Australia.

Objective 2a : The CalfWatch system (using birth sensors and GPS tracking collars) was developed and was able to record calving time and location when both the birth sensor and Gps tracking systems functioned properly. However there were reliability of both the birth sensor and GPS tracking collar reliability (detailed in the report).

Objective 2b: The original project proposed that a system using VHF tracking tags and accelerometers would be used to identify when calves died and allow them to be located for autopsy. However, this required calves to be caught and tagged shortly after birth and this method proved to be unsuitable in this situation and so it was discontinued (it was considered to be unsafe and likely to increase the chances of mismothering). The VHF tag system was demonstrated by setting up a portable yard in the paddock, mustering cows and calves, and tagging 50 calves with the VHF tracking tags. These calves were monitored over the 2019 calving season and the system worked as designed but none of the tagged calves died

3) Have used the systems developed in objectives 1 and 2 to investigate the causes of calf loss on a NT DPIR research site near Katherine, NT.

Objective 3: The details of investigations into the causes of calf loss over two calving seasons using the CalfWatch system are presented in the body of the report.

3. Methodology

This project was approved by the Charles Darwin University Animal Ethics Committee with approval number A19021.

3.1 Objective 1 methodology

The purpose of objective 1 was to gain a good understanding of the remote calf loss monitoring systems used by University of Florida (UF) researchers and to investigate ways to adapt it for use in extensive situations in northern Australia. To achieve this a collaborative relationship was formed with the UF group (led by Dr Raul Boughton) and two NT DITT research staff travelled to Florida to see their system in action, gain an understanding of how they worked, and determine how they might be modified for use in northern Australia.

The UF calf loss researchers use two separate "systems" to study calf loss: 1. A system which uses birthing sensors (Photo 1 in appendix 8.2) to determine the time of calving. 2. VHF tracking tags (Photo 2 in appendix 8.2) with inbuilt movement sensors (accelerometers) that are put on calves soon after birth to find out when calves stop moving (die) and then allow location of the dead calf.

Knowledge gained on trip to Florida and subsequent communication with Dr Boughton was used to develop a system that was suitable for use in extensive conditions in northern Australia. This involved increasing the footprint (range in which a signal could be detected) and devising a way for data to be sent from gateways on the towers to the internet when there was no mobile phone reception. A Katherine based business that specialises in remote communications in the NT (Comcat) was also involved to provide advice, source equipment and help with installation.

The system was used in a pilot study with 20 cows at the Katherine Research Station over the 2018 calving season and a number of problems were identified and resolved. This enabled the system to be modified and then used on a much larger scale in a leased paddock on Manbulloo station near Katherine. Dr Boughton travelled from Florida in 2019 to assist with installation and testing of the system at the Manbulloo site. The system was then used over the 2019 and 2020 calving seasons to investigate the causes of calf loss. Details of the equipment used, modifications made, and the final system used are presented in the Results section (4.1).

3.2 Objective 2 methodology

The system used by UF to remotely monitor calving was evaluated and modified as described in the Methodology and Results sections for Objective 1. This system was then used to remotely monitor calving time and location in a leased paddock on Manbulloo station near Katherine, NT. The site was a 2,215 ha uncleared paddock of native pasture which was approximately 7.7 km long and 6 km wide at the widest point. Four towers gave satisfactory coverage of the paddock to pick up signals from birthing sensors and GPS tracking collars (see Figure 1 in Appendix 8.1). Each tower had a read range radius of about 1.8-2.0 km in 360 degrees from the tower. Calving was monitored over two calving seasons (2019 and 2020).

In both years, cows that were at the right stage of pregnancy for inclusion in the project (ie. were due to calve between October and December, inclusive) were identified at a muster in April. There were approximately 550 cows to select from in two paddocks on Manbulloo, and each year about 200 were selected for inclusion in the CalfWatch study. The selected cows were put in the South Queens paddock where the towers had been set up, while remainder of the cows were put into the neighbouring North Queens paddock. The cows selected for inclusion in the CalfWatch study were pregnancy tested again at another muster in August to confirm that they were still pregnant before birth sensors were inserted. Inserting birth sensors involved setting up a portable antenna and gateway near the yards so that birth sensors could be activated and registered on the Cowmonitor website before being inserted. Registering a birth sensor involved activating it with a magnet which started a small light flashing. The light stopped flashing when the sensor had registered on the website and this was also confirmed by looking on the website (on a laptop in the yards) for the sensor number with a "Sensor ready" message (a screenshot of the website is shown in Figure 2). Once a birth sensor had registered on the website it was soaked in a disinfectant solution (chlorhexidine gluconate and clean water), loaded into the "inserting tool" (see Photo 3 in Appendix 8.2) and inserted into the vagina of the cow. When all birth sensors had been inserted and collars attached, the mob of cows was walked back to their paddock.

When a cow expelled a birth sensor (when calving commenced), the change in temperature caused the sensor to go into beacon mode and it started emitting a UHF signal that was received by an antenna and then the signal was sent from the gateway on the tower to the JMB servers (via the internet). Then an automated process would prompt an email to be sent to an email account that was accessible by the people monitoring calving. In addition, the expelled sensors were recorded as "Expulsion alerts" on the Cowmonitor website and this was monitored regularly by CalfWatch staff.

When a calving alert was received, the person monitoring calving would go to the Smart Paddock website and find the location of the cow (GPS coordinates) at the time when the expulsion alert was first received and also current location. These could be quite different if the expulsion alert was received well before the person was ready to search for the cow (eg. in the middle of the night). The person would then go to the paddock and attend the calving site to look for the expelled sensor and see if a dead calf was present. If the cow was still at the birth site they would record observations on the cow and calf, but if it was not then they would find the cow using the GPS coordinates from the Smart Paddock website (a screenshot of the website showing the information available is shown in Figure 3 in Appendix 8.1) and record observations of the cow and calf. It was possible to access the internet by wifi at each of the towers so staff could check for email alerts and use the websites to find any cows that may have calved while they were in the paddock or to get updated GPS coordinates for cows if they had moved. If a cow had not finished calving when it was found the staff person would leave it alone and come back later to check and record observations. Some cows were very flighty and would run away when approached even though they had a newborn calf. In these cases, if possible, observations were recorded at a distance with binoculars to try to avoid causing mismothering, or observations would be recorded at a later date when the calf was stronger.

The Avenza Maps smart phone/tablet app (Avenza systems Inc.) was used to locate cows and calving sites in the paddock as it has a "Navigate to destination" feature which makes navigating to entered GPS coordinates quite easy. A georeferenced map of the paddock was imported into Avenza Maps, and that allowed the person using it to see their current location in the paddock (phone reception is not required).

If a dead calf was found soon enough after dying (within 12 hours) it was collected for autopsy and samples sent to the Berrimah Veterinary Laboratory for testing. If a calf was seen that was very sick and looked to be likely to die then it was euthanized and an autopsy also done.

Objective 2b was to remotely monitor calves so that deaths could be detected and carcases located. It was originally intended that the system used in Florida by the UF researchers would be used to do this. The system involved catching newborn calves in the paddock and tagging them with ear tags that contained a VHF tracking device and an accelerometer and using the accelerometer data to determine if a calf had died (become stationary). The system required staff to visit the site daily and manually download the accelerometer data and search it to see if any calves had stopped moving. If a stationary calf was identified then the VHF tracking system would be used to locate the dead calf. The VHF tracking tags and the necessary monitoring equipment was purchased and installed, but it soon became apparent that the system was not suitable for use in this situation as it was dangerous trying to catch the calves in the rocky, timbered terrain with long grass, and attempts to catch calves caused large impacts on behaviour and were considered likely to lead to mismothering. This method was discontinued and the system was tested by setting up a portable yard and veterinary crush in the paddock and tagging 50 calves with the VHF tags and monitoring them over the 2019 calving season. The calves that were tagged were mostly between 4-8 weeks old (estimated from their size) at the time of tagging. The tagged calves were not mothered and none of them died, so the technology did not assist in finding dead calves for autopsy but was just used to determine whether it worked.

3.3 Objective 3 methodology

Objective 3: Use the systems developed in objectives 1 and 2 to investigate the causes of calf loss on a NT DPIR (now DITT) research site near Katherine, NT.

The systems developed in Objectives 1 and 2 were used to investigate the causes of calf loss over two calving seasons at the research site at Manbulloo.

In 2019, 189 pregnant cows were fitted with birth sensors and GPS tracking collars on 14/8/2019. Another 10 cows were fitted with GPS collars but not birth sensors (as some birth sensors did not register on the website and so were not inserted). All the cows were Brahman or Brahman cross. 50 were heifers due to calve for the first time and the rest were mature cows. The first calf heifers were transported from Douglas Daly Research Farm (DDRF) to Manbulloo prior to the 1st round muster in early May. They were due to calve between Oct-Jan so the most advanced pregnancies at the time of transport would have been 4.5 months old. No heifers aborted soon after transport (pregnancy was confirmed prior to birth sensor insertion in August). After insertion of birth sensors and attachment of tracking collars the mob was walked to the study paddock and monitored there using the methodology described in 3.2.

In addition to using the Calfwatch system to monitor calving, regular checks of the cows were conducted to pick up and record observations on any cows that may have calved without a calving alert being received. These checks were usually daily unless heavy rain prevented access to the paddock. The wet season was late arriving in 2019 and it had been a very dry year so the cows congregated around the only water point (trough) in the paddock during the day until the first significant rain was received on 2/12/19. This allowed daily visual checks to be made on most cows up until 2/12/19, and if calving cows could not be located using GPS data (eg. if the GPS collar was not working at the time of calving) then observations were recorded when they came for water in the days after calving. Also observations were recorded on any cows that were seen to have calved before an alert was received during these checks. A list of the observations recorded is shown in Appendix 8.3 and an autopsy template and guide to calf death investigations is shown in Appendix 8.8.

Visual inspections of cows were also conducted at approximately monthly intervals from December to April to record the lactation status of cows and this information was used to estimate when calf loss had occurred if cows were seen to be non-lactating (determined by a visual inspection of the udder using binoculars). This involved driving throughout the paddock to try and find and record cow lactation status. While the GPS collars were helpful in finding cows, not all cows could be found using this technique. Lactation status was assessed in the veterinary crush at the weaning muster on 16/4/20 and this was used as the final and conclusive observation in whether a cow had raised a calf to weaning or if calf loss had occurred.

The same procedures outlined above were used to investigate the causes of calf loss over the 2020 calving season. Cows used in the study in the 2020 calving system were selected from all the cows in the two paddocks that DITT lease on Manbulloo (a total of 550 cows) if they were due to calve from October to December. Therefore some (80) cows that were observed over the 2019 calving season were studied again in 2020, but the majority (113) were cows from the other paddock that had not previously been used in the CalfWatch project. There were no heifers calving for the first time in the study in 2020. In 2020, 193 pregnant cows were fitted with birthing sensors and GPS tracking collars on 19/8/2020. All were mature Brahman or Brahman cross cows. Final lactation status assessments were conducted at the weaning muster on 21/4/21.

4. Results

4.1 Results – Objective 1

4.1.1 Review of the University of Florida remote calf loss monitoring systems

A research group from the University of Florida (UF) led by Dr Raoul Boughton were conducting research into calf loss on cattle ranches in Florida and using new technology to enable them to remotely determine when cows calve, when calves die, and to locate their carcases if they do. This technology and the methods they were using were identified as being likely to be useful in studying calf loss in Northern Australia. The first objective of the Calf-Watch project was to review the technology and methods being used by the UF team, evaluate their potential for use in northern Australia and determine what modifications may be required for them to be effective in areas where paddocks are larger and mobile phone coverage is limited.

The UF calf loss researchers use two separate “systems” to study calf loss: 1. A system which uses birthing sensors to determine the time of calving. 2. VHF tracking tags with inbuilt movement sensors (accelerometers) that are put on calves soon after birth to find out when calves stop moving (die) and then allow location of the dead calf.

The birthing sensors are small devices (see Photo 1 in appendix 8.2) that are used to determine when cows calve and alert researchers of the event. They have been adapted from Medria birthing sensors (https://www.medria.fr/en/solutions/calving.html) and are marketed by JMB North America (http://cowmonitor.com/technology/) who also provide the monitoring and support for the sensors. The birth sensors are commercially available and are most commonly used in dairy cows. To use these devices to study calf loss in more extensive situations they were modified by JMB to increase their range, and add Bluetooth and flashing light functions to assist in locating expelled devices. The birth sensors cost approximately $250 (AUD) each, and the manufacturer claims that they can be re-used several times (but this study found that reliability was reduced when they were re-used (details in the 2020 calving season results)).

The birthing sensors are inserted into the vagina of pregnant cows up to 3 months before calving and remain there until they are expelled during the birthing process. The sensors calibrate to the temperature of the cow and then when they pick up a sudden 2-degree drop in temp (ie. at calving) they go into beacon mode and start emitting a (UHF) signal. This can be triggered by either a 2 degree decrease (most commonly) or increase in temperature (which could happen on a hot day if a birth sensor is in the sun). The signals are received by antennas in a low-power wireless-area network (LPWAN) and are transferred by a gateway, via the internet to servers owned by the sensor manufacturer (JMB North America).

The birthing sensors are expelled when the waters break in the calving process. This usually occurs about an hour before calving but can vary from a few minutes to 20 hours before the calf is actually delivered depending on the difficulty of the birth. After expulsion, the sensors go into beacon mode for 10 d. Beacon mode involves emitting a UHF signal, a small orange light that flashes every 10 s and a Bluetooth signal that can be picked up by a smartphone when it comes within about 30 m of the expelled birthing sensor.

When a birthing sensor goes into beacon mode the UHF signal is picked up by the birthing sensor antenna on the tower (Photos 4 and 5 in appendix 8.2). The signal then goes through the gateway (on the tower) and is sent by cellular data (mobile phone network) from the gateway to the internet. Mobile phone reception is only required at the tower, not throughout the paddock. This is an important distinction as it is much easier to boost mobile phone reception at a small site like the tower than it would be to boost mobile phone reception throughout a large paddock. The alert signal is received by JMB servers and their system sends out an alert (either by text or email) to the person responsible for finding calves. In the CalfWatch project, alerts were sent to a group email address so that several people could monitor and respond to alerts. This system worked well and allowed staff to share working over weekends to monitor calving.

When the person monitoring calving gets an alert they then go and attempt to find the calf as soon as possible/practical. It is important to note here that the only information that the person receives with the UF system is that the birthing sensor has been expelled (they are not given any clues to its location). They then have to try and find the birthing sensor (and hopefully the calf) using their knowledge of the paddock and cattle behaviour. This is quite achievable in small, mostly treeless paddocks but much more difficult in larger paddocks in the NT.

The UF team works in quite small paddocks and so only require one tower per site. Their towers have about a footprint of about 600 ac, but this can be increased by using different antennas (directional antennas are much stronger). The work in the NT was conducted in larger paddocks and so multiple towers were required. Four towers gave adequate coverage of the 2,215 ha paddock.

