Final report

.

“Paddock Power”: increasing reproductive productivity through evidence-based paddock design – A pilot study

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Abstract

This final report presents the outcomes of the Paddock Power project, which focused on generating tools and insights for paddock infrastructure development on northern beef cattle stations. The overall outcome of this project was to empower producers in northern Australia to make evidence-based decisions when developing properties and paddocks grazed by beef breeding females.

Many breeder paddocks in northern Australia are too large and under-watered to achieve optimum productivity. Large, poorly watered paddocks negatively impact both reproduction and profitability. They result in uneven feed utilisation, with areas close to water being overgrazed, while distant areas remain relatively unutilised. Large paddocks also increase the risk of incomplete musters and limit opportunities to implement herd segregation, controlled mating or tactical pasture management.

Fencing and water development is expensive and producers have articulated that they need data around potential productivity increases to better demonstrate the business case of development to owners and financiers. This project has delivered objective data and tools to reduce risk and increase confidence to invest in paddock development to cost-effectively increase breeder herd productivity. This final report includes details of development of the Paddock Power tool and of industry engagement with the tool. It also provides details of data collected from breeder herds on two collaborating commercial properties on the Barkly Tableland to quantify the effects of improving infrastructure on reproductive performance. Cattle performance data was recorded over a three-year period on one property and for one year on other property.

This report also used an existing dataset from a Barkly Tableland property to conduct a comparative analysis of the influence of paddock infrastructure on breeding female performance. This comparative assessment provides a commercial case study and gives insights into how varying paddock infrastructure effects breeder performance on a north Australian cattle station.

The Paddock Power Mapping Tool and Investment Calculator allows producers to compare the costs and benefits of water point and fencing options in the context of their own cost base, land types, stocking rates and animal productivity. The tools generate reports that detail the economic viability of the infrastructure investments that producers have in mind. These research outcomes and tools will deliver significant benefits to industry as they can be used by any producer to aid in management decisions that increase economic viability and herd productivity.

Executive summary

Background

As the northern Australian beef cattle industry is characterised by large paddocks and mob sizes, cattle often need to travel long distances to access feed and water. Extensive grazing systems can have considerable impacts on herd productivity and rangeland condition, leading to uneven pasture utilisation, incomplete musters, and limited opportunity for strategic management decisions.

As many beef cattle operations across northern Australia are operated at an extensive scale, the importance of increasing knowledge around the impact of paddock size on productivity is substantial. However, the cost and logistics of increased infrastructure to create smaller paddocks and mob sizes has a large impact on management decisions and labour requirements. Inefficiencies arise with large paddock sizes, and not enough water points, as some areas of the paddock are not being grazed due to their distance from water (Petty *et al*, 2013). Previous research in the region has shown that a combination of increasing water points and paddock subdivisions may be one way to spread cattle out more effectively, optimising carrying capacity (Petty *et al*, 2013).

The costs of infrastructure and labour to increase paddock fencing and water point development is high, and previous studies have indicated that producers want to make additional infrastructure changes to optimise their productivity (Bortolussi *et al,* 2005), yet there is little research to inform the cost benefit of an increase in infrastructure, and to what extent this will impact the productivity of their herd and feedbase.

The main question being addressed in this project was how much impact paddock area and watered area of a paddock has on reproductive outcomes and overall production within a herd. This project aimed to deliver evidence and tools to reduce risk and increase producer confidence to invest in paddock development to lift breeder herd productivity in the extensively managed regions of northern Australia.

The target audience for the outcomes of this project is any producer, manager or owner interested in the financial feasibility and productivity outcomes that could be achieved from increasing carrying capacity and/or improved per head productivity for their livestock.

This project has developed two standalone tools: the Paddock Power Mapping Tool and Paddock Power Investment Calculator, which are freely available for producers and industry advisors to use. These tools help users to decide how much they can afford to invest in infrastructure development to get the best 'bang for their buck'. The Mapping Tool and Investment Calculator can be used by producers and industry advisors to generate reports to take to owners, shareholders or banks to secure funding for development plans, or to see what options there may be for increasing water point development on their property and how changes in livestock productivity influence the economic viability of their development plans.

Objectives

The primary objective of the project was to deliver evidence and tools to reduce risk and increase producer confidence to invest in paddock development to lift breeder herd productivity in the extensively managed regions of northern Australia. How this was achieved is outlined below.

Objective 1- Collect and collate evidence

Use high quality producer data and cohorts of commercially-managed beef heifers to:

- measure the impact of paddock area and distance-to-water on reproductive performance and calf wastage
- assess the impact of reducing paddock area and/or improving watered area on reproductive performance and calf wastage

Objective 2 – Develop the Paddock Power Calculator and train producers.

Operationalise a user-friendly tool (the Paddock Power Calculator) for producers to evaluate the costs and benefits of investing in infrastructure development to improve the productivity and profitability of their businesses in the context of their own cost base, land types, stocking rates and animal productivity.

Methodology

- Historical commercial breeder datasets were obtained from Rocklands Station to retrospectively analyse the impact of reproductive performance over time, as the property increased its fencing and water infrastructure development.
- Commercial breeder datasets were collected from two commercial properties on the Barkly Tableland between 2020 and 2023, with spatial and temporal data and pasture data collected in two paddocks per property, one being poorly watered and the other being well watered.
- A Mapping Tool and Investment Calculator were developed that allow users to compare the benefits and costs of different infrastructure development options in the context of their own cost base, land types, stocking rates and animal productivity.

Results/key findings

The Paddock Power Mapping Tool and Investment Calculator have been developed as standalone tools to assist managers and producers to calculate the return on investment of adding additional infrastructure to their properties, and evaluate the economic viability of their plans.

Analysis of the commercial cattle data from Rocklands Station found that reproductive performance and cattle behaviour were similar in the two paddocks with different levels of infrastructure. However this comparison was somewhat compromised as dry conditions prevailed on the Barkly Tableland during much of the project causing the station to reduce the stocking and utilisation rates in the trial paddocks. As a result, both paddocks were generally well watered and animals were not forced to travel large distances to access feed (due to the lower utilisation rate).

Benefits to industry

The outcomes of this project offer a valuable solution to producers wishing to make informed management decisions regarding the return on investment for additional infrastructure in the northern Australian beef industry. This project has delivered the Mapping Tool and Investment Calculator, tools which producers now can use to make informed decisions that can greatly enhance productivity through strategic allocation of resources and potentially improved reproductive productivity.

Future research and recommendations

Future research in this area could focus on further refining and expanding the Paddock Power tools to encompass additional variables and scenarios. Additionally, conducting long-term studies on the implemented infrastructure developments and their impact on herd productivity and profitability would provide valuable insights and validation of the tools' effectiveness. Furthermore, further exploring applying remote sensing technologies and data analytics is warranted, allowing more accurate and efficient assessments of paddock conditions and their influence on breeder herd productivity.

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1.Background

1.1 Northern Beef Cattle Industry

Many breeder paddocks in northern Australia are too big and under-watered to achieve optimum productivity. In the Barkly Tableland region, for example, average paddock area is 218km² (21,800 hectares) and some are more than 1,000km².

Large, poorly watered paddocks impact on reproduction and profitability: there's over-and under-utilised feed (depending on distance from water), incomplete musters and limited opportunities to implement herd segregation, controlled mating or tactical pasture management.

Walking long distances out to feed erodes live weight gain and body condition. The negative impact of poor body condition on re-conception and calf survival rates further reduces productivity. Some producers speculate that high rates of calf wastage (>20%) in large poorly-watered paddocks may be caused by cows leaving newborn calves to return several kilometres back to water, thus increasing the risk of predation or dehydration.

Foetal and calf losses between confirmed pregnancy and weaning (calf wastage) have been identified by beef producers in northern Australia as a major problem. In a study of the reproductive performance of 142 commercially managed breeding mobs in northern Australian, losses were greatest in the dry tropics (Northern Forest) and Mitchell grass downs (Northern Downs) with 25% of breeder mobs in these regions experiencing losses of greater than 19% and 15%, respectively (McCosker et al., 2023). Fordyce et al. (2022) demonstrated that calf wastage was much higher in pregnant heifers/first-lactation cows than in mature cows, with median losses in breeding mobs on Northern Downs being 14.9% and 6.9%, respectively. Beef CRC studies of 9,678 pregnancies showed that pre-natal loss in the absence of infectious disease is quite low, averaging only ~3%; most losses actually occur in the first week after birth (Bunter et al. 2014).

Research shows that cattle walk further away from water to graze in paddocks that are poorly watered or have large mob sizes per water (Cowley et al. 2015). Both these scenarios are common in large under-developed paddocks in northern Australia. In the hot and humid weather experienced during calving, cows need to drink at least once a day and will leave their newborn calves and walk to the nearest watering point (Pearson *et al.* 2021), which may be several kilometres away. As calf loss is highest in first-lactation cows, it is suspected that inexperienced mothers frequently struggle to relocate their calf, leaving the calves susceptible to mismothering, dehydration and predation. When ambient temperatures are moderate, non-suckling calves lose about 7% of their weight per day, which is equivalent to about 2.5 litres of milk daily (Fordyce et al. 2015). When ambient temperatures approach 40^{O}C, non-suckling calves can lose 15% of their weight in one day and will die without intensive intervention. Unfortunately, periods of very hot and humid weather are not uncommon during the typical peak period of calving (late spring-summer) in northern Australia. Fordyce et al. (2022) demonstrated that when the temperature-humidity index (a measure of risk of heat stress) exceeded 79 for at least 2 weeks during the month of calving, the occurrence of calf wastage almost doubled. Due to the inherent lower milk production of first-lactation cows, calves born during periods of very hot and humid weather are suspected to be at risk of dying due to insufficient milk intake if left unattended.

Large paddocks often have very large herd sizes (several thousand head). It is not unusual for hundreds of cattle to be using the same water point. This can lead to a wide contrast in feed conditions ranging from over-utilised close to water to completely un-utilised distant from water (Cowley et al. 2015). The energy expended walking several kilometres out to better feed each day has a detrimental impact on the live weight gain of growing cattle and energy reserves in pregnant heifers (particularly late in the dry season when pasture close to water points has been grazed out). Poor body condition reduces re-conception rates creating a vicious cycle of inefficient breeder herd productivity (Entwistle 1983).

Mustering a large paddock can take all day. Once mustered, large mobs of cows and calves are often confined together in small holding paddocks or yards for up to 36 hours for processing and their return to the paddock. Fordyce et al. (2022) demonstrated that mustering pregnant heifers/first-lactation cows during the month of predicted calving greatly increased the occurrence of calf wastage (22% mustered vs 13% not mustered). Calves being left behind in the paddock, being abandoned, or being crushed in the yards are thought to be responsible for this marked increase. Producers have also identified production (live weight) losses and workplace health and safety concerns associated with trying to process large numbers (>1,000 head) of cattle through the yards per day.

Concerns about the impacts of declining land condition, high energy expenditure, poor re-conception rates, calf wastage and labour issues on profitability have led some producers to place water points closer together and/or subdivide paddocks to reduce mob size, better manage grazing distribution and improve mustering efficiency (Douglas et al. 2015). Other cited advantages include more opportunities to implement management practices such as controlled mating, breeder herd segregation, prescribed burning and/or pasture spelling. Despite being common-place in other regions, these practices are not widely implemented on extensive northern breeder operations due to insufficient infrastructure (Hunt et al. 2014).

There are millions of hectares of under-developed grazing land in northern Australia. This is negatively impacting on feed supply, land condition, reproductive performance, mortality rates, live weight gain and profitability. The Pigeon Hole experiment demonstrated that investing in paddock infrastructure is a cost-effective way to increase carrying capacity. However, the benefits for improving herd productivity were not fully explored and remain inconclusive (Petty et al., 2013).

Project Objectives

The industry suggests that the rate of property development is constrained by a lack of objective evidence and easy-to-use tools to confidently assess the costs and benefits. This project helps to reduce investment risk by giving producers the evidence and tools they need to fully compare the benefits and costs of infrastructure development options. Importantly, the Paddock Power Mapping Tool and Investment Calculator are the first tools of their type to present this information in the context of the producer's own cost base, land types, stocking rates and animal productivity.

It is estimated that >90% of extensive beef properties in northern Australia have under-developed paddocks and could benefit from the findings of this project. The target audience is extensive beef producers in the NT, northern and western Qld and northern WA who manage a combined 235 million hectares of pastoral land. When we used the ADOPT model (Kuehne et al. 2013) to assess the likely adoption of evidence-based investments in paddock infrastructure development, we found that peak adoption would be about 86% of the target audience within 12 years and a realistic short-term target for adoption of the practices would be 56% within 5 years.

In the absence of objective data, however, producers tell us that it is difficult to weigh up the potential benefits against the high costs of development and ongoing maintenance. Fencing costs currently exceed $5,000 per kilometre and the cost to develop a new water point and associated infrastructure in the Barkly region (for example) exceeds $50,000 (Walsh and Cowley 2016). With the high costs involved (millions of dollars per property), producers need to be confident that new infrastructure will deliver significant benefits to production, land condition and profit. Thus, industry has asked us to undertake this research to deliver objective data and tools so that they can convey a stronger business case to owners and financiers.

Project Outputs

- The "Paddock Power Calculator" and training workshop – a producer-friendly tool to compare the costs and benefits of user-defined water point and fencing options; and at least 20 NT, Qld and WA producers using it by 2022.
- Robust data on the impact of paddock area and distance-to-water on reproductive performance, with a particular focus on calf wastage.
- Measures of weaner production and live weight production from multiple mobs, paddocks and years.
- Evidence-based recommendations for cost-effectively increasing reproductive productivity via paddock development.
- Final report, articles, webinars, field days, journal papers and updated materials for MLA EDGE packages.

The vast majority of northern beef businesses that will benefit from Paddock Power already have sufficient operating scale, so improving the efficiency of production (kg of beef produced per adult equivalent per year) and reducing the cost of producing those kilograms are the keys to increasing profitability (McLean et al. 2014, Walsh et al. 2016). How the Paddock Power project contributes to these goals is outlined below.

On-farm productivity impact – improving the efficiency of production

Carrying Capacity - Based on current watered area and land capability, we estimate there are more than 44 million hectares of pastoral tenure available for sustainable development across Qld, WA and the NT. We estimate this land could carry a further 6 million adult equivalents (AE) and generate an additional annual gross margin (GM) of about $810M (based on a long-term average GM/AE of $135; McLean et al. 2014). This figure likely underestimates the true potential because it does not include non-pastoral tenure. For example, the NT Government estimates that intensification of current pastoral tenure and bringing Aboriginal-owned land earmarked for development into production will grow the NT cattle herd from 2.1M head to 3M head by 2025 and to 4M head by 2035 (Neil MacDonald pers. comm.).

Stocking Rate Management

A study conducted by Hunt et al. (2013) found that half the cattle properties in the Victoria River District of the NT had pasture utilisation rates equal to or greater than the recommended safe level for the land types present and their current watered area. Similarly, Rolfe et al. (2016) found that stocking rates exceeded carrying capacity on more than half of the properties they worked with in the northern Gulf region of Queensland. If these examples are typical across northern Australia, this suggests that about half the industry could benefit from using infrastructure development to spread current grazing pressure rather than increasing herd size. This strategy would be expected to improve per head livestock productivity by reducing the area of degradation around water points and reduce the energy expended walking out to distant feed. The economic implications of poor individual animal productivity has been demonstrated by several studies, including the Wambiana grazing trial where, after 18 years the accumulated GM under recommended stocking was three times higher than for heavy stocking (Department of Agriculture and Fisheries, 2015). In the longer term, improvements in land condition resulting from better stocking rate management would also be expected to restore some of the carrying capacity lost to previous land condition decline. In this project we measured livestock productivity and analysed performance in the context of the stocking rates applied in the paddocks.

Livestock Productivity

The Northern Beef Situation Analysis (McLean et al. 2014) showed that for businesses with adequate scale, improving biological rates (reproduction, live weight gain and mortality) was the key to improving profitability. The CashCow project indicated that the percentage of cows pregnant within four months of calving could be improved from 76% to 81% for Northern Downs country and from 26% to 47% for Northern Forest country (McGowan et al. 2014). Calf wastage for Northern Forest country was as high as 18% and was more than twice the rate of more productive country. The CashCow team identified that this figure could be realistically reduced to 9%. The data also suggested that weaner production could be increased by ~20kg/breeder/year in both these regions. Overall, annual live weight production could be increased by almost 50 kg/year in the Northern Downs and by 34kg/year in Northern Forest country. The most significant factors influencing reproductive performance were found to be the mismatch between energy demand and supply at key times of the year (manifesting as poor body condition and high mortality rates) and disease. High rates of calf loss in first-lactation cows were also partly attributed to mustering operations. Whilst there are many factors contributing to sub-optimal productivity, there can be no doubt that large, poorly watered paddocks contribute to these problems through high energy expenditure, incomplete musters, relatively low levels of herd control and limited opportunity for management intervention.

Farm level costs – reducing the cost of production and improving profitability

Infrastructure investment delivers some of the best returns on invested capital for under-developed properties in northern Australia (Petty et al. 2013). Producers understand this and continue to nominate development as one of their highest priorities. However, water points and fencing are expensive to install and maintain in northern Australia and low profitability is constraining the rate of development for many businesses (Rolfe et al. 2016). Infrastructure development increases capital and maintenance costs. Given that these investments are being made regardless, the Paddock Power tools can help to ensure these are better targeted to maximise carrying capacity and productivity gains.

Some costs might be expected to decline with additional infrastructure. For example, smaller paddocks will lead to quicker and cleaner musters and less energy expended by cattle getting to the yards, resulting in better production outcomes and reduced mustering costs. An analysis of recent infrastructure development options being implemented in the NT (Walsh and Douglas 2016) show that their cost of production can vary by more than 20% and the pay-back period for some options is four times longer than others for the same piece of land. We have also found that some development options on some land types become unprofitable when borrowed funds are used to undertake the development. The Paddock Power Investment Calculator allows users to input the capital costs of proposed (or actual) infrastructure development, paddock and herd management costs (variable costs) and the proportion of overheads attributable to the paddock. The Calculator output then clearly shows what combinations of productivity (live weight production), stocking rates, costs and price received will be profitable.

Adoption of the innovation

Two extensively-managed beef businesses have directly benefited by being involved in the on-property data collection aspects of this project. At least 20 more producers have benefited from training to use the Paddock Power tools. More broadly, the outputs of the project continue to benefit beef producers in the extensively managed regions of northern Australia (western and northern Qld, all of the NT and the Pilbara and Kimberley regions of WA).

How long until adoption commences?

At least 20 producers trained in infrastructure planning and costing using the Paddock Power Calculator will benefit from ongoing advice and servicing as a result of establishing relationships with agency staff and advisers. The ADOPT model estimates that peak adoption could be about 86% of the target audience. This level of penetration represents more than 1,000 properties, about 5.2 million AE and 37.8 million hectares. ADOPT estimates 12 years to peak adoption. The Paddock Power tools will be available as a free stand-alone product and after the project period, NT DITT will use them in its ongoing extension services to producers as part of its core business. We have also trained agency staff and consultants to use the tools so that they can use them with their clients.

Likely environmental, animal welfare and social outcomes

Environmental

- An increased number of producers who can objectively assess carrying capacity and feed supply and use this information to make stocking rate and investment decisions.
- Improved understanding of the relationships between watered-area carrying capacity, stocking rate management and animal production.
- Increased opportunities to undertake stocking rate management, pasture spelling and prescribed burning for the management of land condition and ground cover once the limitations of insufficient paddock infrastructure are removed.
- Improvements in production efficiency to reduce greenhouse gas emissions intensity per kilogram of beef produced.

- Ability to demonstrate industry performance against the Australian Beef Sustainability Framework.

Animal welfare

- Reduce the occurrence of calf wastage by reducing the time that calves are left unattended by their mothers.
- Allow more producers to undertake herd segregation based on pregnancy status or nutrition needs.
- Reduce the proportion of out-of-season calves and thus reduce calf and cow mortality rates.
- Improve nutrition management to prevent large live weight losses and manage body condition decline during the dry season.
- Allow for more cost-effective and cleaner weaning musters, thus reducing the energy demand of heifers in the dry season.
- Reduce the time that cattle spend off feed in cattle yards waiting to be processed.
- Increase opportunities to observe cattle and detect and manage diseases.

Social

- Reducing workplace health and safety problems associated with fatigue by reducing the number of cattle being processed per day in cattle yards.
- Improved employee satisfaction and retention associated with the above.
- Higher quality control for pregnancy diagnosis and foetal aging by reducing the numbers processed per day.
- Empowering producers to work together and be embedded within a research team to solve problems.
- Professional development for producers and early-career researchers to develop new skills (e.g. carrying capacity assessment, forage budgeting, management of technology, capture and analysis of data).
- Reduced risk of travellers in northern Australia seeing cattle in poor condition and questioning the industry's social license to operate.

1.2 Objectives

The primary objective of the project was to deliver evidence and tools to reduce risk and increase producer confidence to invest in paddock development to lift breeder herd productivity in the extensively managed regions of northern Australia. How this was designed to be achieved is outlined below.

Objective 1- Collect and collate evidence

Use high quality producer data and cohorts of commercially-managed beef heifers to:

- measure the impact of paddock area and distance-to-water on reproductive performance and calf wastage
- assess the impact of reducing paddock area and/or improving watered area on reproductive performance and calf wastage

Objective 2 – Develop the Paddock Power Calculator and train producers

Operationalise a user-friendly tool (the Paddock Power Calculator) for producers to evaluate the costs and benefits of investing in infrastructure development to improve the productivity and profitability of their businesses in the context of their own cost base, land types, stocking rates and animal productivity.

2. Analyses of industry datasets

Introduction

The purpose of this activity was to assess historical datasets, specifically focusing on evaluating the reproductive performance of breeding females and assess the strength of their association with various candidate contextual factors summarised at the paddock level.

Consistently monitoring production and evaluating the impact of management decisions facilitates business improvement and enables evidence-based management decisions. Many enterprises utilise breeder herd performance to enable temporal monitoring of performance, identify non-productive females and identify risks or adverse events, including occurrences of disease outbreaks.

A dataset from Rocklands Station was obtained and used for this activity. Rocklands is situated on the border of Queensland and Northern Territory, located approximately 7 km North of Camooweal, Queensland, and is owned and managed by Paraway Pastoral Company Ltd. This property is a breeding operation with mostly moderate-Bos indicus content breeding females that are mated to Angus bulls. The cows are managed using a breeder segregation system, with cows drafted into management groups based on their expected month of calving and culling decisions largely determined by reproductive success and performance (Braithwaite and de Witte 1999).

At Rocklands, comprehensive monitoring of whole-herd individual-animal performance has been ongoing since 2019, coinciding with a property development initiative aimed at improving water infrastructure and reducing paddock size.

To evaluate the impact of paddock development on breeder performance, this existing data set was accessed and a retrospective analysis to explore potential associations between reproductive performance and paddock infrastructure characteristics and utilised to investigate potential associations between reproductive performance and paddock infrastructure characteristics. This section describes the findings derived from these analyses.

Objectives

The primary objective of the activity described in this section was to obtain access to and utilise a commercial dataset to evaluate the:

- impact of paddock area and distance-to-water on the reproductive performance and calf wastage in commercially-managed beef-breeding females.
- effects of reducing paddock area and/or enhancing watered area on reproductive performance and calf wastage in commercially-managed beef-breeding females

Methods

Analytical dataset

An analytical dataset was formed by integrating two distinct data sources. At Rocklands Station, comprehensive monitoring of whole-herd individual-animal performance has been ongoing since 2019. This dataset was accessed to derive contextual and explanatory predictors, as well as outcome variables that described animal performance. Simultaneously, a dataset characterising paddock infrastructure over time was constructed through paddock mapping in consultation with station staff and property records. The integration of these datasets facilitated a retrospective analysis aiming to explore potential associations between reproductive performance and the characteristics of paddock infrastructure.

Animal performance data

An initial dataset was constructed from multiple TSI backup files (data from crush-side recording). The dataset construction followed a sequential approach, starting with the oldest backup file each TSI backup files was sequentially appended to a dataset using a systematic code-based approach using R (Version 4.0.1). Each TSI backup file contained five types of data: Life, Trait, Event, Activity and Note, which were recorded in a transactional manner with multiple rows of data relating to an individual animal on a single day or muster event. The structure of the data management occurred with the use of sessions, which were named using standardised conventions. Session names were a concatenation of standardised short-hand notations separated by the underscore text character "_" including: the date the session presented in the format yyyy-mm-dd, Station [RCK = Rocklands], broad description of the purpose of muster (branding [BND], weaning [WNG] or pregnancy testing [PREG], drafting [DFT], transfer [TNF]), broad animal class category (Breeder [BRD], Weaner [WEA], Heifer [HFR], Joiner [JNR], Bull [BULL]) and the name of the paddock the cattle were mustered from.

After chronologically appending all backups into a unified database, a process of identifying and removing duplicate entries and standardising the presentation of data was undertaken. Data were initially reshaped to consolidate individual animal information into single rows for 'life data' and per-day or event entries for traits, activities, and notes. For each data type, data standardisation and error checking procedures were employed with the purpose of rectifying spelling errors, ensure body condition scores adhered to a 5-point system with half values, recorded live weights and hip heights were biologically plausible. Lactation status was categorised as 'wet' or 'dry.' Pregnancy test outcomes were recorded as 'pregnant' or 'empty,' and if pregnant an expected calving month had been estimated. By using the 15th day of the recorded expected month of calving, foetal age at the time of pregnancy diagnosis was estimated assuming a gestational length of 290 days.

Females generally had one or two processing records annually, either through a single event encompassing both weaning and pregnancy testing or through separate musters for these purposes. To streamline the annualisation process, session records were classified into categories: lactation muster, pregnancy test muster, or combined muster. These categories were determined by two performance traits: lactation status and confirmed pregnancy, identifying key mustering events throughout the year.

Annual lactation status was determined based on the number of processing records, with lactation status summarised as either 'WET' (lactating) at any point during the year or consistently 'DRY' (non-lactating). For females that were only processed once in year and presented as 'dry', they were considered non-lactating. The body condition score and liveweight of females around the time lactation was assessed were determined by averaging the recorded values within a 2-week timeframe before and after the determined lactation assessment date.

Pregnancy testing records were used to determine whether a female became pregnant by the first of September each year. Conceptions after September 1st were attributed to the following joining season.

Paddock infrastructure mapping

The reconstruction of paddock-level infrastructure maps occurred for four pivotal stages of the development program: pre-development, 2018, 2019, and 2020. Essential paddock descriptors such as total paddock area (in km^2) and the areas with water access within 2km, 3km, and 5km radiuses, expressed both in unit area (km^2) and as a proportion of the total paddock area, were calculated for all paddocks during each time period.

Paddock attributes were detailed across 438 different paddock-year combinations. Over a four-year property development initiative spanning from 2016 to 2020, enhancements in fencing and water infrastructure led to the establishment of 35 new paddocks. During this period, the median paddock area decreased from 172 km^2 to 72 km^2 and the average proportion of paddock area within 5 km of permanent water increased from 62% to 93%.

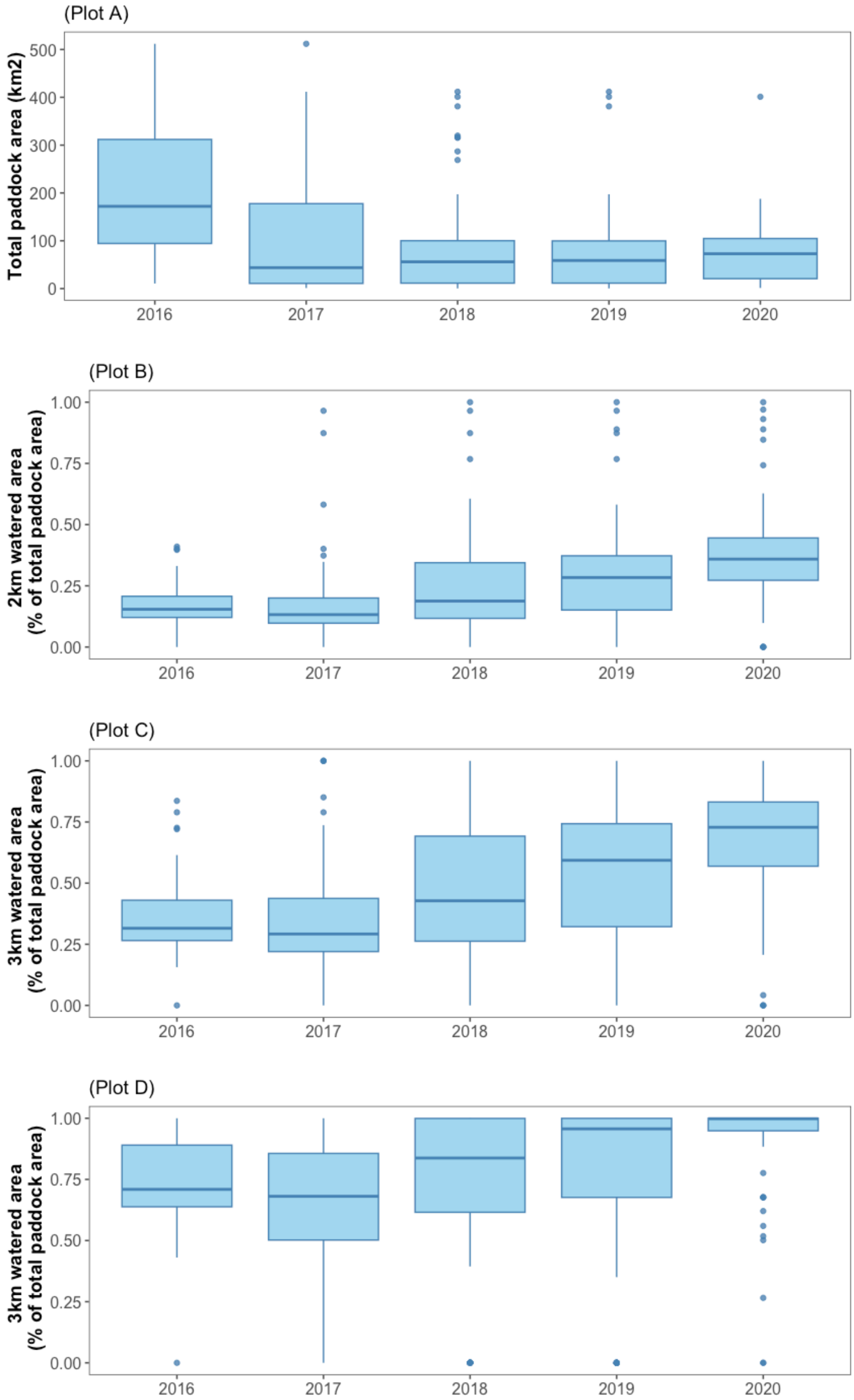


Figure 1. Distribution of total paddock area (plot a) and 2km (plot b), 3km (plot c) and 5km (plot d) watered area expressed as a proportion of total area over time during the property development program undertaken at Rocklands Station.

The resulting data was presented as a paddock-year attribute table and supported cross-referencing to individual animal performance based on the observed paddock and year. To track the paddock movement of females across time, a log documenting paddock transactions was generated using the animal performance data and was based on date of processing and paddock identified in the session file names associated with muster events. This log was used to identify the probable paddocks where the female was grazing at the time of calving. The process was facilitated by cross-referencing the expected calving date with the transaction log. Specifically, it involved identifying the last transaction event that occurred before the expected date of calving and before the next event in the log.

Defining reproduction outcomes

Annual pregnancy represented whether a female animal was pregnant or not during a particular annual reproductive cycle. A value of 1 was ascribed if the animal was determined to be pregnant with conception occurring after September 1 of the previous year and prior to September 1 of that year, and 0 otherwise. September 1 was used as the end of the mating period as the resulting progeny would contribute to the calf crop in the following year in continuously mated herds. Calves born after this date in northern production systems are typically carried across another wet season. Animals coded as 0 included those that were not pregnant (empty) during the defined time period or that conceived after September 1 in the current year.

Pregnant within four months of calving (P4M) was defined as 0 for those cows that failed to conceive within four months of calving, and 1 for those that did. This outcome variable was not generated for cows that were recorded as not-pregnant (Empty) in the previous year or cows that had not reared their calf (FCL=0) in the current year.

Predictions for the dates of calving and re-conception were generated using foetal ageing data from the previous and current production cycles. The predicted month of calving was calculated by estimating the foetal age at the pregnancy test muster and assuming a gestation length of 285 days. Foetal age, recorded in months, was multiplied by 30.2 days per month to estimate foetal age in days. The predicted date of conception was then estimated using the foetal age data from the current year's pregnancy test muster. Females with days to conception less than 120 days were determined as being pregnant within four months of calving.

Foetal and calf loss represented whether females successfully reared their calf or experienced foetal or calf loss, their lactation status in the production cycle they were predicted to calve in was determined from records of lactation status at musters.

Females were considered to have successfully reared a calf if they were recorded as being pregnant and recorded as lactating (wet) after the expected calving date. In contrast, females were considered to have experienced foetal or calf loss if they were recorded as being pregnant in the previous year and were then recorded as not lactating (dry) after the expected month of calving in the following year.

Explanatory factors

Age. The age of animals was calculated by subtracting the year of birth obtained from the life data information from the year of observation. It should be noted that for some animals, this method of calculation will underestimate the actual age of animals by approximately 6 months. The resulting dataset was then saved and used as the starting dataset to summarise reproductive performance.

Animal class. Animals were grouped into three categories (Young females, Mature cows, and Aged cows). This was based on information drawn from session name, lactation status and estimated age. Young females were those under 4 years old, while cows were classified as aged when they exceeded 8 years of age.

Body condition score. A five-point body condition score (BCS) was used, scored in increments of 0.5 BCS. Following an inspection of the distribution values across groups, a simplified categorization was applied, with categories defined as <2.5, 2.5, 3.0, 3.5, and 4.0 or higher.

Period of calving. The predicted month of calving was categorized into two-to-three-month intervals, commencing with July-September from the previous year and subsequently progressing forward. These intervals correspond to the calving periods commonly used in a breeding herd segregation system. The five designated calving periods were Jul-Sep, Oct-Dec, Jan-Feb, Mar-Apr, and May-Jun. An extra category labelled "Pregnancy tested empty (PTE)" was incorporated to characterise reproductive status in the previous year.

Weight at pregnancy muster. Liveweight recorded at the pregnancy test muster was considered as a continuous explanatory factor. To refine the dataset, a basic cleaning process was employed to eliminate outliers. Values greater or less than 3 standard deviations from the mean liveweight were removed.

Statistical analyses

Descriptive summaries of the observed performance of management groups were generated using simple descriptive statistical procedures.

To assess the influence of paddock characteristics on annual pregnancy, pregnancy within four months of calving, and rates of foetal calf loss (all represented as binary variables), a generalized linear model (McCullagh and Nelder, 1989) using the Binomial distribution and logit link for each of these outcomes was employed. A backward-step model development process was used. The significance and 'expected biological importance' for each factor was considered at each step. Using the final model, adjusted mean rates and their confidence limits were estimated for all the terms contained in the model.

All statistical analyses were performed using R and RStudio.

2.4 Results and discussion

The initial animal performance dataset comprised 208,363 rows, each representing a production year for a single cow. This dataset detailed the performance of 77,918 female animals. On average, each female contributed data for an average of 2.7 production years.

Despite multiple attempts to attribute paddock to all production records, matching was unattainable for 19,408 rows of data within the dataset. Consequently, these records do not have the required information to be considered in analyses aimed at investigating the influence of paddock characteristics on the outcomes. This exclusion represents approximately 9% of the starting dataset. This reduced dataset, represents 58,510 individuals, with each female contributing an average of 2.5 production years.

Descriptive summary of reproductive performance

This section presents descriptive summaries of the performance of management groups of females observed across years. The results were derived through establishing management groups and summarising their performance using simple descriptive statistical procedures. Management groups were defined by cow age class, year of observation and paddock.

Using this data structure, the performance of 679 management groups was described. However, this varied between outcome performance measures. For instance, a reduced number of data points were available for outcome measures that drew on information from two annual production cycles, like P4M or foetal and calf loss.

These results are presented by Animal Class due to its known association with reproductive performance. As class was not routinely recorded, this had to be retrospectively generated from the data. Using three categories, animals were classified as either; Young females, Mature cows, and Aged cows based on information drawn from session name, lactation status and estimated age. Young females were those under 4 years old, while cows were classified as Aged when they exceeded 8 years of age.

Pregnancy within four months of calving (P4M)

P4M describes the percentage of cows that were pregnant within four months of calving. This is considered to summarise the percentage of cows that are likely to contribute calves to both the current and subsequent year's calf crop, indicating a desired level of reproductive efficiency.

The determination of the P4M percentage in this report wasn't restricted to cows that successfully reared their calf, primarily due to inconsistent data available describing lactation at the weaning muster. Consequently, these findings might encompass cows that didn't rear their previous pregnancy, potentially inflating the likelihood of achieving P4M due to not having the demand of lactation. However, culling cows that fail to produce a calf was a routine management practice on this station. Hence, the results presented are considered likely to be representative of actual performance.

P4M was described for 333 management groups, comprising 45 groups of Young females, 192 groups of Mature cows, and 96 groups of Aged cows (Figure 2, Table 1). Overall, an approximate 30% success rate for females becoming pregnant within 4 months after calving was observed. The performance between animal class groups used appeared to be relatively uniform.