As each tower has it's own gateway, and each gateway has it's own account, it is possible to identify which tower a birthing sensor is closest to when in beacon mode. This would be helpful in locating calving cows in relatively open paddocks, but in timbered paddocks it is still not adequate to find cows and GPS tracking is required.

The UF system uses VHF tracking tags with movement sensors (accelerometers) to investigate calf loss post calving. They catch calves and attach VHF tracking tags as soon as possible after calving and use them to determine when calves die and to locate the carcases for investigation of the causes of death. These tags are similar to the VHF tracking tags that have commonly been used to track animals in wildlife research for many years, but they have also been fitted with movement sensors (accelerometers) that can be used to tell when a calf may have died (stopped moving). If a tag has been motionless for >2 h when it is scanned (the length of time can be changed), it is assumed that the calf has died and this is recorded by the data logger. Data from the data logger is downloaded (an Excel spreadsheet in CSV format) and searched to see if any calves have "died". This requires a person to go to the tower site each day and download the data (although it should be possible to download this data remotely). The data is transferred to an Excel worksheet with a template that makes it easy to search for any “death” codes (which are a Max pulse rate of 48 instead of 24). When a death code is found, a portable Yagi antenna is used to search for the tag.

To find a dead calf, the tag number of the dead calf is entered into a portable Yagi device (it only searches for one tag at a time) and it is used to scan the paddock for the tag (Photo 10 in appendix 8.2). Audible beeps are heard when the antenna is pointed in the direction of the tag. The beeps get louder when the distance to the tag gets closer. Initially, the gain (squelch) is set quite high to locate the tag but then you reduce it as you get closer to narrow the field (make it more sensitive). Initially, you hear beeps for about a 30-degree range and you don’t know how far away in that direction the tag is. You just head in that direction and keep reducing the gain as you go and attempt to locate the tag.

Once fitted and activated, the VHF tags are scanned for one at a time (sequentially) by the data logger on the tower. It takes about an hour to scan for 100 tags and so each tag gets scanned for about 12 times per day. The list of tags to scan for is uploaded to the data logger and this is done periodically as more tags get fitted (as there is no point scanning for tags that are not in use yet).

Evaluation of the VHF tracking system in the NT found that the technology worked effectively but that it was much more difficult to catch NT Brahman calves in a large rough paddock than Brangus calves at the research sites in Florida. A decision was made to abandon this as it could not be done safely and was likely to contribute to calf loss through causing mismothering. A portable yard was set up in the paddock and 50 calves were tagged and monitored.

4.1.2 Modifications to the University of Florida systems

The main issues that needed to be overcome for the UF birth sensor system to work effectively in the NT were:

1. Poor/no mobile phone coverage to send birth sensor data from the gateway to the JMB server via the internet.
2. Finding the birthing sensors and calves in large paddocks with rougher terrain, more trees and longer grass than the sites being used in Florida. Photos 4 and 5 show the contrast in landscape between the research sites in Florida and at Manbulloo.
3. Difficulty catching calves soon after birth to attach VHF tracking tags.

Overcoming poor mobile phone coverage: The issue of the gateways requiring internet connection to communicate birth sensor data in locations where there was no mobile phone reception was overcome by installing a ruggedised modem and mounting a directional yagi antenna on top of each of the towers. The antennas were directed towards a mobile phone tower at the Tindal airport (about 11 km from the furthest tower) and this provided good internet connection. There are other potential solutions to do this in locations where towers are even further away from a mobile phone tower. The technology to do this is improving all the time, and in more remote locations an assessment would be made to determine which would be the most effective (and cost effective) solution for that particular situation.

The tower design used in Florida is shown in Photo 4 in Appendix 8.2 and the tower design and equipment used in the NT is shown in Photo 5. The electronic equipment used in the NT shown in

Photo 6. Each CalfWatch tower at the Manbulloo site had 3 x 100W 12 V solar panels, two 100 amp hour gel filled batteries, a solar regulator, ethernet gateway, UHF antenna, rugged modem (Comset CM685V-1), and yagi antenna to communicate and send signals via the internet where mobile phone signal strength was poor (Photo 7 in Appendix 1).

Finding birth sensors and cows in large paddocks: When a birth sensor is expelled in the UF system, the person monitoring calving receives an alert, but they do not get any information about the location of the birth sensor (other than that it is within range of the tower). This is not a major problem in Florida as the paddocks are usually small and open enough for the cows and calves to be found fairly easily (Photo 4 in Appendix 8.2). But it is much more difficult in the larger less open paddocks in the NT (Photo 5 in Appendix 8.2). During the pilot study in 2018 it quickly became apparent that finding expelled birth sensors in long grass was almost impossible without GPS tracking, even in a smaller paddock at KRS. The Bluetooth beacon and flashing light features on the birth sensors proved to be of little use in locating expelled birth sensors in long grass. The bluetooth range is only about 40 m so unless a person was close to an expelled birth sensor the Bluetooth feature was of little use. The flashing light could not be seen in long grass (even at night). Fitting birth sensors with a GPS chip would make finding them quite easy, but this still leaves the problem of finding the cows and calves if they have moved from the birth site. Fitting GPS tracking tags to the cows which give their location at the time of birthing sensor expulsion and also their current location is the solution to this problem.

It proved difficult to find a company that could supply suitable GPS tracking devices at a reasonable cost and that met the requirements for this work. There were several types of GPS tracking collars on the market at the time, but none that met our requirements. The specific requirements were:

- The collars must provide the GPS coordinates of animals at a minimum of every 15 minutes and they must be able to do this with a minimum battery life of 4 months. This is because once the collars are fitted, the cattle will not be handled again for >4 months so the batteries in the GPS trackers need to last at least this long (through the calving period).

- The tracking system must be able to provide the GPS location of animals in real time and this information must be able to be accessed whenever researchers need it (ie. when they receive an alert that cows have calved). Therefore the devices cannot just store data on board where it is accessed at a later date, but rather it must be accessible in real time.

- The GPS tracker units must be small enough and robust enough that they can be attached to cattle that are roaming free in large paddocks in northern Australia and not fail.

- The total cost of the GPS trackers and the system to monitor them and provide the data on the location of animals must cost less than $300 per animal.

The frequent “pinging” of the GPS trackers (at least every 15 min to enable cows to be found) requires a good power supply (battery) and the ability to locate the cows in real time (not download data when it comes within range of a reader or store on board) proved problematic for most GPS tracking manufacturers. However after exhaustive searching, a company (SmartPaddock Pty Ltd) was found that were able to supply tracking collars that met our requirements. The product was not yet commercially available and so GPS technology industry experts were consulted to determine whether SmartPaddock had the competency to do what they claimed. The general consensus was that they were competent and reliable, and so a decision was made to purchase 200 GPS tracking collars from them. The collars used over the 2019 calving season are shown in Photo 8 and the updated collars used in 2020 are shown in Photo 9.

The Smart Paddock tracking collars utilise u-blox GPS modules for location, and capture collar temperature and accelerometer data from in-built sensors on a 15 min interval. The collars use LoRaWAN communications to transmit the data over several kilometers to Multitech LoRaWAN gateways located on the towers in the paddock. The gateways transmit the collar tag data over Telstra's 4G/3G network to be stored in a central server where the data can be visualised and accessed from a web dashboard using a mobile phone or computer. The same modems and yagi antenna used by the birthing sensor system were able to be used to communicate with the internet where mobile phone signal strength was not adequate.

Attaching VHF monitoring and tracking tags to calves: Initially it was intended that newborn calves would be caught and fitted with VHF tracking tags to determine when a calf dies and locate it for autopsy. However, after a few initial attempts to catch calves a decision was made not to continue with this as it was not able to be done safely due to the terrain in the paddock (long grass and trees hiding numerous sharp rocks, ant hills and fallen timber), the nature of the cows (most were not very quiet when they had a small calf), and the fact that it was considered likely to affect cow behaviour and possibly lead to mismothering.

Despite newborn calves not being caught and tagged in the paddock, the VHF tracking and accelerometer technology was tested by setting up a portable yard in the paddock and tagging 50 calves with the devices on 3/3/20. The VHF receiver successfully recorded accelerometer data showing that all calves were moving and no alerts were received for calves that died (stopped moving). So the technology did not assist in finding dead calves for autopsy but was just used to determine whether it worked in this environment (which it did).

4.2 Results – Objective 2

The UF systems were evaluated and modified to suit extensive northern Australian conditions as described in the results section for Objective 1 in section 4.1. The modified systems were tested over a pilot study in 2018 at KRS and then at the Manbulloo site over two calving seasons in 2019 and 2010. The results from each of these test periods are described below.

4.2.1 2018 Pilot study

A tower was set up at Katherine Research Station (KRS) in early November 2018 and birthing sensors were inserted into 18 cows on 9/11/18. Initially the tower worked well and an alert was successfully received for a calf born on 13/11/18. The next calf wasn't born until 20/11/18 and no alert was received for this birth. Several more calves were born over the next few weeks without alerts being received and it became apparent that there was a problem with the system. It became apparent that the type of antenna that had been used to try to extend the read range of towers was causing gateways to fail. Once this was determined and the large Blackhawk Omni Trucker EDGE antenna replaced with the same small Kerlink antenna used in Florida, the system worked well. Alerts were successfully received for calves born on 23/1/19, 22/2/19 and 24/2/19. Unfortunately, all the other calves were born during times when the tower was not working. As a result a water bath set at 38^{o}C was used to mimic inserting sensors into cows and sensors were removed at various times and locations to mimic expulsions. Alerts were successfully received from all these tests.

From this pilot study it was found that alerts were successfully received for all birthing sensors that were expelled or tested when the tower was working properly. This combined with the successful performance of birthing sensors in Florida gave confidence that the birthing sensor system would work well in northern Australia (provided that the Kerlink UHF antennas were used).

A separate issue to whether the birthing sensors worked correctly was whether the expelled sensors could be found in the paddock and this proved to be problematic in the pilot study. In Florida the paddocks are small, there are not many trees and the grass is short and so newborn calves and expelled sensors are relatively easy to find. However this is not the case in northern Australia and only 9 of the 18 expelled birth sensors were able to be located in the smaller (87 ha) cleared paddock at KRS due to the long grass that is common in northern Australia during the wet season. It was expected that very few expelled sensors would be able to be located in the larger uncleared paddock at Manbulloo so it became apparent that GPS tracking would be required. This resulted in the acquiring of the Smart Paddock tracking collars described in section 4.1.2.

4.2.2 2019 Calving season

The modified CalfWatch system was used over the 2019 calving season to evaluate it's performance on a bigger scale and to investigate the causes of calf loss. Calving observations were recorded for 189 pregnant cows that were fitted with birth sensors and GPS tracking collars on 14/8/2019 and for another 10 cows that were fitted with GPS collars but not birth sensors. Regular (usually daily) checks of the cows were conducted to pick up any cows that may have calved without a calving alert being received. The wet season was late arriving in 2019 and it had been a very dry year so the cows congregated around the only water trough in the paddock during the day until the first significant rain was received on 2/12/19. This allowed daily visual checks to be made on most cows. Data recorded on the Cowmonitor website and the visual observations were used to assess the performance of the calving alert system.

Birth sensor performance: Alerts were received from 85% of birth sensors soon before calving. Of the sensors that did not give an expulsion alert correctly; 4 sensors were expelled early (more than one month before calving), 2 alerts were received after cows had been observed to have calved, and no alert was received from 21 sensors. Failure of these 21 sensors is difficult to assess but could be due to internal malfunction (equipment failure), or inability of a base station to receive a signal due to the location where the sensor landed on the ground (environmental interference). The 2 alerts that were received after cows were seen to have calved could have been due the lack of a rapid temperature change at calving, however in most cases this did not seem to be a problem and the study found that the birthing sensor system was generally successful in remotely identifying time of calving. This was regardless of high temperatures during the study that reduced the temperature difference between the environment and inside the cow's body, which potentially could have resulted in birthing sensors failing to activate. Successfully receiving an alert from 85% of birthing sensors is one of the better results achieved using these birthing sensors in extensive situations (Raoul Boughton *pers. comm*.).

Theoretically the birthing sensors have enough battery life to be used two or three times but locating expelled sensors in a large paddock with many trees and tall grass proved to be virtually impossible without GPS tracking. Most of expelled sensors were found if a cow had a working GPS collar at the time of expulsion, but few were found if it did not. Most cows were found for observation shortly after calving if their GPS tracking collar was working but few were found if it was not. In these cases the cow was usually located in the days after calving by searching for her among the cows gathered around the water point.

GPS tracking collar performance: The GPS tracking collar performance during the 2019 calving season was mixed. When collars worked correctly they were very good and the website used to obtain the location of cows at the time of calving was excellent. The website showed the current location of cows, both by displaying her GPS coordinates and by showing her location on a map/photo of the paddock, as well as showing her previous locations for a period that could be specified (Figure 3 in Appendix 8.1). However, while some collars worked well with GPS fixes being recorded every 15 min allowing calving cows and birth sites to be found easily, other collars worked intermittently while some stopped working altogether. Also some collars fell off cows, mostly due to the catches breaking. The proportion of GPS collars that continued to function correctly declined over time (Figure 4 in Appendix 8.1). The decline over time in the number of fixes received from all GPS collars appeared to be generally linear with approximately 2000 less GPS locations per day being captured each month. Overall 46% of collars were able to provide the GPS location of cows when a calving alert was received. A more detailed report on the performance of the Smart Paddock GPS collars used over the 2019 and 2020 calving seasons is presented in Appendix 8.4.

When a cow calved without a working GPS collar it was not possible to locate the birth site and retrieve the expelled birth sensor. So while calving alerts were successfully received from 85% of birthing sensors, the GPS collars were only working correctly on 51% of cows that an alert was received from. So overall both the birth sensor and GPS tracking systems functioned properly on 43% of cows at calving. Calving location was only able to be definitively determined by finding the expelled birth sensor for 69 cows. These birth sites were distributed quite evenly throughout the paddock (Figure 1 in Appendix 8.1) although there were some “hot spots” where multiple cows calved and heifers calving for the first time tended to calve closer to the water point than older cows (average distance of calving location from the water point was 1.19 km for first calf heifers vs 2.78 km for mature cows). Despite most cows congregating around the water point during the day, it seems that the majority either walked away to calve or did not come in to the water point on the day that they calved (Figure 1 in Appendix 8.1).

This project was the first deployment of Smart Paddock GPS collars in northern Australia and the harsh conditions (high temperature and humidity during) caused a high percentage of failures with the first model. Examination of the collars determined that there were two reasons for the failures observed over the 2019 calving season:

1) Mechanical: The mechanical failures were primarily due to the plastic buckle mechanism breaking. 12 collars fell off prior to calving and so were not attached when needed and another 6 fell off later. Quite

2) Electronics: The electronics failures were determined through an independent engineer to be related to the LoRaWAN antenna circuitry design which would scramble the outbound signal during exposure to high temperature. This was seen most predominantly when the plastic enclosure on the collars were exposed to direct sunlight during the daytime periods. The electronics would continue to function but the timed data transmission would fail to reach the local network gateway.