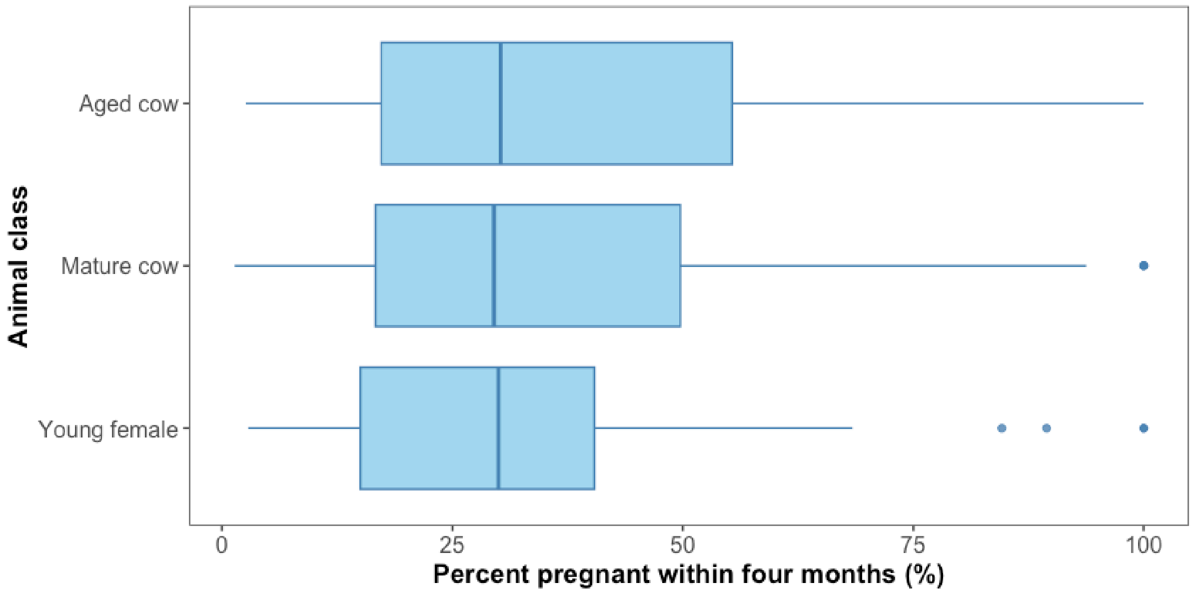


Figure 2. Box plot depicting Pregnant within 4 months of calving (P4M) rates among management groups categorized by animal class. The central line inside each box represents the median P4M rate, while the box edges signify the 25th and 75th percentiles. Whiskers denote the typical range of observed performance values, with 'o' marks indicating outliers beyond this range.

Table 1. Summary of P4M rates recorded for management groups by animal class.

Class	No of management groups	Median	Percentage P4M (%) 25th Percentile	75th Percentile
Young female	45	30.0	15.0	40.4
Mature cow	192	29.5	16.7	49.7
Aged cow	96	30.2	17.2	55.3
Overall	333	29.7	16.7	50.0

These results appear to indicate that that about a third of females achieved early pregnancy after calving. If the 75th percentile of observed performance is considered as a potential benchmark for achievable level of reproductive performance, aged cows exhibited the highest capability at 55%, followed by mature cows at 50%, and young females at 40%. This reduced performance among young females is likely due to their higher maintenance requirements associated with lactation and the energy allocated for growth.

The temporal changes in P4M are depicted by presenting P4M rates across different years of observation (Table 2, Figure 3). A substantial variation was noted between years, indicating fewer animals achieving P4M in 2017 and 2018, compared to the other years. The observed outcomes are likely explained by seasonal differences, particularly the below-average rainfall experienced in 2017 and 2018. Adverse seasons often lead to nutrient-deficient pastures and limited pasture growth, which subsequently impairs reproductive performance. As evidenced by an approximate 16%

success rate for achieving P4M among females during these years.

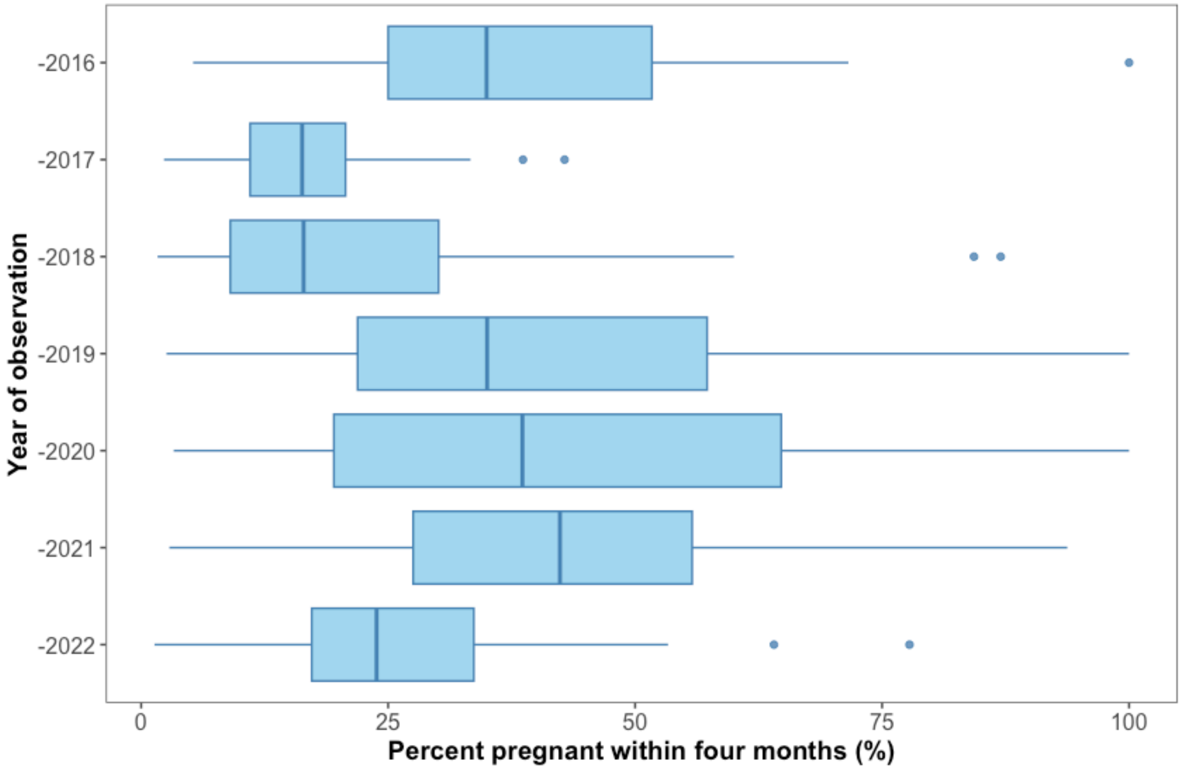


Figure 3. Box plot depicting P4M rates among management groups by year of observation. The central line inside each box represents the median P4M rate, while the box edges signify the 25th and 75th percentiles. Whiskers denote the typical range of observed performance values, with 'o' marks indicating outliers beyond this range.

Table 2. Summary of P4M rates recorded for management groups by year of observation.

Class	No of management groups	Percentage P4M (%)		
		Median	25th Percentile	75th Percentile
2016	41	35.0	25.0	51.7
2017	48	16.3	11.0	20.7
2018	48	16.4	9.0	30.1
2019	56	35.0	21.9	57.3
2020	68	38.6	19.5	64.8
2021	52	42.4	27.5	55.8
2022	20	23.8	17.3	33.7
Overall	333	29.7	16.7	50.0

Annual pregnancy

The results presented in this section relate to the descriptive analyses with management-group annual pregnancy rates as the outcome. These analyses present results categorized by cow age class and year. To derive the outcome data, individual animal-level information was aggregated into management groups, delineated by cow age class, year of observation, and paddock.

It's important to note that the annual pregnancy status outcome in this analysis refers to pregnancies where conception occurred within the 12 months preceding September 1 of the current year. Additionally, data validation procedures involved adjusting the current pregnancy status for subsequent lactation. This implies that animals initially identified as empty but subsequently recorded as lactating in the following year were retrospectively considered as pregnant in the current year.

Annual pregnancy rates were examined across 262 management groups, including 6 groups of young females, 161 groups of mature cows, and 95 groups of aged cows (Figure 4, Table 3). Overall, an approximate 80% success rate for annual pregnancy was observed. The annual pregnancy rate for lactating cows was slightly lower compared to cows not observed to lactate, with rates recorded at 84.0% and 79.8%, respectively.

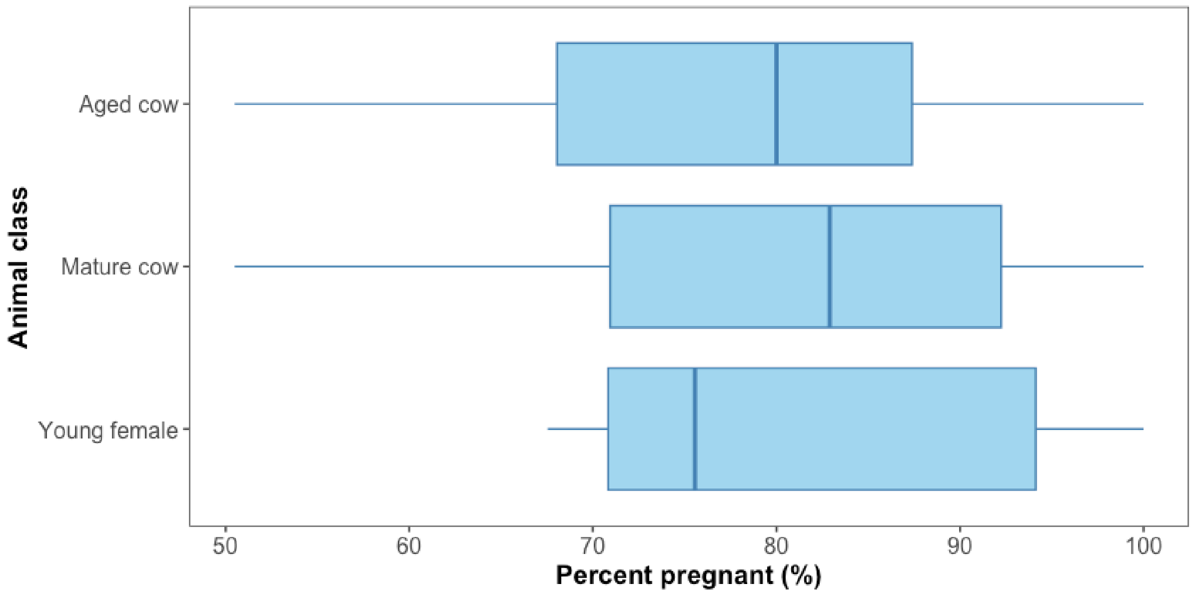


Figure 4. Box plot depicting annual pregnancy rates among management groups categorised by animal class. The central line inside each box represents the median pregnancy rate, while the box edges signify the 25th and 75th percentiles. Whiskers denote the typical range of observed performance values, with 'o' marks indicating outliers beyond this range.

Table 3. Summary of annual pregnancy rates recorded for management groups by animal class.

Class	Percent pregnant (%)

	No of management groups	Median	25th Percentile	75th Percentile
Young female	6	75.6	70.8	94.1
Mature cow	161	82.9	70.9	92.2
Aged cow	95	80.0	68.1	87.4
Overall	262	81.3	69.8	90.3

These results appear to indicate that that about a three quarters of young females achieved pregnancy. If the 75th percentile of observed performance is considered as a potential benchmark for achievable level of reproductive performance for heifers was similar to mature and aged cows at 90%.

Annual pregnancy across years was summarised and presented as Table 4 and Figure 5. Less variation was noted between years than compared with the P4M, indicating that P4M is a more sensitive measure of reproductive performance than annual pregnancy. Fewer animals achieved pregnancy in 2018, compared to the other years. Again, likely due to seasonal effects (low rainfall).

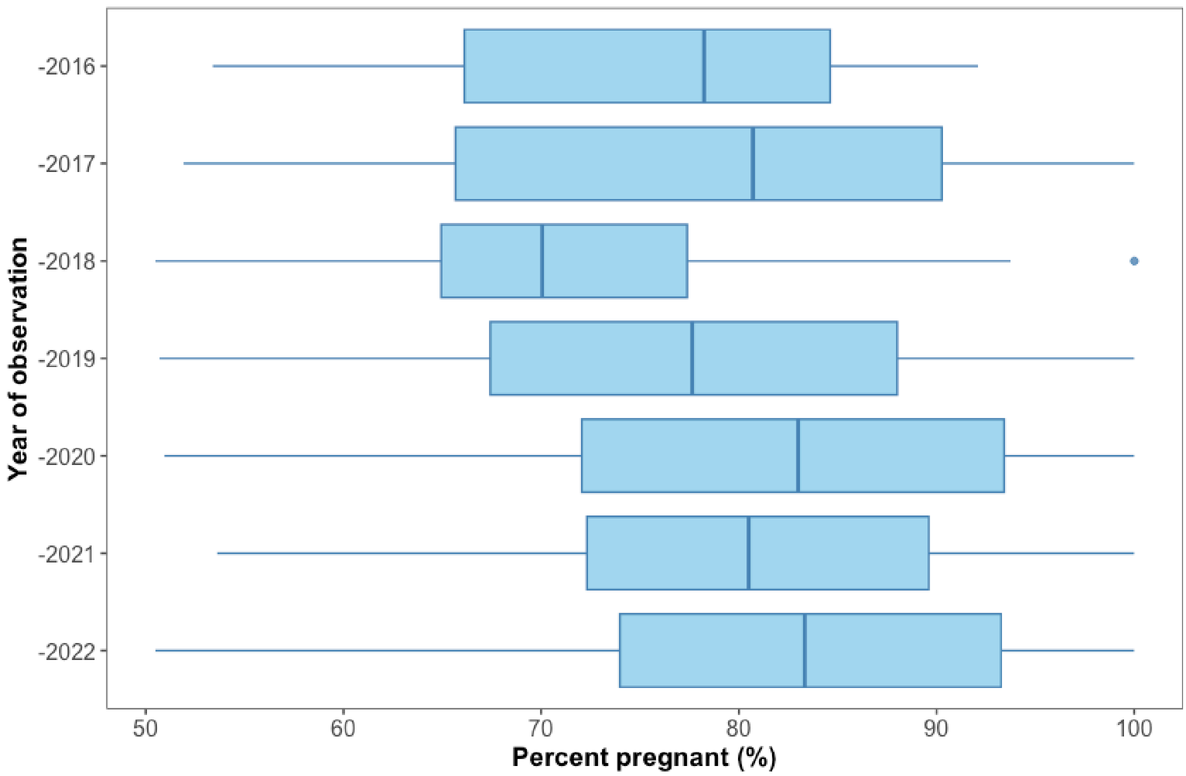


Figure 5. Box plot depicting pregnancy rates among management groups by year of observation. The central line inside each box represents the median pregnancy rate, while the box edges signify the 25th and 75th percentiles. Whiskers denote the typical range of observed performance values, with 'o' marks indicating outliers beyond this range.

Table 4. Summary of annual pregnancy rates recorded for management groups by year of observation.

Class	Percent Pregnant (%)

	No of management groups	Median	25th Percentile	75th Percentile
2016	19	78.2	66.1	84.6
2017	32	80.7	65.7	90.3
2018	15	70.1	64.9	77.4
2019	26	77.6	67.4	88.0
2020	48	83.0	72.1	93.4
2021	65	80.5	72.3	89.6
2022	57	83.3	74.0	93.3
Overall	262	81.3	69.8	90.3

Across time, a noticeable trend toward an increased annual pregnancy rate was evident (Figure 6). For instance, in 2016, the annual pregnancy rate was approximately 75%, whereas by 2022, this rate had risen to around 80%. The increasing trend for annual pregnancy potentially could be attributed to the concurrent improvements in paddock development during this period, supporting enhanced management practices aimed at mitigating seasonal variations on individual females.

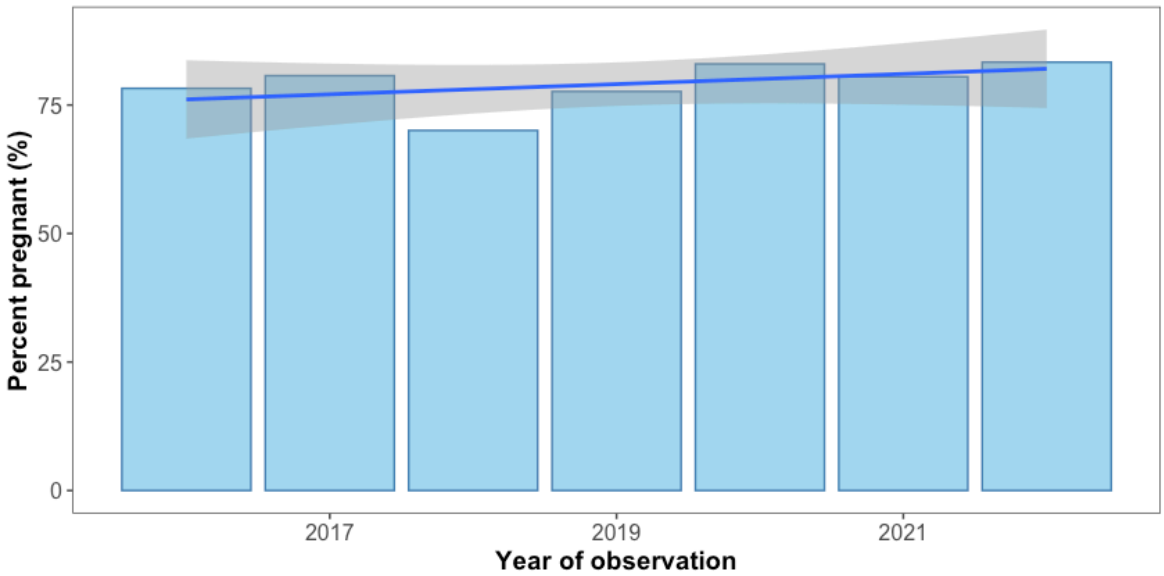


Figure 6. Column plot of median annual pregnancy for management groups across time. A linear regression across time is also shown, depicting an upward trend for annual pregnancy across time.

Foetal and calf loss

The results presented in this section relate to the descriptive analyses with management group foetal and calf loss rates as the outcome. The results from these analyses have been presented for each animal class and year. Animal-level data were aggregated to management groups defined by animal class, year and paddock to derive the outcome data.

Foetal and calf loss from a confirmed pregnancy was determined if a female was diagnosed as pregnant in one year and recorded as dry (non-lactating) at an observation at least 1 month after the expected calving month the following year. Cows lactating during the following year were recorded as successfully rearing their pregnancy.

As the outcome, foetal and calf loss, combines information from two annual production cycles (pregnancy and survival) a reduced number of observations were able to contribute to this analysis compared to other derived outcome variables such as annual pregnancy.

The outcome of foetal/calf loss summarising the performance of 226 management groups was described. An overall median level of foetal and calf loss observed across all management groups was 14.7%, and commonly ranged between 7 and 20%. Young females displayed an elevated incidence of foetal/calf loss compared to other animal classes, recording approximately 23% occurrence, whereas the older age classes experienced rates of less than 15%.

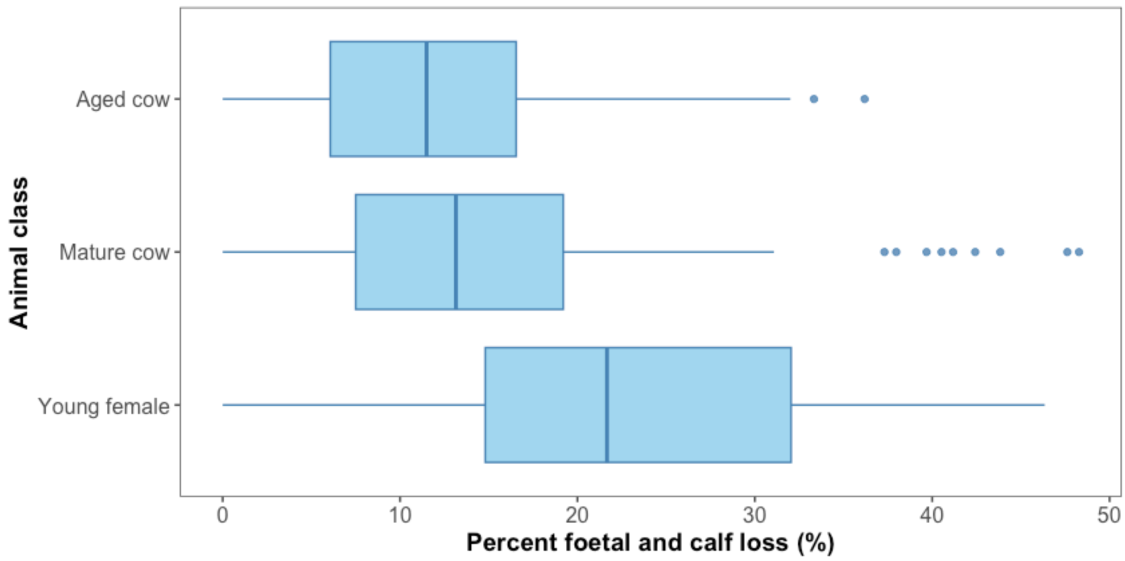


Figure 7. Box plot depicting foetal and calf loss rates among management groups by year of observation. The central line inside each box represents the median pregnancy rate, while the box edges signify the 25th and 75th percentiles. Whiskers denote the typical range of observed performance values, with 'o' marks indicating outliers beyond this range.

Table 5. Summary of foetal and calf loss rates recorded for management groups by animal class.

Class	No of management groups	Foetal and calf loss (%)		
		Median	25th Percentile	75th Percentile
Young female	23	21.7	14.8	32.0
Mature cow	129	13.1	7.5	19.2

Aged cow	74	11.5	6.1	16.5
Overall	226	13.0	7.5	19.4

These results appear to indicate that that the occurrence of foetal and calf loss for young females is about 1 in 5 confirmed pregnancies and in the order of 1 in 10 confirmed pregnancies for older age groups. If the 25th percentile of observed performance is considered as a potential benchmark for achievable level of reproductive performance, this would calculate as a 15% incidence rate in heifers and ~7% for mature and aged cows.

The results indicate a trending increase in foetal and calf loss over time (Figure 8, Table 6). Notably, from 2016 to 2017, foetal and calf loss rates were around 11% to 12%. Larger variations in calf loss were observed in the last few years, possibly due to poor wet seasons in 2019/2020, and a change in stocking rate to account for this the following year. This rise in foetal and calf loss is not easily explained and may be due to season variation. However, it also corresponds with the incorporation of Angus bulls on the station. One potential contributing factor might be the increased heat load exposed to calves produced from black angus bulls due to their breed and coat colour, potentially heightening the risk of calf mortality.

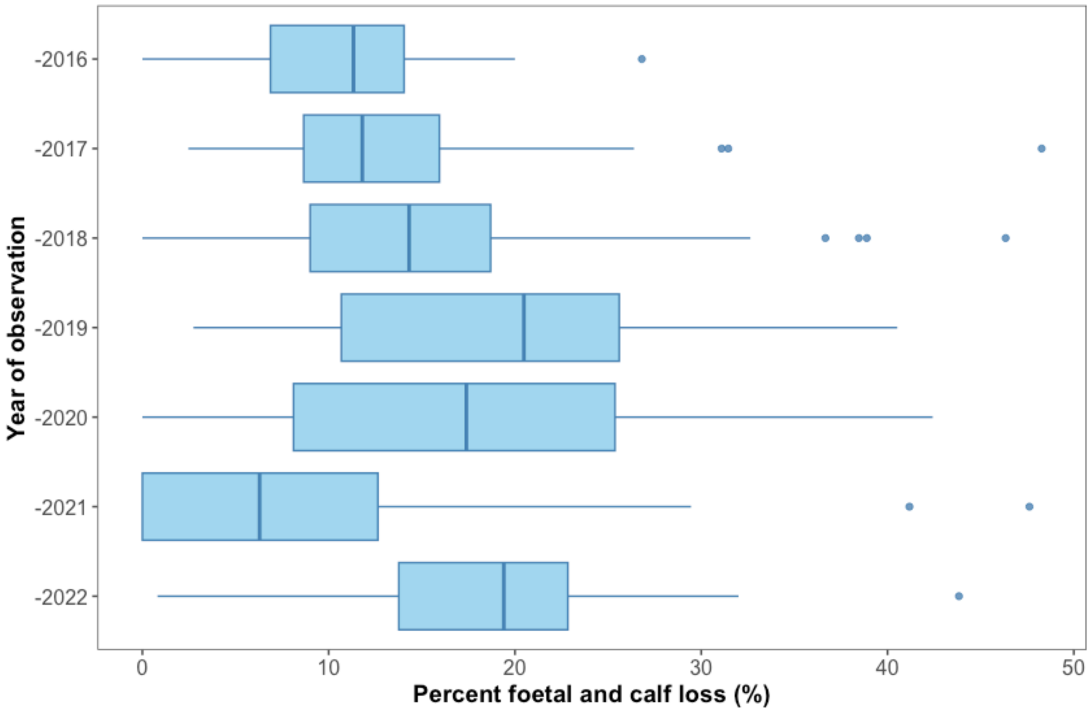


Figure 8. Box plot depicting foetal and calf loss rates among management groups by year of observation. The central line inside each box represents the median pregnancy rate, while the box edges signify the 25th and 75th percentiles. Whiskers denote the typical range of observed performance values, with 'o' marks indicating outliers beyond this range.

Table 6. Summary of foetal and calf loss rates recorded for management groups by year of observation.

Class	No of management groups	Foetal and calf loss (%)		
		Median	25th Percentile	75th Percentile
2016	34	11.3	6.9	14.0
2017	42	11.8	8.7	15.9
2018	42	14.3	9.0	18.7
2019	40	20.5	10.7	25.6
2020	23	17.4	8.1	25.4
2021	32	6.3	0.0	12.6
2022	13	19.4	13.8	22.8
Overall	226	13.0	7.5	19.4

Assessment of Paddock Area and Distance-to-Water effects on reproductive performance

This section presents the findings from multivariable modelling conducted to investigate the impact of paddock characteristics on three measures of reproductive performance, after accounting for other animal-level factors. An individual model was developed for each outcome variable, annual pregnancy, pregnancy within 4 months of calving and foetal and calf loss.

In the multivariate modelling process, all potential factors were initially included in the modelling process. However, only factors that had both a significant association and biologically plausible relationship with the outcome were retained in the final model. The modelling process also considered all possible interactions and examined non-linear relationships for continuous variables.

Among the candidate factors describing the proportion of paddock area located at 2, 3, or 5 km from permanent water, high correlations were observed between these variables. As the variable representing the proportion of area within 3 km of permanent water accounted for the greatest variation for two of the reproductive outcomes, it was selected for inclusion in the modelling process.

After settling on a final model, the average occurrence of the outcome at each level of all factor and interaction terms refined in the model were predicted, after accounting for the effects of all other factors in the model.

Pregnancy within four months of calving (P4M)

The starting dataset for this logistic regression analysis included all female records that had valid entries for the outcome pregnancy within four months of calving (n = 76627). This outcome was a binary outcome with 0=failed to become pregnant within four months of calving and 1 represented a positive outcome.

The full model utilised 55448 animal records from 35098 individual cows. Animal records that were missing data for any of the variables included in the final model resulted in that animal-record being omitted from the model. This meant that 21179 (28%) animal-year records with an outcome for pregnancy within four months did not contribute to the final model. The average number of records per animal was 1.6.

The final multivariable model P4M contained the following terms:

Main effects:

- Total paddock area (continuous)
- Proportion of paddock area within 3km of permeant water
- Animal class (young female, mature cow, aged cow)
- Body condition score assessed at the pregnancy test muster
- Estimated period of calving expressed as predicted window when the cow calved in the previous year (Oct- Dec, Jan-Feb, Mar-Apr, May-Jun and Jul-Sep)
- Year (2016-2017, 2017-18, 2018-19, 2019-20, 2020-21, 2021-22, 2022-23)

The predicted occurrence of P4M expressed as a percentage and generated as marginal means from the final multivariable model for each of the explanatory variables in the final model is presented below. Pair-wise statistical comparisons have been conducted to generate p-values for comparisons between different levels within each variable or interaction term from the final model.

Please note that the estimated marginal means derived from the multivariable model consider the influences of all other major factors included in the final model. Consequently, these means predict the average occurrence of the outcome at each level of a factor while holding all other factors constant at their respective reference levels. This approach is suitable for evaluating the general trend in response concerning the factor under examination and estimating its effect size. However, it's important to emphasize that less emphasis should be placed on the actual observed rates.

The overall median level of P4M observed for management groups observed in this dataset was 27% (95% conf. limits: 25.1, 29.9).

<u>Total paddock area</u>

After accounting for all other variables within the model, including proportion of paddock within 3km from permanent water, the influence of total paddock area on P4M yielded a non-significant result (P=0.15). However, the trend observed suggested a slight improvement for P4M with expanding paddock areas, albeit not statistically significant (Figure 9). The absence of a statistical response is logical if the stocking rate of paddocks was based on available pasture and paddock infrastructure, such as amount number of permanent water points.

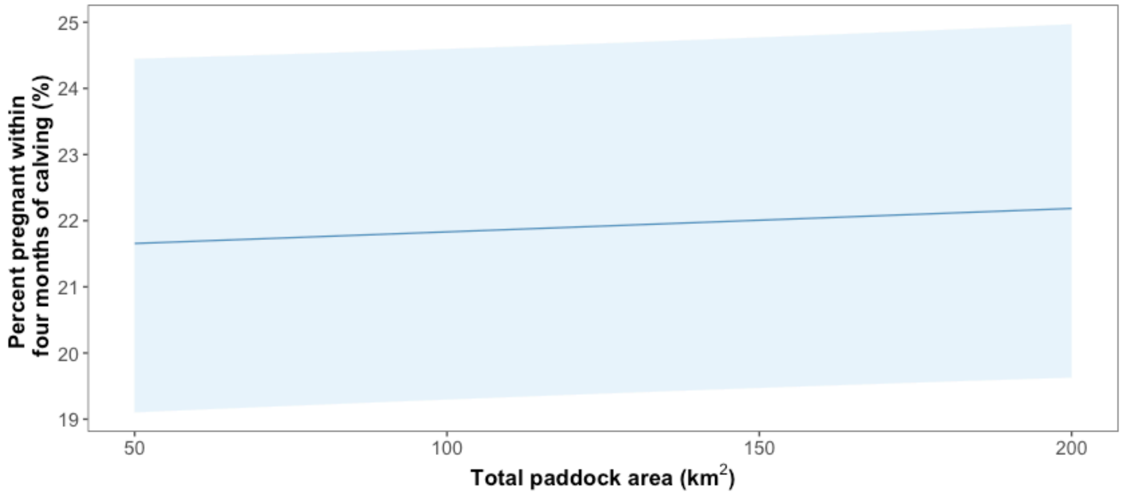


Figure 9: Predicted relationship between the occurrence of P4M and paddock area, based on marginal means generated from the final multivariable model. Shading represents 95% confidence interval.

Proportion of paddock area within 3km of permanent water

The association between proportion of paddock area within 3km of permanent water and P4M was found statistically significant (P<0.001). The results suggest a potential increase of approximately 5 percentage points in P4M by enhancing the proportion of paddock area within 3km of water, from 25% to 80% (**F**igure 10).

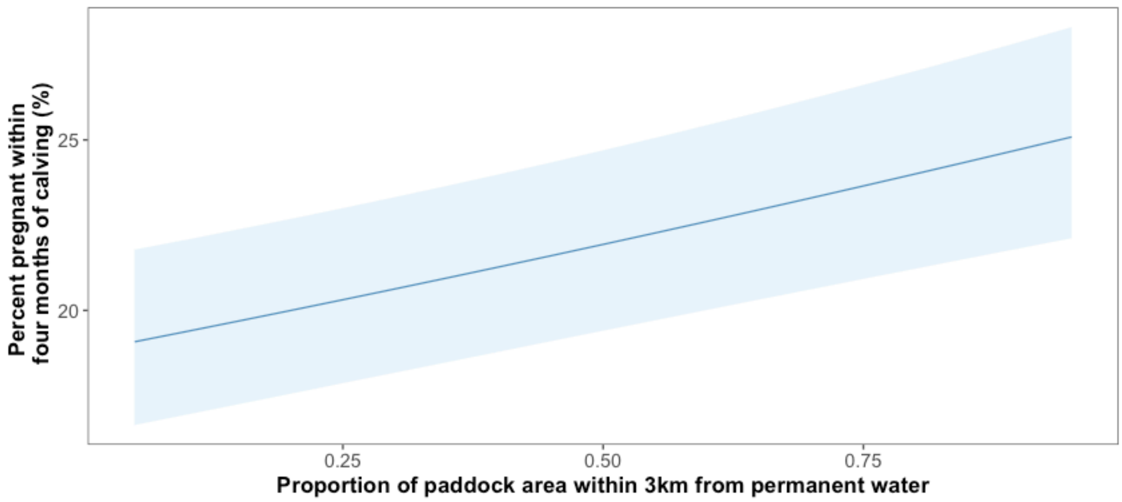


Figure 10: Predicted relationship between the occurrence of P4M and proportion of paddock within 3km of water, based on marginal means generated from the final multivariable model. Shading represents 95% confidence interval.

This observed performance is possible due to increased pasture availability and reduced energy expended by cows walking to water and reduced grazing time. Nonetheless, the precise effect could fluctuate depending on the current stocking rate. This finding further justifies the rationale behind investing in cost-effective water development programs to improve sustainable grazing practices and the likely production benefits.

Estimated period of calving

The predicted month of calving was calculated using estimated foetal age at the date of the pregnancy test muster and projected forward using an assumed gestation length of 285 days. The predicted months of calving were grouped into two or three month periods beginning with July-September of the previous year and moving progressively forward to May-June in the current year. These groupings closely aligned to those commonly used in a breeding herd segregation management system, segregating breeders according to their expected calving period.

As anticipated, calving period exerted a significant impact on P4M (P<0.001). Notably, P4M occurrence varied significantly across all calving periods, except for cows expected to calve in Oct-Dec and Mar-Apr, which exhibited similar P4M rates. Among these periods, cows calving in Jan-Feb displayed the highest probability of P4M compared to others. This aligns with the regional climate pattern, corresponding with the likely commencement of the wet season, and associated with pastures having high nutritional quality. These findings also reflect the effectiveness of a breeder herd segregation system that enables the management of out of season pregnancies. This was achieved by deliberately removing bulls from mating groups to prevent calving occurring during periods of lower nutritional quality.

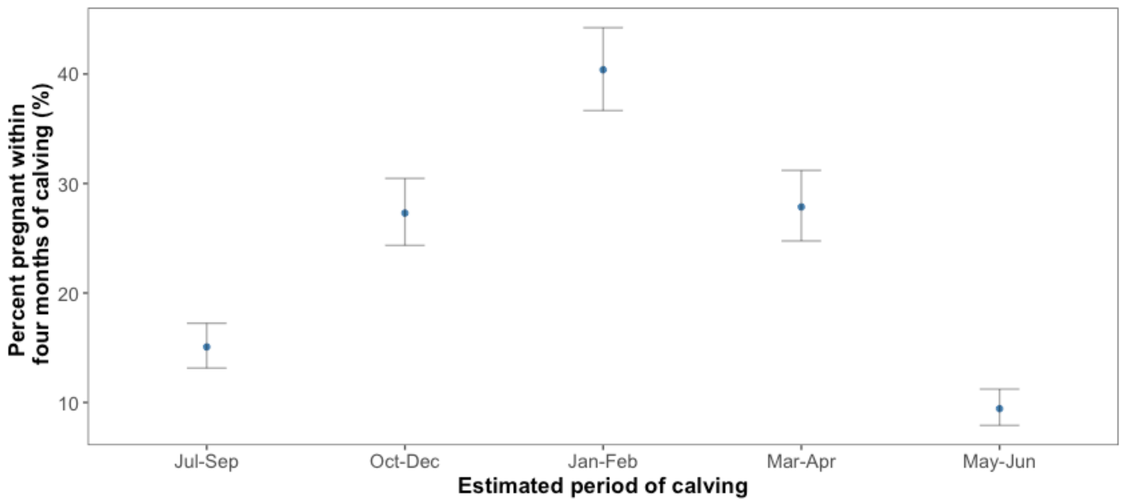


Figure 11: Predicted occurrence of P4M by estimated period of calving, based on marginal means generated from the final multivariable model. Error bars represent 95% confidence interval.

Body condition score at pregnancy muster

This predictor is a likely indicator of the body condition score for cows around the time of calving. As consistently demonstrated in many previous studies, body condition significantly influenced the percentage P4M (P<0.001), with the occurrence of P4M incrementally increasing with increasing BCS. The percentage P4M increased with increasing body condition scores (**Fi**gure 12). Cows calving at 3.5 or 4+ body condition scores were predicted to have a 5 to 10 percentage point higher likelihood of P4M (P<0.05).

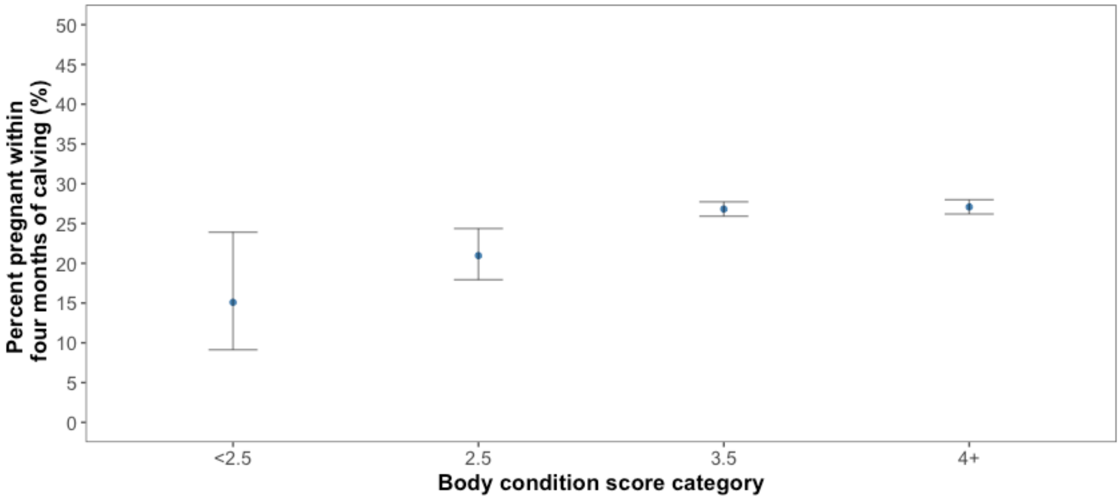


Figure 12: Predicted occurrence of P4M by body condition score (1-5) assessed at the pregnancy test muster, based on marginal means generated from the final multivariable model. Error bars represent 95% confidence interval.

Across years, a trending incremental improvement in the average body condition score of cows measured at the pregnancy test muster was observed (**F**igure 13). This trend coincided with the implementation period of the paddock development program, suggesting a potential correlation. This improvement may reflect the herd manager's increased ability to align the nutritional needs of management groups with pasture resources.

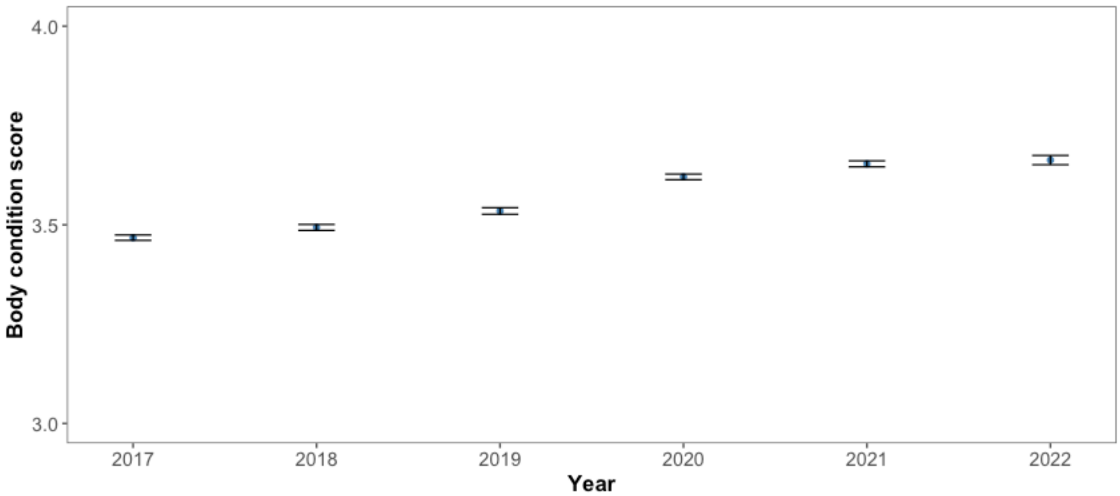


Figure 13: Average body condition score (1-5) assessed at the pregnancy test muster by year of observation. Error bars represent 95% confidence interval.

These findings highlight the importance of maintaining optimal body condition in calving cows. Herd managers have access to strategies to enhance cow condition, depending on the resources available to them, such as molasses or on-property cropping. However, implementation of practices like paddock resting and aligning stocking rates with specific paddock infrastructure remains the most likely cost-effective option.

Cow age class

Cow age class was a significant determinant of predicted P4M (*P*<0.001). The mean percentage P4M for young females was significantly lower than that for mature cows (6 percentage points; *P*<0.001) and aged cows (9 percentage points; *P*<0.001; Figure 14). The mean percentage P4M for aged cows tended to 3 percentage points higher than for mature cows (*P*<0.001).

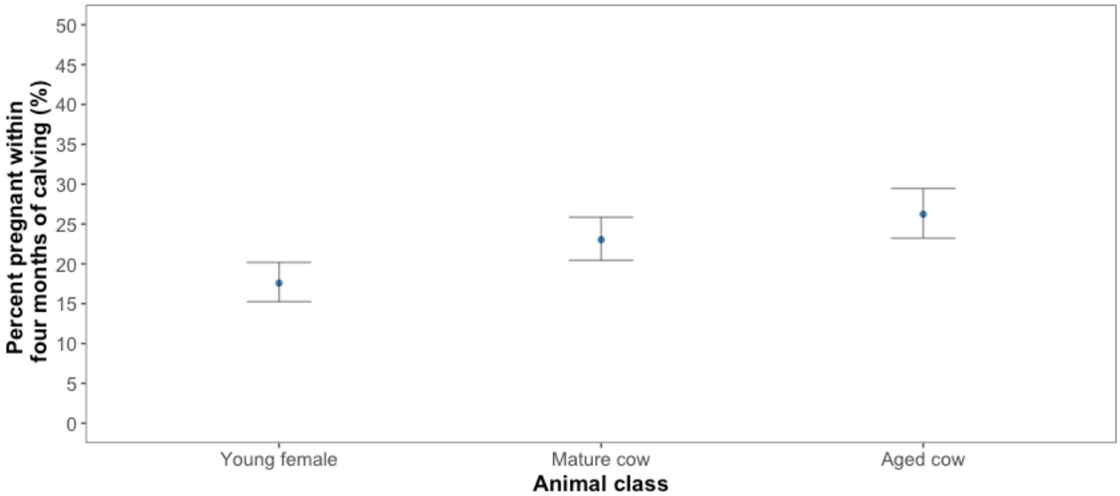


Figure 14: Predicted occurrence of P4M by cow age class, based on marginal means generated from the final multivariable model. Error bars represent 95% confidence interval.

These findings are consistent with previous research that mature and aged cows have a greater likelihood of achieving pregnancy while lactating than younger age classes. Within the dataset, the classification 'young females' likely represents cows experiencing lactation for the first or second time. Cow age classes that are likely also experiencing growth, requiring additional energy demands and a likely contributor of their reduced performance.

Year of observation

When all other factors in the model were taken into account, year of observation had a significant impact on P4M (P<0.001). The reason for the elevated results observed in 2016 is not known, when the highest P4M was observed (**Fi**gure 15). Generally, there was an incremental increase from 2017, when the lowest P4M was observed. Comparisons between years, indicated that with the exception of 2020-21 and 2022-23 production years, all performance rates were statistically significant (p<0.05).

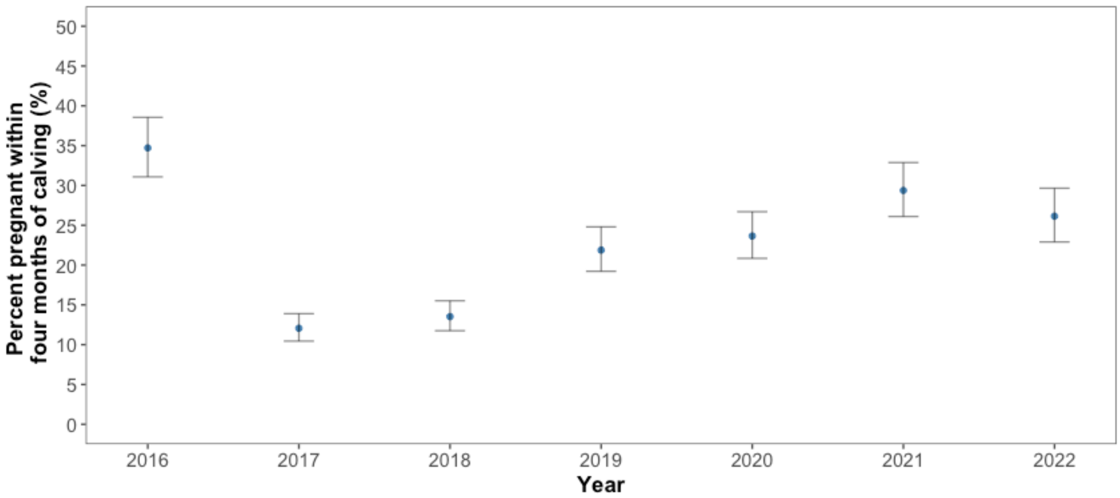


Figure 15: Predicted occurrence of P4M by estimated period of calving, based on marginal means generated from the final multivariable model. Shading represents 95% confidence interval.

The year's effects are likely attributed to seasonal differences. Incorporating risk factors that represented annual differences in pasture availability, nutritional quality, and management potentially would have explained the impact of year observed in the analysis.

Annual pregnancy

The starting dataset for this logistic regression analysis included all female records that had valid entries for the outcome annual pregnancy (n = 208363). This outcome was a binary outcome with 0=failed to become pregnant and 1 = pregnant by the 1st September.

The final model incorporated 70,484 animal records representing 40,193 individual cows. Omission of animal records lacking data for any variables within the final model led to the exclusion of these specific records from the analysis. Consequently, 137,879 (66%) animal-year records did not contribute to the final model due to missing information. Notably, the primary factor contributing to this substantial reduction in records was the absence of reproductive outcome data from the previous year. On average, each animal contributed 1.8 records to the dataset.

The final multivariable model annual pregnancy contained the following terms:

Main effects:

- Total paddock area (continuous)
- Proportion of paddock area within 3km of permeant water
- Animal class (young female, mature cow, aged cow)
- Body condition score assessed at the pregnancy test muster
- Reproductive history (Oct- Dec, Jan-Feb, Mar-Apr, May-Jun, Jul-Sep, Preg, PTE)
- Year (2016-2017, 2017-18, 2018-19, 2019-20, 2020-21, 2021-22, 2022-23)

The predicted occurrence of annual pregnancy expressed as a percentage and generated as marginal means from the final multivariable model for each of the explanatory variables in the final model is presented below. Pair-wise statistical comparisons have been conducted to generate p-values for comparisons between different levels within each variable or interaction term from the final model.

Please note that the estimated marginal means derived from the multivariable model consider the influences of all other major factors included in the final model. Consequently, these means predict the average occurrence of the outcome at each level of a factor while holding all other factors constant at their respective reference levels. This approach is suitable for evaluating the general trend in response concerning the factor under examination and estimating its effect size. However, it's important to emphasize that less emphasis should be placed on the actual observed rates.

The overall occurrence after adjustment for all other factors observed in this dataset was 77.3% (95% conf. limits: 77.0, 77.6).

<u>Total paddock area</u>

A statistically significant association between annual pregnancy rates and total paddock area was determined (P<0.001). The relationship was curvilinear with the highest occurrence of pregnancy in larger paddocks, predicted with approximately 10 percentage point higher pregnancy rates (Figure 16). The cause for this effect is not straightforward, but it could potentially reflect differences in stocking rates or cows grazing farther from water sources than accounted for in carrying capacity assessments. Additionally, 2017 and 2018 production years were below average seasonal conditions in this region, and the availability of 'buffer' zones available to cows grazing larger paddocks during these production years may be responsible for this effect.

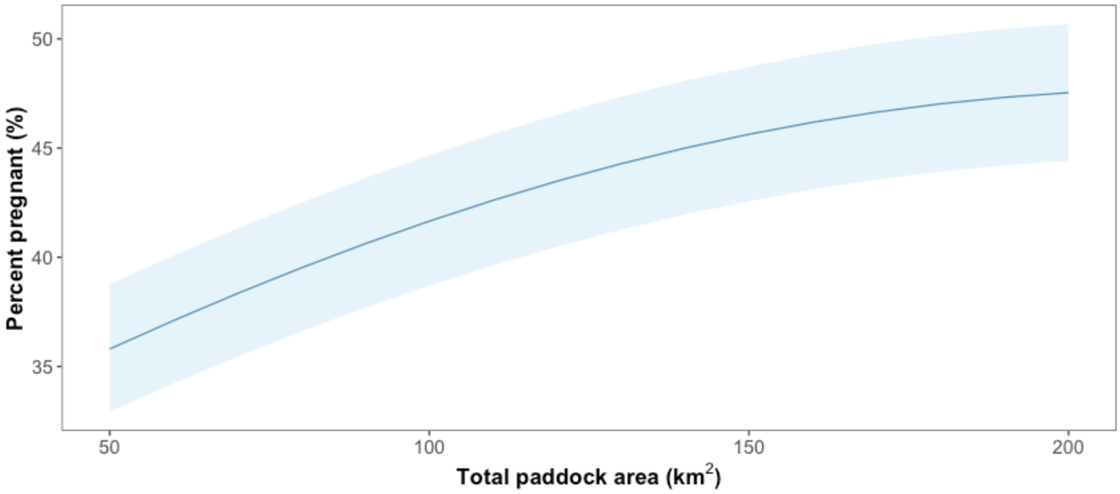


Figure 16: Predicted relationship between the annual pregnancy and paddock area, based on marginal means generated from the final multivariable model. Shading represents 95% confidence interval.

<u>Proportion of paddock area within 3km of permanent water</u>

The association between proportion of paddock area within 3km of permanent water and annual pregnancy was found to be statistically significant (P<0.001). The results suggest a potential increase of approximately 3 percentage points in pregnancy by enhancing the proportion of paddock area within 3km of water, from 25% to 80% (Figure 17).

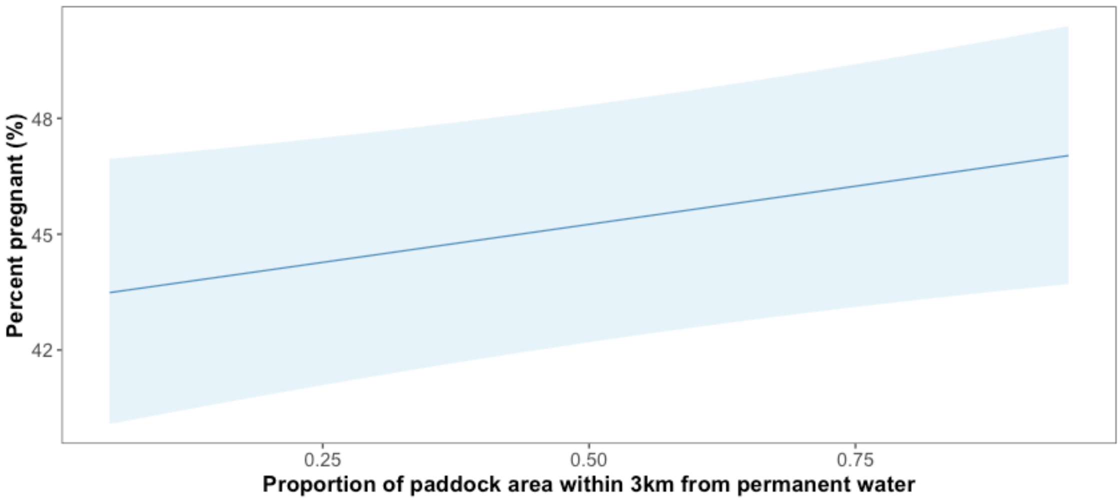


Figure 17: Predicted relationship between the annual pregnancy and proportion of paddock area within 3km of permanent water based on marginal means generated from the final multivariable model. Shading represents 95% confidence interval.

The effect of watered paddock area on annual pregnancy was of similar magnitude to that observed for P4M. The specific cause for this effect is not known however increased areas within close proximity is associated with more even grazing distribution, preventing overgrazing in specific areas and in the longer term corresponds with better pasture health. This improvement in pasture health is presumably correlated with increased nutritional quality of pasture. Furthermore, more evenly distributing grazing by cows is thought promote increased diet selection by cows, potentially augmenting the nutritional quality of their diet. Additionally, increased accessibility to water minimizes energy expenditure associated with walking, potentially corresponding with improvements in reproductive performance.

<u>Animal class</u>

Cow age class was a significant determinant of predicted annual pregnancy (*P*<0.001). The mean percentage pregnancy for mature cows was significantly higher than that for aged cows (3 percentage points; *P*<0.001) and young females (9 percentage points; *P*<0.001; Figure 18). The mean percentage P4M for mature cows tended to 6 percentage points higher than for aged cows (*P*<0.001).

In the dataset, the category 'young females' likely contains first-lactation cows. This particular cow age class is recognised for having lower pregnancy rates, which could be responsible for their comparatively reduced performance when compared to other cow age groups.

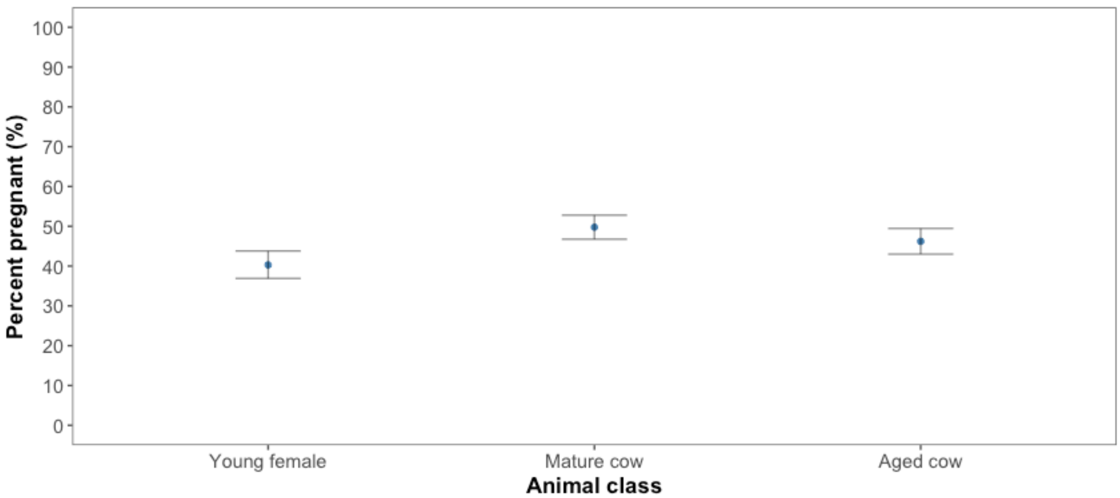


Figure 18: Predicted relationship between the annual pregnancy and animal class based on marginal means generated from the final multivariable model. Error bars 95% confidence limits.

<u>Body condition score</u>

Body condition assessed at the pregnancy test muster significantly influenced the percentage pregnant (P<0.001), with the occurrence of pregnancy incrementally increasing with increasing BCS (Figure 19). Cows recorded with 3.5 or 4+ body condition scores were predicted to have a 55 or 60 percentage point higher occurrence of pregnancy, than 2.5 (P<0.05). Only 12.5% pregnancy was predicted for cows with <2.5 BCS, which was ~8 percentage points lower than cows with BCS 2.5 (P<0.05).

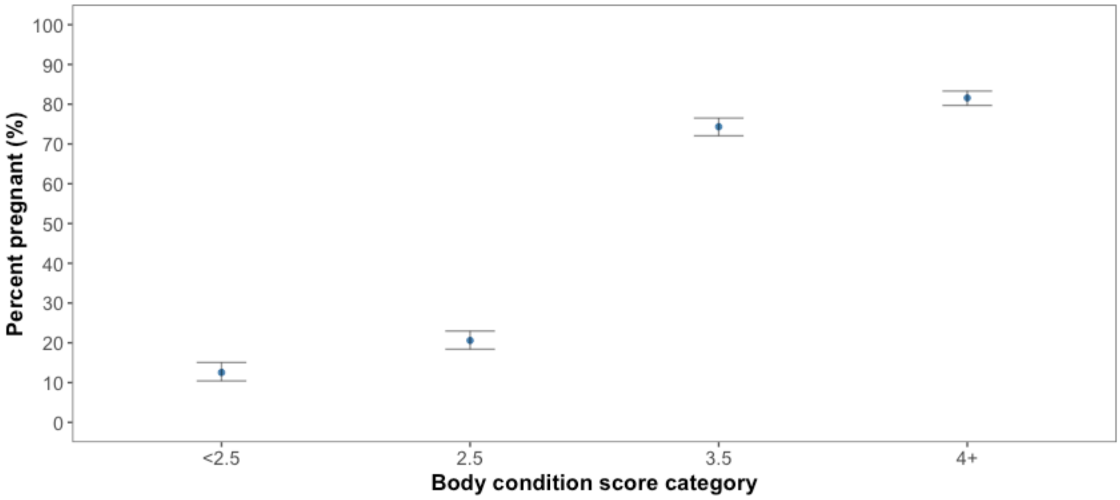


Figure 19: Predicted relationship between the annual pregnancy and body condition score at the pregnancy diagnosis muster based on marginal means generated from the final multivariable model. Error bars 95% confidence limits.

Body condition score is a practical tool available to managers and likely represents the nutritional and lactational history of a cow. The observed disparity between cows in BCS 3.5 or 4, compared to those below 2.5 or at 2.5, in this study likely relates to reproductive history, primarily lactation, with cows not able to be weaned early in the year presenting in lower body condition score categories at the pregnancy test muster.

A benefit of the breeder herd segregation system is the ability for herd managers to manage management groups of similar reproductive status to minimise the chance of cows calving during unfavourable times of the year. This approach ensures that cows present at the pregnancy test muster in favourable body condition scores, subsequently enhancing their likelihood of pregnancy.

<u>Reproductive history</u>

As expected, reproductive history was determined as having significant impact for annual pregnancy ($P<0.001$; Figure 20). Generally, with advancing predicted periods of calving in the previous year a lower likelihood of pregnancy corresponded. Cows that were 'PTE' in the previous year were observed to have similar pregnancy rates to cows calving between periods Jul-Sep, Oct-Dec and Jan-Feb.

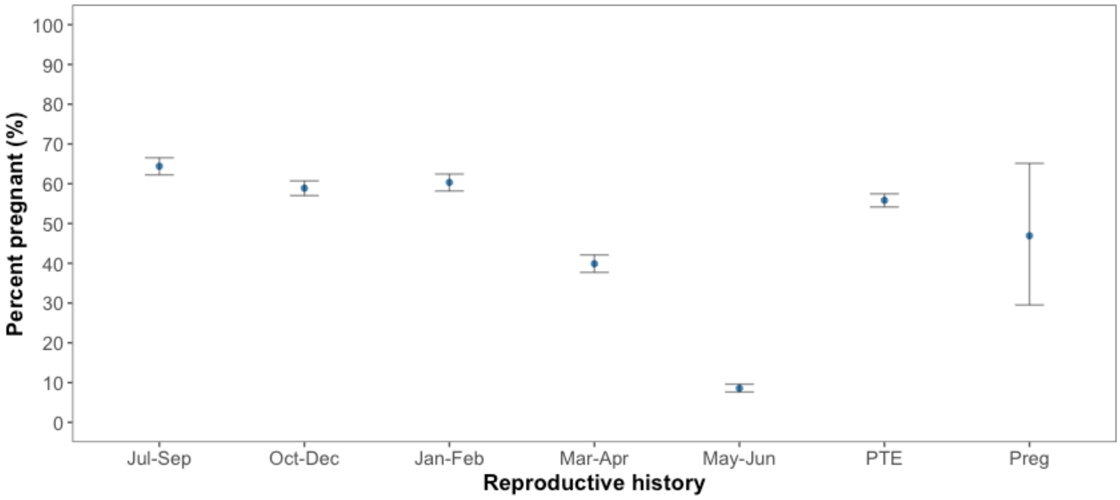


Figure 20: Predicted relationship between the annual pregnancy and reproductive history based on marginal means generated from the final multivariable model. Error bars 95% confidence limits.

These findings are likely explained by differences in nutritional and lactational history and their effects on BCS, but likely primarily due the time available for the cow to resume cycling and pregnant in the current production year. These results indicate that cows calving after February display much lower performance and highlights to herd managers the importance of reducing the proportion of cows calving during these periods to sustain high overall herd performance.

<u>Year of observation</u>

Year was a significant influence on annual pregnancy (P<0.001), with production years 2018-19, 2019-20 and 2021-22 observed with lower pregnancy rates than other years (Figure 21). These findings demonstrate the dominating effect season can have on pregnancy rates are largely considered to be explained by annual differences in nutritional quality of the pasture and available biomass.

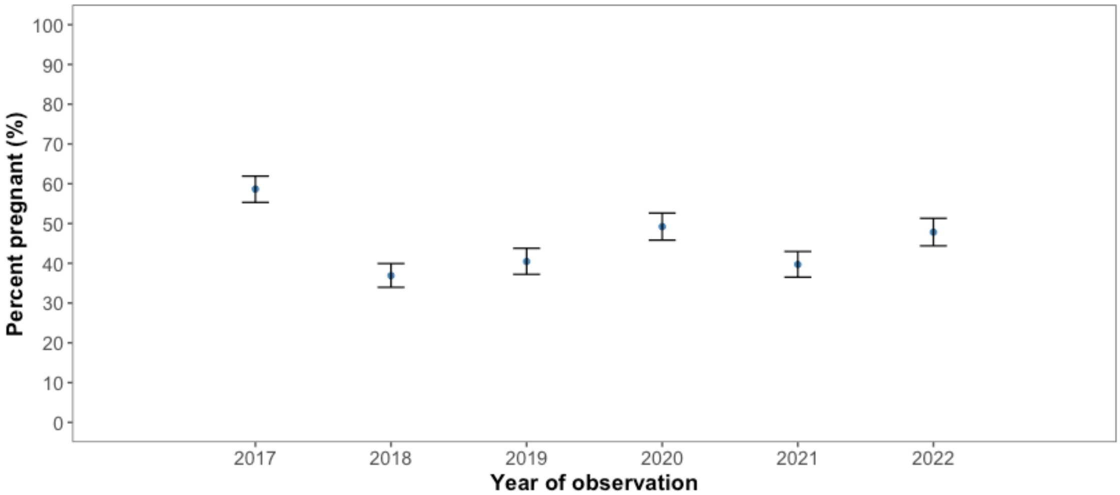


Figure 21: Predicted relationship between the annual pregnancy and year based on marginal means generated from the final multivariable model. Error bars 95% confidence limits.

Foetal and calf loss

The starting dataset for this logistic regression analysis included all female records that had valid entries for the outcome foetal and calf loss (n = 79313). This outcome was a binary outcome with 0=successfully produced a calf and 1=failed to rear a pregnancy.

The full model utilised 63900 animal records from 36950 individual cows. Animal records that were missing data for any of the variables included in the final model resulted in that animal-record being omitted from the model. This meant that 15413 (19%) animal-year records with an outcome for foetal and calf loss did not contribute to the final model. The average number of records per animal was 1.7.

The final multivariable model foetal and calf loss contained the following terms:

Main effects:
- Total paddock area (continuous)
- Proportion of paddock area within 3km of permenant water
- Animal class (young female, mature cow, aged cow)
- Estimated period of calving expressed as predicted window when the cow calved (Oct- Dec, Jan-Feb, Mar-Apr, May-Jun and Jul-Sep)
- Year (2016-2017, 2017-18, 2018-19, 2019-20, 2020-21, 2021-22, 2022-23)

Interaction terms:
- Cow age class x estimated period of calving

The predicted occurrence of foetal and calf loss expressed as a percentage and generated as marginal means from the final multivariable model for each of the explanatory variables in the final model is presented below. Pair-wise statistical comparisons have been conducted to generate p-values for comparisons between different levels within each variable or interaction term from the final model.

The overall incidence of foetal and calf loss after adjustment for all other factors observed in this dataset was 16% (95% conf. limits: 14.7, 17.3). This finding highlights a considerable reproductive inefficiency in the northern beef production system.

Total paddock area

After adjusting for all other variables, the association between incidence of foetal and calf loss and total paddock area was statistically significant ($P<0.001$). The relationship was found to be curvilinear, with the occurrence of foetal and calf loss lowest in smaller paddocks. A near-linear increase in the incidence of foetal and calf loss was predicted up to a paddock area of 150 km^2, beyond which the effect seemed to remain similar in larger paddocks.

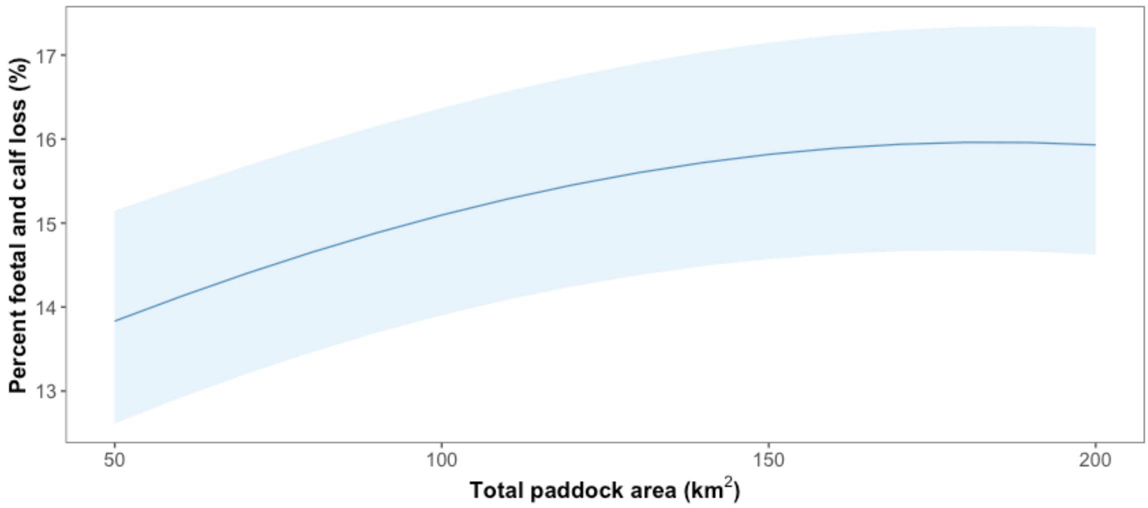


Figure 22: Predicted relationship between the occurrence of foetal and calf loss and paddock area, based on marginal means generated from the final multivariable model. Shading represents 95% confidence interval.

Overall, the analysis indicated that larger paddocks were associated with a 2 percentage point rise in foetal and calf loss among calving cows, regardless of their proximity to water sources. While the specific cause of this effect remains uncertain, one possible explanation could be that larger paddocks typically accommodate larger herds and increased risk of misadventures, subsequently elevating the risks of predation or dehydration due to calves being separated from cows. Additionally, it's reasonable to consider that when cows are grazing in smaller paddocks, management practices can be more consistently applied to individual cows. The reduced space allows for closer monitoring and more precise application of management practices.

Proportion of paddock area within 3km of permanent water

Upon adjusting for all other variables, no significant association was found between the incidence of foetal and calf loss and the proportion of paddock area within 3km of permanent water (P=0.47). The absence of a response does not have a logical explanation. One possible reason could be that stocking rates were calculated based on the proportion of watered paddock area rather than total paddock area. Consequently, the potential impact of the watered area might have been influenced by the stocking rate, confounding the interpretation of its effect.

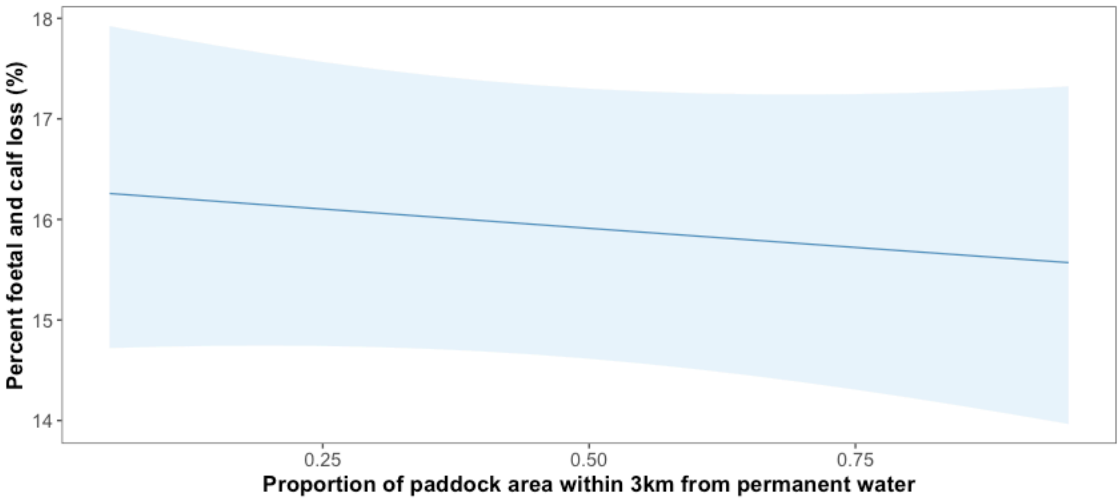


Figure 23: Predicted relationship between the occurrence of foetal and calf loss and proportion of paddock area within 3km of permanent water, based on marginal means generated from the final multivariable model. Shading represents 95% confidence interval.

Estimated period of calving and animal class

Associations between both the estimated period of calving and the animal class and foetal and calf loss were determined (Figure 24, P<0.001). Differing impact for estimated calving period was observed between animal class with aged cows sustaining a relatively constant loss rate across all calving periods (P<0.001).

Overall, young females, which were likely to be experiencing their first lactation, were observed with a 10 percentage point higher incidence of calf loss, compared to either mature or aged cows (P<0.001). Conversely, the incidence of calf loss remained statistically similar between mature and aged cows (P=0.95).

When considering calving periods, cows estimated to calve during the Jul-Sep or Oct-Dec periods experienced the highest risk of calf loss, approximately 4 percentage points higher than those calving in either Jan-Feb or Mar-Apr periods (P<0.001).

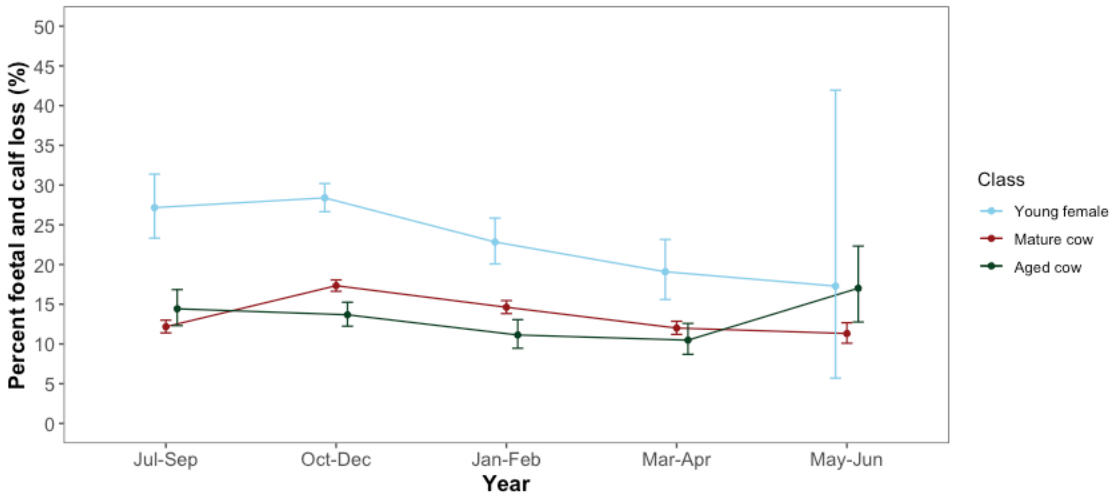


Figure 24: Percentage foetal and calf loss by the predicted interaction between cow age class and estimated period of calving, based on marginal means generated from the final multivariable model and adjusted for all other factors in the model. Bars represent 95% confidence interval.

Year of observation

Year observed was a significant factor contributing to the percent foetal and calf loss (P<0.001). Females calving in 2021-22 had a lower foetal calf loss than those calving in most other years (Figure 25). Alternatively, cows calving in 2019-20, incurred elevated levels of calf loss compared to all other years. These findings demonstrate the dominating effect season can have on performance.

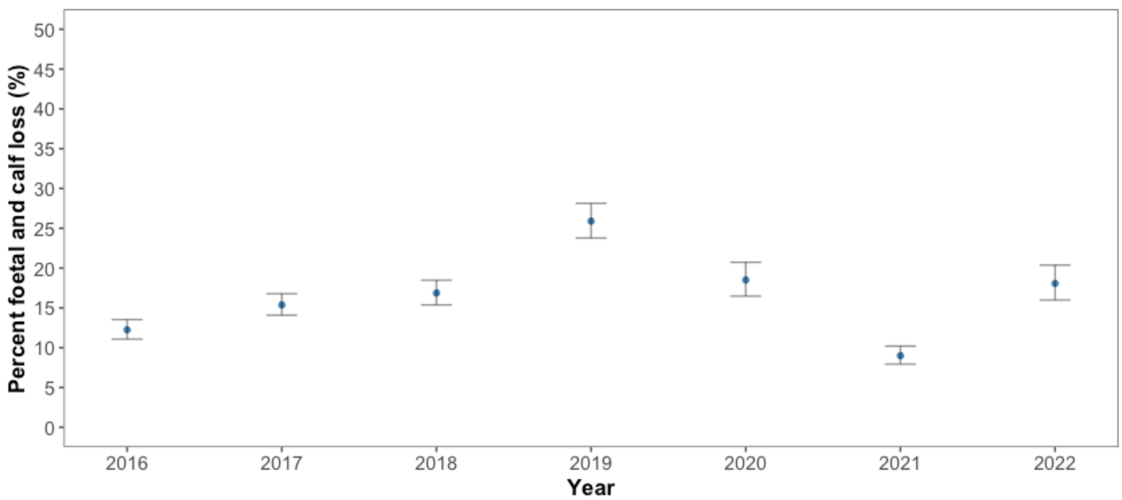


Figure 25: Predicted temporal changes for occurrence of foetal and calf loss, based on marginal means generated from the final multivariable model. Error bars represent 95% confidence limits.