Smart Paddock undertook the following steps to rectify the issues and produce a new improved collar (the first and the improved model of collars are shown in Photos 8 and 9 in Appendix 8.2):

- The 50 mm plastic buckles were replaced with 45 mm metal buckles.

- The collar webbing material was replaced with a higher grade and thickness material (note that there were no failures due to the webbing material but Smart Paddock thought it was prudent to upgrade to give a longer overall life of the collar so that they could be used in multiple projects).

- The antenna circuitry design was modified to suit the high temperature environment of northern Australia.

- The original plastic enclosure was replaced with a more rugged option and the colour changed from black to light grey to reduce the impact of direct sunlight on the internal electronics.

- The firmware was upgraded to gather more accelerometer and GPS location data than the previous deployment and increase the GPS accuracy. The GPS update rate can be reduced to every 10 minutes and the batteries will still last for more than 6 months.

- A higher grade of battery was used that allows for use in up to 85^{o}C. Two industrial C 3.6 V batteries are being used which more than tripled the previous capacity.

The GPS collars also have accelerometers which store data about the cow's movements, and it is hoped that analysis of this data combined with knowledge of the time of birth from the birthing sensors will allow characteristic movements associated with calving to be identified. Work to achieve this is underway and Figure 5 in Appendix 8.1 shows a definite change in movement pattern around the time of calving for one of the cows whose data has been analysed. If this method of identifying calving can be fully developed, tested and proved to be accurate then it would remove the need for birth sensors, and collars alone could be used to identify the time of calving. If signals could be sent in real time notifying that calving had occurred then birth sensors would not be necessary to identify calving, and this would be a positive animal welfare outcome as well as being a major cost and labour saving.

The new technology used in the CalfWatch project (birthing sensors and GPS tracking collars) allowed some interesting observations to be made. Most cows (71%) commenced calving during daylight hours which goes against the common perception that the majority of calving occurs at night. Studies in the USA have found that most cows that are fed at night calve during the day. While the cows in this study were not fed, they grazed pasture extensively at night as they congregated around the water point during the day where there was no grass due to overgrazing that had occurred throughout the year. A high proportion of calves being born during the hottest times of day in northern Australia may contribute to calf loss and supports cause for conducting research on providing shade where cattle congregate around water points where there is no natural shade. Although there was little difference in the calf loss rates of cows calving at different times of day (details provided in section 4.3.1).

The GPS tracking collars also allowed the distance travelled per day to be estimated for cows. These were derived by summing the distance between successive points for a single collar over a day. This estimate is likely to be an under representation of actual. Location error needs also to be taken into consideration. The cumulative distance for individual cows was calculated daily and averaged for collars that contributed more than 75% of the scheduled fixes for that day. The distance travelled per day was relatively constant during the months Sept, Oct, Dec and Jan, and was between 8 and 11 km per day. The distance travelled per day was less during November and February and the supressed activity is potentially explained by calving in November and rainfall events resulting in more surface water in February.

4.2.3 2020 Calving season

Similar procedures as used in the 2019 calving season were used to evaluate the technologies (and investigate the causes of calf loss) over the 2020 calving season using the new model of GPS tracking collars. 193 pregnant mature Brahman or Brahman cross cows were fitted with birthing sensors and

GPS tracking collars on 19/8/2020. Two cows escaped from the paddock and so could not be monitored as they were out of range of the towers. Also, there was one cow that had an imbedded birthing sensor from the previous year but had managed to re-conceive over the 2019/20 mating period, and so it was kept in the study paddock for observation but another birth sensor was not fitted. In total there were 191 pregnant cows for observation over the 2020/21 calving season. Final lactation status assessments were conducted at the weaning muster on 21/4/21.

The cows congregated around the water trough during the day up until the wet season broke which allowed easy observations of cows and calves during this time. However, following the rain in late November the cows scattered throughout the paddock which made it difficult to record observations if a cow did not have a working GPS collar. During the period when cows were congregating around the trough during the day, it was easy to do daily visual checks and if calving cows could not be located using GPS data (eg. if the GPS collar was not working at the time of calving) then observations were recorded when they came for water in the days after calving. Observations were recorded on any cows that were seen to have calved before an alert was received. On several occasions in late December, January and February a 4WD buggy was used to search the paddock and record the lactation status of any cows that a caving alert had not already been received from. This did allow additional information to be collected, but not all cows could be found using this method. As a result, calving outcomes were able to be recorded for 192 cows.

Birth sensor performance: The same type of birth sensors (manufactured by JMB North America) were used in the 2020 calving season. Alerts were received from 51% of birth sensors soon before calving and the GPS collars were working properly on 82% of cows that an alert was received from, so overall 42% of cows had correctly functioning birth sensor and GPS tracking systems when they calved.

The percentage of birth sensors that worked properly in 2020 (51% was much lower than in 2019 (85%) and this contributed to the disappointingly high number of calf losses due to unknown causes. The reason for the worse performance of birth sensors in 220 was not easy to identify. Some birth sensors deployed in 2020 had previously been used. Only birth sensors that gave a sensor ready notification after being activated were inserted into cows, so theoretically all of the birth sensors that were used should have been OK (any that did not give a sensor ready alert were not inserted). While the climactic conditions were somewhat different during the 2020 calving season (eg. higher rainfall and lower average temperatures than the previous year) it is unlikely that this would be a reason for the performance of birth sensors during the 2020 calving season.

One birth sensor became implanted in the vaginal wall in each year. This equated to about 0.5% of birth sensors becoming stuck and not being expelled each year. A description of each case is presented here:

1) At the pregnancy testing muster in 2020 it was found that one cow still had a birth sensor in her birth canal, but despite this she had raised her calf to weaning and was pregnant again. She successfully raised her calf to weaning in 2021 and at the pregnancy testing muster the previously stuck birthing sensor was gone and she appeared quite normal (although was not pregnant again). It was assumed that the stuck birth sensor must have been dislodged during her 2020 calving. A calving alert was not received.
2) At the pregnancy testing muster in April, 2021 it was found that a birth sensor had become implanted in the vaginal wall of a different cow over the 2020/21 wet season and not been expelled during calving. This birth sensor was able to be removed. The cow had raised her calf to weaning but had not become pregnant again.

GPS tracking collar performance: As occurred during the 2019 calving system, when the GPS collars worked correctly during the 2020 calving season they were very good and made locating calving cows easy. The website was excellent, easy to use and there were no problems with it throughout the calving season. While performance of the new collars was improved from the previous model, again there were some issues with collar reliability due to both physical and electronic causes. Soon after the cows were returned to their paddocks with the new model collars on, it became apparent that some collars were falling off as the catches were coming undone. After a couple of weeks the number of collars falling off became concerning and so a decision was made to re-muster the cows and fit cable ties to the catches to stop them from coming undone. This was done on 16/9/20. Despite this 8% of collars still fell off during the 2020 calving season (after 16/9/20) due to the catches coming undone.

Smart Paddock provided data that showed when each collar recorded its last location fix. According to this data, 70% of collar were still working after 4 months in 2020 compared to 58% in 2019. If collars that fell off and were removed from the paddock (and so would not be recorded by Smart Paddock from that point onwards) are removed from the analysis then 78% were still working after 4 months and 48% were still working 7 months after deployment (they were intended to last at least 4 months). However, this is an over estimate of the percentage of collars that were effective, as on some collars, the number of fixes that were recorded per day reduced over time and they became ineffective if only a couple of fixes were being recorded per day and these did not correspond with when a calving alert was received.

A less technical but more practical method of evaluating performance of collars was done by recording if collars were working and helpful in finding cows when a calving alert was received. This was recorded at the time of an alert by the person responding to alerts. Using this method, overall 66% of collars were definitely working when needed to find cows after a birth sensor alert was received during the 2020 calving season (an increase of 20% from the previous year). It is possible that the actual figure was higher than this, as whether or not a collar was working was not always recorded if a cow was observed to have calved without a calving alert being received (and the cow and calf were seen near the trough). In these cases the Smart Paddock data was used to determine if the collar was still recording fixes at the time that the cow was seen with a calf. Using combined data from both of these methods it is was calculated that 74% of collars were working when needed to find a cow after a calving alert was received.

Smart Paddock did their own evaluation of GPS collar performance on 5/2/21 (note- more than a month after collars were required to last) and found:

- Average lifetime of battery was 132 days (this could be skewed by collars that have come off and were removed from the paddock so their signal would not have been picked up by the towers).

- 37 (19%) seemed to fail before battery drain (or have come off)

- Average GPS Time to Fix per message was 24+ seconds

- Average GPS Time to Fix per message was <10 seconds for last season

The main cause of the collars stopping working during the 2020 calving season was running out of battery power which was primarily caused by the longer GPS Time to Fix (the time it takes the GPS modules to go from sleep mode to an accurate location detection). This was because the accuracy setting was increased to a higher level than the previous. Figures 1 and 2 below show the battery life of two of the collars that failed (the green line is GPS fix time and orange is battery level). Collar

9564 failed due to battery issues but should have lasted much longer. Either it had a bad battery or was using only one of the two batteries. The batteries on Collar 9135 lasted until mid-January before failing (which was more than the 4 months required for this study).

Figure 1. Collar 9135 – Functional.

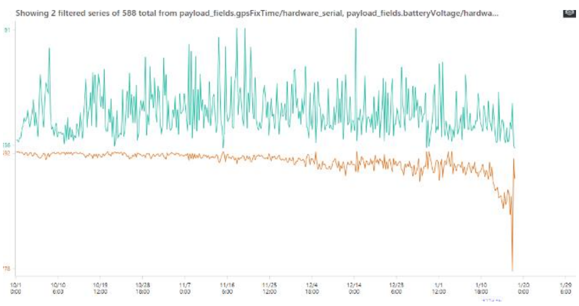


Figure 1. Collar 9564 – failed.

The location of calving sites during the 2020 calving season was able to be determined for cows that had a working GPS tracking collar when their calving alert was received. These sites are shown in Figure 6 of Appendix 8.1. In 2019, calving sites were dispersed throughout the paddock in 2020, although more calving sites were located towards the back of the paddock (the opposite end to where the water trough was located) in 2020. This is likely to be because the wet season commenced earlier in 2020 and other water points would have been available to cows towards the back of the paddock (Figure 6 in Appendix 8.1) and so not all would have had to walk to the trough for a drink. Most cows calved after mid November when the wet season started and no longer congregated around the water trough during the day after this period.

The average distance of calving sites from the single water trough in the paddock was 4.05 km in 2020. The average distance of calving site from the trough was actually higher for cows whose calves survived (4.15 km) than for cows that lost calves (3.30 km), however as explained above, due to the location of other water points in the paddock, this does not prove that calving further from a water point does not increase calf loss.

A more detailed evaluation of the Smart Paddock GPS tracking collars over both calving seasons is presented in Appendix 8.4.

4.3 Results – Objective 3

The CalfWatch system was used to investigate the causes of calf loss over two calving seasons at the research site at Manbulloo station.

4.3.1 2019 Calving season

It was very hot and dry during most of the 2019 calving season with mean maximum temperatures of 39.8°C, 40.4°C and 40.8°C in October, November and December respectively (a summary of the weather during the calving period is shown in Table 1 in Appendix 8.5). During this time cows congregated around the single water point for most of the day before leaving in the late afternoon to graze. This allowed daily visual checks to be made on most cows and if calving cows could not be located using GPS data (eg. if the GPS collar was not working at the time of calving) then observations were recorded when they came for water in the days after calving. Also observations were recorded on any cows that were seen to have calved before an alert was received.

The 2019-20 wet season at Katherine was one of the lowest on record for rainfall. The first meaningful rain (>10 mm) did not fall until 2/12/19 when 24 mm was received and then a further 16 mm fell on 16/12/19 (Figure 1 in Appendix 8.5). This resulted in the cows no longer congregating near the water point for most of the day making it difficult to locate cows if they did not have a working GPS collar.

Sufficient data/observations were collected to be able to determine the outcome of 208 pregnancies for the 2019 calving season. This was possible as there were some cows in the paddock that did not have birth sensors or collars but their calving outcome was able to be determined by observation. The foetal and calf loss rates were evaluated separately for cows and heifers calving for the first time as their calf loss rates are quite different (Entwistle 1983).

The foetal and calf loss rate in cows in the 2019 calving season (16.8%) was at the high end of the normal range for mature cows. The CashCow project reported that the 25th and 75th percentiles for foetal and calf loss in mature cows in the Northern Forest zone were 9.4% and 19.2% respectively (McCosker *et al.* 2020). The foetal and calf loss rate in first calf heifers (36%) was very high and was well above the 75th percentile reported for fist calf heifers in the Northern Forest zone by the CashCow report (20%). The calving outcomes and reasons for foetal and calf loss over the 2019 calving season are summarised in the Table 1.

The calf loss rates in mature cows in the previous 4 years at this site were 10.3% in 2016, 7.4% in 2017, 14.5% in 2018, 10.6% in 2019 and the average loss over the 4 years was 10.7%. The calf loss reported in mature cows in this study was 6 percentage units higher than the average calf loss that has occurred at this site in the previous 4 years. It is difficult to determine the reason for this increase in calf loss, and it is likely to be due to the cumulative effect of several different factors. The late start to the wet season and very poor wet season (Fig. 3 in Appendix 8.5) may have had an effect, and the extra activity of people in the paddock taking observations of cows at calving may also have contributed (although care was taken to disturb cows as little as possible when they were calving). Wild dogs were present in the paddock as evidenced by trail camera photos (eg. Photo 11 in appendix 8.2), but actual evidence of dog attack was quite low. Two calves died after having been attacked by wild dogs, but one of these calves had previously been recorded as being sick and "wobbly" (case 6 in Appendix 8.6). The other calf that died due to dog attack was euthanised due to infection at a bite site and not actually killed by dogs (case 2 in Appendix 8.6). The level of damage to calves caused by dogs (bite marks, ripped ears etc.) recorded at the weaning muster in April 2020 was actually quite low with only 4 calves out of 161 with bite marks (ie. 2.5%). In comparison McCosker and Dobbie (in press), in a study of 42 mobs throughout the NT, found that on average 6.2% of unbranded cattle presented at their first muster with signs of wild dog attack and the incidence ranged from 0.2% to 18.2%.

Table 1. Summary of the causes of foetal and calf loss over the 2019 calving season. Where the cause of death is listed as unknown it is because a calf carcase was not found to investigate the cause of death.