Conclusion

In conclusion, the commercial dataset utilised in this study provided the opportunity to investigate the impact of paddock characteristics on reproductive performance. Overall, there appeared to be a general trend between the development program and enhanced annual pregnancy and pregnancy within four months. This general increase tended to coincide with an overall improvement in body condition score at the pregnancy test muster, suggesting a potential improvement in nutritional quality that occurred as a result of management, reducing paddock size and unwatered area, or seasonal differences.

However, despite the improvements in body condition score and pregnancy being observed, a trending increase in foetal and calf loss over time warrants further investigation.

Summarising the performance of management groups for P4M and foetal calf loss highlighted that >50% P4M was potentially achievable for aged and mature aged cows, and 40% for young females. The results of this study further demonstrate the considerable lost production incurred on northern beef breeding properties due to calf loss with 75% of young female management groups exceeding 15% incidence rate and roughly 7% for mature and aged cows.

The multivariable modelling determined that total paddock area had a significant effect on annual pregnancy rates and foetal/calf loss, but not P4M. Additionally, the proportion of paddock area within 3km of permanent water was associated with P4M and annual pregnancy but not foetal and calf loss. This finding further justifies the rationale behind investing in cost-effective water development programs to improve sustainable grazing practices and the likely production benefits. Additional research is warranted to investigate the observed 2 percentage point rise in foetal and calf loss among calving cows calving in larger paddocks. The analyses also highlighted the significance of animal-level factors such as body condition score during calving, reproductive history, calving time, cow age class, and year, reaffirming their impact on reproductive outcomes.

3. On-station studies

3.1 Introduction

Previous research in northern Australia has shown that there are benefits from smaller paddocks and more water points (McIvor et al, 2011). There is little research that quantifies the impact of smaller paddocks (with more even grazing distribution) on the reproductive success of the herd. The cost of infrastructure associated with fencing and water points is high, and the impact that additional infrastructure has on productivity of commercial beef enterprises is not well understood (Hunt et al,. 2014). Hence research around how paddock size and watered area impacts performance is necessary to make informed decisions about how to better develop extensively-managed enterprises in northern Australia.

Two commercial stations, Rocklands and Brunette Downs, were selected to be part of the on-station element of the project, and two paddocks of similar lands types were selected per property, one well-watered at 3km, and the other less well watered. The purpose of the on-station studies was to evaluate the impact of watered area on reproductive performance.

3.2 Objectives

The main objectives of the on-station studies were to collect commercial data to:

- measure the impact of paddock area and distance-to-water on reproductive performance and calf wastage
- assess the impact of reducing paddock area and/or improving watered area on reproductive performance and calf wastage

It was important to ascertain to what extent, if any, watered area of paddocks in extensive commercial conditions had on the performance of animals grazing in them. This information could then be used to inform management decisions such as increasing paddock infrastructure to increase watered areas or subdivide paddocks. This could be used in conjunction with the Paddock Power Investment calculator and Mapping tool, to further quantify the cost benefits, and strike a balance between economic viability and realistic potential production increases.

3.3 Methods

To assess the influence of underlying paddock factors on the grazing behaviour and reproductive performance of commercial breeding females, a research activity involving two stations (Rocklands and Brunette Downs Stations) located in the Barkly Tableland, Northern Territory (Figure 26), was conducted between 2020 and 2023. To pursue this, a research agreement was formed between the Northern Territory Department of Industry, Tourism and Trade and each Australian Agricultural Company Ltd., and Paraway Pastoral Company Ltd. The activities completed in association with this research were conducted under the Animal Ethics Permit A19013: "Paddock Power": increasing reproductive productivity through evidence-based paddock design issued by the Charles Darwin Animal Ethics Committee.

Figure 26. Location of the two study sites (Rocklands Station and Brunette Downs Station) on the Barkly Tablelands, Northern Territory.

3.3.1 Collaborating Stations

Through a process of self-nomination two stations that satisfied the requirements of the project were identified and were enrolled into the trial paddocks. The requirements, in summary, were:

- provide researchers access to relevant existing paddock records that could help to quantify the impact of paddock area and/or distance from water on livestock performance
- support the capture of data on two consecutive year-groups of first-calf heifers (at least 500 head per paddock) between pregnancy testing to weaning to determine foetal and calf loss at the individual animal-level in at least two large, under-watered paddocks with similar land type composition
- include in each paddock 20 indicator steers of similar breed, age and weight to the heifers to provide live weight gain data in the absence of pregnancy factors
- subdivide and/or significantly improve the watered area of one of the above paddocks part way through the project as per existing property development plans
- document any management practices that are imposed on experimental paddocks during the course of the project (e.g. mustering operations, weaning management, changes to stock numbers, wild dog control)
- document the nutritional management (e.g. supplement records) of each project mob using either project templates or existing on-station recording systems.

Rocklands Station is situated on the border of Queensland and Northern Territory, located approximately 7 km North of Camooweal, Queensland, and is owned and managed by Paraway Pastoral Company Ltd. This property is a breeding operation populated by moderate-*Bos indicus* content breeding females that are mated to Angus bulls. The cows were managed using a breeder segregation system, with cows drafted into management groups based on their expected month of calving and culling decisions largely determined by reproductive success and performance (Braithwaite and de Witte 1999).

Brunette Downs is situated in the middle of the Barkly Tableland and is located 350km northeast of Tennant Creek, Northern Territory and 660km north-west of Mt Isa, Queensland. The breeding and backgrounding station is owned and operated by the Australian Agricultural Company and is populated by the company’s composite herd.

3.3.2 Selection of trial paddocks

Two large paddocks with similar land type composition were selected on each station. Trial paddocks were initially selected based on their land type (similar between paddocks) and then trying to identify one paddock that was poorly watered (a lower proportion of the paddock within 3km of water), and the other paddock well-watered (a higher proportion of the paddock within 3km of water).

On Brunette Downs Station, Fish Hole and Connell’s paddocks were the two designated trial paddocks. Connell’s paddock was originally one large paddock, which was subdivided into eight smaller paddocks immediately prior to the start of the trial (Figure 27). Fish Hole paddock is a large paddock with similar land types but is less well-watered than Connell’s.

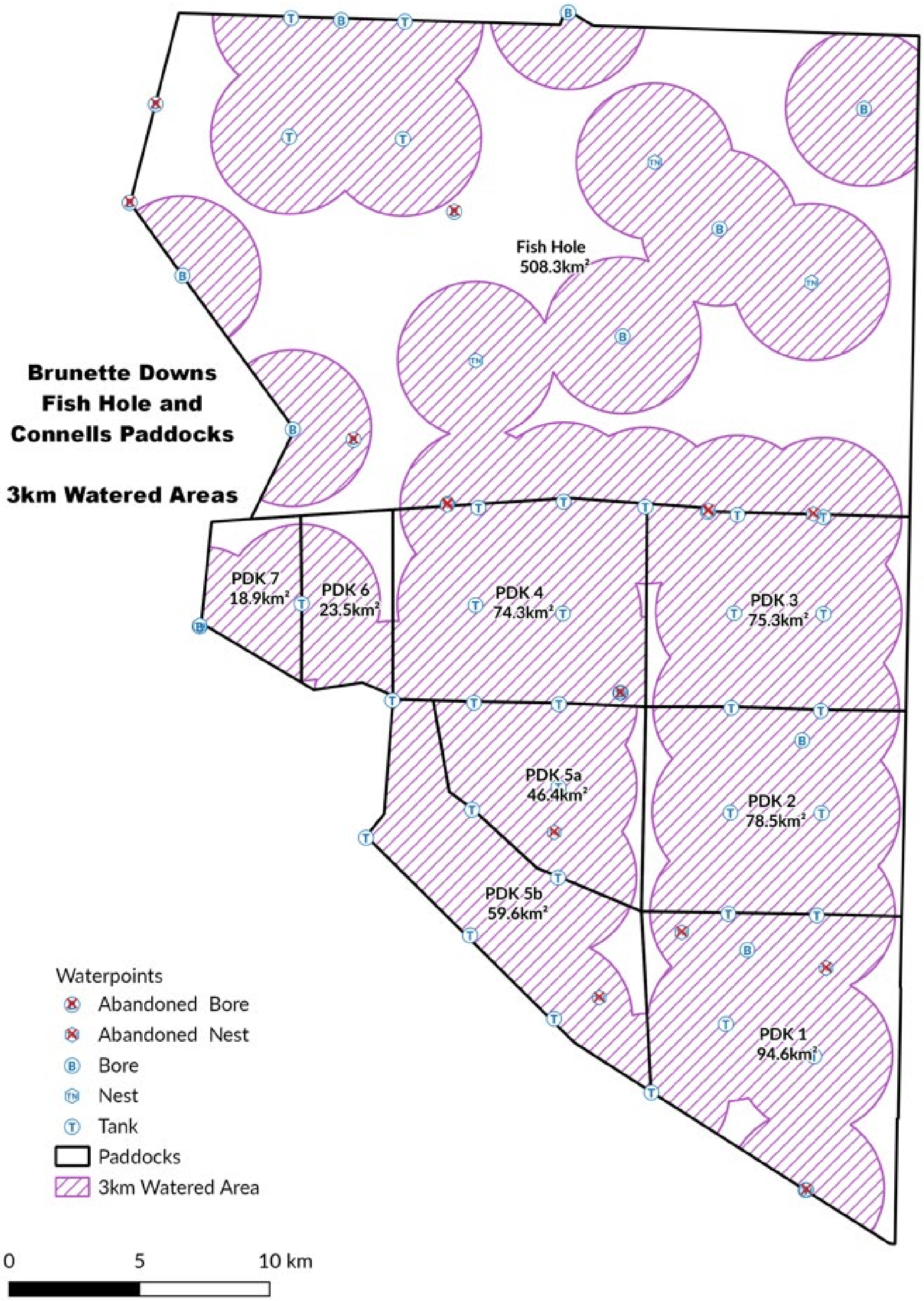


Figure 27. Trial paddocks at Brunette Downs station on the Barkly Tableland of the NT, showing the 3km watered area. Connell's paddock 4 was selected as the trial paddock in the Connell's paddock subdivision.

At Rocklands station, the study designated Grassy and Big Mudgee as the two trial paddocks (Figure 28). Big Mudgee had an area of 114 km^2 and featured five water points (Table 7). In contrast, Grassy spanned 157 km^2 in area and contained four water points, and was the less well-watered of the two trial paddocks.

Table 7. Summary of trial paddock characteristics on Rocklands Station.

Paddock	Big Mudgee	Grassy
Total Area (km²)	113.8	157.4
3km Watered Area (km²)	69	58.2
5km Watered Area (km²)	107.1	131.4
50% of area 3-5 km	19.1	36.6

Figure 28. Two trial paddocks at Rocklands Station, Grassy and Big Mudgee, showing water points and watered area.

3.3.3 Assessing the feedbase

A thorough on-ground assessment of each trial paddock was undertaken shortly after the first wet season of the trial (April 2019) using the standard NT DITT carrying capacity assessment method. This entailed a stratified paddock traverse to collect data for all land types at several distances from water. At each assessment location, data including photographs and land type, soil type, pasture and overstorey species, grazing defoliation score, percent groundcover, average dry matter yield per ha (using photo standards), land condition (using the ABCD Land Condition framework), tree basal area and GPS location were captured on a hand-held tablet using a digital template designed in Mobile Data Studio. These assessments provided baseline paddock descriptions and allowed the later development of customised GRASP model parameter files for each trial paddock. Using watered area data derived from GIS, and modelled pasture growth from GRASP, the current watered-area carrying capacity of each paddock was calculated.

Annual pasture utilisation rate was calculated post-hoc for each experimental paddock using the method published by Walsh and Cowley (2011). As per that method, total annual pasture growth was estimated using GRASP and consumption was estimated using monthly paddock herd reconciliation data provided by the property managers (converted to Adult Equivalents). Pasture utilisation rate, which is the proportion of total annual pasture growth that is consumed by livestock, is a key driver of animal production and land condition performance and is considered essential for inclusion as a variable in the statistical analysis of livestock performance in studies like this.

Both Rocklands and Brunette Downs Stations are subscribers to Cibo Labs satellite-derived pasture biomass mapping which provides real time and historical comparisons of total standing dry matter (TSDM), groundcover and change over time. This data was utilised to create maps of the trial paddocks and their respective cover and TDSM, and GNSS data from trial animals was then overlaid to show the relationships between spatial behaviours of animals and the TC and TDSM in the trial paddocks. Maps showing the Normalised Difference Vegetation Index (NDVI) and Normalised Difference Moisture Index (NDMI) were used to interpret whether vegetation, groundcover and moisture were influencing the location patterns of cattle in the trial paddocks at Rocklands and Brunette Downs. The NDMI is a normalized difference moisture index which uses near infrared (NIR) and shortwave infrared (SWIR) bands to display moisture. The SWIR band reflects changes in both the vegetation water content and the mesophyll structure in canopies, while the NIR reflectance is affected by leaf structure, but not by water content (Gao, 1996). NDMI was used in this study to identify areas of surface water in the trial paddocks, and at what time throughout the year they were present.

The Paddock Power project collaborated with the Sweet Spot project (an MLA-funded project also run by NT DITT). The objectives of Sweet Spot were to understand factors contributing to breeder productivity rates in northern Australia, including pasture utilisation and to develop recommended practices and tools to improve breeder productivity. The Sweet Spot modelling aimed to find the combination of factors that optimises land condition, production and profitability to inform management recommendations and decisions. Pasture growth estimates were used to calculate carrying capacities for the study paddocks as well as back-calculate pasture utilisation rates at the end of each year. Pasture utilisation data from the Paddock Power trial paddocks at Rocklands were modelled by the Sweet Spot team and included in this report as an important factor to consider when comparing the trial paddocks and the reproductive performance in each.

3.3.4 Study animals and animal measurements

Over the course of the project, two management groups of mature-aged breeders were monitored for three annual production cycles at Rocklands Station and one production cycle at Brunette Downs Station. On each station, the groups of breeding females were managed in the same way except for differences between paddocks for their level of development and infrastructure.

At the commencement of the trial at Rocklands station (2019), all mature aged breeding females were pregnancy tested and separated into three management groups, based on their expected month of calving, as per standard operations. The necessary number of cows to achieve the appropriate stocking rate for each trial paddocks was randomly selected from the group of females that were due to calve within the Oct-Dec calving period,. At induction, information describing each animal's breed, year of birth, weight, body condition score, lactation status and hip height was recorded. Subsequently, treatment groups were moved to either Big Mudgee or Grassy Paddocks.

The treatment groups were observed regularly and mustered twice per year for data collection.

The trial at Brunette Downs had delays to the start of the trial throughout 2022. Animals were segregated into trial paddocks during second round muster in 2022 prior to being fitted with GNSS collars late in December 2022. Breeders selected in the Connell's 4 paddock and Fish Hole paddock were due to calve during the wet season from December 2022 to February 2023. Data recording was done as per standard commercial operations at Brunette Downs, with information describing each animal's breed, year of birth, lactation and pregnancy status and estimated date of calving. During 2023, individual animal data could not be collected in the trial paddocks at Brunette Downs, meaning some reproductive performance calculations were not possible.

Crush side data collection

All animal data was recorded electronically using a rapid-entry individual-animal data management system, which ascribed recorded data against each animal's NLIS number.

At the time of induction, each pregnant animal had its breed, year of birth, weight, body condition score, lactation status and hip height recorded. Following, all cows were pregnancy tested at least once per year at an annual pregnancy test muster and foetal age estimated if pregnant. Body condition score, lactation status and liveweight were recorded at each mustering event. Animals that were absent at two consecutive musters and did not reappear at subsequent musters were marked as "missing".

To summarise animal performance, traits were annualised to a single summary record per animal per year. Pregnancy was summarised as a female successfully becoming pregnant by the 1st of September in the production year of interest. Pregnancy was recorded as a binomial outcome with 0 for cows not achieving pregnancy and 1 for females confirmed pregnant. Conceptions occurring after the 1st September were attributed to the following production year.

For females that were confirmed pregnant, the expected month of calving was determined by estimating the date of conception by subtracting the estimated foetal age from the date the female was pregnancy test was performed and then assuming a gestation length of 285 days. As foetal age was recorded in months, it was multiplied by 30.4 days per month to estimate foetal age in days. Animals were recorded as having experienced calf wastage if they were not lactating more than one month after the expected calving date (as calculated from foetal ageing and using a gestation period of 285 days). It is recognised that this measure does not include calf loss between branding and weaning, nor losses associated with heifer mortality.

Pregnancy within four months of calving while lactating (P4M) was generated by using the expected date of calving and the date of conception, which was estimated from the foetal age data recorded in the next production year. Females that had conceived in less than 108 d or 3.5 m (or ≤13 m inter-calving interval) were defined as being positive for P4M while cows that did not conceive or failed to do so within 108 d were negative for the outcome. Only cows that successfully reared their first confirmed pregnancy were eligible for this outcome variable to be generated.

The age of animals was calculated by subtracting the year of birth obtained from the life data information from the year of observation. It should be noted that for some animals, this method of calculation will underestimate the actual age of animals by approximately 6 months. The resulting dataset was then saved and used as the starting dataset to summarise reproductive performance.

Annual changes in liveweight and body condition score were determined by calculating the difference between the liveweight or body condition score measured at the previous year's pregnancy test muster and the corresponding figures in the current year.

The liveweight of calves at weaning was measured soon after being separated from cows. The average liveweight of weaners was determined using a simple arithmetic mean. The annual weaner production was calculated as the percentage of retained females lactating multiplied by the average liveweight of weaners. It should be noted that as all retained females were pregnant, the lactation rate was equivalent to one minus the proportion of cows failing to raise a calf.

Indicator steers

The influence of underlying paddock factors on performance was also investigated by measuring the annual liveweight gain of 20 indicator steers co-grazing with the first year heifer mob at Rocklands Station for the first year of data collection (to exclude the influence of pregnancy and lactation). Indicator steers were similar in breed, age and weight to the heifers at the time of selection.

Due to the unavailability of steers in the second and third year of data collection (2021/2022 and 2022/2023), only breeders were collared in each of the trial paddock at Rocklands and Brunette Downs.

Global Navigation Satellite System (GNSS) collars and fitting technique

GNSS collars used in the project at both commercial properties were based on a design by CQ University which have been used on animals in various other projects across Australia and the United States. The GNSS units were housed in a 61mm x 89mm x 89mm polycarbonate component boxshell, with a metal, wide “U” shaped bracket bolted to the top and PVC coated webbing that was 1 inch wide. The collar was secured onto the animal using a buckle system that allowed for adjustments on both sides of the neck (refer to Figure 29). This attachment method ensured the GPS unit was suspended at the base of the animal's neck.

Figure 29. Image of GNSS collar and components used on both commercial properties during the study.

The inner components of the collar were a 3.7V, 6 or 10Ah battery pack (depending on the deployment year), with a DC connection to a GNSS logger from IGotU (both GT600 and GT600B models used). A piece of foam and a silicone pack was included in the collar housing to prevent moisture damage and cushion the components during the deployment period (Fig 29).

Animals to be fitted with a GNSS collar for trial purposes were restrained in the crush and collars fitted by an experienced technician. Collars fitted to animals were secured so that when an animal grazed or had its head toward the ground, the collar was not loose enough that it came over the top of the head, but also that when the animal raised its head in flexion, the collar was not too tight that it restricted movement of the animal in any way. The device id of the unit fitted to animals was recorded against the NLIS tag of the animal using the TSI crushside data capture system.

During the three years of observation at Rocklands Station, three GNSS collar deployments were successfully completed. GNSS collars were made up of an i-gotU GT-600 GNSS Travel and Sports Logger with an upgraded battery. To enhance readability of this report, these deployments are referred to as: Deployment 1 (August 2020 to August 2021), deployment 2 (August 2021 to March 2022), and Deployment 3 (June 2022 to June 2023). In deployment 1, 118 collars were fitted to trial cows and 40 collars fitted to indicator steers. In this deployment, the collars were scheduled to capture location data at a fix rate of either 1 per 5, 10 or 15 minutes to evaluate fix rate and battery life. For deployments 2 and 3, all devices were scheduled to capture location data at a fix rate of 1 per 10 minutes, with 150 and 100 collars fitted in deployments 2 and 3 respectively. At Brunette Downs Station a single GNSS deployment was completed from December 2022 to June 2023, deployment 4, where 50 collars were deployed. Throughout all deployments, the collars were evenly distributed, ensuring an equal number of animals were fitted with collars in each paddock.

GNSS collar data analyses

At the end of each deployment, collars were retrieved from trial animals and the GNSS logger was connected via cable to a laptop to download the GNSS data. Over the trial period, there were some devices which were unable to be connected via laptop so their data was unable to be retrieved. Similarly, data could not be retrieved from devices that were lost in the paddock, either via animals losing devices or by animals not presenting at the yards during the trial period. As the GNSS collars used in this project were 'store on board' devices, there was no way to track the whereabouts of a collared cow unless it was mustered and brought to the yards for processing.

Scripts were developed to automatically combine data from multiple downloaded files from GNSS units and identify the source of the information using the program R. A standardised naming convention was used when downloading GNSS units so the data could be automatically combined while ascribing each row of data to the GNSS unit it was collected on and the deployment, creating a starting analytical file. GNSS data cleaning involved removing any erroneous data such as those without a latitude and longitude value, those with geolocation fix intervals of less than 5 minutes and those with fixes greater than 30 minutes (less than 10 % total cases), as well as speeds over 5.39m/s as described in Norman *et al.* (1988).

The distance between GNSS locations, including distance to water calculations was calculated by employing the 'distHarversine' function within the R 'geosphere' package. This method assumes a spherical earth, ignoring ellipsoidal effects. The time between GNSS measurements was calculated by calculating the difference in time between when the GNSS measurements were recorded using the 'difftime' function in R. The average speed (km/h) was calculated by dividing the distance by the difference in time between fixes (sec). Distance to water calculations were done by calculating the minimum, average and maximum distance from all water points within each paddock to each fix of each animal, and then averaged across all animals per day.

Once GNSS data was collated per animal and merged into a single file, the home range of animals was calculated in R using the *adehabitatHR* package. Home ranges of animals are important to understand how animals use and interact with paddock infrastructure and feed availability. Home range data was calculated for individual animals and groups of animals and was then mapped in their respective paddocks, and under-layed with monthly Cibo Labs biomass and groundcover data, to show the interaction of animal movement with pasture availability over time. When mapping and calculating distances and home range images for trial animals, GNSS collar data was clipped to only include those points inside the trial paddocks and points to within a 20m buffer on the outside of the trial paddocks (to account for GNSS error).

3.3.5 Impacts of other variables

Nutrition and climate

The pasture quality (dietary protein and metabolisable energy content) for each experimental paddock was estimated by collecting fresh faecal samples and analysing them using faecal near-infrared spectroscopy (F.NIRS). Sample collection was done by either taking a per rectum faecal sample from 10-15 animals during pregnancy testing or from available fresh faecal matter in the yards. Faecal phosphorous (P) and calcium (ca) were determined using wet chemistry techniques (Dixon et al 2007).

3.1.4 Statistical analyses

Differences for reproductive performance between treatment groups were compared using parsimonious statistical methods at annual time points throughout the study. Frequency differences between treatment groups for calf loss (alive/dead), annual pregnancy and pregnant within four months (pregnant/not pregnant) were compared using Pearson chi-squared test. When the chi-squared assumption was violated the Fisher's exact test was used. Overall differences between treatment group means for foetal and calf loss and pregnancy were compared after employing a generalised linear mixed model with treatment fitted as a main effect and year as a random effect. Data analyses were conducted using R, ver. 4.1.1 and R Studio, ver. 1.4.1106, (R Core Team 2021).

4. Results

4.1 Rocklands Station

4.1.1 Assessment of carrying capacity and grazing utilisation

Long-term pasture growth estimates were generated for each land type in the study paddocks on Rocklands using the GRASP model in 2020. Carrying capacity was also calculated using the GRASP model (Table 8). The timing coincided with the modelling of the Barkly region datasets involved in the MLA-funded Sweet Spot project (and thus was an efficient use of the modelling capacity across the two projects).

Table 8. Current safe carrying capacity using GRASP predicted pasture growth

Paddock	Big Mudgee	Grassy
Total Area (km²)	113.8	157.4
3km Watered Area (km²)	69	58.2
5km Watered Area (km²)	107.1	131.4
50% of area 3-5 km	19.05	36.6
Pasture Growth for 56%ile rainfall (kg/ha)	1487	1487
Carrying Capacity (AE/km^2)	10.2	10.2
Paddock carrying capacity (AE) for watered area	898	967
Total paddock carrying capacity (AE)	1161	1605

Stocking rate varied between the paddocks at Rocklands for the years during the trial (Table 9), after a number of dry years in the lead up to the trial commencing meant steps had to be taken to reduce the number of animals in the paddocks.

Table 9. Stocking rate in AE/km^2 per watered area through time in Grassy and Big Mudgee Paddocks at Rocklands

Date	Big Mudgee	Grassy
1/01/2019	9.7	9.1
26/08/2020	12.5	11.9
9/08/2021	10.0	7.6
10/08/2021	10.3	3.8
10/03/2022	9.0	3.8

Paddock yield observations and satellite green ground cover from the paddocks were used to adjust the model so that it predicted observed yields (Figure 30) and green cover (Figure 31) to a high level of accuracy. Intake was assumed to be 8kg/AE/day. The simulated pasture growth combined with paddock level intake was then used to calculate pasture utilisation at the sites.

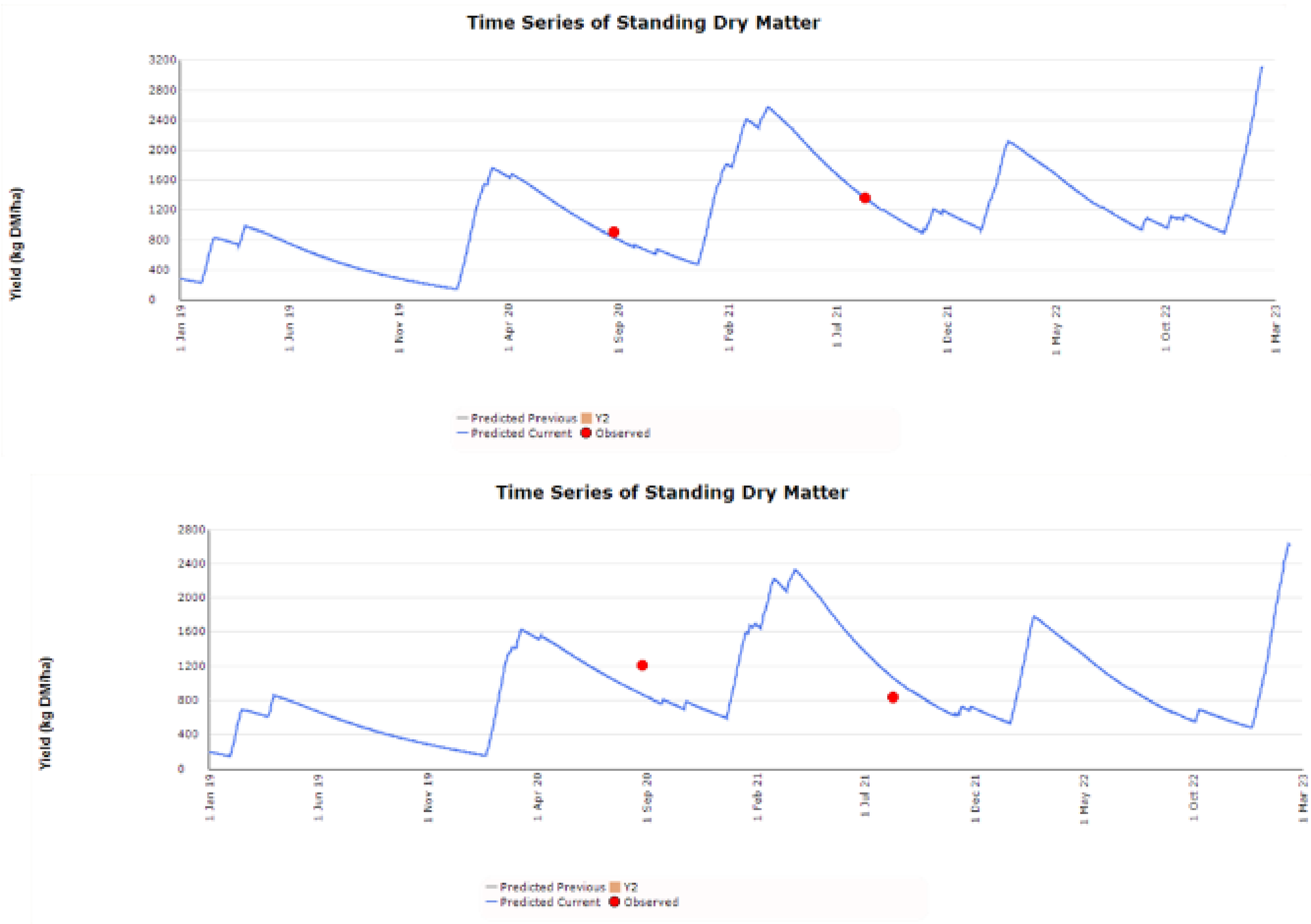


Figure 30. Simulated (blue line) vs. observed (red dots) yield in Big Mudgee (top) and Grassy (bottom) paddocks at Rocklands, from the onset of the trial in 2019, through to 2023.

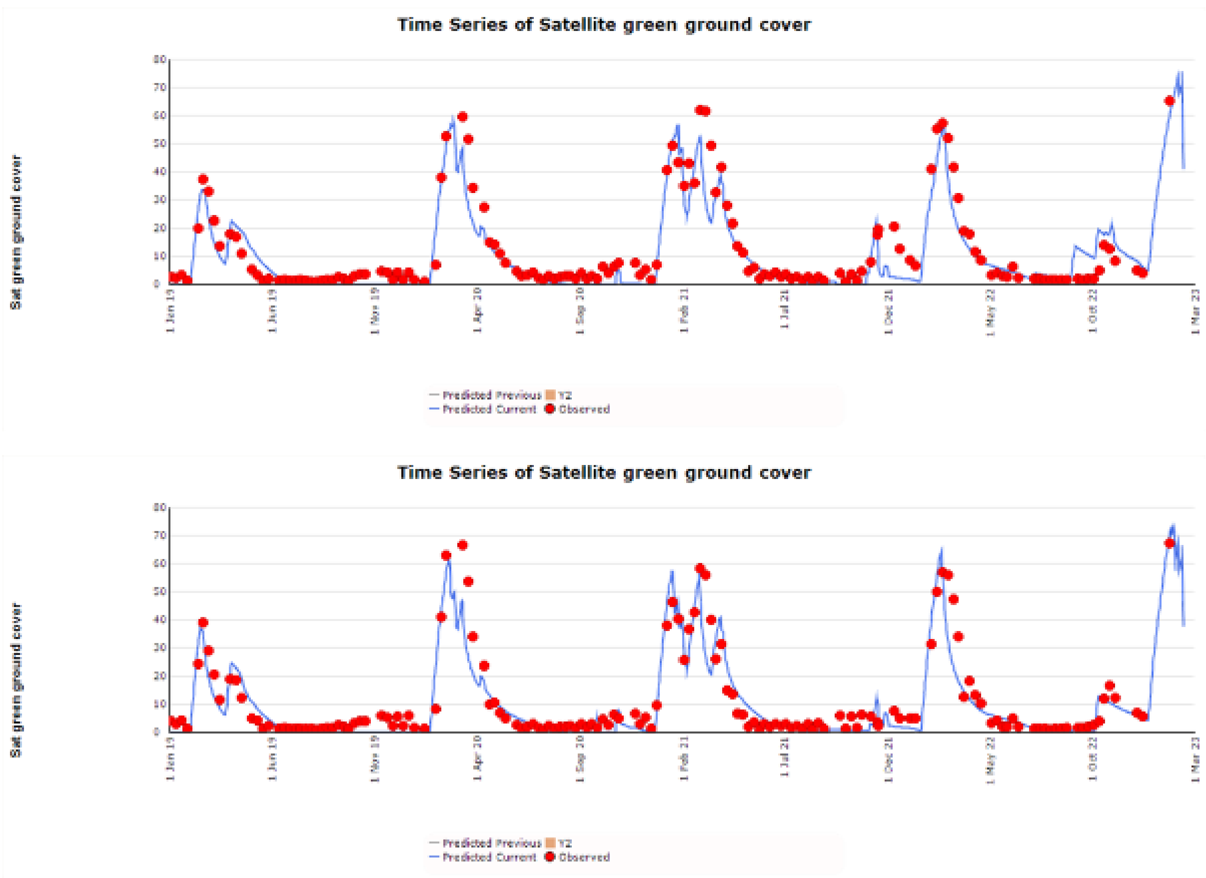


Figure 31. Simulated (blue line) vs. observed (red dots) green ground cover in Big Mudgee (top) and Grassy (bottom) paddocks at Rocklands.

Pasture utilisation was well within recommended levels for optimal pasture condition and animal performance in both paddocks during the Paddock Power trial (Figure 32). The lower stocking rates in Grassy paddock from late 2021 led to lower pasture utilisation in 2022. The trial paddocks had similar simulated pasture growth (Figure 32).

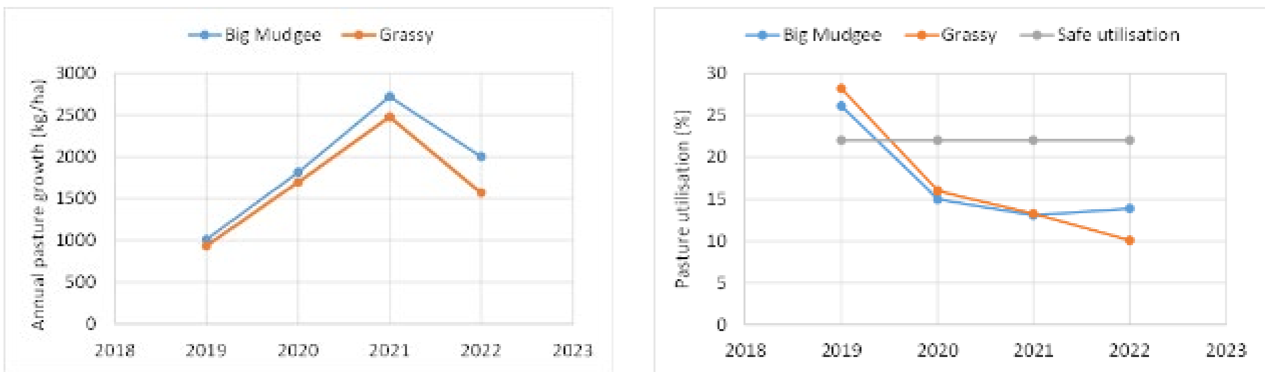


Figure 32. Simulated annual pasture growth (left) and pasture utilisation (right) at Rocklands Paddock Power sites.

NDMI and GNSS data from the trial paddocks at Rocklands show the distribution of animals on the same day during each deployment year and how this is associated with the NDMI. February 2023 was just after the heavy rainfall at Rocklands and large areas of the paddock had significant surface water (Figure 33).

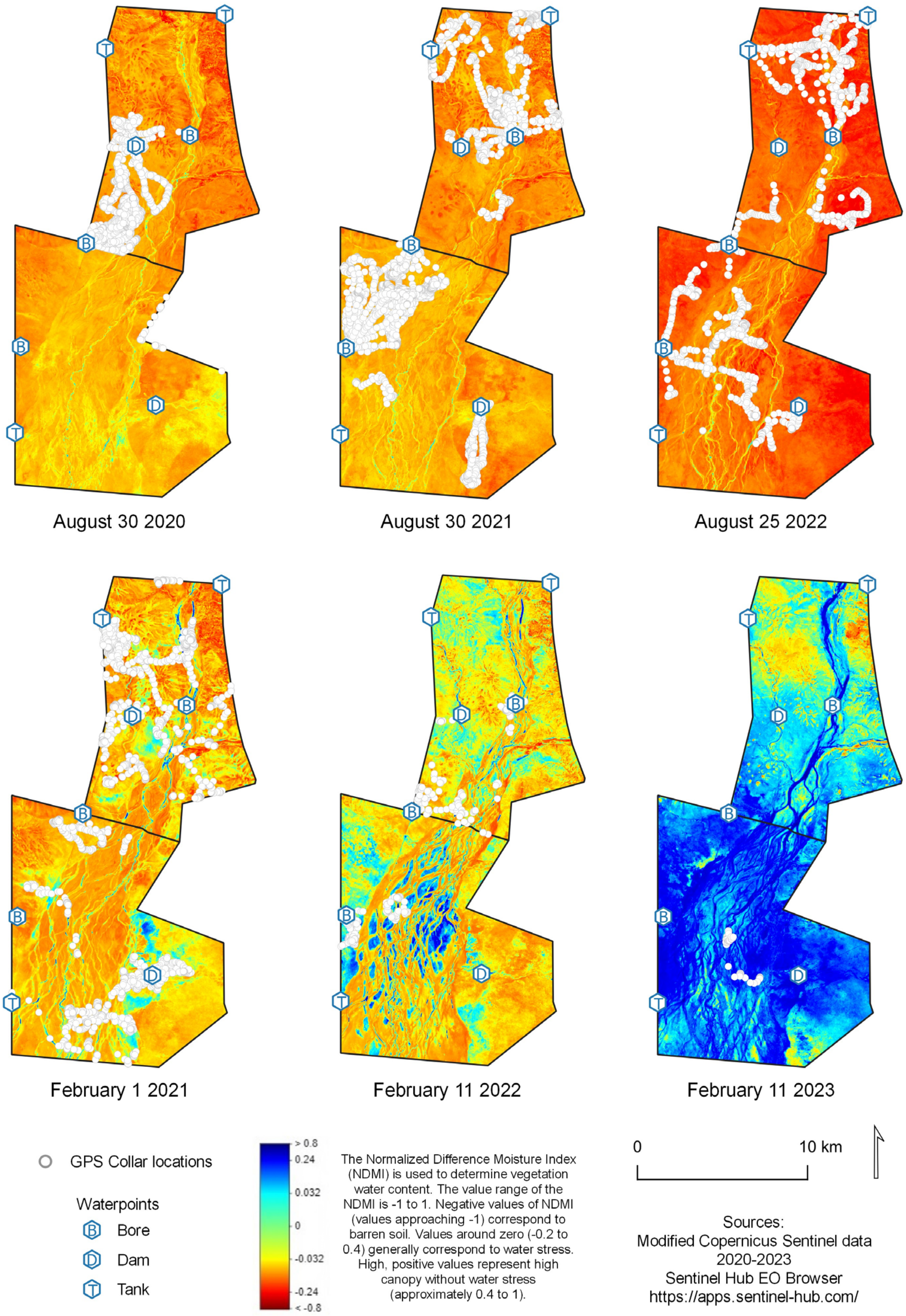
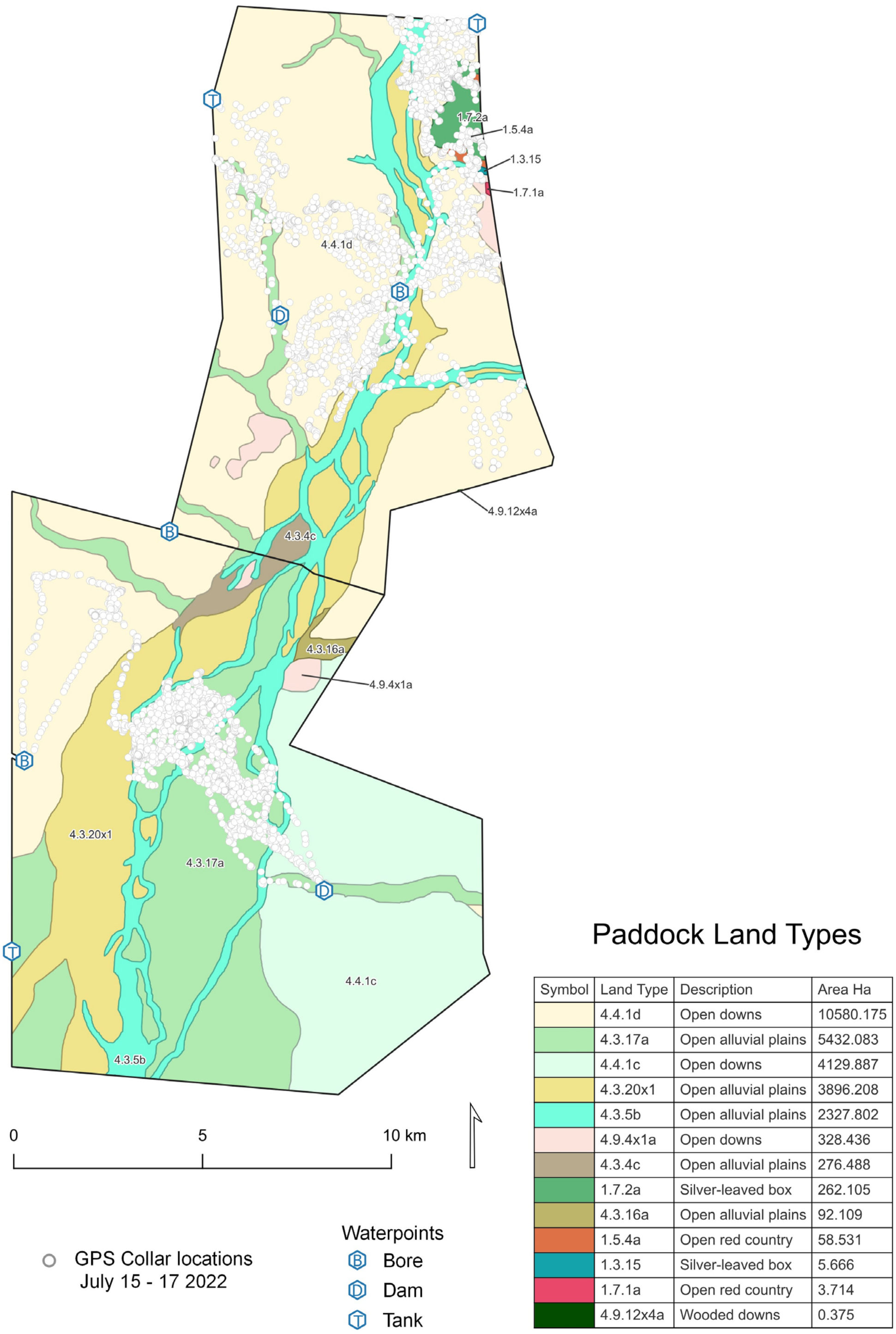


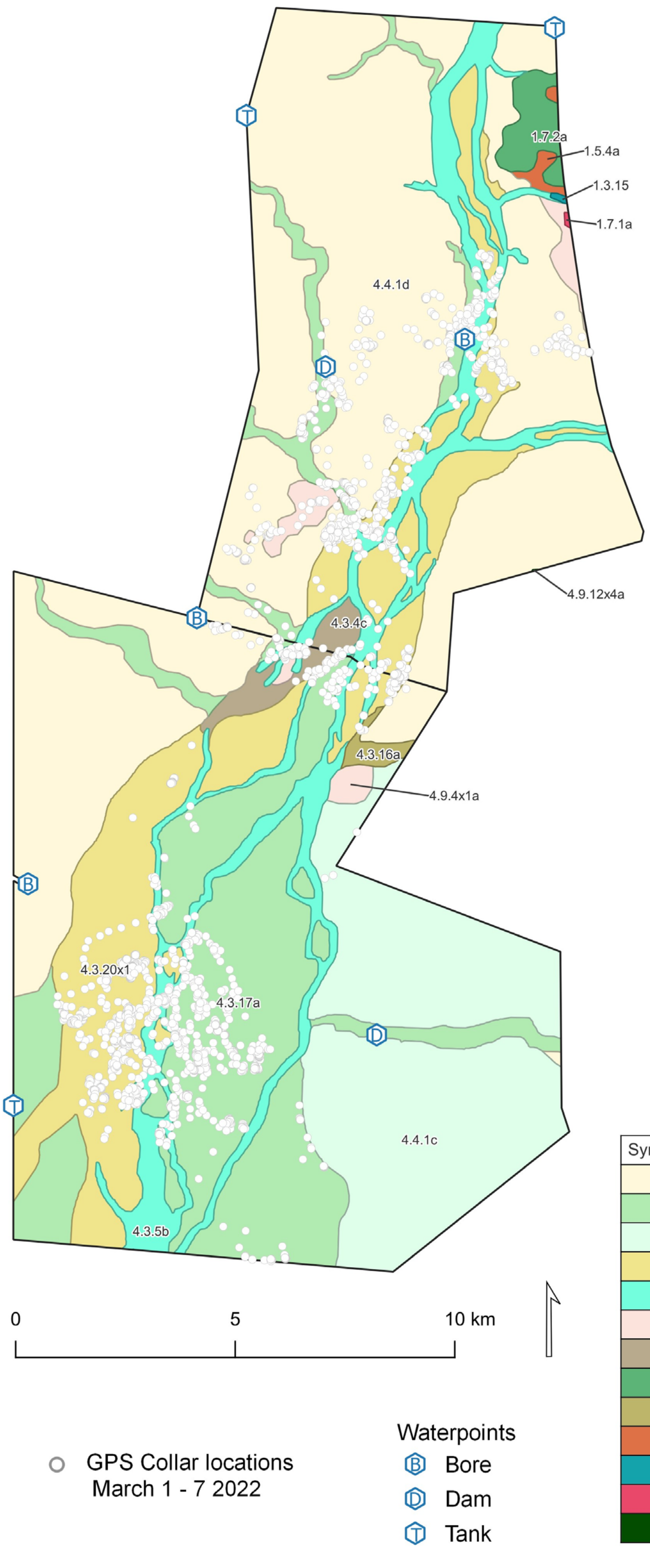
Figure 33. Normalised Difference Moisture Index (NDMI) in the wet and dry season across the 3 deployment years at Rocklands Station with GNSS locations of animals grazing in each paddock.

The distribution of animals according to land type can help to make more informed decisions about paddock subdivisions and carrying capacity estimates. It was of interest in this project to monitor how animals graze in relation to land type, and Fig. 34 and 35 shows the locations of animals over a given period in the wet and dry season at Rocklands with land type underlaid to show preferential grazing areas.



Symbol	Land Type	Description	Area Ha
	4.4.1d	Open downs	10580.175
	4.3.17a	Open alluvial plains	5432.083
	4.4.1c	Open downs	4129.887
	4.3.20x1	Open alluvial plains	3896.208
	4.3.5b	Open alluvial plains	2327.802
	4.9.4x1a	Open downs	328.436
	4.3.4c	Open alluvial plains	276.488
	1.7.2a	Silver-leaved box	262.105
	4.3.16a	Open alluvial plains	92.109
	1.5.4a	Open red country	58.531
	1.3.15	Silver-leaved box	5.666
	1.7.1a	Open red country	3.714
	4.9.12x4a	Wooded downs	0.375

Figure 34. Land types at Rocklands Station and GNSS locations of trial animals in the dry season from 15-17 July in 2022.



Symbol	Land Type	Description	Area Ha
	4.4.1d	Open downs	10580.175
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	4.3.16a	Open alluvial plains	92.109
	1.5.4a	Open red country	58.531
	1.3.15	Silver-leaved box	5.666
	1.7.1a	Open red country	3.714
	4.9.12x4a	Wooded downs	0.375

Figure 35. Land types at Rocklands Station and GNSS locations of trial animals from 1-7th March of 2022.

The final year of feedbase data was collected at Rocklands on the 12th of May 2023 at the completion of the project at the collaborating property. A pasture assessment was undertaken and initial sites from 2019 were revisited and pictured with pasture ID of present species (Appendix 10.2)

On average, the cattle in both paddocks spent most of their time at or within 3-5 km of the permanent watered area with the exception of Grassy paddock in 2022-2023 where they used considerably less of the paddock (Figure 20 and 21)

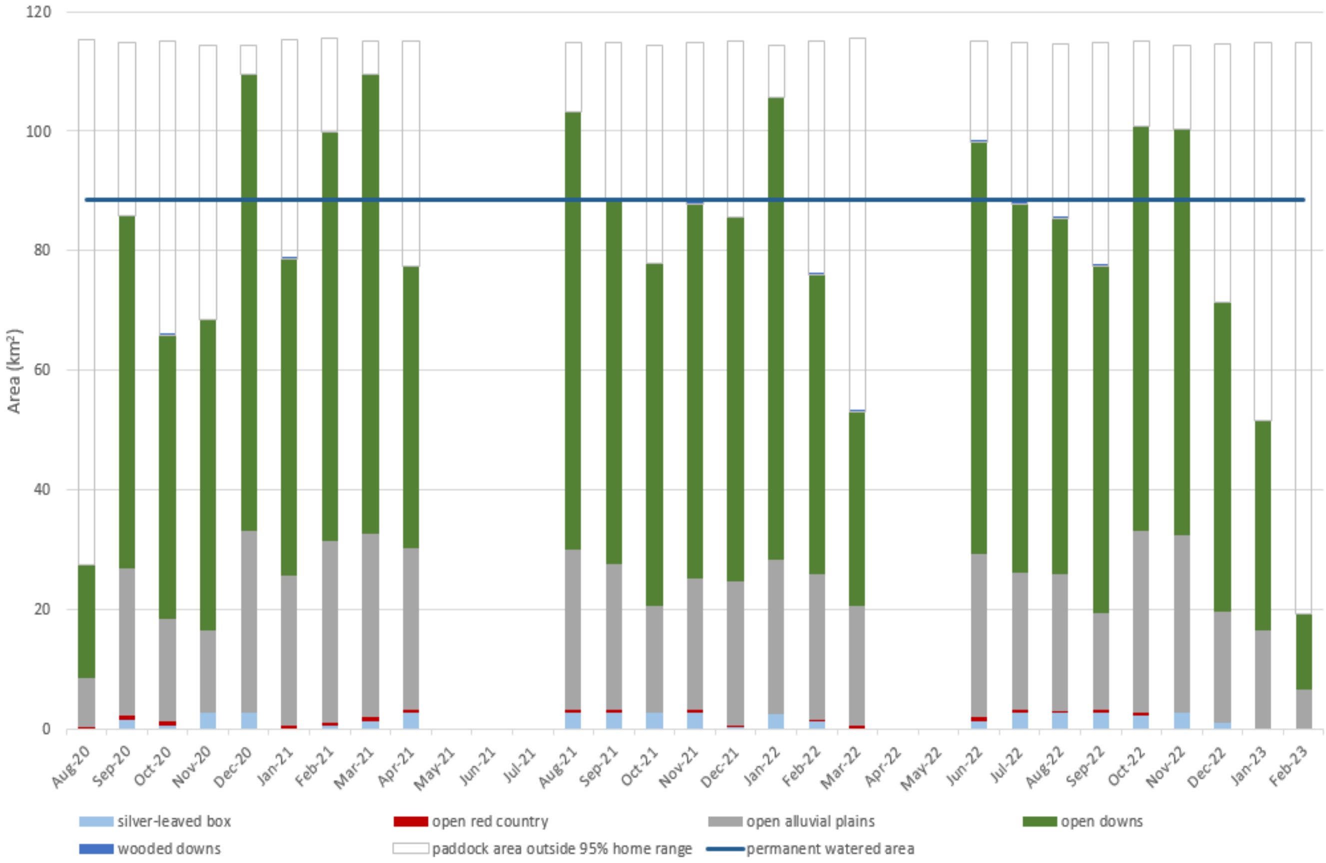


Figure 36. Monthly total area of each land type within the 95% home range in Big Mudgee paddock at Rocklands Station.

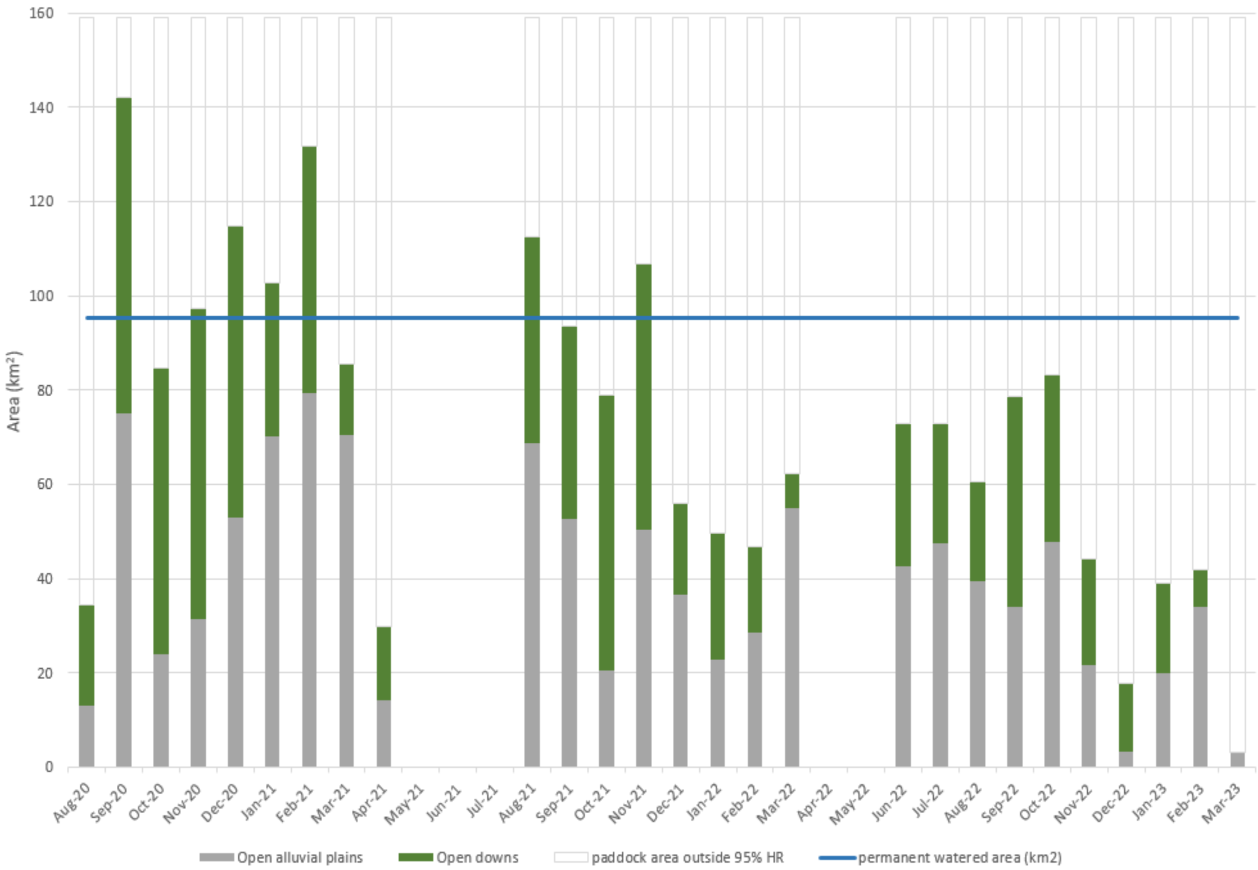
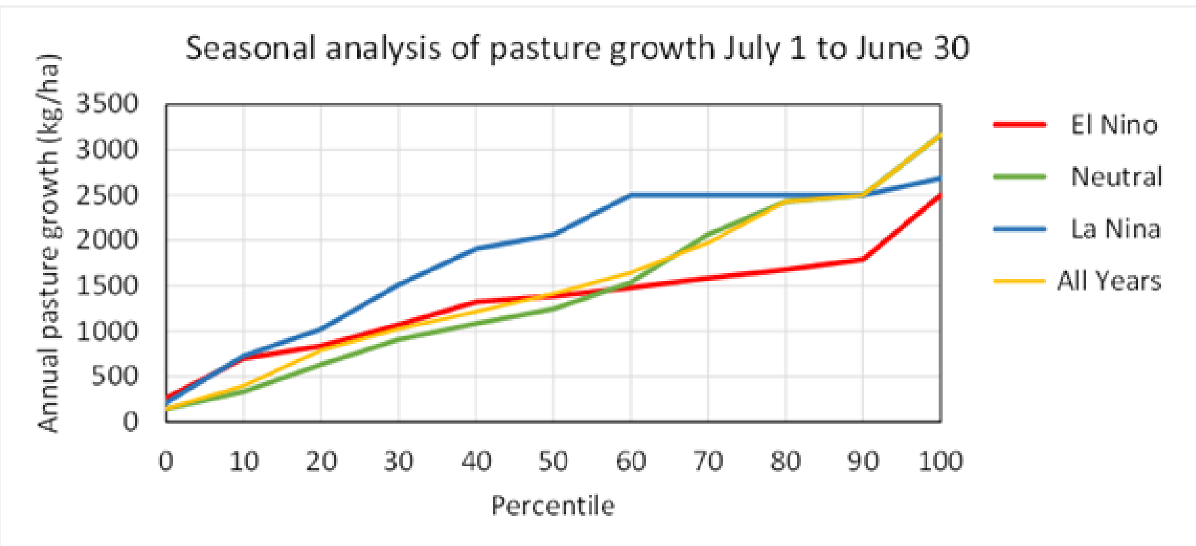


Figure 37. Monthly total area of land types within the 95% home range in Grassy paddock at Rocklands Station.

Preliminary GRASP pasture growth modelling using a locally relevant black soil model was used to provide indicative stocking rates for Big Mudgee and Grassy paddock for 2022 (Figure 22). The model was not specifically calibrated for these paddocks but was calibrated on a nearby comparative land type.



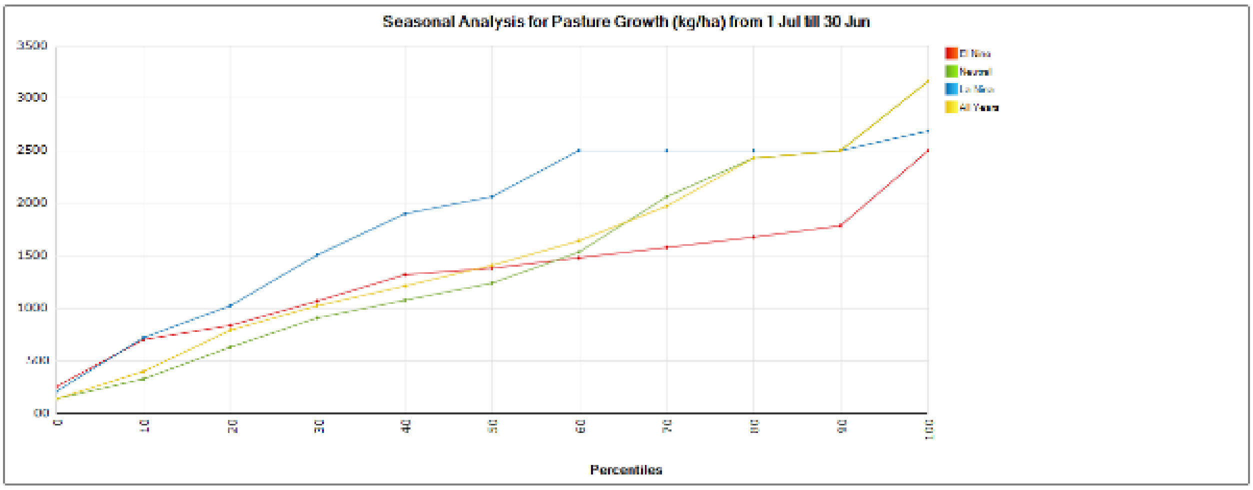


Figure 38. GRASP percentile pasture growth output for Barkly black soil using interpolated rainfall file for Rocklands station.

Throughout the trial, and following poor seasons on the Barkly, the stocking rate and utilisation rate was well under the long-term carrying capacity estimates for this region on the black soil. Impacts that this may have had on the trial and animal performance include a reduction in the distance animals travelled in a larger paddock, due to the utilisation rate being below 20% (Table 10). The reason for this is that animals did not need to travel as far to select the diet they required.

Table 10. Long term stocking rates and paddock carrying capacity using GRASP pasture growth model outputs for Barkly black soil using Rocklands interpolated rainfall data.

	Percentile of annual rainfall			
Long Term Stocking Rate - Rocklands station, Black soil	30th	50th	**56th**	70th
Median growth (kg/ha/yr)	1024	1412	**1487**	1975
Safe utilisation rate (%)	20	20	**20**	20
Intake @8kg/AE/day	2920	2920	**2920**	2920
Safe Carrying Capacity (AE/km^2)	7	9.7	**10.2**	13.5

4.1.2 Assessment of pasture quality

Faecal samples were collected from a subsample (N ~10) at the time of mustering for weaning in 2022 and 2023 to estimate the quality of the pasture being consumed by trial animals. Table11 presents the outcomes obtained from both F. NIRS and wet chemistry analyses.

Table 11. Rocklands faecal NIRS and wet chemistry results in Grassy and Big Mudgee paddocks.

NIRS and wet chemistry measures	Grassy Paddock March 2022	Big Mudgee Paddock March 2022	Grassy Paddock May 2023	Big Mudgee Paddock May 2023
Dietary Crude Protein (CP)%	10.70	11.30	8.70	9.20
Dry Matter Digestibility (DMD)%	62.90	62.90	59.70	61.10
Faecal Nitrogen (FN)%	1.60	1.70	1.60	1.70
Faecal δ13C	15.60	16.10	18.20	18.20
Non-grass %	15.10	18.70	33.80	33.60
Ash %	24.20	23.40	20.30	21.90
Metabolisable energy (MJ/kg)	9.10	9.10	8.60	8.80
DMD:CP	5.90	5.60	6.90	6.70
Wet chemistry				
Calcium %	1.84	2.12	1.86	2.40
Phosphorus %	0.58	0.24	0.35	0.27
Ca:P ratio	3.17	8.83	5.31	8.89

*outlier values - interpret with caution.

Faecal NIRS results indicated a high ash content for all samples, and a high protein content for the reported dry matter digestibility (DMD) (Table 11). This comparative study allowed animals in both trial paddocks to select a diet of similar nutritional value, so similarities between the paddocks and across multiple seasons is to be expected.

The climatic conditions during the trial period were extremely variable, from some of the driest years in recent history experienced on the Barkly tablelands in 2019, delaying the onset of the project, and some of the largest rainfall events in recent times in the wet season of 2021-2022, flooding many areas in the region to a significant extent. With such large variability in only a few years, this must be taken into consideration when interpreting results.

4.1.3 Crush side animal performance data

Rocklands Station

Data describing the reproductive performance of breeding females grazing the two trial paddocks was successfully captured for three annual production years at Rocklands Station.

The age distribution and expected calving months for each management group of retained females at the annual pregnancy test muster have been summarised and presented as Figure 39 and Figure 40. All females were predicted calve within an October to December calving window, with the females expected to calve within each month anticipated to be approximately equal within each production cycle. Similarly, the age distribution of groups was approximately equal within year. However, in 2022, there was a marginally higher percentage of retained females under 3 years old in Big Mudgee compared to Grassy.

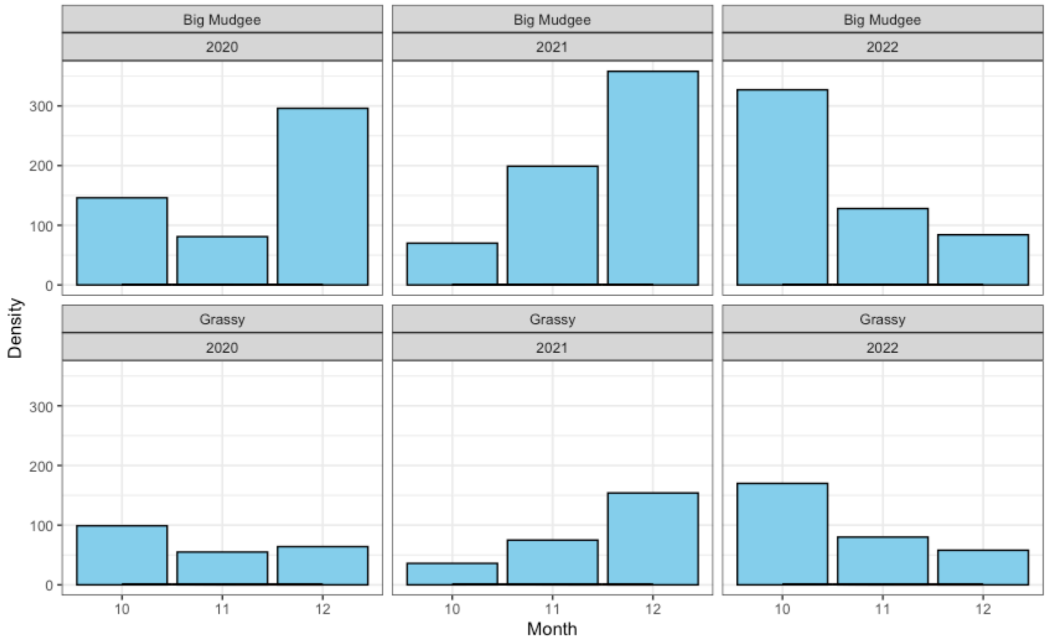


Figure 39. Distribution of calving for treatment group & paddocks across years at Rocklands Station.

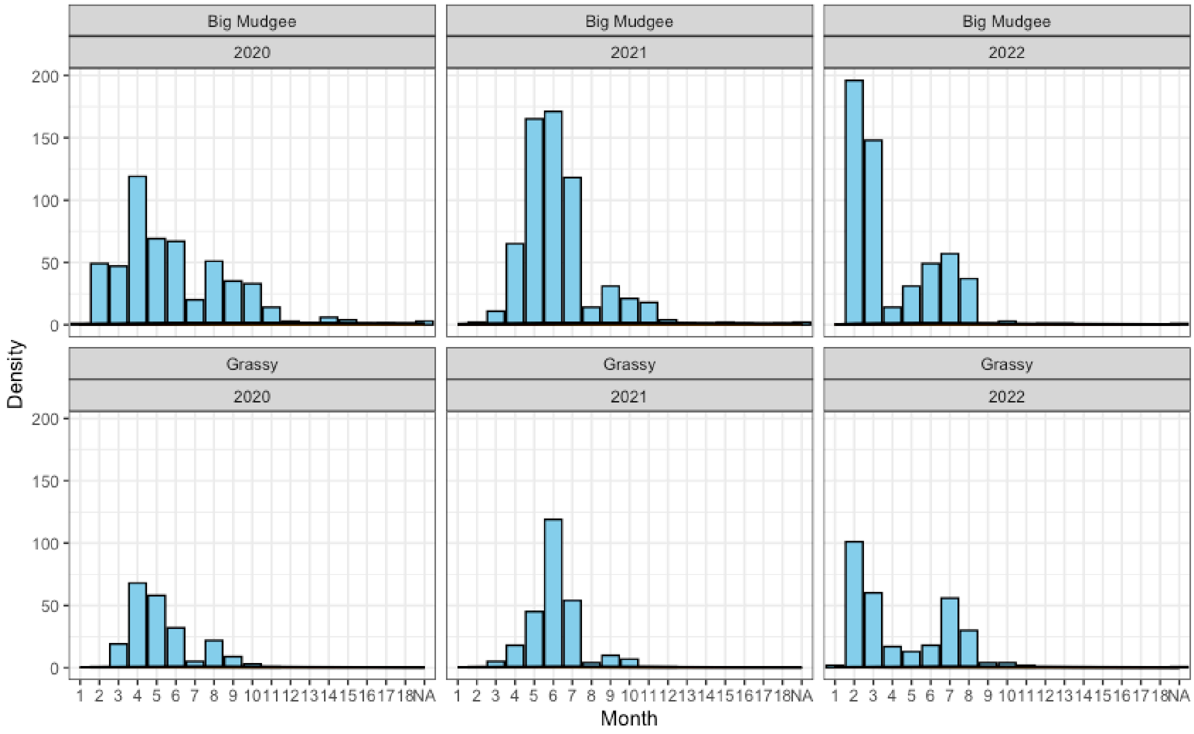


Figure 40. Distribution of age of retained females across year for each treatment group and paddock at Rocklands Station.

The performance of animals in each trial paddock at Rocklands over the study period is summarised in Table 12. Across various performance metrics, females grazing Grassy Paddock exhibited elevated performance in comparison to those in Big Mudgee. Notably, females in the Grassy Paddock displayed consistently higher annual growth rates, as measured by changes in body condition score and liveweight between annual pregnancy test musters. Overall, a weaner production of 206kg weaner per retained female was calculated for Grassy, compared to 188 kg for Big Mudgee. This heightened performance aligns with the observed elevated levels of pregnancy and weaner weight for Grassy compared to Big Mudgee, suggesting potentially better nutritional conditions in the Grassy Paddock.

Table 12. Summary of reproductive performance observed at Rocklands between 2020 – 2023

Outcome	Year	Big Mudgee Paddock			Grassy Paddock			Sig.
		Tally	Mean	(95% CI	Tally	Mean	(95% CI	
Annual BCS change	2021	467	-0.35	(-0.4, -0.29)	97	-0.21	(-0.32, -0.09)	<0.05
	2022	213	-0.18	(-0.26, -0.1)	181	-0.15	(-0.24, -0.07)	NS
	Overall	680	-0.26	(-0.31, -0.22)	278	-0.18	(-0.25, -0.11)	NS
Annual LW change (kg)	2021	238	5.1	(-4.98, 15.19)	42	28.57	(4.57, 52.58)	NS

	2022	213	9.26	(-1.4, 19.92)	179	32.66	(21.04, 44.29)	<0.01
	Overall	451	7.18	(-0.16, 14.52)	221	30.62	(17.28, 43.96)	<0.01
Pregnancy %	2021	721	79.8	(76.7, 82.5)	692	78.5	(75.2, 81.4)	NS
	2022	498	67.1	(62.8, 71.1)	179	88.8	(83.3, 92.7)	<0.01
	2023	616	44.3	(40.4, 48.3)	294	71.1	(65.6, 76)	<0.01
	Overall	1835	65	(62.6, 67.3)	1165	80.6	(77.5, 83.3)	<0.01
Pregnant within 4 months of calving (%)	2021	421	40.1	(35.6, 44.9)	177	23.7	(18, 30.5)	<0.01
	2022	575	40.7	(36.8, 44.8)	178	62.9	(55.6, 69.7)	<0.01
	2023	454	25.6	(21.7, 29.8)	311	53.7	(48.1, 59.2)	<0.01
	Overall	1450	35.1	(32.6, 37.6)	666	45.9	(41.7, 50.2)	<0.01
Foetal and calf loss (%)	2021	531	21.3	(18, 25)	221	21.7	(16.8, 27.6)	NS
	2022	672	10.1	(8.1, 12.6)	272	15.4	(11.6, 20.2)	<0.01
	2023	546	20	(16.8, 23.5)	349	14.3	(11, 18.4)	<0.01
	Overall	1749	16.4	(14.7, 18.3)	842	16.9	(14.5, 19.7)	NS
Weaning weight (kg)	2021	323	240.7	(236.1, 245.4)	287	274.4	(269.5, 279.3)	<0.01
	2022	574	217.7	(214.3, 221.2)	215	244	(238.3, 249.7)	<0.01
	2023	475	224.7	(220.9, 228.5)	247	231.2	(225.9, 236.5)	0.06
	Overall	1372	227.7	(225.4, 230)	749	249.9	(246.8, 252.9)	<0.01

While these findings align with the commonly held belief that increased development leads to enhanced animal performance, it is important to note that the treatment effects in this study are being applied at the mob level, and comparing the mob performances over three years is unlikely to produce sufficient statistical power to make broad inferences from. Therefore the results from this activity might be better suited for consideration as a case study.

An overall incidence of 16.7% (95% confidence limits: 15.2% to 18.3%) foetal and calf loss was observed in this trial across various years and paddocks. Divergence in foetal and calf loss was evident between paddocks across different years, while maintaining statistically similar rates overall. These observations were contingent upon the respective years. In 2021, both paddocks exhibited similar occurrences for foetal and calf loss. However, in 2022, Big Mudgee demonstrated a reduced incidence compared to Grassy, whereas in 2023, Big Mudgee displayed a higher incidence in comparison to Grassy (Figure 41, Table 12).

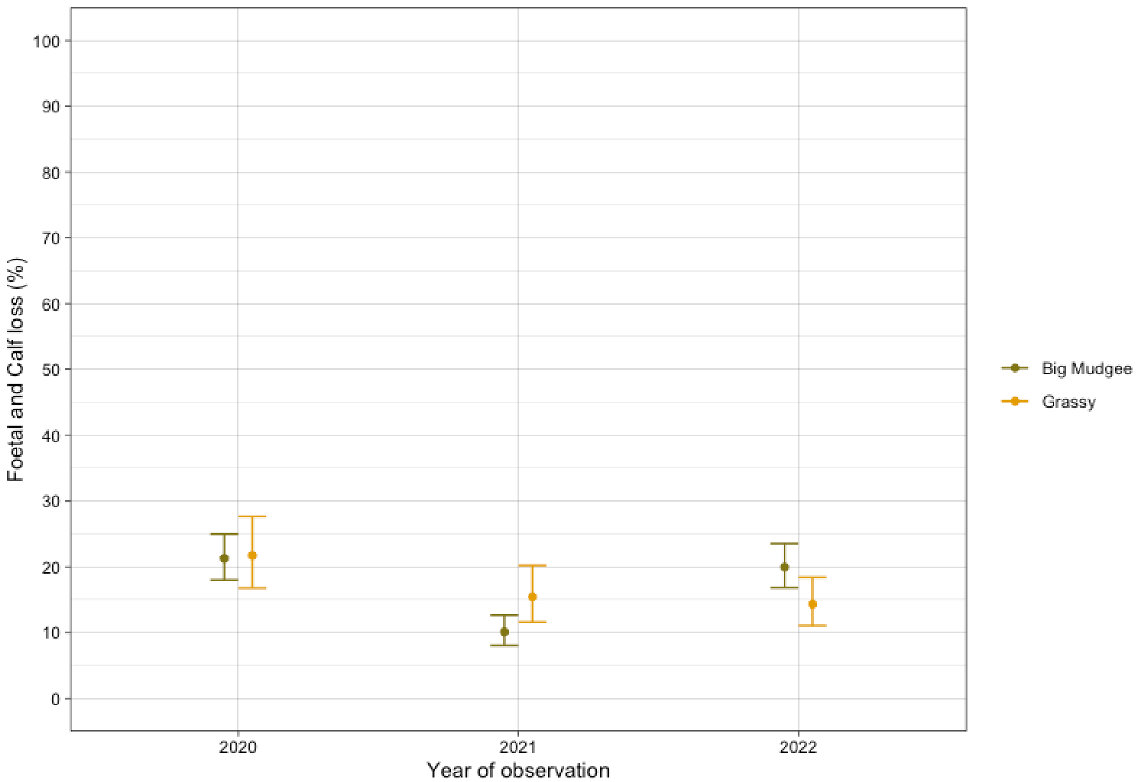


Figure 41. Observed Foetal and calf loss between 2020 and 2022 for both trial paddocks on Rocklands Station. Error bars represent the 95% confidence limits for the mean.

Overall, 73.5% (95% CL, 71.4, 75.5) of retained females achieved pregnancy by 1st September. Considerable variation was observed across different paddocks over the years. Both paddock and year emerged as significant factors influencing annual pregnancy rates.