Calving outcome	Number of cows	Number of heifers	Cow foetal/calf loss (% of the total number of cows)	Heifer foetal/calf loss (% of the total number of heifers)
Pre-natal loss		3	0%	6%

Dystocia loss	2	3	1%	6%
Peri-natal loss - unknown cause	7	6	4%	12%
Post-natal loss - unknown cause	7	4	4%	8%
Post-natal loss - bottle teats	9		6%	0%
Post-natal loss – pneumonia		1		2%
Post-natal loss - dog bite infection		1		2%
Post-natal loss – Neonatal septicaemia	1		0.6%	
Post-natal loss – infection of the umbilical cord	1		0.6%	1%
Missing - not enough information to determine calving outcome	2	1	1%	2%
Total losses	27	18	17%	36%
Number that weaned a calf	134	32		
Total number	161	50		

*Detailed autopsy reports for the 2019 calving season are presented in Appendix 8.6.

The most common identified cause of calf loss in mature cows was bottle teats (6% of losses). In most cases the cow was noted with bottle teats and the calf carcase was not found. In 3 cases the calf was present with the cow and was observed over a number of days. When it became evident that the calf was not able to suckle and would die of dehydration, it was recorded as dying but was removed and bottle fed on animal welfare grounds. While this study was of only one herd, it suggests that bottle teats are likely a bigger problem in northern herds than previously thought. The calving alerts allowed a greater number of cows to be observed shortly after birth than normally happens in extensive situations in northern Australia, and from these early observations, a number of cows that lost their calves were observed to have bottle teats shortly after calving. However, several weeks later their udders looked normal (after losing their calves) and so they would not be identified as having bottle teats at a muster several months later. It is likely that cows with bottle teats are remaining undetected in herds and losing multiple calves.

The majority of causes of foetal and calf loss in mature cows were due to unknown causes (because calf carcases were not found) around the time of birth (peri-natal = 4%) and between birth and weaning (post-natal = 4%). Two calves (1%) of mature cows died due to dystocia but another 7 (4%) peri-natal losses were due to unknown causes. The majority of these occurred in cows whose GPS tracking collars were not working at the time of calving and so the causes were not able to be identified. The reasons for the post-natal losses of unknown cause were not able to be identified as most calf carcases were not found (only 8 calf carcases were found in time for an autopsy to be conducted and details of the autopsy findings are presented in appendix 8.6). The VHF tracking system using accelerometers would allow more calf carcases to be found, but a decision was made not to use it after a few early attempts determined that it was going to be too dangerous chasing calves in long grass with lots of rocks, ant hills and fallen timber. Also many of the cows became agitated when approached with a newborn calf and attempting to catch their calves could have contributed to calf loss through mismothering. Therefore VHF tracking tags were not fitted to newborn calves and so the causes of most post-natal losses remain unknown and were only identified by cows which had been recorded as having a live calf, later turning up dry (not lactating) at the weaning muster.

The causes of post-natal loss in calves from mature cows were able to be identified in two cases in which calf carcases were able to be located quickly enough for post-mortems to be conducted. The causes of loss in these instances were neonatal septicaemia (Case 3 in Appendix 8.6) and umbilical cord infection which in turn caused nephritis, hepatitis, interstitial pneumonia and septic arthritis (case 6 in Appendix 8.6). Some of the peri-natal and post-natal losses where the cause remained unknown are likely to be due to poor mothering (cows abandoning calves). A number of cows were agitated when a person approached to conduct calving observations. In these circumstances the person would try to record observations from a distance with binoculars and then leave the area to try to prevent impacting the cow's behaviour and potentially increasing the likelihood of calf loss through poor mothering. In these cases it is likely that some of the calves that were recorded as being lost due to unknown causes, were in fact lost due to poor mothering. This also applies to calves recorded as being lost due to unknown causes where no observations were recorded (due to failure of the birth sensors and/or GPS tracking collars).

While foetal and calf loss is typically higher in first calf heifers than mature cows, the loss rate in first calf heifers in this study was very high (36%). In comparison Schatz and Hearnden (2008) found that the average calf loss in first calf heifers was 22% in 14 herds on commercial properties in the NT. The most likely reasons for the high calf loss seen in these heifers was that they were transported during pregnancy from the Douglas Daly Research Farm (improved pasture) to the Manbulloo site (native pasture) where nutrition is not as good and the paddock was much larger (requiring more walking). Also the total number of first calf heifers observed was low (n=50) and so any loss made up a relatively large percentage of the total. Some pre-natal calf loss (3%) was seen in first calf heifers, but most losses were perinatal (18%) comprising 6% dystocia and 12% unknown causes. As with the mature cows, more of the reasons for the peri-natal losses of unknown cause may have been able to have been identified if more of the GPS tracking collars had been working at the time of calving allowing the heifers to have been observed shortly after calving, and some of the losses would have been due to poor mothering. Two calves (4%) of first calf heifers died of known post-natal causes (cases 2 and 5 in Appendix 8.6) and 4 calves (8%) died of unknown post-natal causes.

There were numerous causes of calf loss and a number of cases where the cause was unknown. This is consistent with the findings of several other studies in northern Australia (eg. (Holroyd 1987; Fordyce *et al.* 1990; Brown *et al.* 2003). Therefore it was difficult to recommend strategies to reduce calf loss from the findings of the 2019 calving season apart from identifying and culling cows with bottle teats and not transporting first calf heifers to a different environment during pregnancy. It was hoped that repeating the study in 2020 with more reliable GPS trackers would shed more light on the unknown causes of calf loss.

One finding from the 2019 calving season was that most cows calved during daylight hours which differs from the common perception that most calves are born at night. This may be due to the fact that the cows grazed at night, as studies in the USA have found that night feeding results in a high proportion of calves being born during the day. Studies in Iowa (Iverson 1981) and Idaho (Jaeger et al. 2008) both found that 85% of cows that were fed at night calved between 6:00 and 18:00. While the cows in this study were not fed but grazed extensively, most pasture was consumed at night since they congregated around the water point during the day. Calving alerts were recorded for 158 cows and 71% (95% CI = 63-78%, Binomial Exact test) of birth sensors were expelled during daylight hours (6:00 to 19:00) with the peak period being between 12:00 and 15:00 (Figure 3). A high proportion of calves being born during the hottest times of day in northern Australia may contribute to calf loss and provides cause for conducting research on providing shade where cattle congregate around water points where there is no natural shade. Although there was little difference in the calf loss rates of cows calving at different times of day. The calf loss rates in cows calving at different times of day were: 0:00 - 3:59 (n=11) 27% calf loss, 4:00 - 7:59 (n=22) 23% calf loss, 8:00 - 11:59 (n=35) 26% calf loss, 12:00 - 15:59 (n=42) 19% calf loss, 16:00 - 19:59 (n=36) 22% calf loss, and 20:00 - 23:59 (n=16) 25% calf loss. Statistical analysis has not been performed on this data, but it is unlikely that the percentages are significantly different due to the low numbers of cows in each group.

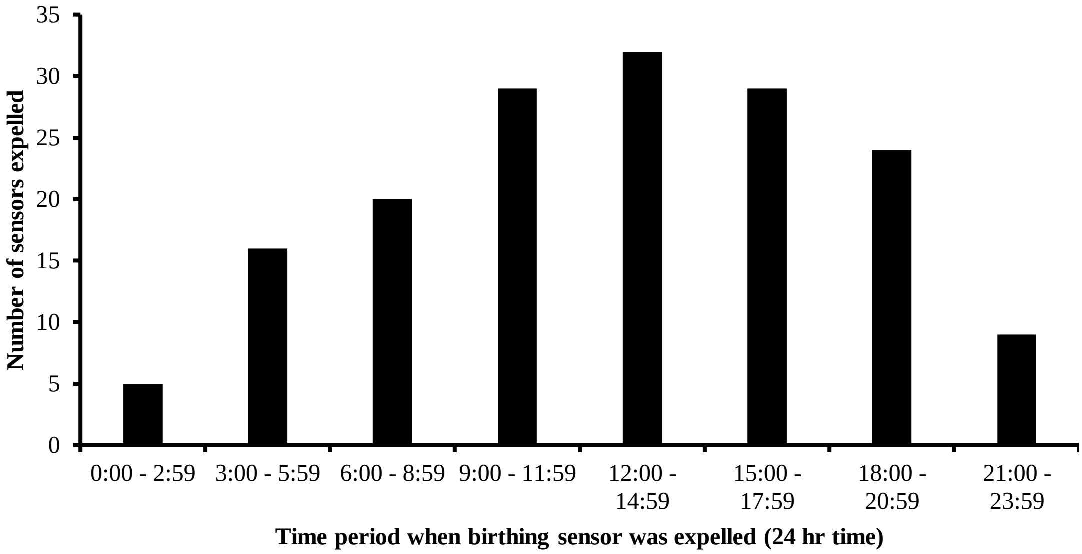


Figure 3. The number of birthing sensors expelled at different times of day.

4.3.2 2020 calving season

The 2019/20 wet season at Katherine was one of the lowest on record for rainfall (Figure 2 in Appendix 8.5) and as a result pasture growth was lower than normal. The trial paddock became overgrazed during the 2020 dry season and during the start of the 2020 calving season (until mid-November). The decision was made to supply hay (large round bales of 80% Pangola / 20% Tully grass) to the cows near the water trough from 30/10/20 to 15/11/20. This resulted in different behaviour to the previous calving season as cows were able to eat during the day, whereas they could not in the previous year as there was no grass left around the water trough.

It was very hot and dry during the start of the calving period with mean maximum temperatures of 38.6°C in October and 40.0°C in November and 20 days during this period when the maximum temperature exceeded 40 degrees. The wet season broke in late November with 29 mm on 15/11/20, 40 mm on 23/11/21 and then good follow up rain through December (December monthly total = 316 mm). The mean maximum temperature during December was only 34.8°C (Table 2 in Appendix 8.6). The 2020/21 wet season was much better than 2019/20, with well above average rainfall being received (Figure 3 in Appendix 8.6).

The cows congregated around the water trough during the day up until the wet season broke which allowed easy observations of cows and calves up to that time. However, following the rain in late

November the cows scattered throughout the paddock which made it difficult to record observations if a cow did not have a working GPS collar. During the period when cows were congregating around the trough during the day it was easy to do daily visual checks and if calving cows could not be located using GPS data (eg. if the GPS collar was not working at the time of calving) then observations were recorded when they came for water in the days after calving. Observations were recorded on any cows that were seen to have calved before an alert was received. On several occasions in late December, January and February a 4WD buggy was used to search the paddock and record the lactation status of any cows that a caving alert had not already been received from. This did allow additional information to be collected, but not all cows could be found using this method. As a result calving outcomes were able to be recorded for 192 cows.

When both the birth sensor system and the GPS tacking collars worked correctly it was easy to find calving cows in the paddock and record observations. However, this was not always the case and calving alerts were only received for 51% of cows and GPS tracking collars were working correctly when needed to locate cows on 66% of cows (see section 4.2.3).

The overall foetal and calf loss rate for the 2020 calving season was 17.1%. This was very similar to the loss rate in the 2019 calving season (17.0%) and is at the high end of the normal range for mature cows in this region. The CashCow project reported that the 25th and 75th percentiles for foetal and calf loss in mature cows in the Northern Forest zone were 9.4% and 19.2% respectively (McGowan *et al.* 2014).

Calf loss rates in both years of the CalfWatch study were 6 percentage units higher than the average calf loss that occurred at this site in the previous 4 years (ie. 10.7%). This suggests that the observation of calving cows following a calving alert may have contributed to higher calf loss. Even though care was taken to disturb cows as little as possible when they were calving, the extra activity of people taking observations may have contributed to calf loss. Some cows were noted to hide their calves and not return to them while being observed. In these cases a person would come back a couple of times a day to try and find a calf, but the cows were observed to be intentionally trying to hide the location of their newborn calves. It is possible that this could have contributed to dehydration of calves and possibly calf loss.

The breakdown of the causes of calf loss are shown in the Table 2 below. Disappointingly, and consistent with many previous studies (Holroyd 1987; Fordyce et al. 1990; Brown et al. 2003), again the highest loss category was "Unknown losses". If the GPS tracking collar was not working when a calving alert was received it was almost impossible to find the cow in the large paddock, and if a calf was lost in this situation then the cause was unknown. It was hoped that the new model of tracking collar would be more reliable and reduce the number of calf losses due to unknown causes compared to the 2019 calving season. However, while there were 20% fewer tracking collar failures in 2020 (2020 = 66%, 2019 = 46%), there were more birth sensor failures (alerts were only received for 51% of cows in 2020 compared to 85% in 2019). Also, the fact that the wet season started sooner in 2020 meant that the cows scattered sooner and stopped coming into the water trough each day where they could be observed. It was not possible to identify calf losses in the early stages for cows from which a calving alert had not been received. The combination of birthing sensor failures and GPS tracking collar failures in 2020 meant that there was still a high proportion of calves lost due to unknown causes (9.9 percentage units out of a total of 17.1 were due to unknown causes in 2020). It is likely that many of the losses where the cause was not able to be determined were due to poor mothering (ie. cows abandoning young calves). It was not possible to identify this as we did not do the frequent observation that would have been required to determine it, as we tried not to impact cow/calf behaviour as much as possible, especially when cows were observed to be nervous and agitated when approached. It was thought that frequent observation of "shy" cows would likely contribute to the problem of mismothering.

Table 2. A summary of the causes of calf loss during the 2020 calving seasons. Where the cause of death is listed as unknown it is because a calf carcase was not found to investigate the cause of death.

Cause of calf loss	Calf loss (%of total number of cows)
Early abortion - unknown cause	1.0%
Dystocia	0.5%
Unknown Peri-natal loss	
Unknown Post-natal loss	2.6%*
Unknown - No information	7.3%*
Post-natal loss - bottle teats	4.7%
Possible dog predation	0.5%
Deformity	0.5%
Total loss	17.1%

**many of the post-natal losses where the cause could not be identified may have been due to poor mothering (eg. cows abandoning calves). The frequent observation required to confirm this was not conducted as it would have impacted cow behaviour.*

In some cases it was not possible to identify the cause of calf loss even when a calving alert was responded to promptly, the birth site (expelled birth sensor) found and the cow located with a working GPS tracking collar. An example of this is described in case 8 in Appendix 8.7. As with the 2019 calving season, the next biggest cause of calf loss after "unknown causes" in 2020 was bottle teats. Although the percentage of losses due to bottle teats was lower in 2020 (4.7%) than 2019 (6.0%), it was still a major cause of calf loss. The calving alerts allowed a greater number of cows to be observed shortly after birth than normally happens in extensive situations in northern Australia, and from these early observations, a number of cows that lost their calves were observed to have bottle teats shortly after calving. Several weeks later (after losing their calves) these udders appeared normal and so they would not be identified as having bottle teats at a muster several months later. It is likely that cows with bottle teats are remaining undetected in herds and losing multiple calves, and one of the findings of this project is that bottle teats are likely a bigger problem than previously thought.

Due to the wet season starting earlier in 2020, less calving outcomes were able to be determined for cows that a calving alert was not received from (as the cows stopped congregating around the water trough earlier in 2020). It was not possible to differentiate the "Unknown losses" in 2020 into peri-natal or post-natal.