The average annual pregnancy observed in females grazing Big Mudgee paddock was 65.0 (95% CL, 62.7, 67.3), which contrasted with 80.6 (95% CL, 77.6, 83.5) observed for females grazing Grassy Paddock (P<0.01). Although, this effect was dependant on year, with similar annual pregnancy rates observed between paddocks in 2020. Large variation was evident between years with lower occurrence observed in 2023, compared to other years (P<0.01). In 2021, 2022 and 2023, respectively annual pregnancy was observed as 79.1, 80.1 and 58.3%.

It is also noteworthy that the pregnancy percentage in non-lactating cows was 26.1% higher, when compared to lactating cows (93.8% vs. 67.7%).

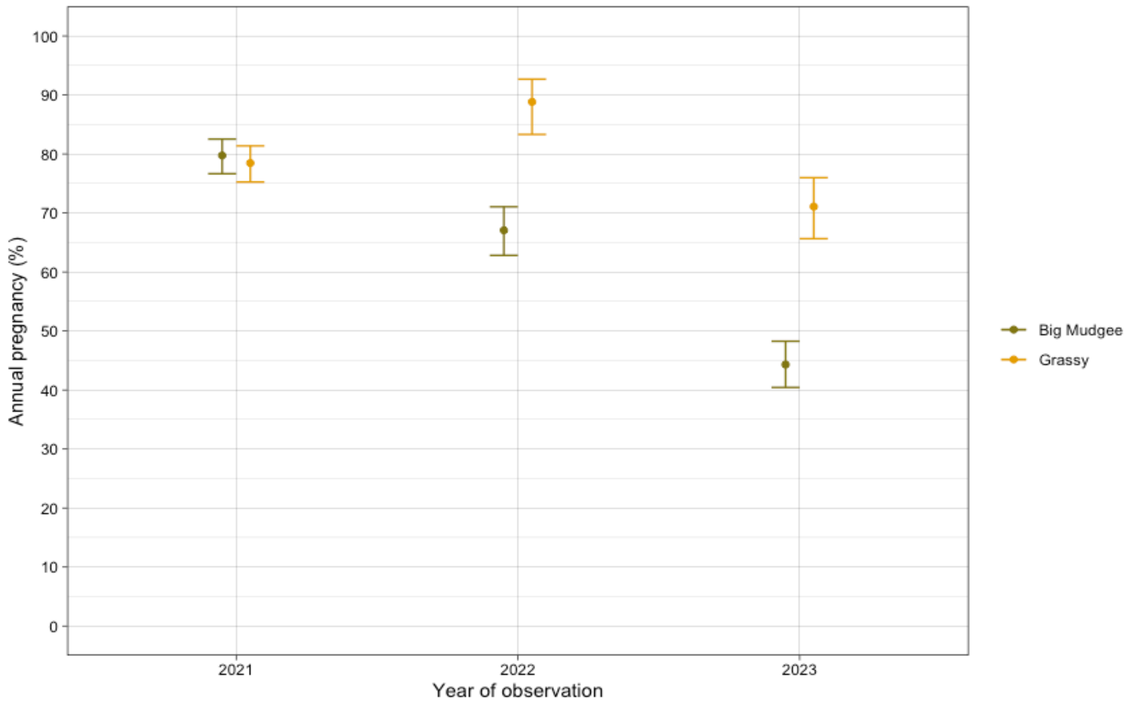


Figure 42. Mean pregnancy percentage observed for breeders grazing Big Mudgee and Grassy paddocks for each year. Error bars represent the 95% confidence limits for the mean.

The overall occurrence of P4M in females observed in this study was estimated at 41.8% (95% CI: 35.5% - 48.4%). An overall effect was observed between paddocks, with Grassy Paddock, on average, observed with 13.6% higher P4M, compared to Big Mudgee (P<0.01; Table 7). However, this effect was contingent upon year. Specifically, 2021 and 2022 exhibited higher performance levels in the Grassy paddock, while in 2020, higher performance was observed in Big Mudgee.

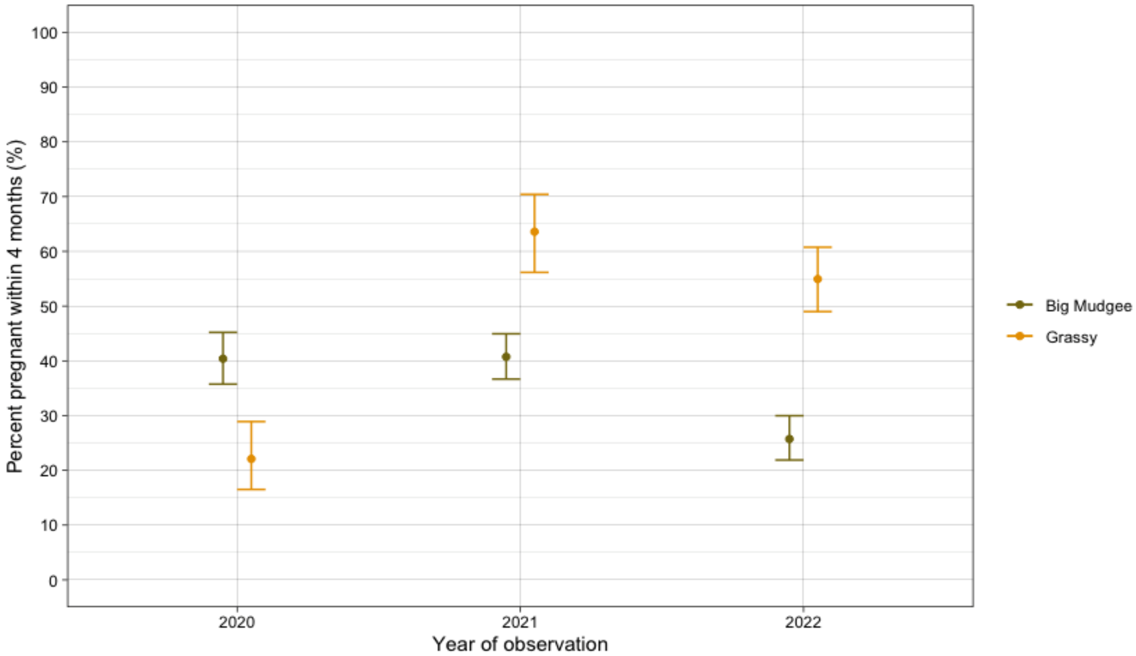


Figure 43. Percent pregnant within 4 months of calving while lactating for breeders grazing Big Mudgee and Grassy paddocks. Error bars represent the 95% confidence limits for the mean.

Overall, indicator steers grazing Grassy Paddock displayed higher growth (25.9 $\pm$ 5.0kg), when compared to Big Mudgee (176.1 *vs.* 150.3; P<0.001; Figure 27). Breed was a clear determinant of growth (P=0.001), with Brahman steers displaying 15.1 and 29.4kg greater growth than Brangus Steers in Big Mudgee and Grassy Paddocks, respectively.

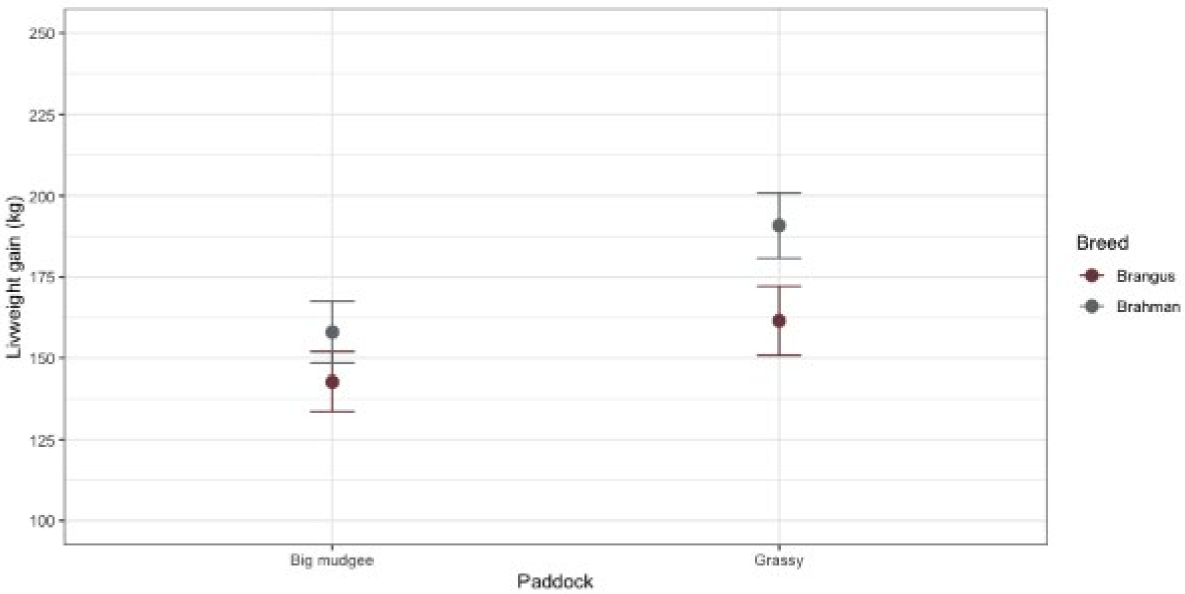


Figure 44. Liveweight of steers in the trial paddocks at Rocklands according to their breed.

4.1.4 GNSS device, recording and retention

Combined data from the GNSS units retrieved during the project contained over 300 million location fixes. Data cleaning processes included removing records that contained latitude and longitude values that were equal to zero or had missing values, which removed approximately 10% of location records. Further cleaning including removing dates outside the trial period, removing repeated values, and removing other erroneous data.

GNSS units varied in their battery life, despite having the same configuration settings and deployment times for the majority of cases. Units were also variable in their fix rate, with some fixes occurring every few seconds despite GNSS units being programmed to record fixes at intervals of 5, 10, or 15 minutes (which was generally an indication that the unit was running low on battery or was faulty) and not recording a fix at an allotted time.

A summary of the GNSS units and their performance over the trial period showed that there was a significant decrease in the number of units recording a certain number of fixes per day and for each day within each monthly timestep (Figure 45). Units that recorded 48 or more fixes in a 24hr period, and recorded a fix for 28 days within a month are shown in Figure 31. It's important to highlight that in Deployment 1, GNSS units were set to capture locations at fix intervals of 5, 10, or 15 minutes, primarily to assess battery longevity and duration. Consequently, the performance summary depicted in Figure 45, representing Deployment 1, may be influenced by this setup, offering a somewhat optimistic perspective on their performance. Understanding the likely decline in fix frequency and its impact on distance and home range calculations is important, as there may be a lower number of animals represented in the results as the deployment period goes on and additionally differences in the time since the last fix can impact the error associated with the actual distance travelled.

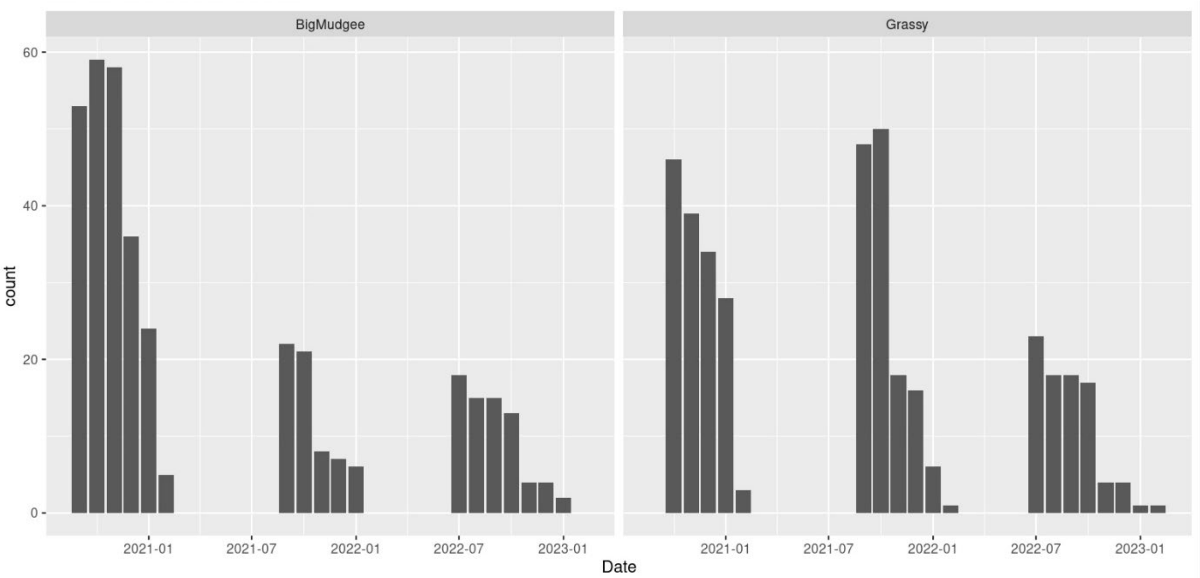


Figure 45. Number of active GNSS units (Y axis) over the period of the trial per month- with a threshold minimum of 28 days active per month and a minimum 48 fixes per day.

GNSS fix interval was predominantly less than 20 minutes apart, with 90% of fixes occurring 5-20 minutes apart. There were a number of fixes that occurred on the paddock boundary between Grassy and Big Mudgee paddocks, and this impacted the daily distance values for some animals, if they were between two paddocks on the same day. For this reason, low distance values should be interpreted with caution, as they may not have been representative of the actual distance travelled on that day.

There were a number of fixes and GPS units that swapped paddocks during each year of the trial, and this is documented in Figure 46. This is due to animals escaping to another paddock and highlights the challenges of working in remote commercial conditions when animals often move freely around paddocks.

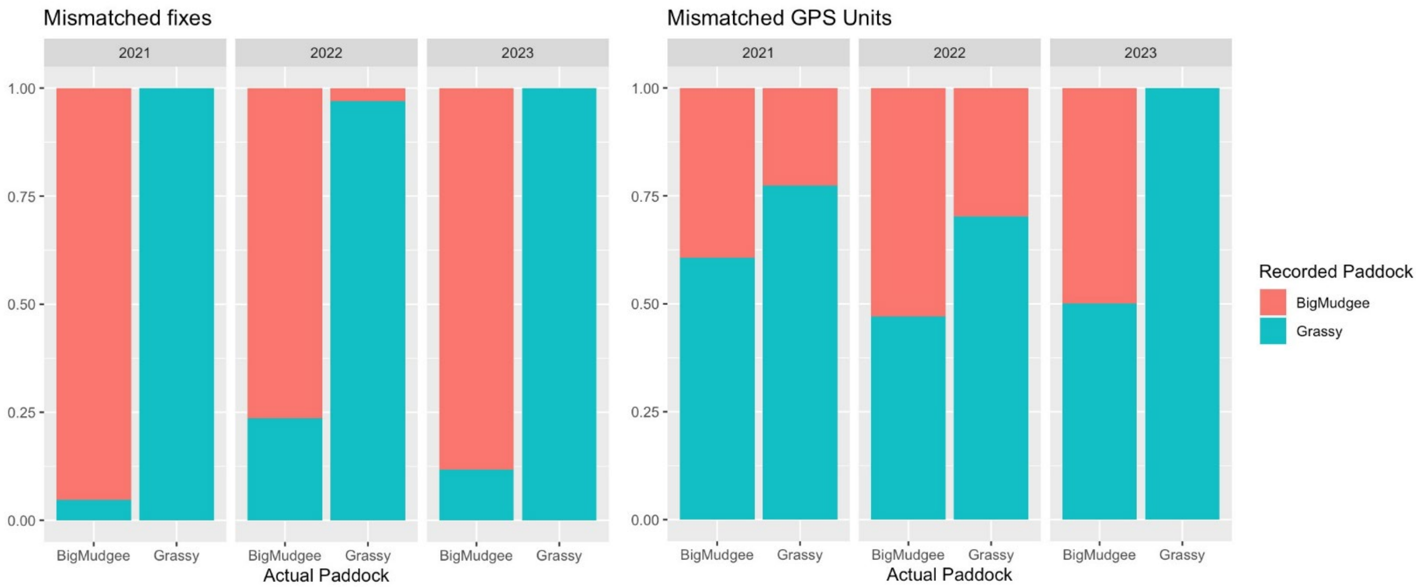


Figure 46. Proportion of mismatched fixes (left) and mismatched GNSS units (right) assigned to each paddock in the trial at Rocklands Station, and the proportion of each that were recorded in the other paddock.

4.2.3 Assessing Battery Longevity and Duration: Implications for Outcome Calculations

In Deployment 1, GNSS units were programmed to record fixes at intervals of 5, 10, or 15 minutes to evaluate battery life and performance. As anticipated, units with higher fix frequencies generally displayed shorter active durations, but substantial variability within each scheduling configuration was evident (Figure 47). Based on an inspection of density plots for the deployment, there appeared to be limited benefit from using a 15-minute interval despite the trade-off in data quantity. Consequently, in subsequent deployments (2 and 3), the units were set to record at 10-minute intervals.

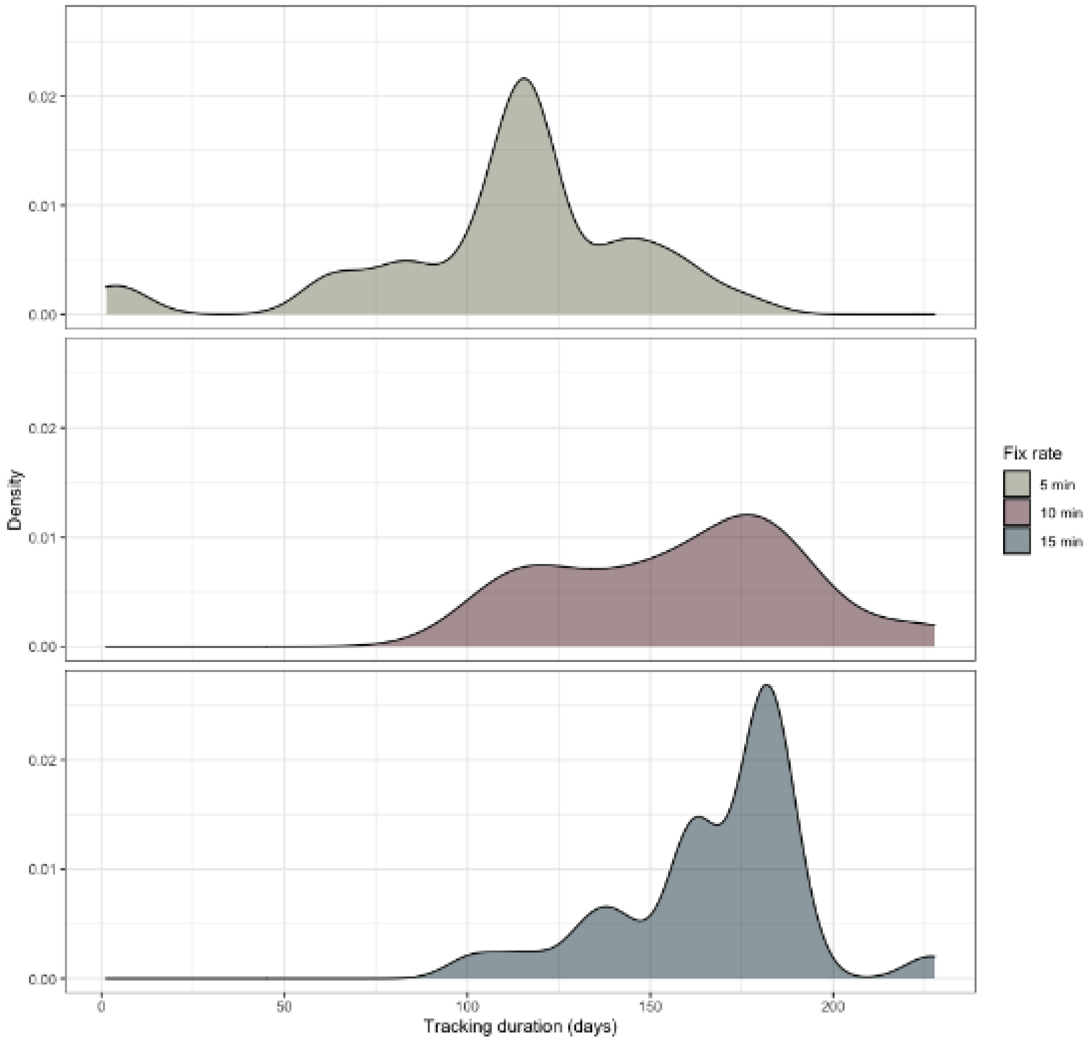


Figure 47. Distribution of tracking duration for GNSS units scheduled at either 5, 10 or 15 minute capture rates that were deployed at Rocklands Station in the first deployment. This was for units that had an upgraded 6Ah battery.

The distance between GNSS locations was calculated by employing the 'distHarversine' function within the R 'geosphere' package. This method assumes a spherical earth, ignoring ellipsoidal effects. The distribution of observed distances within each paddock by fix rate is presented as Figure 48. The time between GNSS measurements was calculated by calculating the difference in time between when the GNSS measurements were recorded using the 'difftime' function in R.

Setting units to record at less frequent fix intervals seemed to result in a higher proportion of outcomes suggesting the animal was active. Therefore, decreasing the fix interval increased the likelihood of capturing the animal in motion, resulting in animals, on average, covering a greater distance between consecutive recorded readings.

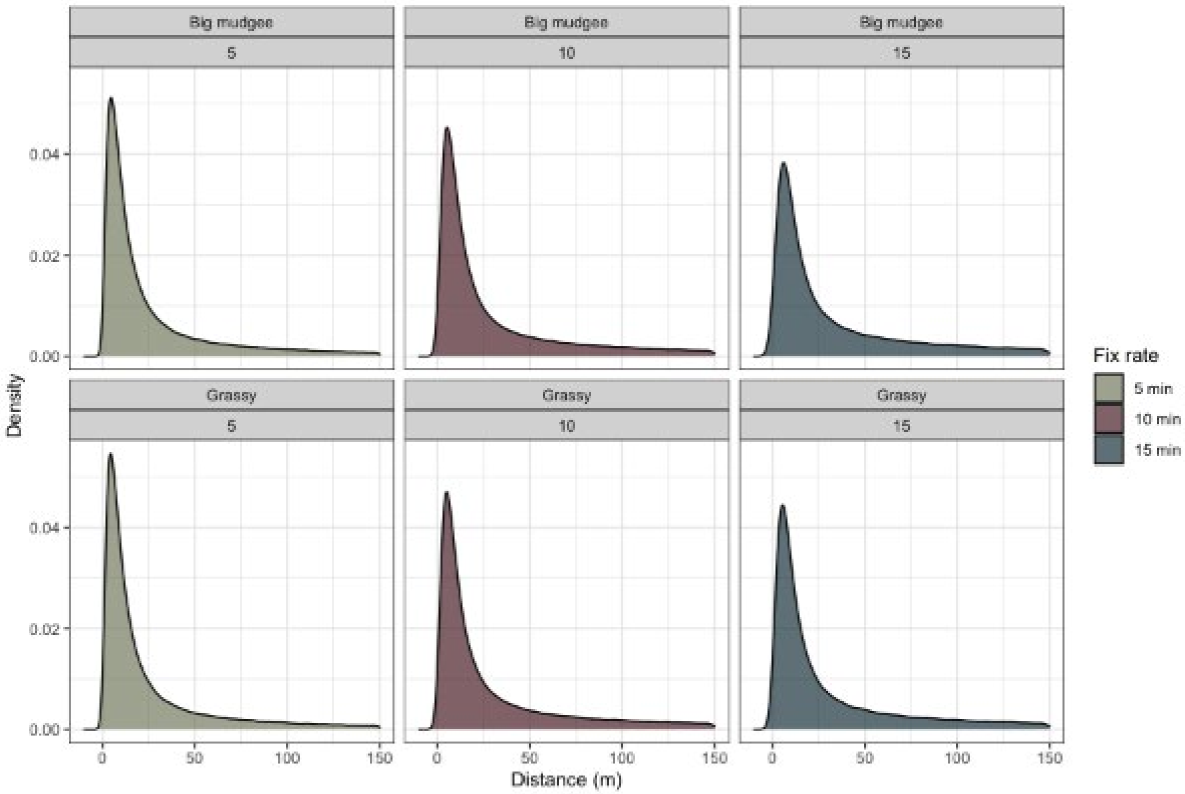


Figure 48. Distribution **of distance between sequential GNSS points for GNSS units scheduled at either 5, 10 or 15 minute capture rates that were deployed in Big Mudgee and Grassy Paddocks on Rocklands Station during the first deployment.**

The total daily distance covered was computed by summing the distances between successive GNSS locations recorded by a single device within a day. Examination of the distribution graphs for total daily distance revealed a left-skewed distribution, displaying a concentration of values around 0. A comparison of configurations highlighted that reducing the fix interval led to a reduction in the concentration of values near 0 and a less pronounced tail in the distribution (Figure 49).

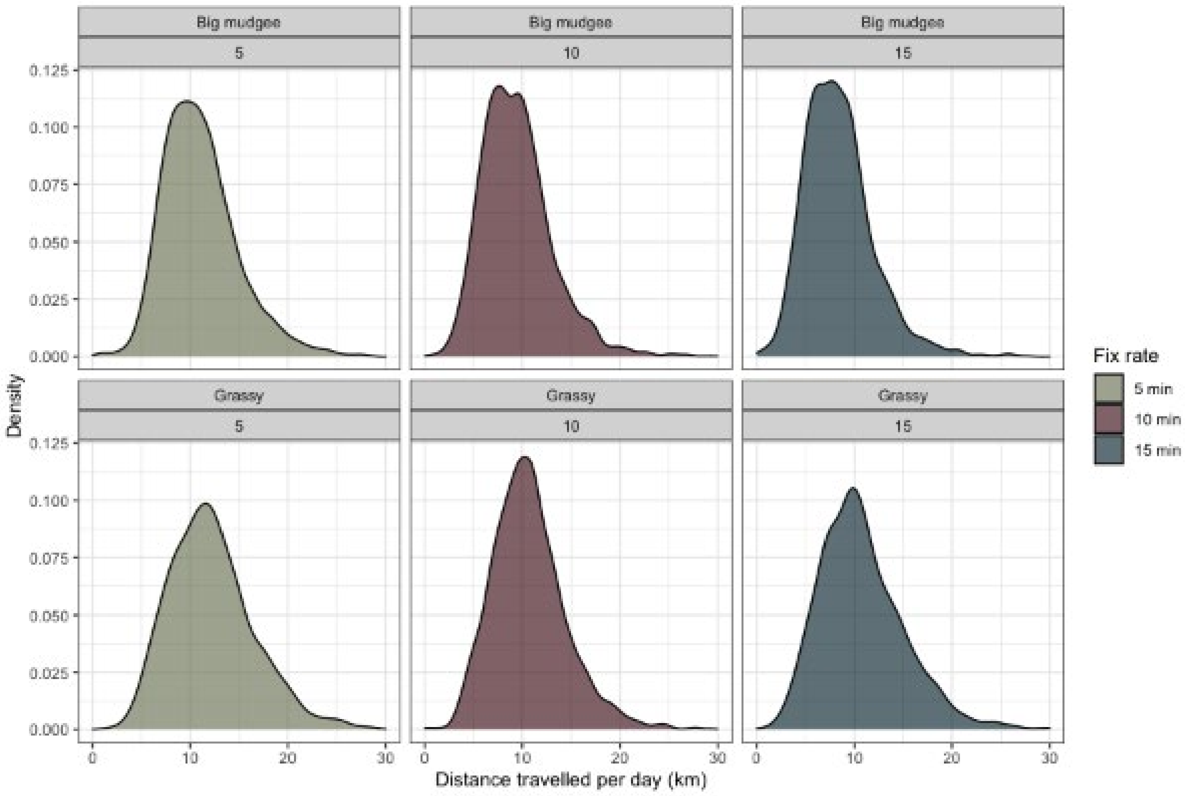


Figure 49. Distribution of total daily horizontal displacement for GNSS units scheduled at either 5, 10 or 15 minute capture rates that were deployed in Big Mudgee and Grassy Paddocks on Rocklands Station.

4.2.3 Distance travelled and distance to water

Rocklands Station

During the 3 deployments at Rocklands, animals in Grassy paddock tended to walk around 1.5km/day more than those in Big Mudgee paddock, although this was not statistically significant (P>0.05; Figure 50). An interesting finding was that in deployment 3, the daily walking patterns of breeding females in Big Mudgee and Grassy were more similar than in other deployments. This observation occurred when the stocking rate of Grassy paddocks stocking rate had been lowered the year before.

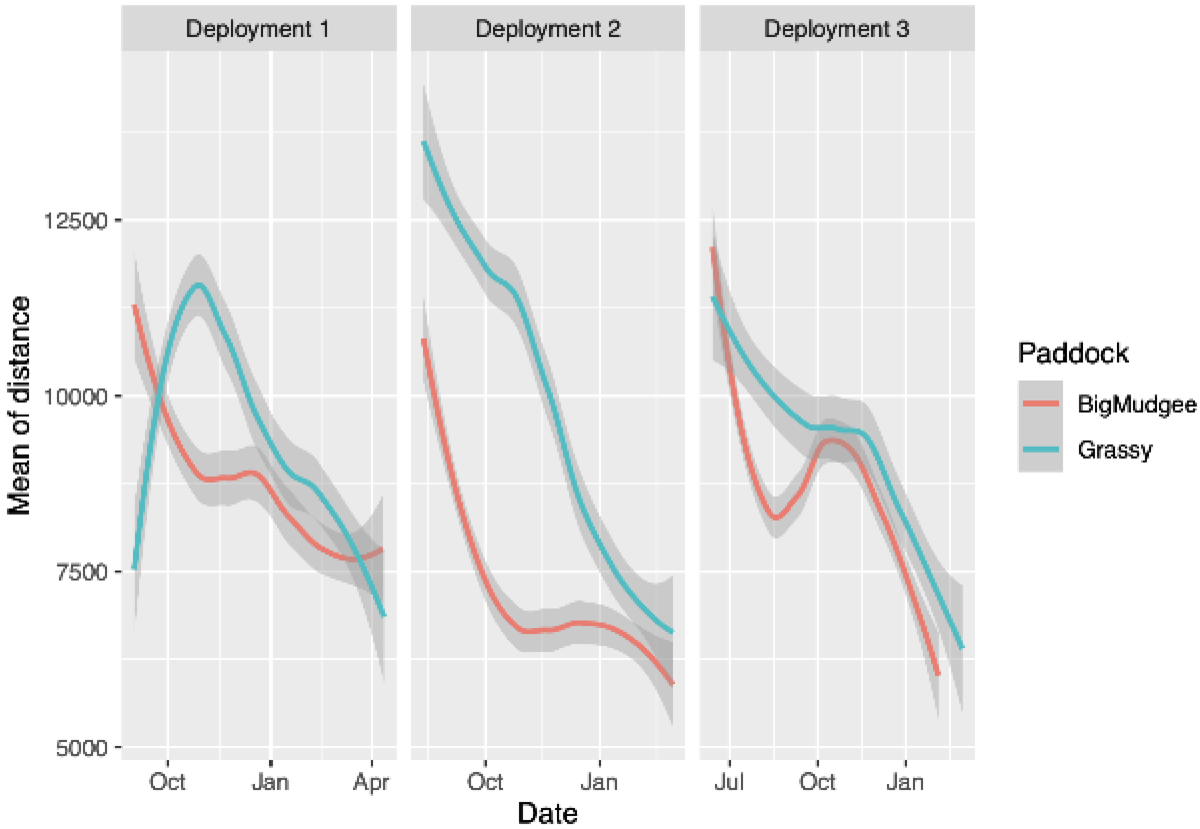


Figure 50. Average daily distance (metres) travelled by GNSS collared cows over the three deployment periods at Rocklands Station.

Minimum distance to water results between the two paddocks indicated that animals in Grassy paddock were further from permanent water points compared to animals in Big Mudgee paddock ($P<0.05$), for the duration of the trial over all 3 deployment periods.

Table 13. Mean minimum distance to permanent water sources in metres in each trial paddock over the three deployments at Rocklands Station.

Paddock	Deployment	Mean	SD	Min	Max
BigMudgee	Deployment 1	2308	762	1168	5963
BigMudgee	Deployment 2	2047	573	1096	3592
BigMudgee	Deployment 3	2082	658	630	4169
Grassy	Deployment 1	2667	828	538	5820
Grassy	Deployment 2	2270	674	881	3833
Grassy	Deployment 3	2507	859	604	4380

Monthly distance from water between the two trial paddocks at Rocklands showed how animals were closer to permanent water points later in the dry season, perhaps when there was less availability of surface water elsewhere in the paddocks. This increased as rain started, with animals moving away from water and relying on other water sources during the wet season (Figure 51).

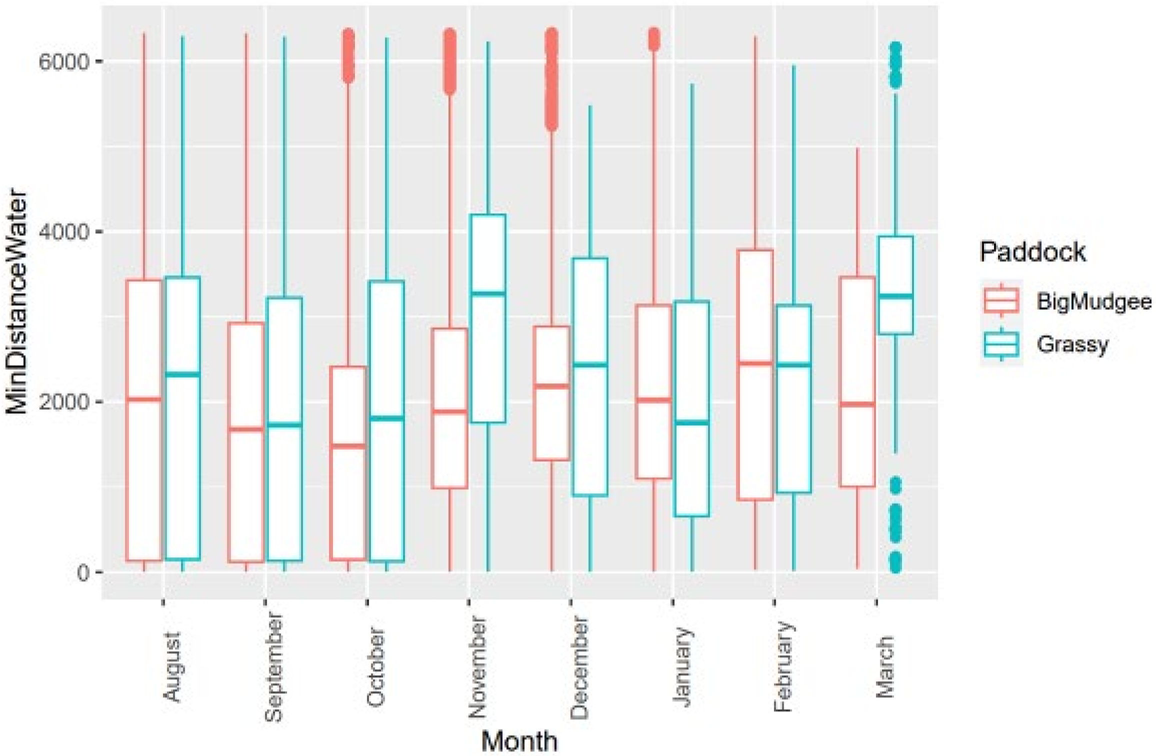


Figure 51. Boxplots showing average minimum distance to a permanent water source at Rocklands Station in the second deployment period from August 2021 to March 2022.

The proportion of fixes that GNSS collared animals had within certain distances from water in each paddock was important to show how animals may be distributed differently depending on paddock size, watered area, and access to other water sources. Around 75 % of geolocation fixes in Big Mudgee paddock were within 3 km of a permanent water source, while in Grassy paddock, only around 58 % of fixes were within 3 km of a permanent water source (Figure 52).

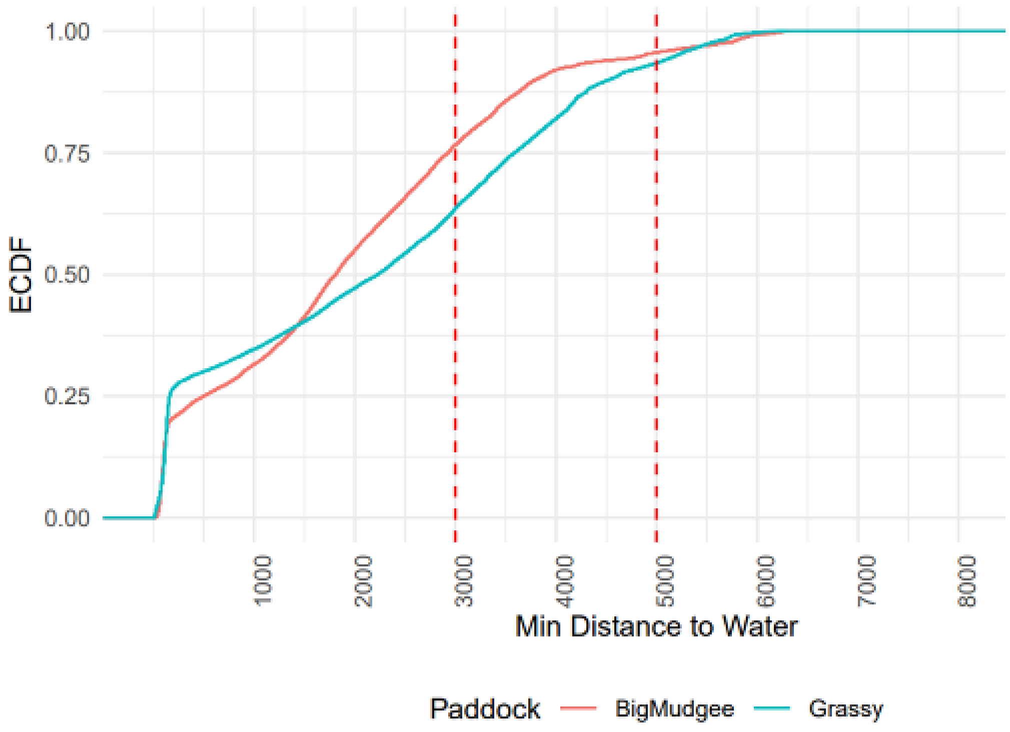


Figure 52. Empirical cumulative distribution frequency (percentage of fixes) within certain distances from a water point in the second deployment period at Rocklands from August 2021-March 2022.

Overall, steers and breeders that were grazing Grassy paddock tended to travel greater distances per day than in Big Mudgee paddock between September 2020 and April 2021 (Figure 53).

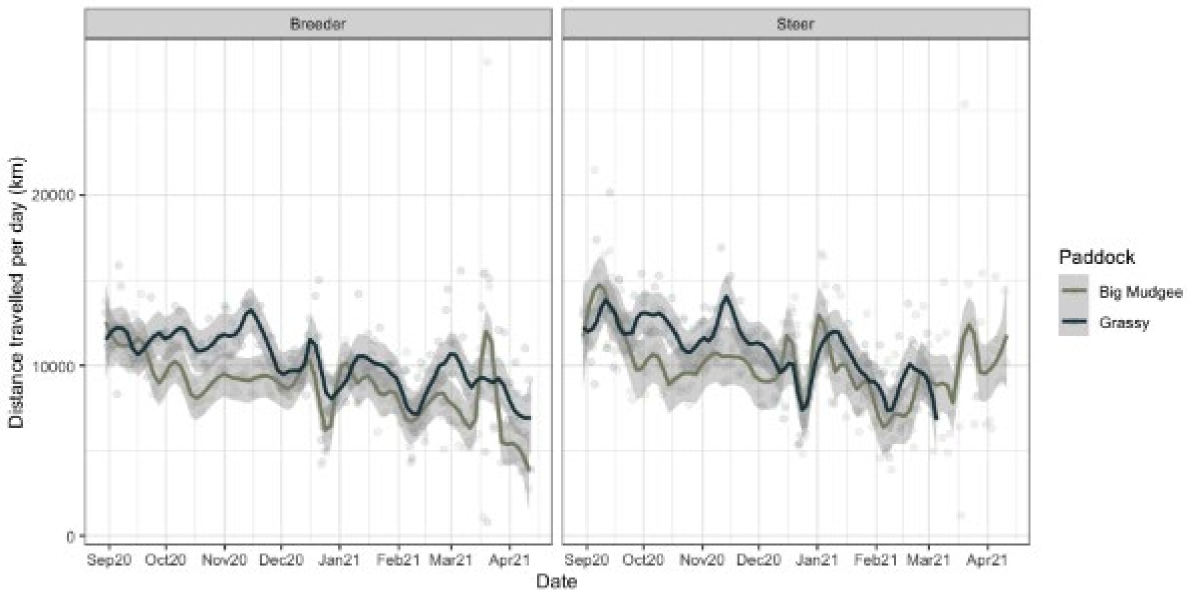


Figure 53. Average total distance walked by Breeders and Steers grazing Big Mudgee and Grassy Paddocks on Rocklands Station in the first deployment period.

Animals in Grassy paddock displayed a tendency to travel less in the last deployment year. One possible explanation for this observation is that it occurred in the same year that a lower utilisation rate was recorded for the paddock, potentially indicating that more feed was available closer to water points (Table 14).

Table 14. Summary of daily distance travelled in metres by animals in each trial paddock over the three deployments at Rocklands Station.

Deployment	Big Mudgee			Grassy			P value
	Mean±SD	Min	Max	Mean±SD	Min	Max	
1	8652±1761	2362	14144	9550±2327	1919	15134	<0.05
2	7191±1598	4385	12778	9846±2688	4264	19940	<0.05
3	8618±1764	3666	13503	9187±2320	2541	16065	<0.05

The average total distance walked by cows tended to decline as they approached their expected month of calving and remained relatively constant afterwards (Figure 54).

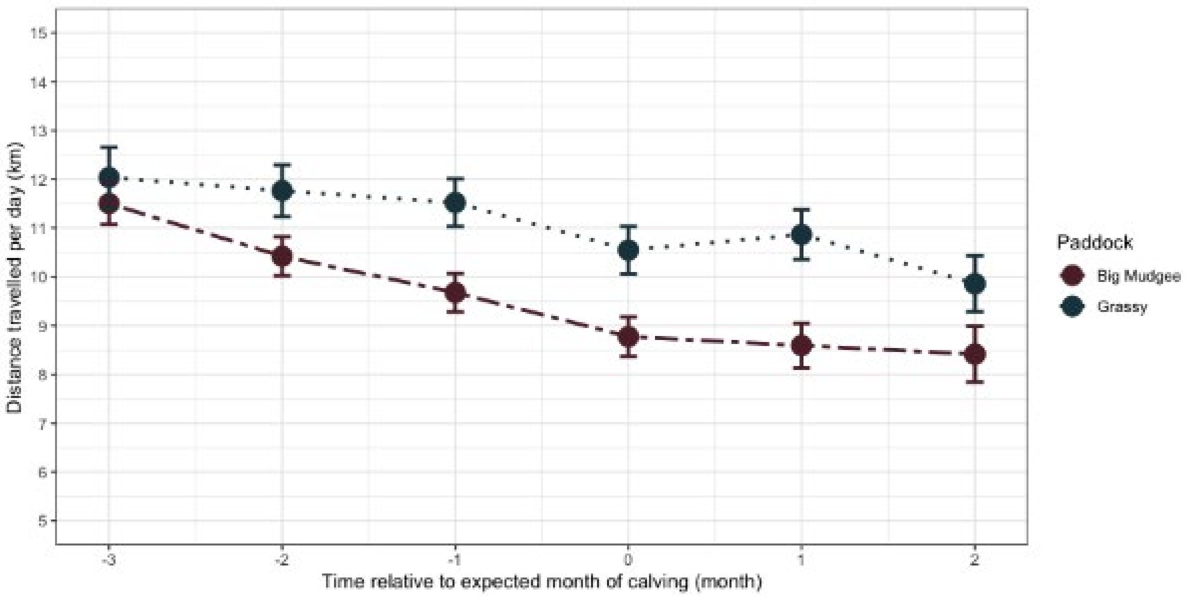


Figure 54. Average total distance walked by Breeders grazing Big Mudgee and Grassy Paddocks on Rocklands Station in the first deployment year.

The month of expected calving did not appear to influence the average daily distance travelled. (Figure 55). There was some variation in distance travelled according to expected month of calving with cows due to calve in November travelling less in the smaller paddock than the larger paddock, although this difference was less obvious in cows due to calve in October or December than November (Figure 55).

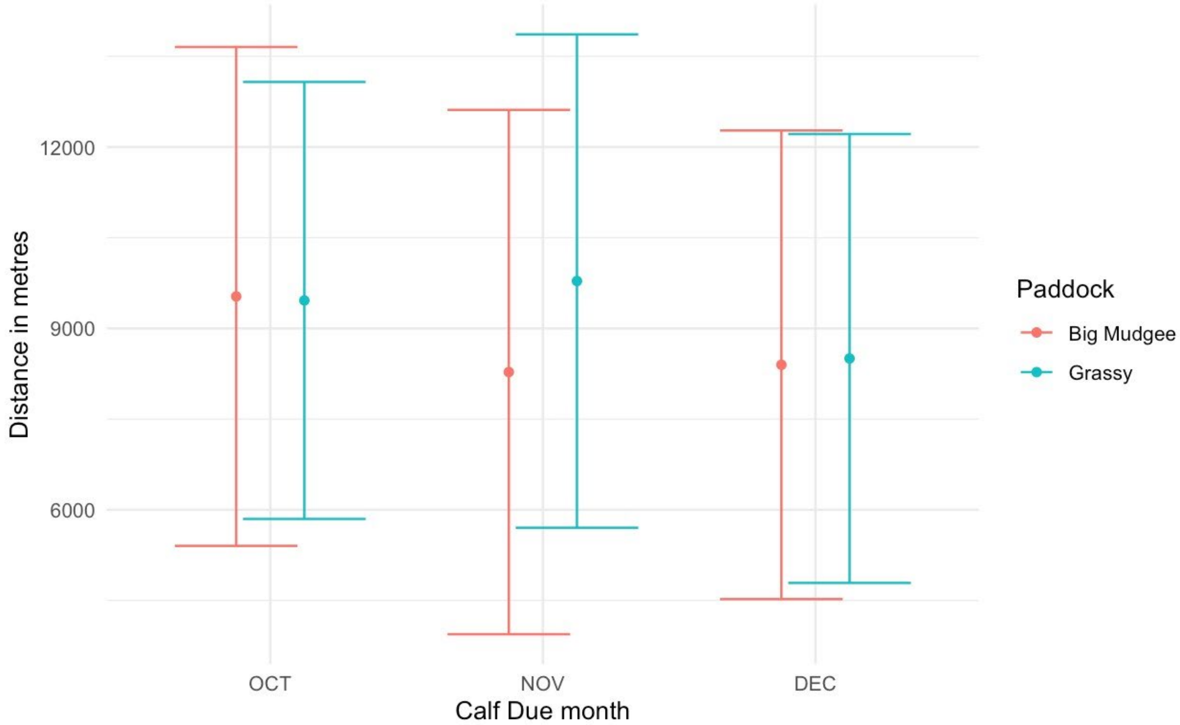


Figure 55. Average daily distance travelled by cows in metres in each trial paddock according to their expected month of calving across the 3 deployment years at Rocklands Station.

Overall, breeding females that were recorded as experiencing calf loss were observed to travel further on average than those which did not (P<0.05; Figure 56). This observation is possibly attributed to cows accompanied by a calf exhibiting a reduced travel speed and more frequent inactive periods to facilitate suckling, which could contribute to a decrease in the overall distance covered per day.

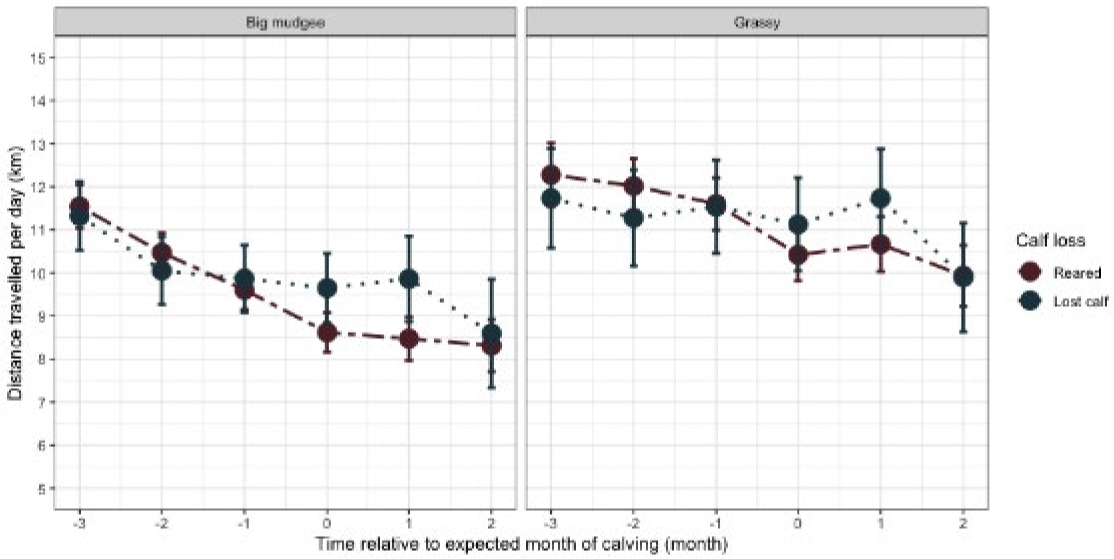


Figure 56. Average total distance walked by Breeders grazing Big Mudgee and Grassy Paddocks on Rocklands Station in the first deployment year.

4.1.5 Home range results

The home ranges of trial animals wearing GNSS collars at Rocklands and Brunette Downs were calculated for the deployment periods. Home range is a measure of the proportion of fixes within a certain area that can be used to show habitat and utilisation of certain areas within the paddock. Home range was used in this project as a way of visualising how animals behaved spatially in the paddock, and if these behaviours related to variables, such as water point distribution, land type, total standing dry matter, total cover or moisture content of the vegetation in the paddock. Home range was calculated for two collared animals per paddock at 50%, 75% and 95%, representing the proportion of fixes and their respective locations within the paddock. Home range varied depending on the paddock, season, month and individual animal. Individual animal home ranges showed little variation between the two trial paddocks at Rocklands station late in the dry season of 2022, with both animals appearing to spend a fair portion of time in the river system running through both paddocks (Figure 57).

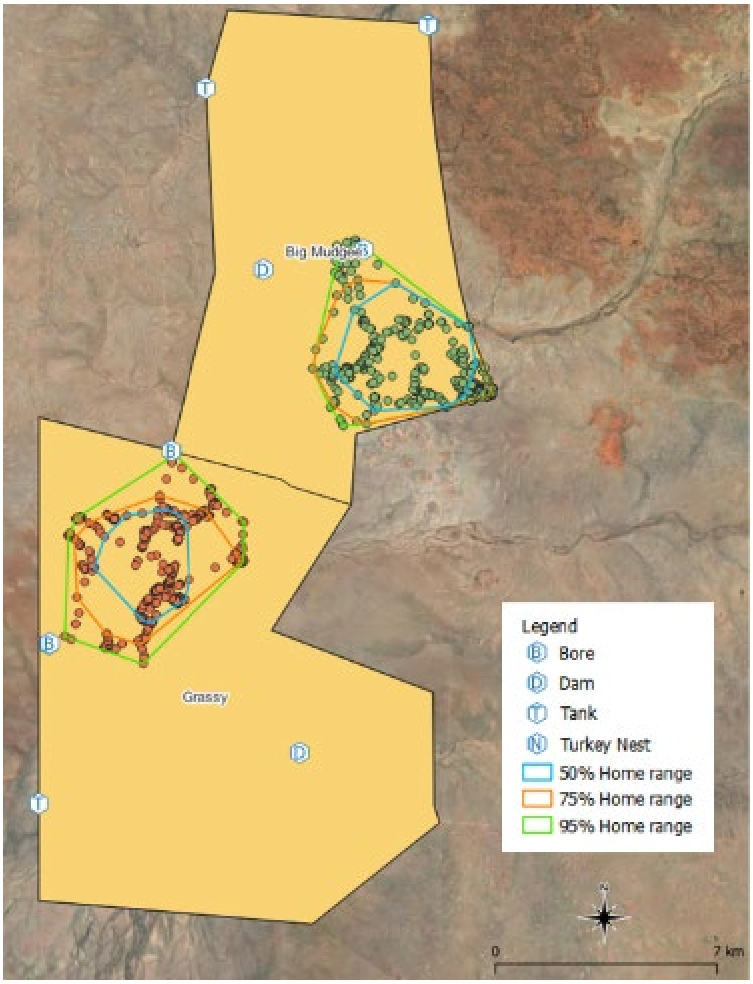


Figure 57. Home Range of two trial animals per paddock over a week in October 2022, showing 50, 75 and 95% kernel density polygon.

Home range polygons were overlaid onto Cibo Labs total cover and total standing dry matter maps for Big Mudgee paddock through dry and wet seasons, to visualise how animals moved according to feed available and season (Figure 58).

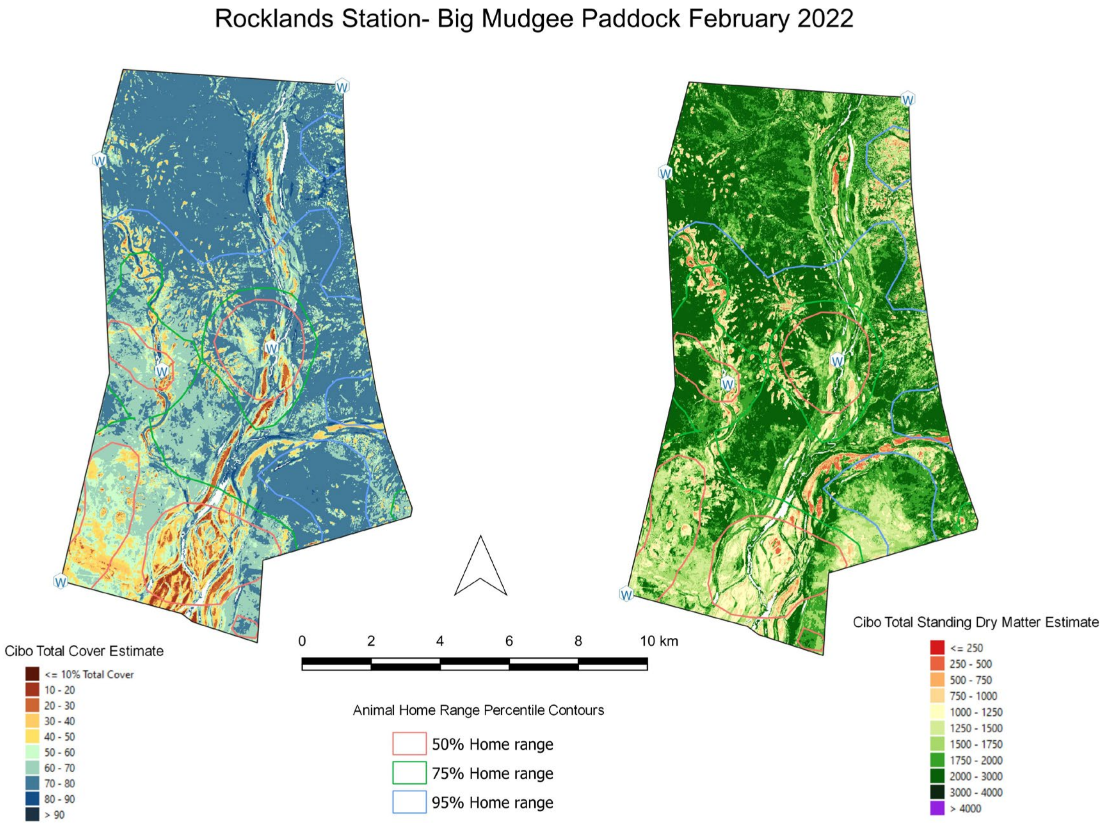


Figure 58. Big Mudgee paddock at Rocklands station in February 2022 and the total cover (left) and total standing dry matter (right) estimate from Cibo Labs with the 50, 75 and 95% home ranges of GNSS collared animals in the same month overlayed.

Animals tended to utilise the river country to the south of the paddock in the dry season, and moved to northern parts of the paddock in February. This shift in paddock utilisation may be of interest for calculating utilisation of pasture, as animals did not graze at all in some parts of the paddock at certain times of year. Although it should be kept in mind that only a small number of animals were collared in each paddock.

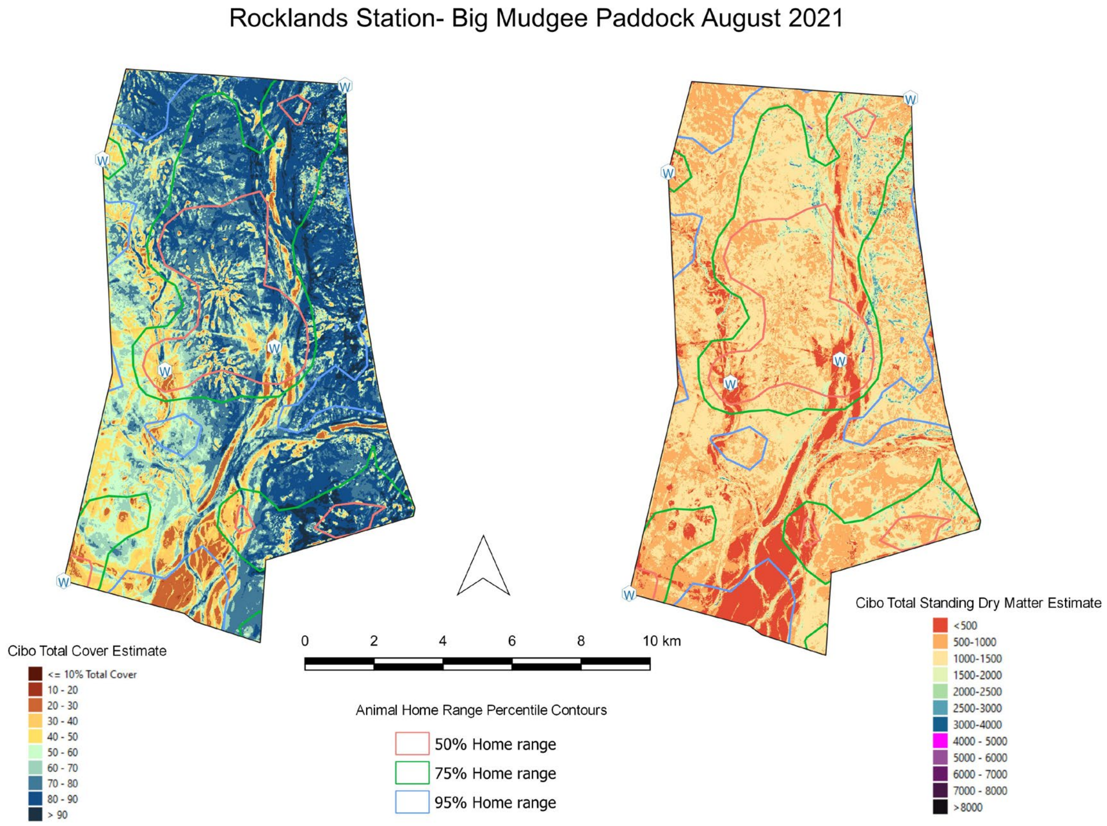


Figure 59. Big Mudgee paddock at Rocklands station in August 2021 and the total cover (left) and total standing dry matter (right) estimate from Cibo Labs with the 50, 75 and 95% home ranges of GNSS collared animals in the same month overlayed.

It was evident that individual animals displayed different behaviours when it came to accessing water in the paddocks. Some animals travelled further to access permanent man-made waters, while others travelled much less and accessed water from the river system in the paddock (Figure 60).

Figure 60. GIF showing GNSS collared animals in Big Mudgee paddock at Rocklands during a day in November 2021, noting how they utilise the Georgina River system throughout the paddock. Each animal represents one GPS collared animal in the trial paddock, regardless of colour.

At the commencement of the project, watered area was calculated based on permanent water points within the trial paddocks. However, data collected during the project indicated there were far more water sources than suspected due to surface water, especially in wetter years. Rocklands experienced above median rainfall for all years of the project, and this may have been a factor impacting the extent of water in the Georgina River system persisting into the later dry season through the trial period. This availability of surface water throughout the year influenced animals' spatial behaviour and impacted how far they had to walk to access feed. It was clear at Rocklands that animals were utilising areas of the paddock with water outside of the permanent water points in the paddock throughout the year (Figure 61, 62).

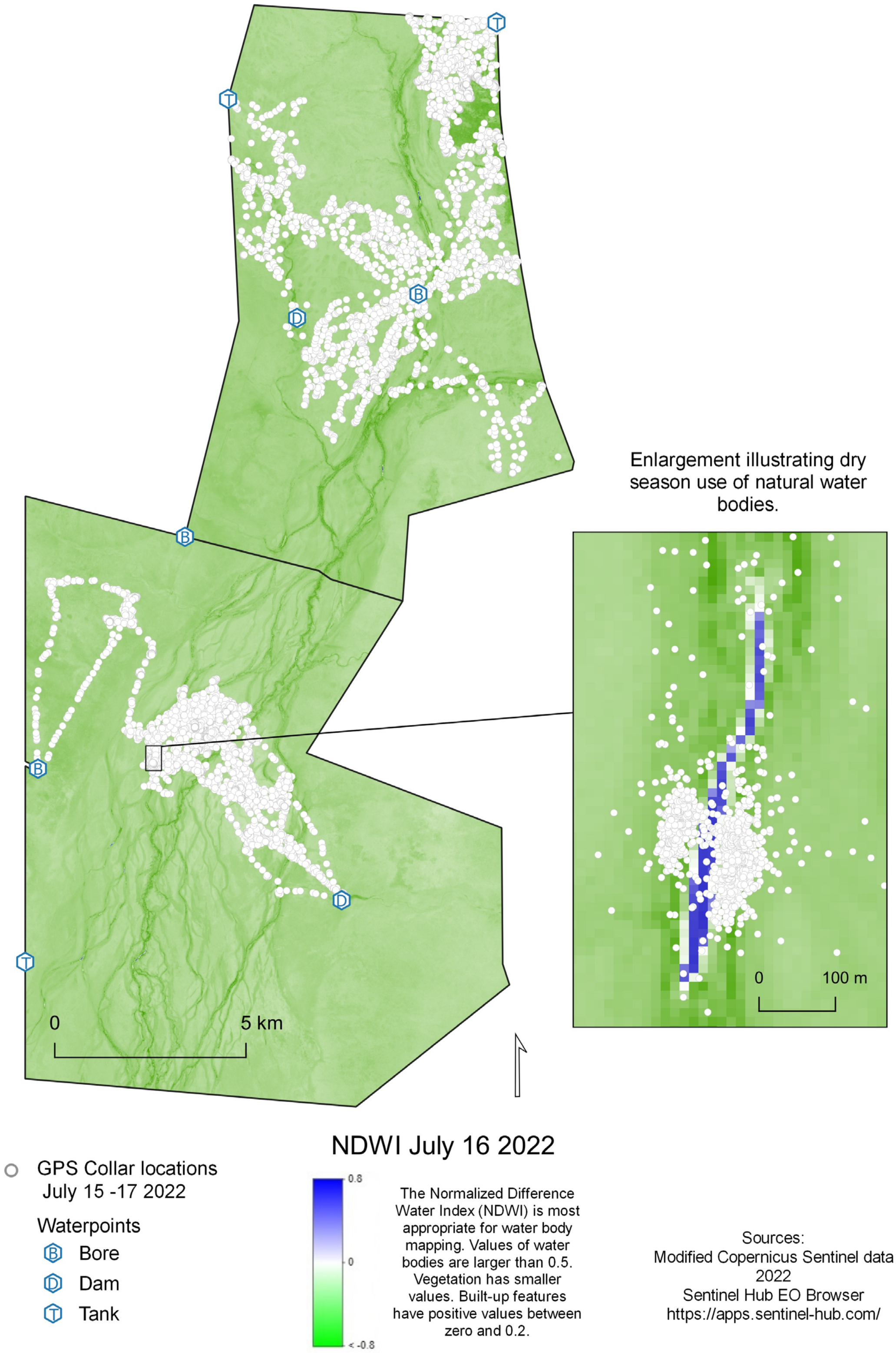


Figure 61. GNSS locations of trial animals at Rocklands Station during the dry season (July 15-17, 2022), showing the Normalized Difference Water Index in the Georgina River system which flows through trial paddocks.

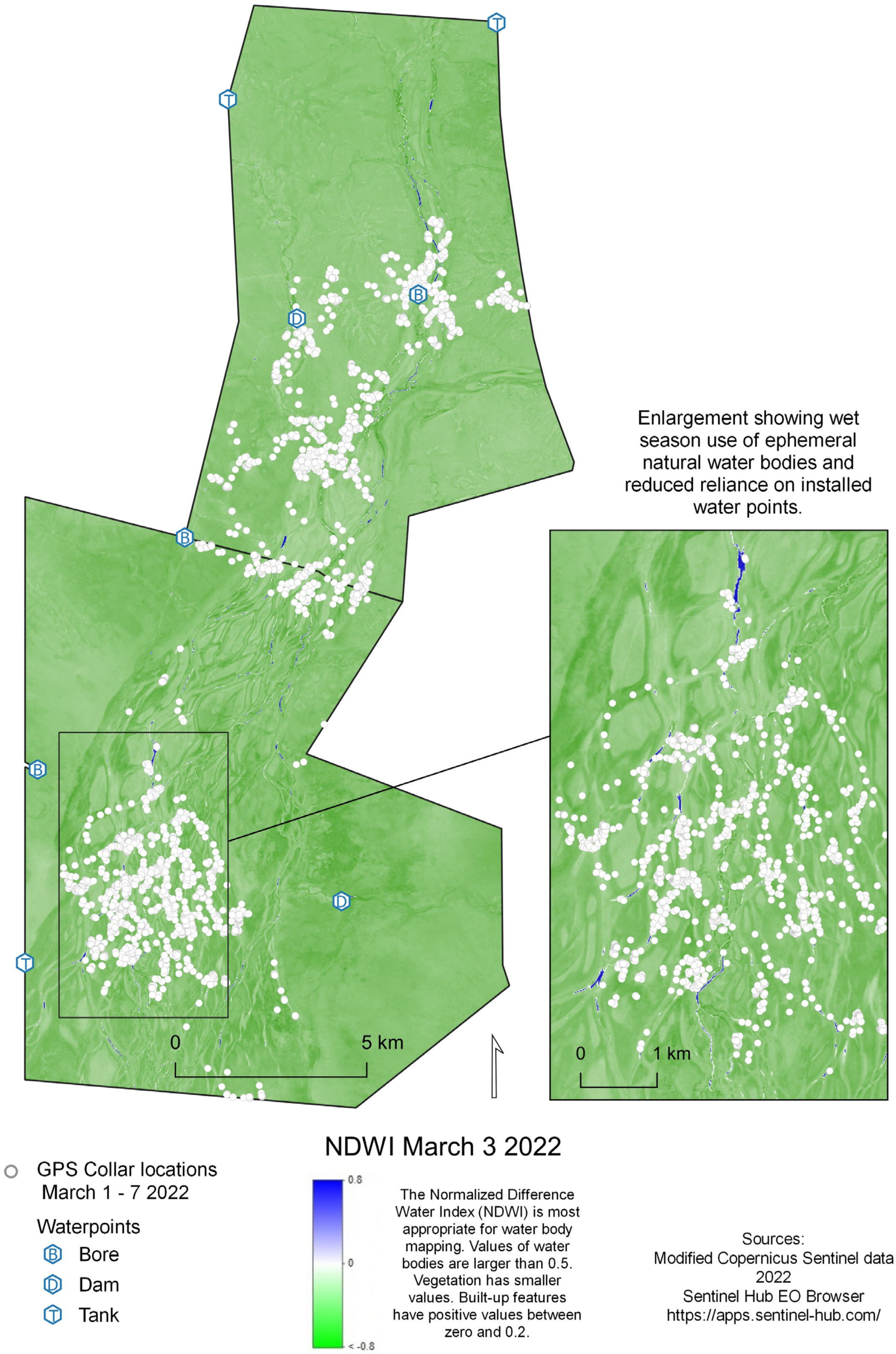


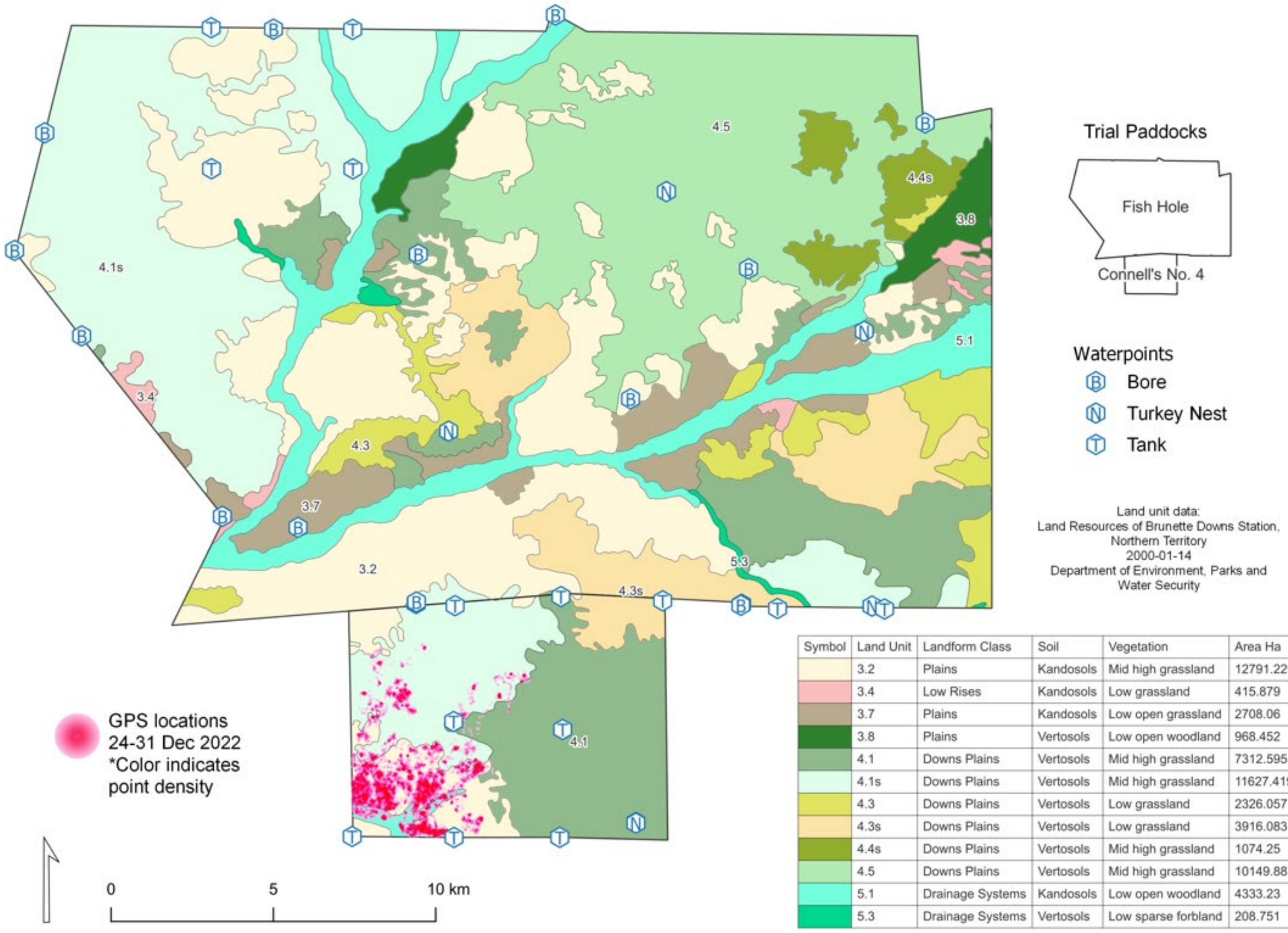
Figure 62. GNSS locations of trial animals at Rocklands Station during March 2022, showing the Normalized Difference Water Index in the Georgina River system which flows through trial paddocks.

The braided system of surface water in the trial paddocks at Rocklands made calculations of watered area difficult to interpret, and a more realistic estimate of watered area when surface water was plentiful would be almost 100% (within 3 km of water)

4.2 Brunette Downs

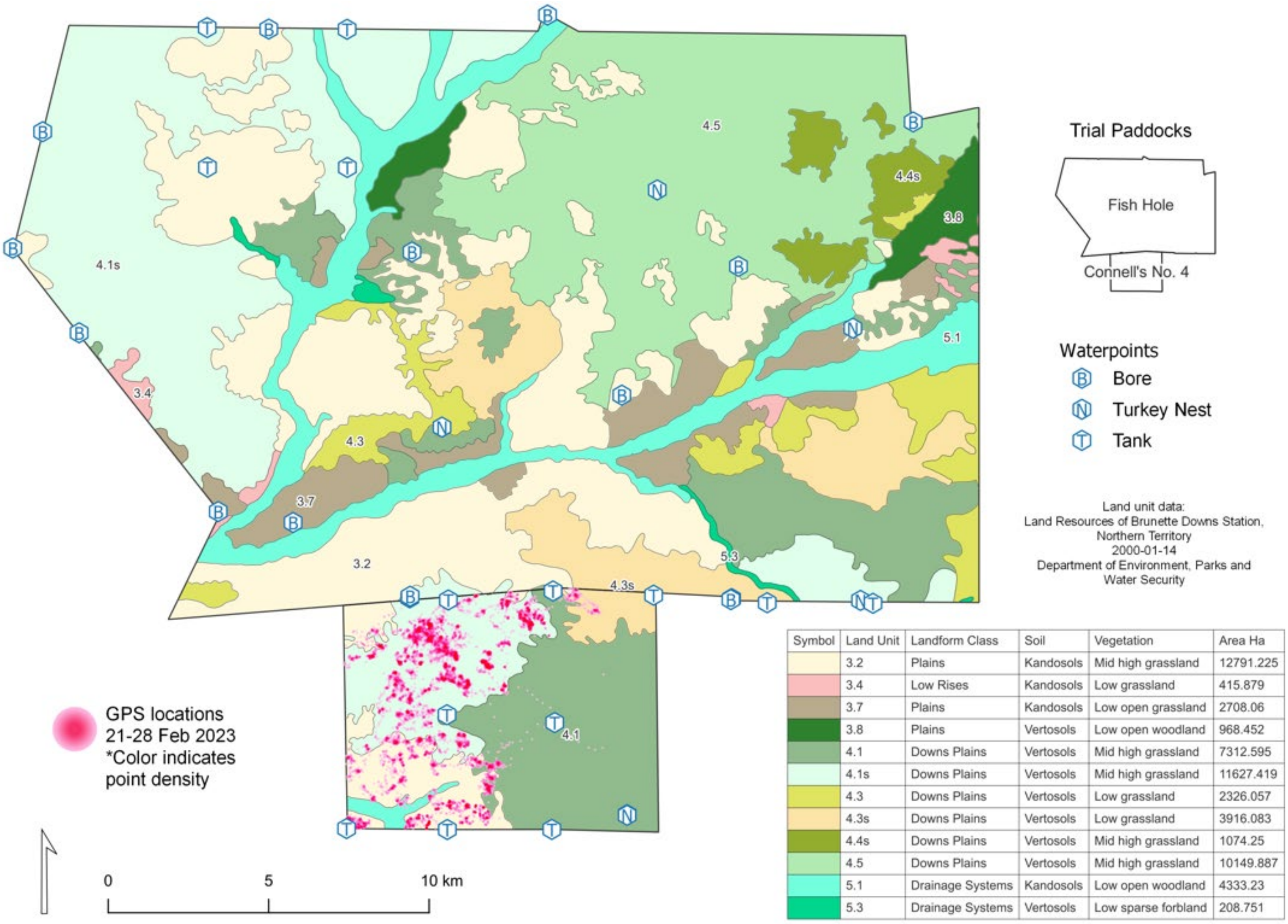
4.2.1 Feedbase results

Fish Hole was the larger paddock at Brunette Downs (504km²) and has had water points added to it progressively over the past few years. The adjoining Connell's paddock was also a large paddock (472km²) until 2020 when it was subdivided into 8 smaller paddocks and had a number of new water points installed. Animals in Connell's paddock clearly utilised some land types more than others, with around half the paddock not being utilised by collars animals during the week of the end of December (Figure 63) and although they spread out more in February (Figure 64), half the paddock still appeared to be less frequented. This data raises many questions about land type preference and grazing behaviour, and more research is needed in this area to better understand how animals graze and what impacts grazing preferences may have on utilisation rate.