Bottle teats and unknown causes were the only causes of more than 1% of calf losses. All the other identified causes only accounted for losses of 1% or less (Table 2). Where calf losses are listed as being from unknown causes it is because a carcase was not found to investigate the cause and there were no observations recorded that gave clues as to the cause of death eg. bottle teats noted. Detailed reports on the incidences of calf deaths due to known causes are shown in Appendix 8.7.

The incidence of damage to calves caused by dogs (bite marks, ripped ears) recorded at the weaning muster in April 2021 was 2.6% of calves, which was very similar to the previous year (ie. 2.5%). It is thought that one calf may have died due to dog attack as it was seen with injuries (see Appendix 8.7).

Calving was not concentrated during daylight hours in 2020 (Figure 4) as it had been in 2019 (Figure 3) and this is likely to be because hay was fed near the water trough from 30/10/20 to 15/11/20. This meant that cows were able to eat during the day during this period and so the effects observed where cows fed at night calve during the day and vice versa, did not result in a high proportion of calves being born during the day.

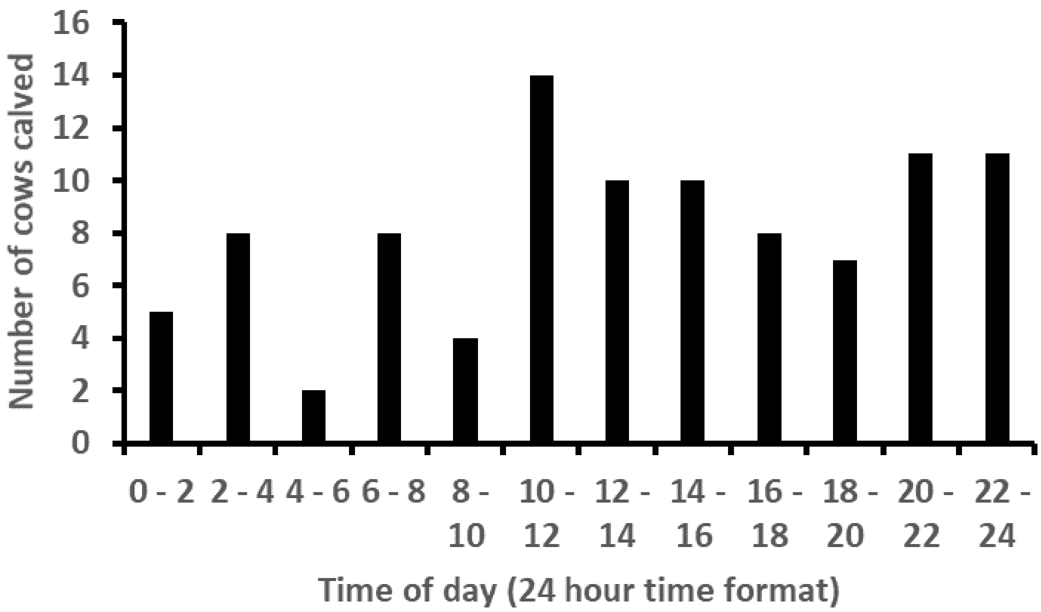


Figure 4. The number of cows calving at different times of day during the 2020 calving season.

80 of the cows that were observed in 2020 had been in study in the previous year and were included again as they had re-conceived and were due to calve in the required period (Oct-Dec) for study in 2020. Of these cows, 57 had weaned a calf and 23 had lost their calf in 2019. Of the 23 cows that lost calves in 2019, 8 (35%) lost calves again in 2020. The rate of calf loss in these cows was much higher than in the 57 cows that raised a calf the previous year (16% calf loss).

5. Conclusions

The technology used in the CalfWatch system was found to work well if both the birth sensors and GPS tracking collars were working correctly at the time of calving. However, if one or both were not, then it was difficult to monitor calving and investigate calf loss in an extensive environment.

Performance of the birth sensor system was variable: It was quite good in the first calving season (85% worked correctly in 2019) but disappointing in the second calving season (51% worked correctly in 2020). Due to the cost, the knowledge required to use them and the invasive nature of birth sensors it is a recommendation of this project that they don't have much potential for use on commercial properties, although they may be useful for specific research purposes or in stud herds with high value animals when it is important to know when cows calve. If GPS tracking collars can be developed that contain accelerometers and send calving alerts in real time then this would be a preferred option.

Studies to investigate the causes of foetal and calf loss over the 2019 and 2020 calving seasons were hampered by equipment failure but were still able to provide useful insights into the causes of calf loss in extensive northern herds. Low level losses (1% or less) were identified as being due to abortion, dystocia, infection and septicaemia via the umbilical cord, pneumonia deformity and wild dog attack, while the major causes of loss were bottle teats (6% in 2019 and 5% in 2020), and unknown causes (8% in 2019 and 10% in 2020).

One of the major findings of the project was that bottle teats are likely to be a bigger problem in extensive northern herds than previously thought and it is likely that cows with bottle teats are remaining undetected in herds and losing multiple calves. The CalfWatch system allowed a greater number of cows to be observed shortly after birth than normally happens in extensive situations, and from these early observations, a number of cows that lost their calves were observed to have bottle teats shortly after calving, but several weeks later (after losing their calves) their udders appeared normal and so would not be identified as bottle teats at a muster several months later. Culling all cows that don't rear a calf to weaning would remove these cows from the herd. While some cows may be culled who lost a calf, the impact on herd numbers would not be great if cow re-conception rates and pregnancy rates in replacement heifers were adequate.

5.1 Key findings

- The technology and systems used by the University of Florida to remotely monitor calving were evaluated and successfully adapted to suit extensive NT conditions where mobile phone reception is limited.

- The performance of the birth sensors used to give calving alerts was variable with 85% working correctly in the first calving season and 51% in the second (although many of the birth sensors used in the second calving season were being used for the second time).

- When a birth sensor worked correctly and a cow had a GPS tracking collar, the system worked very well and enabled cows to be found for observation at calving. The best performance from the tracking collars was in the second calving season (2020) when 75% of collars were working properly when required to find calving cows. If either the birth sensors or GPS tracking collars failed then it was usually not possible to find cows to for calving observations unless we saw them by chance near the water trough shortly after calving. As a result there were still a number of calf loss cases each year where the cause was unknown.

- The adapted "CalfWatch" system was used to investigate the causes of calf loss in an extensive herd in the NT over two calving seasons. Foetal and calf loss was 17% in both years which is at the high end of the normal range for northern herds. Minor causes of calf loss (1% or less) included abortion, dystocia, infection and septicaemia via the umbilical cord, pneumonia, deformity and wild dog attack, while the major causes of loss were bottle teats (6% in 2019 and 5% in 2020), and unknown causes (8% in 2019 and 10% in 2020). It is likely that some of the unknown causes of post-natal losses were due to poor mothering

- Observations made possible through use of the CalfWatch system indicate that bottle teats are probably a bigger problem in extensive northern herds than previously thought, and it is likely that cows with bottle teats are remaining undetected in herds and losing multiple calves.

6. Benefits to industry

This project developed a system that could be used to remotely monitor calf loss in extensive cattle herds. The system is unlikely to be used by commercial cattle producers due to the cost and complexity, but rather it is only likely to be suitable for research purposes or where it is important that the time of birth of high value animals is known.

The project increased the understanding of the causes of calf loss in extensive northern herds, although there was still a significant proportion of losses due to unknown causes where the equipment failed or loss occurred after calving observations were made. Observations made possible through use of the CalfWatch system indicate that bottle teats are likely to be a bigger problem in northern herds than previously thought.

The project played a role in the development of affordable GPS tracking collars that can be used to locate cows in extensive areas, and efforts are underway to further develop the collars to identify calving from accelerometer data in real time and send calving alerts. If this can be done it would enable birth date to be recorded remotely in extensive areas without the need for birth sensors. This would enable more animals to be involved in Breedplan recording where birth date is necessary.

7. Future research and recommendations

The CalfWatch system was found to be useful for studying calf loss in extensive situations. Calving alerts were received for 85% of cows in 2019 and if all had functioning GPS tracking collars then this would have enabled calving observations to have been recorded on 85% of cows. In addition, it is possible to record calving observation on other cows if they are seen at a water point, supplement site or while in the paddock searching for a cow after receiving an alert. It is possible that around 90% of cows could be observed around calving using the system. However, the birth sensors are invasive, expensive (especially if they can only be used reliably once) and the system is complicated. Using accelerometer data in real time to identify calving and send alerts would be a preferable option. A recommendation of this project is to develop collars that enable GPS tracking of cows in real time and can send calving alerts from accelerometer data.

The fact that the cause of calf losses could not be identified in a high proportion of causes (8% of a total of 17% in 2019 and 10% of 17% in 2020) suggests that further research on calf loss is warranted. Some of the “unknown loss” in this study is likely to have been due to poor mothering (cows abandoning calves), but this was unable to be quantified, and methods to study this may need to be developed.

Observations from expulsion times of birth sensors in this project showed that most cows calve during daylight hours when they feed mostly at night. This is common in northern Australia when cattle graze in large mobs and congregate around water points during the day and these areas become over grazed. It seems likely that if most calves are born during the day and during the hottest time of the year, that providing shade in areas where there is none may reduce calf loss. Research in this area is recommended and is currently underway in the MLA funded DITT project; B.GBP.0031 - Reducing calf loss due to exposure.

8 Appendixes

8.1 Figures

Figure 1. The trial paddock at Manbulloo showing the read range (red circle outline) of each tower (yellow diamond). The location of birthing sensors that were found after expulsion are shown by circles (cow=green, heifer=red).

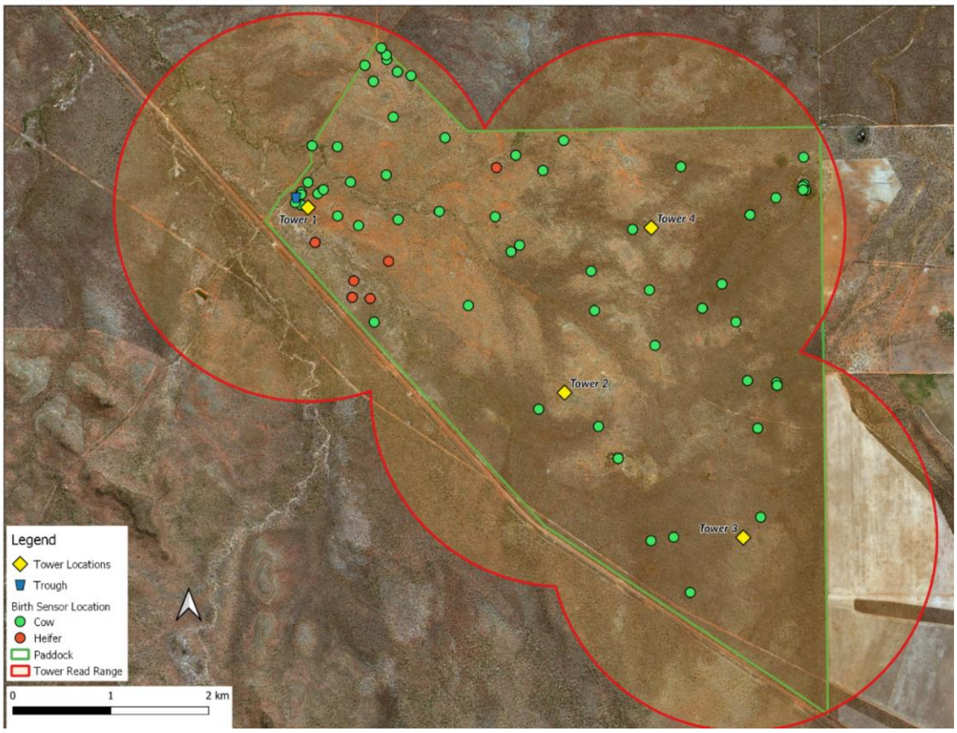


Figure 2. A screenshot of the Cowmonitor website used to record alerts from birthing sensors.

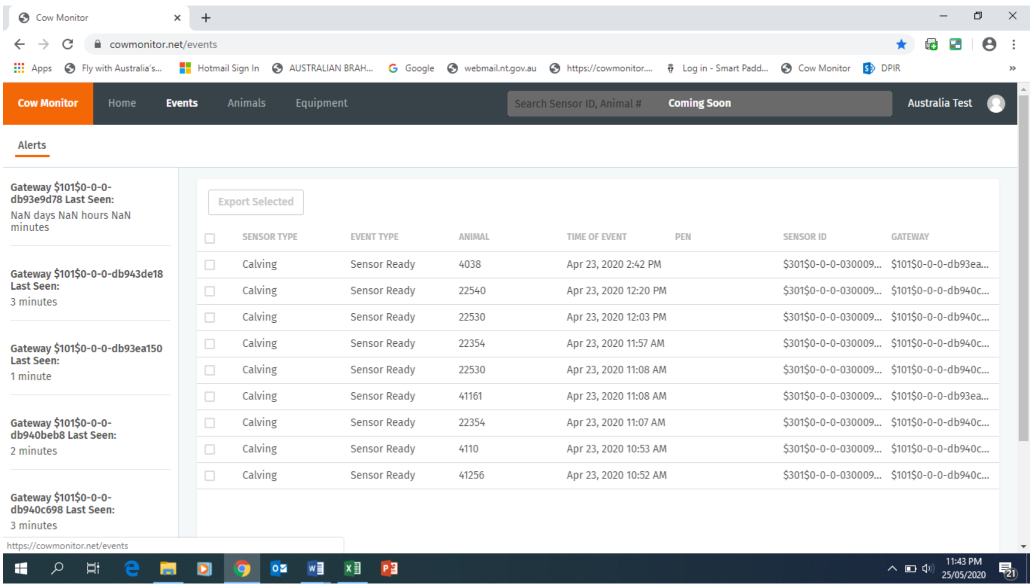


Figure 3. A screenshot of the Smart Paddock website used to locate expelled birthing sensors and calving cows. The red areas are a heat map showing where the cow stayed in the same place for an extended period of time

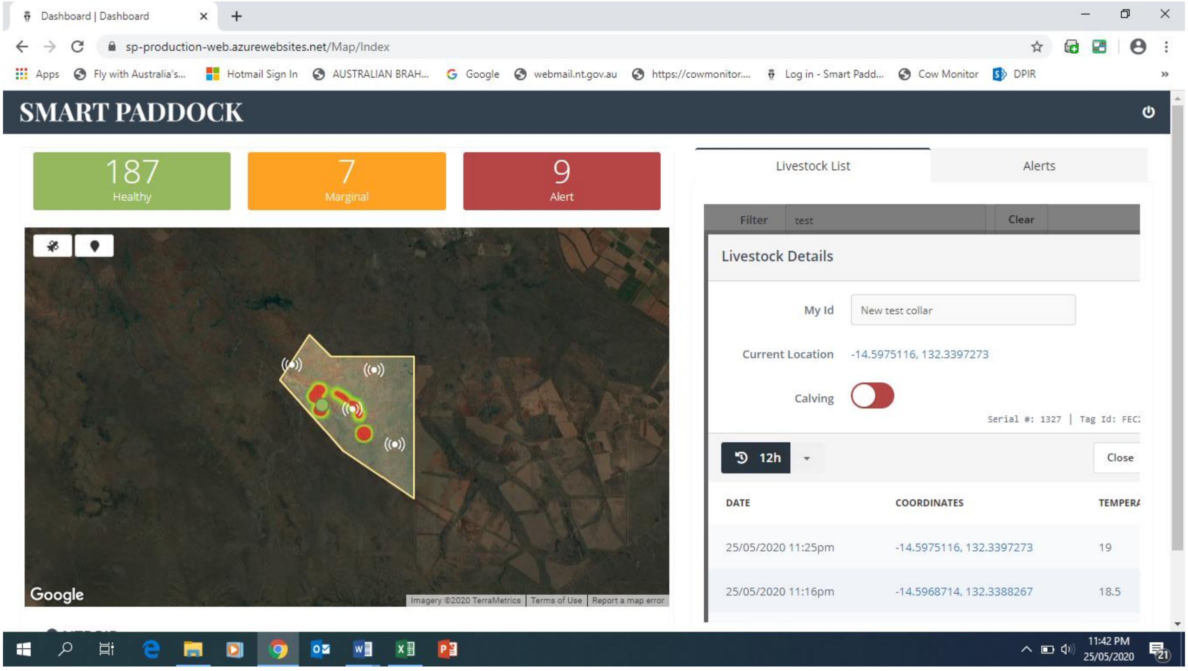


Figure 4. Plot of the total number of GPS locations recorded by all collars over 24 hours from 17th August, 2019 to 28 February, 2020. The decline over time in the number of fixes received from all GPS collars appeared to be generally linear with approximately 2000 less GPS locations per day being captured each month. (The 3 spikes are potentially where the data has been merged together or transformed for time – as data was collated from 3 separate downloads).

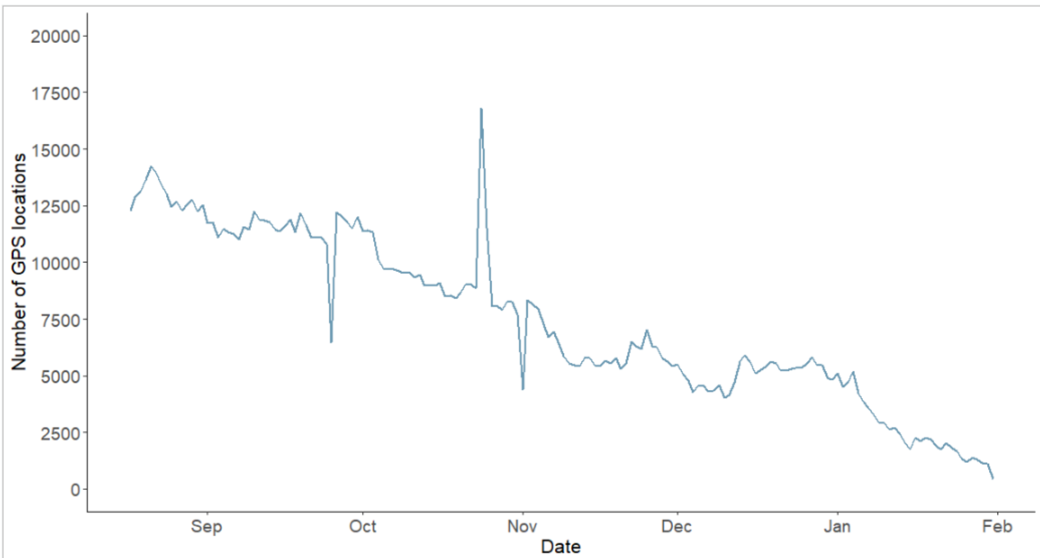


Figure 5. Graph of accelerometer data for a cow that a birthing sensor alert was received from on 24/11/19.

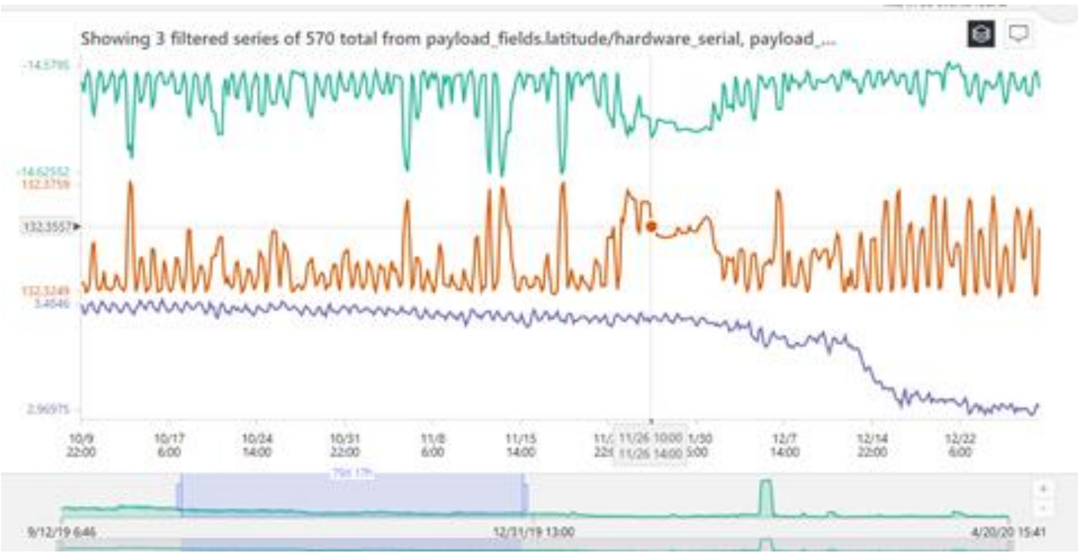
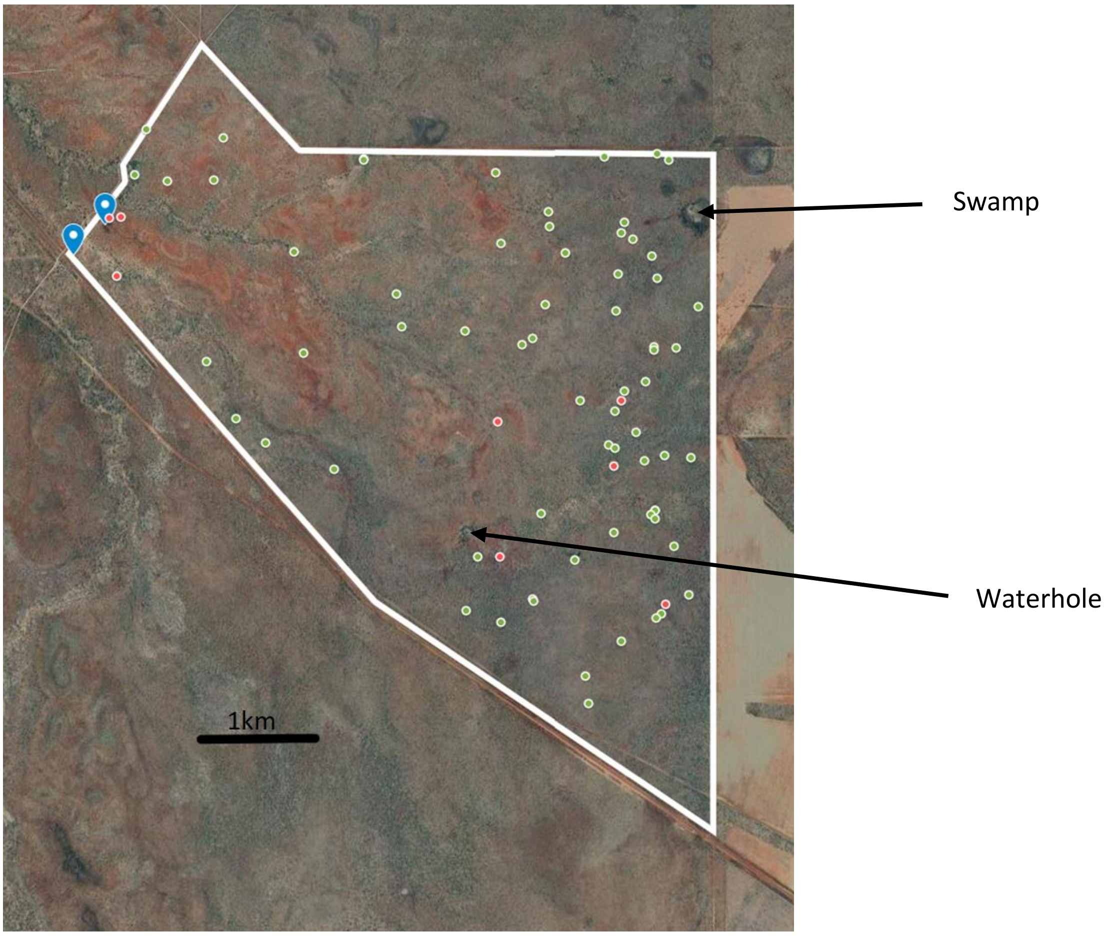


Figure 6. Map showing birth sites in 2020 calving season. Calving locations of cows that lost their calves are represented by red dots while green dots are for cows whose calves survived.



8.2 Photos

Photo 1. UF researchers Dr Raoul Boughton and Kelly Koriakin preparing to insert birthing sensors into pregnant cows. **Photo 1b.** A birth sensor.

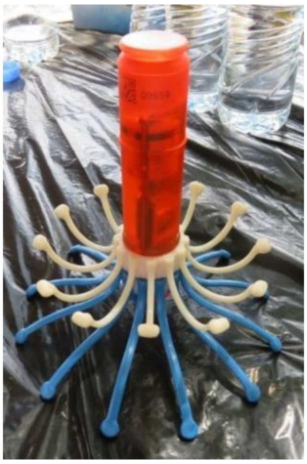


Photo 2: A calf with a VHF tracking tag containing an accelerometer at a research site in Florida.

Photo 3. A birth sensor being inserted.

Photo 4: UF tower set up at the Buck Island ranch site in Florida. Note the flat, treeless paddock which enables expelled sensors and calving cows to be easily found.

Photo 5. One of the towers at the Manbulloo CalfWatch site. Note the trees and long grass making it difficult to find expelled sensors.

Photo 6. The electronic equipment used on each of the towers in the NT. The blue device is a gateway to receive birth sensor alerts and send them to the internet, via the modem (red/grey device), and the small black box is a POE (power over ethernet) adaptor for the Smart Paddock GPS tracking collar gateway. The VHF receiver used to monitor the calf VHF tracking tags has been removed in this photo.

Photo 7. Raising a tower at the Manbulloo site.

Photo 8. A cow with a GPS collar (first Smart Paddock prototype used in 2019) near one of the towers in the paddock at Manbulloo.

Photo 9. A cow with the second model GPS collar (used in 2020) at Manbulloo.

Photo 10. Tim Schatz using a portable yagi antenna to find a VHF tracking tag in Florida.

Photo 11. Trail camera shot of wild dogs in the paddock feeding on the carcase of a cow that died during calving.

Photo 12. A GPS collared cow with a newborn calf at the Manbulloo site. The CalfWatch system (birth sensors and GPS tracking collars) allows calving cows to be located and observations recorded.

8.3 Calving observations recorded

Visual Tag No.
Birth Sensor No.
Collar No.
Sensor/collar issues
GPS collar working at calving (Y/N)
Breed
Birth Year
Est. Birth Date
Cow colour
Birth sensor alert received (Y/N)
Date of alert
Time of Alert (24 hr)
Type of Alert
Date Cow Found
Time Cow Found
Sensor Found (Y/N)
Sensor Location (GPS)
Birth Location (GPS)
Calf Born (Y/N)
Calf Still Alive (Y/N)
Bottle Teat Score (0 = None, 1 = Mild, 2 = Bad)
Cow Maternal Score (1=poor, 2= normal, 3=strong)
Calf Health (0 = Dead, 1 = sick/weak, 2=normal)
Calf Size (1 = small, 2=normal, 3= large)
Calf Suckling (Y/N)
Calf Standing (Y/N)
Calf Walking (Y/N)
Calf Gender
Calf Comments
Calf colour
Cow Comments
Calf loss Y/N
Calf loss reason

Summary of observation results

	Score	N 2019	% Loss 2019	N 2020	% Loss 2020
Bottle teats (0,1,2)	0	188	10%	188	10%
(0 = None, 1 = Mild, 2 = Bad)	1	11	18%	11	18%
	2	15	53%	15	53%
	Not known			29	34%
Calf health score (0,1,2)	0	14	100%	3	100%
(0 = Dead, 1 = sick/weak, 2=normal)	1	14	64%	16	25%
	2	173	4%	146	5%
	Not known	4	50%	27	67%
Calf size	1	15	60%	17	6%
(1 = small, 2=normal, 3= large)	2	170	5%	124	7%
	3	3	67%	22	14%
	Not known	14	36%	29	69%
Calf seen suckling	No	13	77%	12	42%
	Yes	161	4%	103	5%
	Not known	26	46%	77	30%
Calf seen standing	No	4	50%	7	29%
	Yes	181	8%	155	7%
	Not known	29	41%	30	67%
Calf gender	Female	59	8%	63	10%
	Male	51	12%	57	7%
	Not known	92	20%	72	32%
Cow maternal score	1	1	100%	6	33%
(1=poor, 2= normal, 3=strong)	2	176	9%	141	6%
	3	7	43%	4	25%
	Not known	28	36%	41	54%

8.4 Evaluation of the Smart Paddock GPS tracking collars for the 20019 and 2020 calving seasons.

Evaluation of collar performance was conducted by analysing the number of fixes recorded by the Smart Paddock system. The variables that were provided were: Ingress date, TagID, Latitude, Longitude, Temperature and PDOP. Most variables are logically understood, however, DPOP maybe new or some readers. Position of Dilution of Position (PDOP) can be thought of as the mean of Dilution of Position, and is a measure of the accuracy of the data collected by a GPS receiver.

Gross level analyses of location data were performed to investigate the ability of the GPS tracking system to monitor cows across time and to assess the quality and quantity of information the system was able to provide. Investigating the proportion of collars that successfully contributed data across time and how frequently collars were providing data were key areas of interest.

The cows were due to calve October and December (inclusive) as assessed by pregnancy testing in both years of this study. Therefor the target observation period was defined as from the time of collar deployment until the 31st December in each year. Individuals within the mob varied between years, as cows that did not reconceive over the 2019/20 wet season were replaced with pregnant cows from a neighbouring paddock. Each cow within the management group (n=199 in 2019 and 194 in 2020) was fitted with a collar scheduled to record a GPS location every 15 min (ie. 96 per 24 hours) meaning that up to 20,640 GPS locations could be recorded per day. Collars that fell off cows were removed from the analysis.

In 2020 the performance of the GPS tracking collars was evaluated between 20/8/20 and 31/12/20 (a period of 133 days or 4.4 months) and the Smart Paddock system recorded 3,313483 fixes of GPS location from collars during this period. Figure 1 shows how the number of GPS fixes declined over time in both the 2019 and 2020 calving seasons in comparison to the shaded area which shows the potential number of fixes if all collars were working correctly.

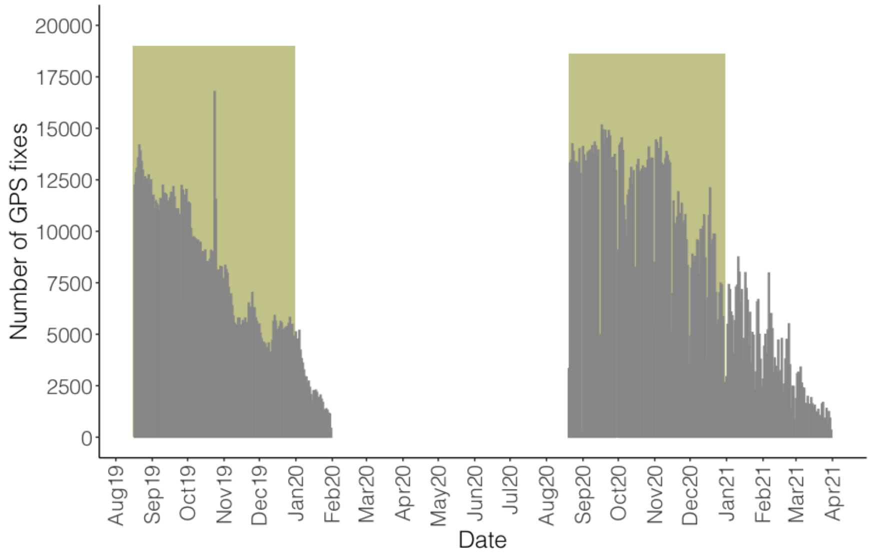


Figure 1. The aggregated number of GPS locations submitted by all the collars each day over time. The maximum number of GPS locations over the defined observation period is represented by shading.

The GPS data provided by the system was summarised, with the aggregated number of GPS locations submitted by all the collars each day over time presented as Figure 1. Variation in the number of GPS locations per day provided by the system was evident, with a general trend for the system to drastically fewer GPS locations provided per day with increasing time since deployment.

Further descriptive analyses were performed to describe gain further explanatory information around relating to the declining number of fixes per day. These analyses were performed with day of observation (day = date deployed) as a main explanatory variable, which allowed both deployments to be presented on a common scale and supporting a comparison between them (Figure 2).

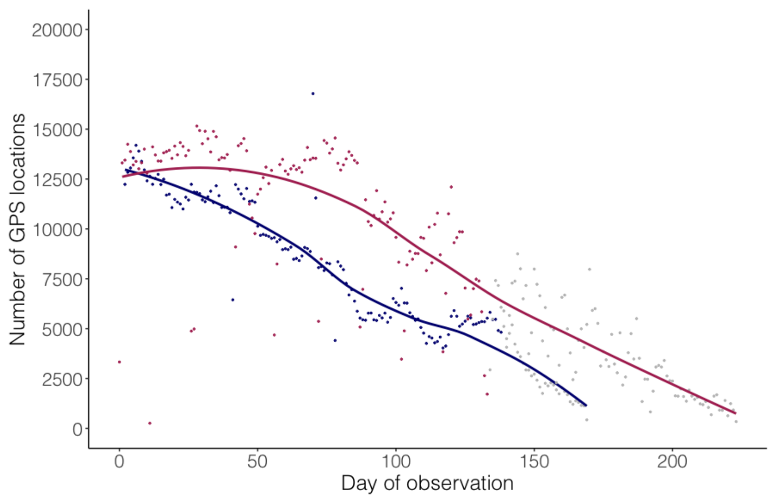


Figure 2. The aggregated number of GPS locations submitted per day across time. A loess regression smoother was fitted to through to the points for each deployment (red = 2020-21, navy = 2019-20). Data captured after the defined observation period have been greyed out.

To describe the change in GPS location data over time, a regression analysis was performed. For 2019/20, 84% of the variance was explained by fitting day of observation as the sole predictor and had a regression coefficient -71.3 and y intercept of 13531 (P<0.0001). This meant that fixes per collar declined at a rate of 0.35 fixes per day (or 70 per day in total).

For 2020-21 season, descriptive analyses highlighted a relatively constant number of GPS locations being submitted to the system for a length of time and then drop off over time. To explore this concept further a broken-stick analysis was performed to calculate the break point, explaining most of the variation in the data. However, this concept is also practically plausible in the example of power supply meeting demand for a certain period until a critical threshold is reached, after which a rate of change in data submitted rapidly declines. The critical break point calculated for 2020-21 was at 78.0 (95% CI 62, 93) days after deployment. The system was modelled as providing an 76 fixes per collar per day at day 0 with a slight decline of 0.6 fixes per day in total (or 0.003 fixes per collar per day) up until day 78, when the change in total fixes was best explained by a regression coefficient of -118.5 , meaning that collars were submitting 0.7 less fixes per day on average.

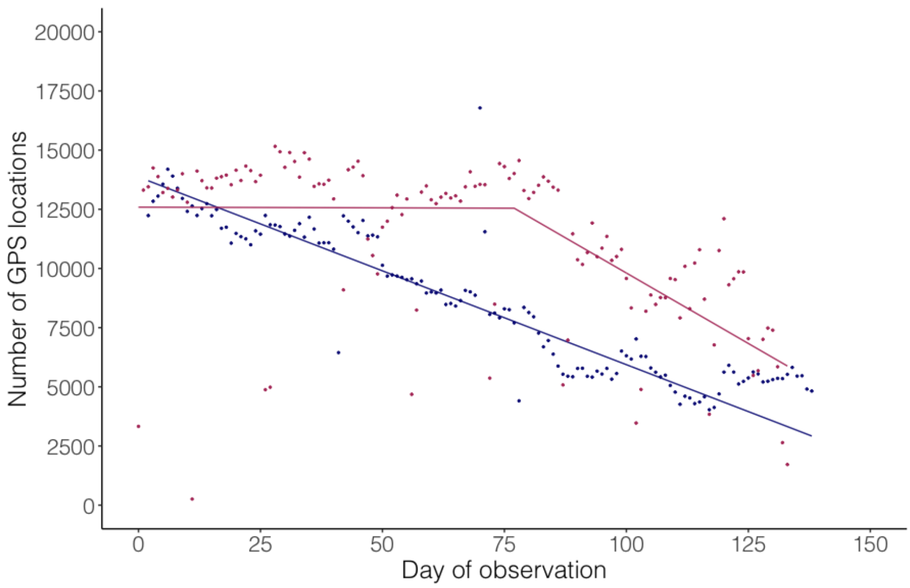


Figure 3. The aggregated number of GPS locations submitted per day across time. A loess regression smoother was fitted to through to the points for each deployment (red = 2020-21, navy = 2019-20).

Also of interest was the incidence of failure over time (Figure 5). A survival analysis was performed to summarise the proportion of functioning units over time. Overall, the collars deployed in 2020/21 had significantly fewer failures during the observation period when compared to 2019/20. For example at day 100, there was approximately 15% more active collars in 2020/21 than at the same time in 2019/20.

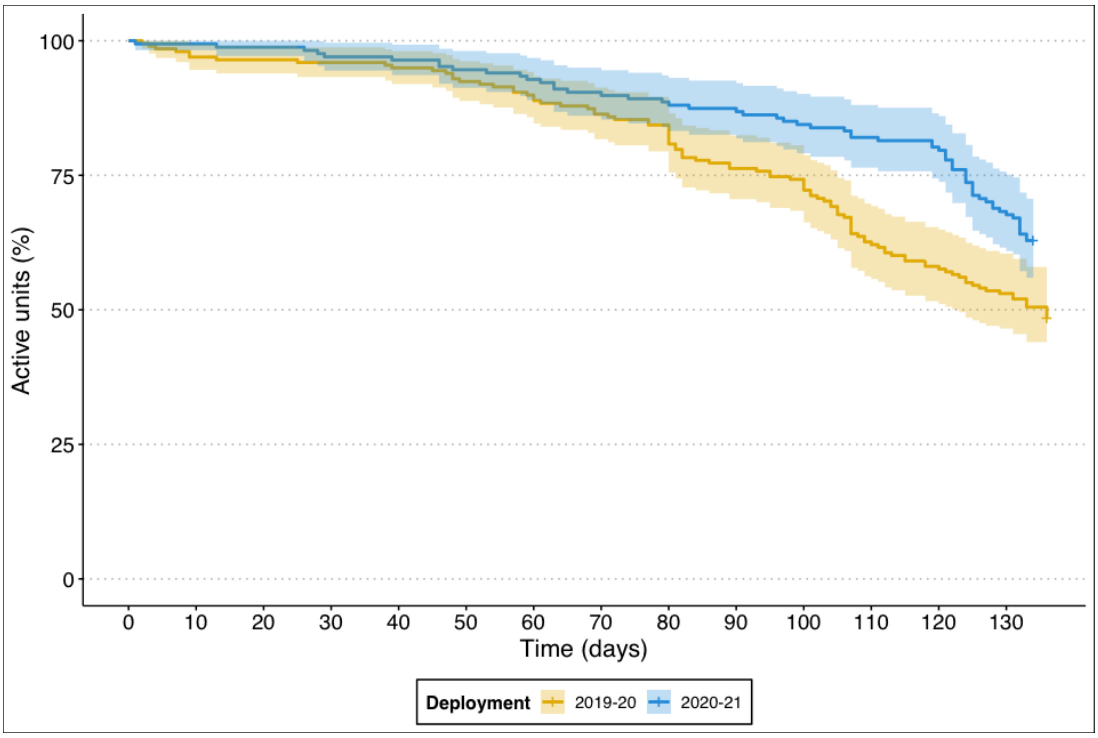


Figure 4 Plot of Kaplan-Meier estimate of active units for each deployment over time.

Distance to water: The proximity of cows to water was calculated at each coordinate using R's geosphere::distHaversine package. This method calculated the distance on a "as a crow flies" basis. Therefore, barriers such as natural topography or infrastructure are not accounted for in this calculation.

- Closer until there was more rain in December.
- Highly variable after Christmas – drop off in collars / preference of animals etc.
- Compare to rainfall.
- Daily variation supports cow speeds – on water over the middle of the day and grazing at night.

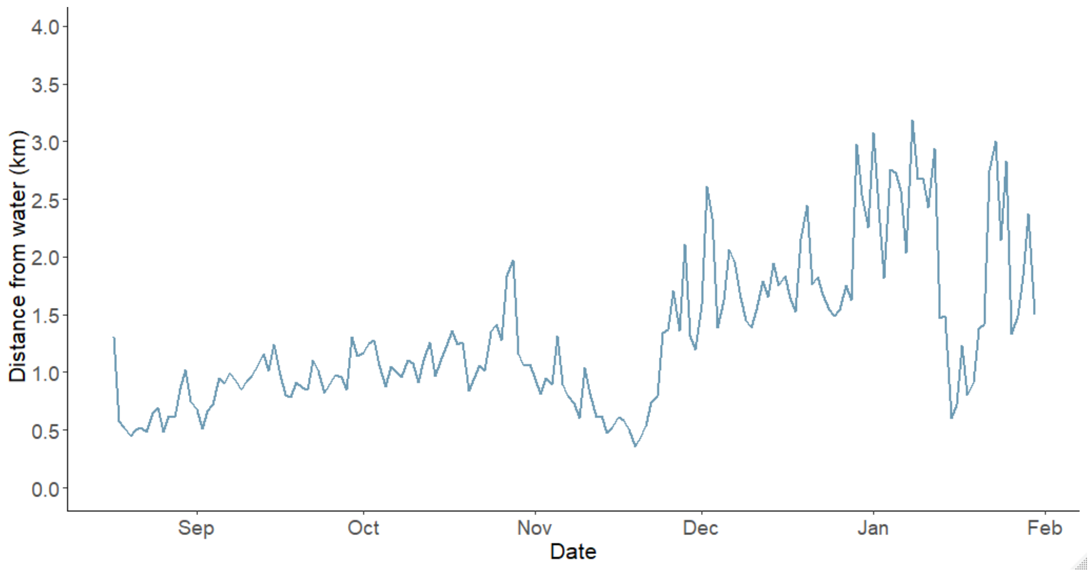


Figure 5 Average daily distance from water for cows over the 2019-20 calving season.

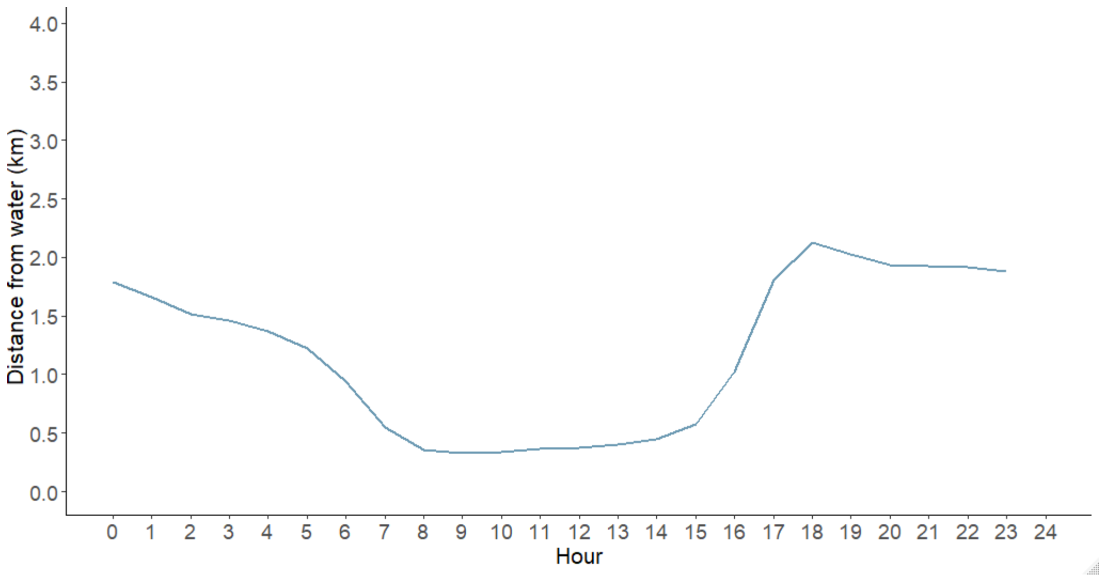


Figure 6 Average distance from water (km) for hours of the day over the 2019-20 calving season.

8.5 Summary of climactic conditions during the project.

Table 1. Summary of weather data during the 2019 calving season from the Tindal weather station (about 8 km from the Manbulloo paddock).

Month	Mean Min Temp. (°C)	Mean Max Temp. (°C)	Total Rainfall (mm)	Rel. Humidity 9am (%)
Sep	16.2	35.9	0	43
Oct	21.2	39.4	0.4	40
Nov	25.5	40.4	15.2	51
Dec	26.8	40.8	64.4	54
Jan	25.5	36.7	169	70
Feb	25.1	35.6	134	75
Mar	23.1	36.2	54.6	67
Apr	21.7	36.7	19.6	61

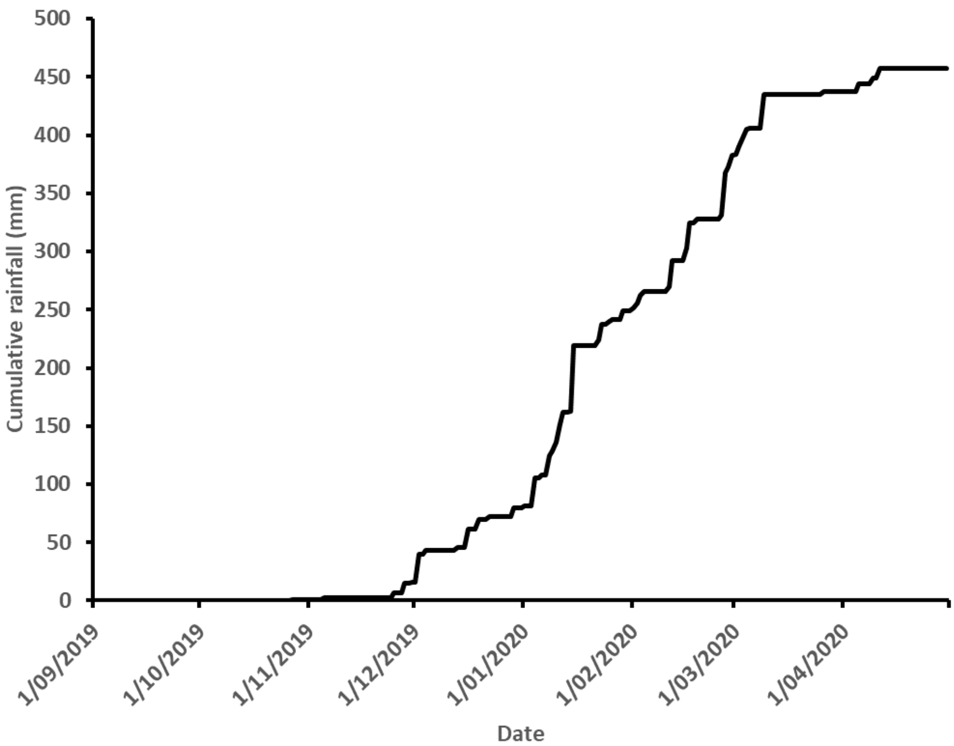
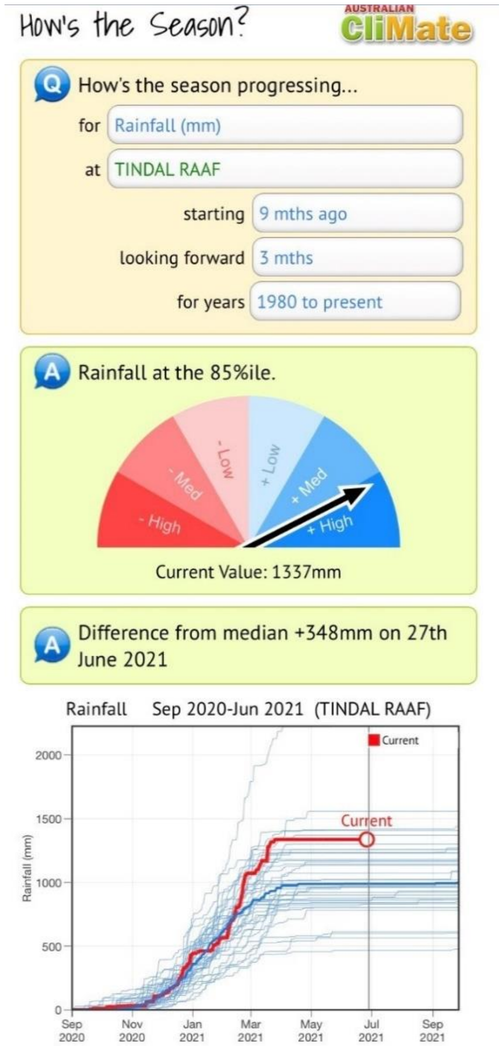


Figure 1. The cumulative rainfall received at the Tindal weather station (about 8 km from the paddock) between 1/9/19 and 30/4/20.

Figure 2. 2019 wet season.

Figure 3. 2020 wet season.



Figures 2 and 3: Data from "Climate" showing that the cumulative rainfall recorded at the Tindal weather station (which is about 8 km from the paddock). The red line on the graph is the current wet season and the thick blue line is the median of the last 50 years.

Table 2. Summary of weather data during the 2020 calving period from the Tindal weather station (about 8 km from the Manbulloo paddock).

Month	Mean Min Temp. (°C)	Mean Max Temp. (°C)	Total Rainfall (mm)	Rel. Humidity 9am (%)
Sep-2020	21.4	37.5	6	49
Oct-2020	24.6	38.6	21	54
Nov-2020	26.5	40.0	83	55
Dec-2020	24.7	34.8	316	76
Jan-2021	25.4	35.1	130	75

8.6 Calving season autopsy reports – 2019

Available on request

8.7 Calving season autopsy reports – 2020

Available on request

8.8 Autopsy Template

Autopsies for the CalfWatch project were conducted by the NT DPIR veterinarian based at Katherine Research Station. The template/instructions on the following pages for doing “bush autopsies” are useful in conducting examinations in the paddock.

Bush autopsy instructions and diagnostic chart for dead calves or aborted foetus (Fordyce and Hill 2017, MLA Final report for project B.GBP.0001).

It is not common to see a dead newborn calf under extensive grazing conditions. When this occurs a systematic assessment including post-mortem, even if very basic, can be of great value in understanding why an animal died. Too often, a freshly dead animal is left to rot, while the owner/manager wonders why it died. If an untrained person does a simple assessment and observation, they may work out the problem using common sense. Alternatively, they may see critical changes that, when described to a trained person, clearly indicate the cause of the problem. Using a digital camera to record what you saw can vastly improve the quality of a bush post mortem.

There are a few basic steps in assessing any dead animal, which maximise the chances of finding the cause (Tables 1 and 2). Even doing part of the procedure can be of immense value in diagnosing a disease. After on-site assessment, seek professional opinion on findings and for sample evaluation.

Table 1. Steps for assessing the cause of mortality in cattle.

Consider the animal’s history	- Consider the site, management, handling, weather, animals around, feed, water, etc
Prepare the animal, equipment and situation for a suitable safe post-mortem	- Select a good place to do it. Make sure what is left will not affect anyone or anything adversely, eg, the carcass can be burnt where it lies if required. This might entail shifting the animal. - Do the job on freshly-dead animals. Immediately after euthanasia for very ill animals is optimum. Within hours, significant changes occur in the carcass and the carcass becomes a less-than-choice place to be working. - Sometimes animals can carry infectious diseases. So take precautions to avoid unnecessary contact with tissue and fluids. Eg, do not eat and drink around the procedure, wear PPE (gloves, shoes etc.), have water and soap on hand to clean up, wear a mask if you think it is warranted.
Start by detailed examination of the carcass before opening	- Look over the whole animal first. Note its tag numbers, number brands, property brand, sex, age, and anything unusual. - Throughout the procedure, take careful note of what you see, and try to compare it against what you have previously seen, or what you think might be normal. If possible, have someone note and or photograph what you see.
Open and examine the carcass in a systematic way	- It is best to have cattle on their left side to do a pm. - Skin the side from the middle of the belly and roll the hide back, along with the back and front legs which are cut through to the hip and up through under the shoulder, respectively. - Take a blood sample from the neck area. - Open the chest and gut areas without puncturing any of the organs, especially the gut. The chest is opened by slicing between each rib right to the backbone. Cut through the ribs where they bend near the sternum with either a knife, tippers, or axe. Then fold each rib back.

	- Have a look at the lungs, heart, liver and kidneys. Cut each out, slice it, and describe it.
At all stages, take photographs and any appropriate samples	- If you suspect a poison or something (bacteria, virus) you can grow out of these organs, put a clean sample in a sealed container, and chill it immediately. Freezing will kill most things you want to grow. And failure to chill quickly usually results in a useless sample. The best organs to sample are the liver and kidney. Often there is little point in chilling other samples. - Open the gut last. Sometimes opening the paunch to get an idea of what the animal has been eating can be helpful. - Write a report as soon as possible.

Table 2: Diagnostic chart for neonatal calf loss

Indications/post mortem findings	***Likely condition***
General history	
Calving ahead of time (especially where controlled mating)	Abortion
Increased deaths within the first day of life (especially if a late term infectious agent is operating)	Abortion
Inspection prior to opening	
Larger calf size and or small frame cow	Stillborn or weak at birth
Carcase decomposition at birth (pre-partum death)	Abortion
Meconium (= faeces produced before birth) staining of the carcase (foetal distress during calving)	Stillborn or weak at birth
Calf not cleaned after birth (reflects maternal behaviour)	Starvation/mismothering
Not clean, e.g., mud from bogging	Mismothering
Head and shoulders swollen (subcutaneous oedema fluid)	Stillborn/Dystocia
Domed head, floppy ears, short thin hair coat, joint laxity	Abortion or premature birth
Hoof membranes present - did not stand	Stillborn or weak at birth
No hoof membranes present - the calf had walked	Starvation/mismothering/predation
Navel cord prominent, reddish and moist	Stillborn or weak at birth
Navel cord dark, dry and shrivelled, especially if 2-3 days old	Starvation/mismothering
Evidence of diarrhoea - faecal material around tail or hind quarters	Dehydration
Possible congenital abnormalities (especially mouth and or perineal regions)	Weak at birth

After skin first removed

Pale carcase (from blood loss)	Predation
Visible evidence of trauma; consistent wound punctures; missing organs AND associated haemorrhage	Predation
Tissue over the rib cage remains moist with adequate fat cover (indicating normal hydration)	Weak at birth
Tissue over the rib cage lacks lustre (indicating dehydration)	Starvation/mismothering

Chest cavity to mouth examination

Swollen tongue, froth in windpipe, bruising, haemorrhages, hernias	Dystocia
Excessive red-tinged fluid in the thoracic and abdominal cavities (fibrin tags suggesting infectious agent operating)	Abortion
Lungs dark red, ‘meaty’, will not float (did not breath)	Stillborn
Lungs inflated and pink (breathed)	Weak at birth/Starvation/Mismothering

Abdominal cavity examination

Fat reserves depleted, soft, reddened and jelly-like	Starvation/mismothering
Normal fat reserves (white; firm; around kidneys, heart and in abdominal mesenteries)	Stillborn/Weak at birth/Predation

Open the stomach

Stomach contains clotted milk	Predation
No milk in the stomach	Weak at birth/Starvation/Mismothering

8.9 Data

Excel files containing all the data and observations from each calving season have been stored by the author and are available on request.

Files containing the data recorded from the GPS collars have been stored and are also available on request for further interrogation .

8.10 References

BOM (2020) http://www.bom.gov.au/climate/dwo/201912/html/IDCJDW8048.201912.shtml. [Accessed 15 January 2020].

Brown A, Towne S, Jephcott S (2003) An observational study on calf losses on the Barkly Tableland. Northern Territory Government, Agdex 421/41, Darwin, NT, Australia.

Bunter KL, Johnston DJ (2014) Ge Entwistle KW (1983) Factors influencing reproduction in beef cattle in Australia. *AMRC Review* No. 43:1-30.

Burns BM, Fordyce G, Holroyd RG (2010) A review of factors that impact on the capacity of beef cattle females to conceive, maintain a pregnancy and wean a calf – Implications for reproductive efficiency in northern Australia. *Animal Reproduction Science* 122, 1–22. doi:10.1016/j.ani reprosci.2010.04.010

Burrow HM, Johnston DJ, Barwick SA, Hill BD, Holroyd RG and Sullivan M (2009) Clinical and pathological findings associated with congenital hypovitaminosis A in extensively grazed beef cattle. *Aust. Vet. J.* 87:94-98.

Entwistle KW (1983) Factors influencing reproduction in beef cattle in Australia. AMRC Review No. 43, 1-30.

Holroyd RG (1985) Aspects of reproduction in Bos indicus genotypes. *PhD Thesis,* James Cook University of North Queensland, Townsville.

Holroyd RG (1987) Foetal and calf wastage in Bos indicus cross beef genotypes. *Aust. Vet. J.* 64:133-137.

Iverson CI (1981) Proceedings of the Tenth Annual Cornbelt Cow-Calf conference, Ottumwa, IA, February 1981.

Jaeger JR, Olson KC, DelCurto T, Qu A (2008) The Professional Animal Scientist, 24 (3): 247-253.

Sunrise-and-sunset.com (2020) [Accessed 15 January 2020].

Knott SG and Dadswell LP (1970) An outbreak of bovine abortions associated with leptospirosis. *Aust Vet. J.* 46:385-386.

Lane J, Jubb T, Sheppard R, Webb-Ware J, Fordyce G. (2015) Priority list of endemic diseases for the red meat industries. *MLA Final Report B.AHE.0010.* p. 50.

McCosker KD, Fordyce G, O'Rourke PK, McGowan MR. (2020) Reproductive performance of northern Australia beef herds. 2. Descriptive analysis of monitored reproductive performance. Animal Production Science https://doi.org/10.1071/AN17495

Schatz TJ and Hearnden MN (2008) Heifer fertility on commercial cattle properties in the Northern Territory. *Aust. J. Exp. Agr.* 48:940-944.

8.10 Acknowledgments

The main author of this report (Tim Schatz) would like to gratefully acknowledge and thank the following:

- Meat and Livestock Australia for funding this project.
- Raoul Boughton (University of Florida) for his help throughout the project and for hosting and organising our trip to Florida to learn about the systems they use there.
- The staff of Katherine Research Station for their help in conducting the project, especially Jack Wheeler, Dave Hancock, Will Mathers, Stephen Rose and Shaun Johnson. They were invaluable in designing, building and erecting the towers, looking after the cattle, mustering and working in the yards for data collection. The design and method to erect the towers was a fantastic bit of bush engineering.
- Kieren McCosker for assistance throughout the project and in particular for analysing data and writing the report on the performance of the GPS tracking collars.
- NT DITT staff who recorded calving observations and assisted with data collection. This often involved working well outside of normal hours. The staff include: Elle Fordyce, Georgia Glasson, Melissa Wooderson, Mel Bethel, Gretel Bailey-Preston and Jane Douglas. Also two visiting students from Brazil (Gabriel Ribeiro and Hugo Mello) assisted while they were based at KRS.
- Kim Window and Steve Allen from ComCat (Katherine) who assisted with finding solutions and sourcing equipment to enable the birth sensor signals to be received and sent to the internet from a location with limited or non-existent mobile phone reception.
- NT DITT for providing the support and resources to conduct the project.