Symbol	Land Unit	Landform Class	Soil	Vegetation	Area Ha
	3.2	Plains	Kandosols	Mid high grassland	12791.225
	3.4	Low Rises	Kandosols	Low grassland	415.879
	3.7	Plains	Kandosols	Low open grassland	2708.06
	3.8	Plains	Vertosols	Low open woodland	968.452
	4.1	Downs Plains	Vertosols	Mid high grassland	7312.595
	4.1s	Downs Plains	Vertosols	Mid high grassland	11627.419
	4.3	Downs Plains	Vertosols	Low grassland	2326.057
	4.3s	Downs Plains	Vertosols	Low grassland	3916.083
	4.4s	Downs Plains	Vertosols	Mid high grassland	1074.25
	4.5	Downs Plains	Vertosols	Mid high grassland	10149.887
	5.1	Drainage Systems	Kandosols	Low open woodland	4333.23
	5.3	Drainage Systems	Vertosols	Low sparse forbland	208.751

Figure 63. The current configuration and land types of the study paddocks at Brunette Downs station in the Barkly region of the Northern Territory. Geolocations of collared animals are shown in Connell's paddock in late December with a large proportion being within the 3.2 Land Unit, characterised by low stoney rises, forbs and annual grasses.



Symbol	Land Unit	Landform Class	Soil	Vegetation	Area Ha
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	4.4s	Downs Plains	Vertosols	Mid high grassland	1074.25
	4.5	Downs Plains	Vertosols	Mid high grassland	10149.887
	5.1	Drainage Systems	Kandosols	Low open woodland	4333.23
	5.3	Drainage Systems	Vertosols	Low sparse forbland	208.751

Figure 64: The current configuration and land types of the study paddocks at Brunette Downs station in the Barkly region of the Northern Territory. Geolocations of collared animals are shown in Connell's paddock in late February with a large proportion being within the 3.2 Land Unit, characterised by low stoney rises, forbs and annual grasses.

Animals grazing Connell's 4 paddock showed varying spatial behaviours depending on the moisture index, with more clustered geolocations for the collared animals in late December, when MI was low, compared to in mid-February, when MI was high (Figure 65).

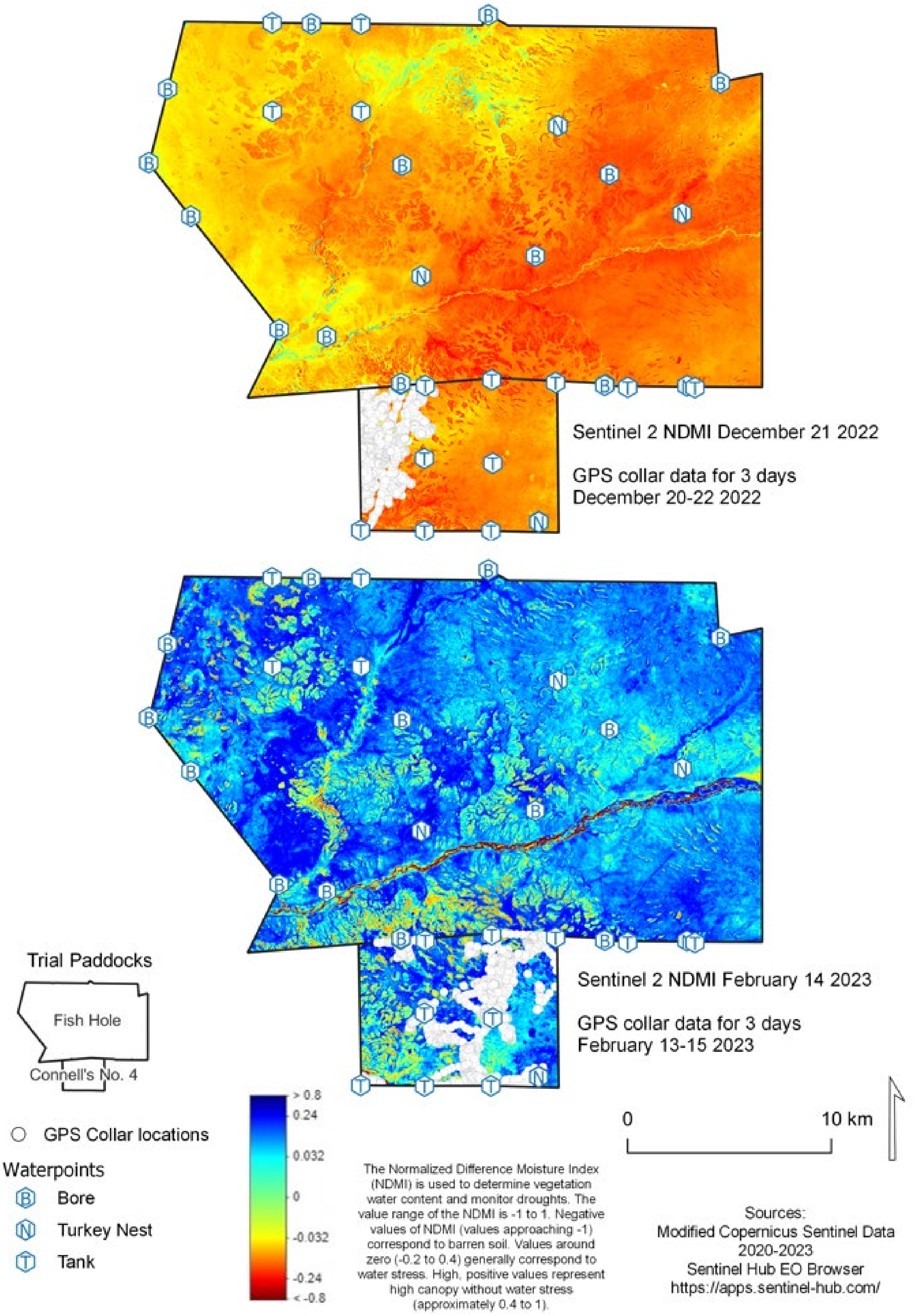


Figure 65: Normalised Difference Moisture Index (NDMI) in late December 2022 and mid-February 2023 in Connell's 4 paddock at Brunette Downs with GNSS locations of animals grazing in each paddock.

Total standing dry matter estimates from Cibo Labs data overlayed with collared cows GPS data showed that animals did not appear to have a tendency for grazing in areas of the paddock with higher TSDM. With isolated rainfall events during this time of year early in the wet season, animals tended to frequent land types that were characterised by stoney rises (Figure 66).

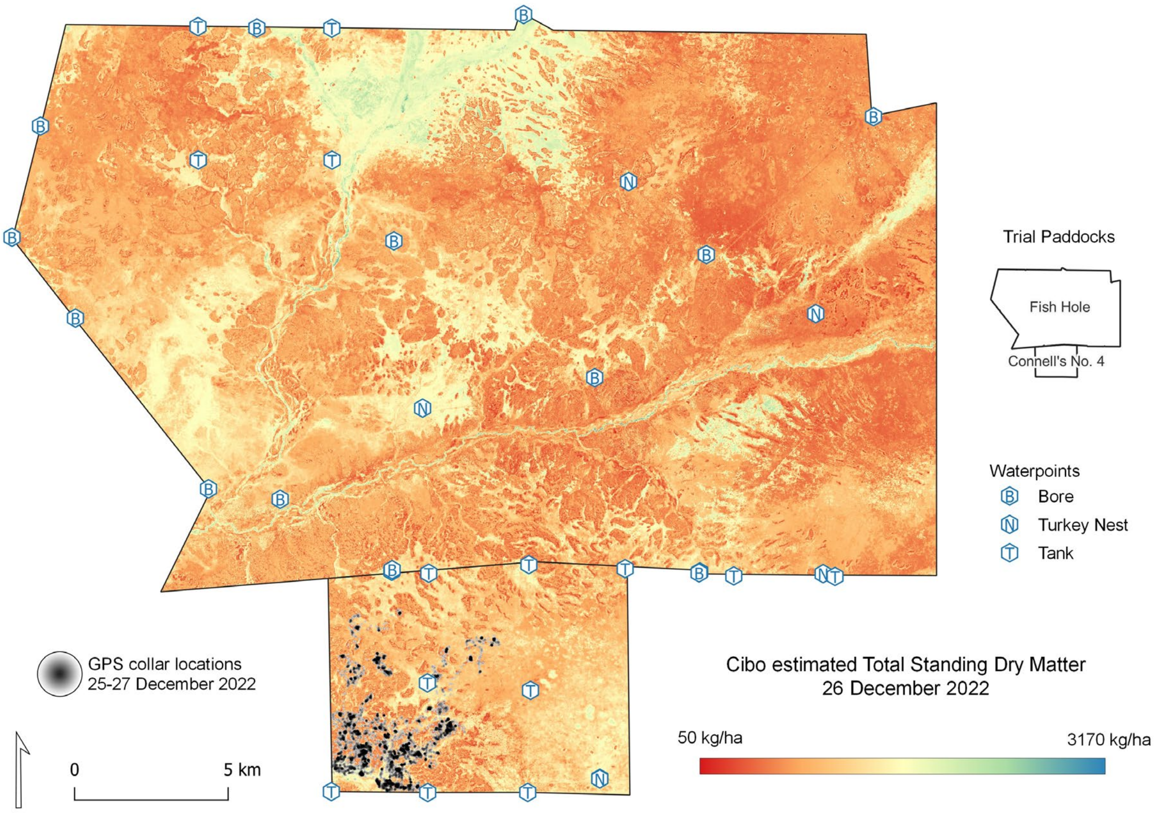


Figure 66: Total standing dry matter estimate from Cibo Labs in Connell's and Fish Hole paddock during 3 days in late December 2022 at Brunette Downs Station.

Total cover estimates from Cibo Labs showed that during a few days in February 2023, animals in Connell's paddock preferenced the moderate cover areas, and not areas with high cover (Figure 67). These findings suggests that preferential grazing may be impacted by other factors other than feed availability and land type, requiring further investigation into this area.

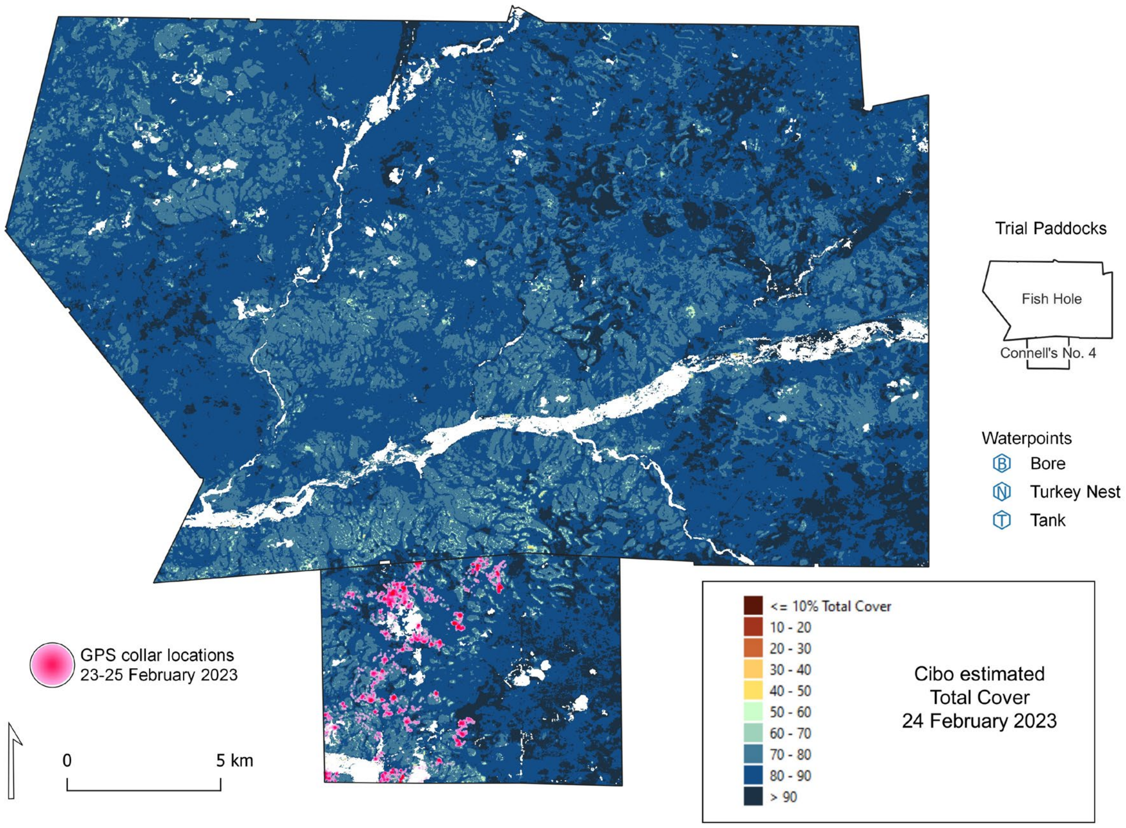


Figure 67. Total cover estimate from Cibo Labs in Connell's 4 and Fish Hole paddock at Brunette Downs during the trial period. GPS data from collared animals over 2 days in late February is overlayed to show spatial behaviours in relation to total cover estimates.

The Brunette study paddocks are now considered well-watered on a 5km grazing radius basis, but Fish Hole is less well watered on a 3km basis compared to the new smaller paddocks of the Connell's complex (Table 15).

Table 15. The total and watered areas of the study paddocks at Brunette Downs station at the commencement of the project.

Paddock	Total Area (km²)	3km Watered Area (km²)	5km Watered Area (km²)
Fish Hole	508	316 (62%)	499 (98%)
Connell's 1	95	82 (86%)	95 (100%)
Connell's 2	79	71 (90%)	79 (100%)
Connell's 3	75	70 (93%)	75 (100%)
Connell's 4	74	72 (97%)	74 (100%)
Connell's 5a	46	43 (94%)	46 (100%)
Connell's 5b	60	56 (93%)	60 (100%)
Connell's 6	24	18 (75%)	24 (100%)
Connell's 7	19	16 (84%)	19 (100%)

A series of formal pasture assessments were conducted in the trial paddocks at Brunette Downs in July 2019 using the paddock traverse method used by the NT DITT when conducting carrying capacity assessments. This approach aims to assess each major land type in order to characterise the pastures in the paddock. This helped to understand the pasture resources of the paddock, parameterise the GRASP pasture growth model and monitor changes in biomass and land condition over time, particularly in relation to distance from water. Data recorded at each site included location, soil type, pasture composition, perennial grass basal area, tree species present, tree basal area, ground cover percentage, pasture yield (kg dry matter/ha) and ABCD land condition score. A photo was also taken at each assessment stop. It was quite challenging to identify the pasture species during the drought conditions in July 2019 because most grasses had lost all their leaves via grazing or extreme defoliation as a result of the very poor wet season in 2018/19. Examples of the contrast in pasture conditions in the study paddocks are shown below (Figure 68). Average pasture yield in the study paddocks was 1,195kg/ha but ranged between 50 kg/ha and 2,500kg/ha depending on distance from water.

Figure 68. Images of trial paddock assessment points in 2019. The commencement of the trial was pushed back due to poor conditions.

Brunette Downs received multiple years of below average rainfall in the first years of the trial. This delayed commencement of the trial until late 2022. While Rocklands received slightly above average rainfall for the 3 years of the trial, the final year of the trial saw over 95th percentile rainfall for both commercial properties in the 2022-2023 wet season (Figure 69).

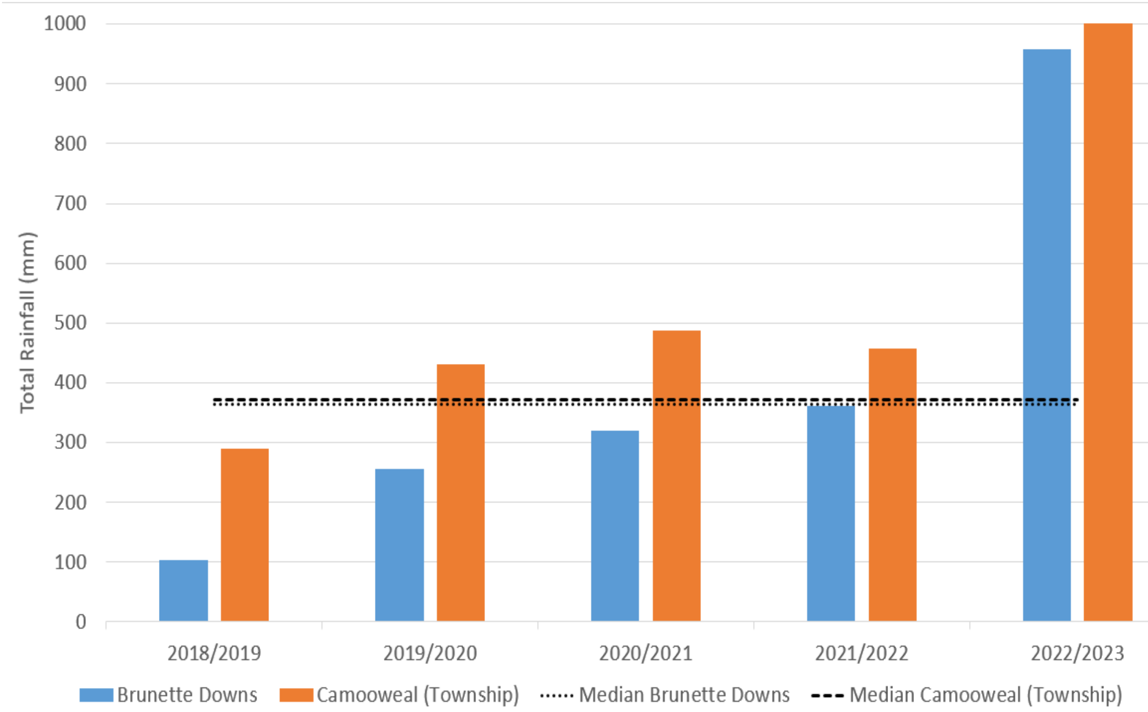


Figure 69. Seasonal rainfall for the two collaborating properties from the initial stages of the project in 2019 to the end of the project in 2023

The 2021-22 wet season was still below average at Brunette Downs but the pasture in trial paddocks responded well after being spelled for two seasons and the property decided it was able to participate in the final year of the project. During the wet season of 2022-2023, the property experienced above average rainfall and many paddocks had substantial areas of surface water. This was evident from the NDMI during March in 2023 (Figure 70), where much of Connell's 4 paddock had very high moisture content.

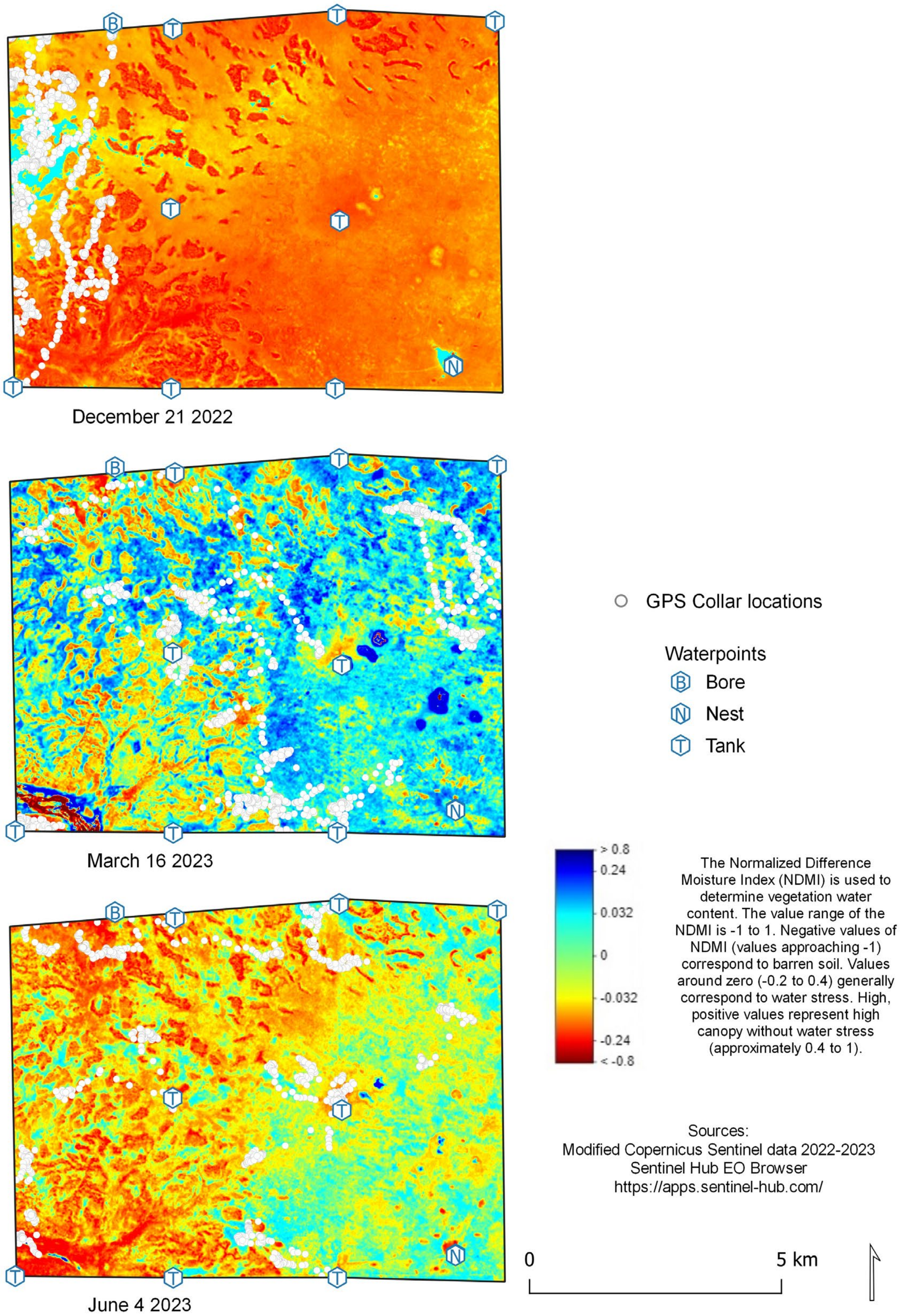


Figure 70 Brunette Downs trial paddock Connell's 4 Normalised Difference Moisture Index (NDMI) and GNSS locations of trial animals December 2022, March 2023 and June 2023.

4.2.2 Faecal NIRS data

Faecal samples were collected at the induction of trial animals to their paddocks at Brunette Downs in December 2022. Samples were collected in the yards at the completion of processing animals and results reflect some level of contamination within the samples. Therefore results from this sample may be unreliable.

Table 16. Brunette Downs faecal NIRS and wet chemistry results from the induction of trial animals in December 2022.

NIRS measures	**Fish Hole Paddock**	**Connell's Paddock**
Dietary Crude Protein (CP)%	9.60*	11.80
Dry Matter Digestibility (DMD)%	58.80*	62.60*
Faecal Nitrogen (FN)%	1.20*	1.70
Faecal δ13C	19.30*	17.10
Non-grass %	41.30*	25.40*
Ash %	75.90*	46.60
Metabolisable energy (MJ/kg)	8.40	9.10
DMD:CP	6.10	5.30
Wet chemistry		
Calcium %	0.69	0.93
Phosphorus %	0.10	0.14
Ca:P ratio	6.90	6.64

*outlier values - interpret with caution.

4.2.3 Crush side animal performance

Weather events at Brunette Downs caused musters to be cancelled on several occasions throughout the trial. This meant that some of the planned evaluation of performance and treatments was not possible.

Animals in Connell's paddock were collared in the wet season of 2022 (late December), which meant that a full muster of the paddocks was not possible, so the collaring process was done by taking a cut of animals present at the yards and collaring these animals on an opportunistic basis. Crush side data was not collected at this event, but was collected by the station staff in early 2023. Data describing reproductive performance in 2022-23 was only available for Connell's paddock due to inconsistencies in data recording. Similarly, for the 2021-2022 seasons, crush side performance data was only available for Fish Hole paddock. In 2023, pregnancy percentage couldn't be determined due to insufficient individual animal data, specifically pregnancy testing records. However, an elevated incidence of calf loss was observed for Fish hole, when compared to Connell's 4 paddock, in 2022 (P<0.05; Table 17).

The large difference in foetal and calf loss in Connell's paddock between 2022 and 2023 may have been due to animals having already been visually drafted by lactation status prior to recording their individual data. There was a significant difference in foetal calf loss between the two trial paddocks at Brunette Downs in 2022, which may have been impacted by breeder age (with higher proportion of heifers in Connell's paddock (P<0.05; Table 17).

Table 17. Foetal calf loss in each trial paddock at Brunette Downs Station during the trial period with p values showing significance between paddocks for each deployment year.

Foetal Calf Loss	Connell's Paddock	Fish Hole Paddock	P value
2021	NA	11.4%	NA
2022	19.5%	7.2%	<0.05
2023	1.4%	NA	NA

Fish Hole paddock saw a larger proportion of breeders become pregnant within 4 months of calving, and similarly to Rocklands Station, this may have been due to the different ages of breeders within the paddocks, with younger heifers less likely to be pregnant within 4 months of calving (P<0.05; Table 18).

Table 18. Proportion of cattle pregnant within 4 months of calving (P4M) at Brunette Downs Station during the trial period with p values showing significance between paddocks for each deployment year.

P4M	Connell's Paddock	Fish Hole Paddock	P value
2022	30.0%	38.8%	<0.05

Fish Hole paddock had a significantly higher proportion of lactating breeders in 2022, compared to Connell's paddock (P<0.05), which aligns with the lower calf loss percentage experienced in this paddock (Table 19). The high lactation percentage in 2023 was potentially due to a prior draft only retaining wet cows for the individual data collection.

Table 19. Proportion of cattle lactating at the pregnancy testing muster at Brunette Downs Station during the trial period with p values showing significance between paddocks for each deployment year.

Proportion Lactating	Connell’s Paddock	Fish Hole Paddock	P value
2021	NA	46.0%	NA
2022	56.0%	89.8%	<0.05
2023	98.3%	NA	NA

The proportion of breeders that were pregnant at the pregnancy testing muster was higher in Fish Hole paddock (P<0.05) compared to Connell’s paddock. This may have been due to the difference in proportion of breeder ages in each paddock with a larger percentage of heifers in Connell’s paddock compared to Fish Hole (Table 20).

Table 20. Proportion of cattle pregnant at the pregnancy testing muster at Brunette Downs Station during the trial period. P values show significance between paddocks for each deployment year.

Proportion Pregnant	Connell’s Paddock	Fish Hole Paddock	P value
2021	NA	63.2%	NA
2022	64.9%	76.7%	<0.05

The re-conception times between the two paddocks in 2022 were consistent with the reproductive data results and showed that there was a much larger spread of re-conception times in Connell’s paddock compared to Fish Hole (Figure 71). Most breeders in Fish Hole paddock were pregnant within 5 months of calving, whereas just over half were in Connell’s paddock (Figure 71).

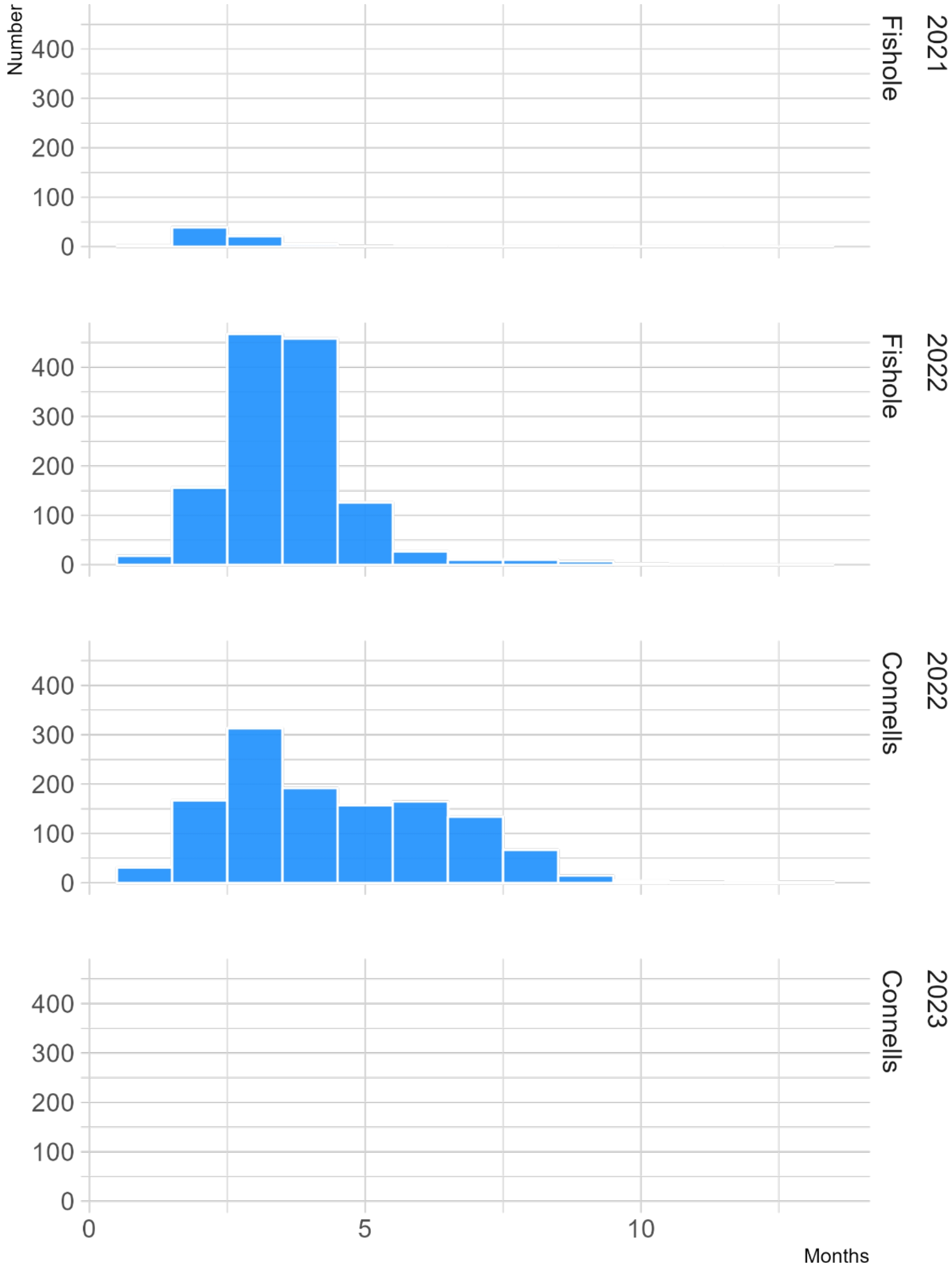


Figure 71. Re-conception times for cattle in each trial paddock at Brunette Downs Station over the trial period. Re-conception times calculated from previous calving date and pregnancy testing results. Variation in pregnancy testing estimation may occur due to different technicians across both properties. Re-conceiving within 4 months (P4M) is considered a target re-conception time in a northern herd.

4.2.4 GNSS device recording and retention

Brunette Downs had a late start to the trial and the initial collaring was challenging due to heavy rain at the station in the days leading up to the planned collaring event. There were initially 200 collars to be placed on animals between the two trial paddocks over the wet season (100 collars in each paddock), however due to rain and accessibility issues on the station, only 24 and 25 collars were able to be fitted in Fish Hole and Connell’s 4 paddock, respectively. Collar retention was good with 20 collars (83%) being returned after the deployment. Fish Hole cattle have not come back in for processing so collars will be removed at the next mustering event, when GPS data will be retrieved. Collar battery duration varied between 3 and 7 months, with 30% of the collars collecting data for 7 months. Only one collar collected data for less than 2 months. One collar collected data intermittently skipping a month and starting to collect data again the following month (Figure 72). Moisture presence in the collar housing may have been a factor that contributed to this occurrence.

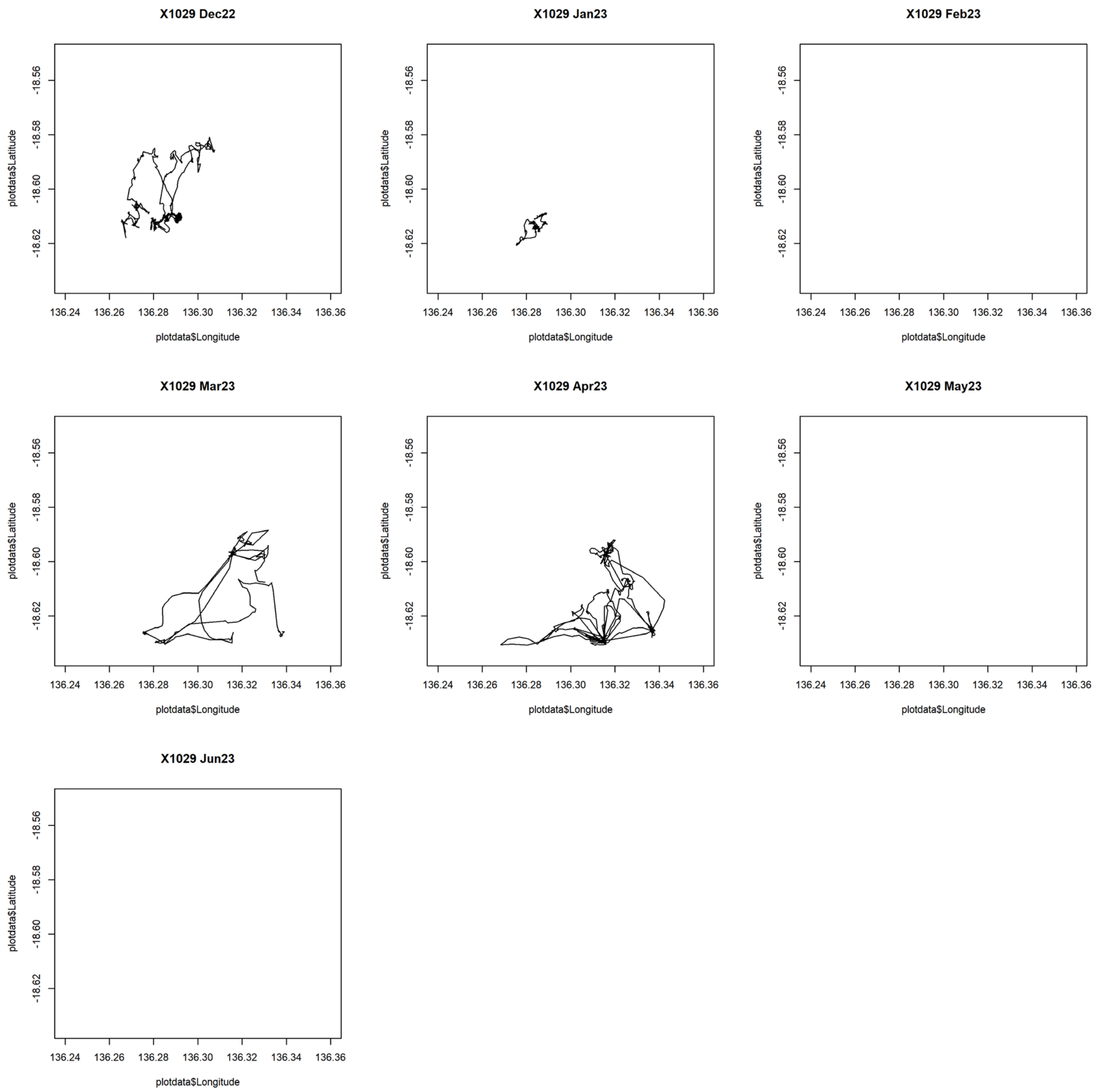


Figure 72. One collared animal from Connell’s 4 paddock during the deployment period at Brunette Downs Station. Each month’s tracks are shown to display the spatial use of the paddock during each month by an individual animal. The collar stopped collecting GPS fixes during the month of March 2023, but resumed collection in April, showing the variability of data that is collected from collars in extensive environments.

4.2.5 Distance travelled and distance to water

Animals in Connell's 4 paddock at Brunette travelled an average of 8.8 ± 1.6 km/day for the duration of the trial period between December 2022 and June 2023 (Figure 73).

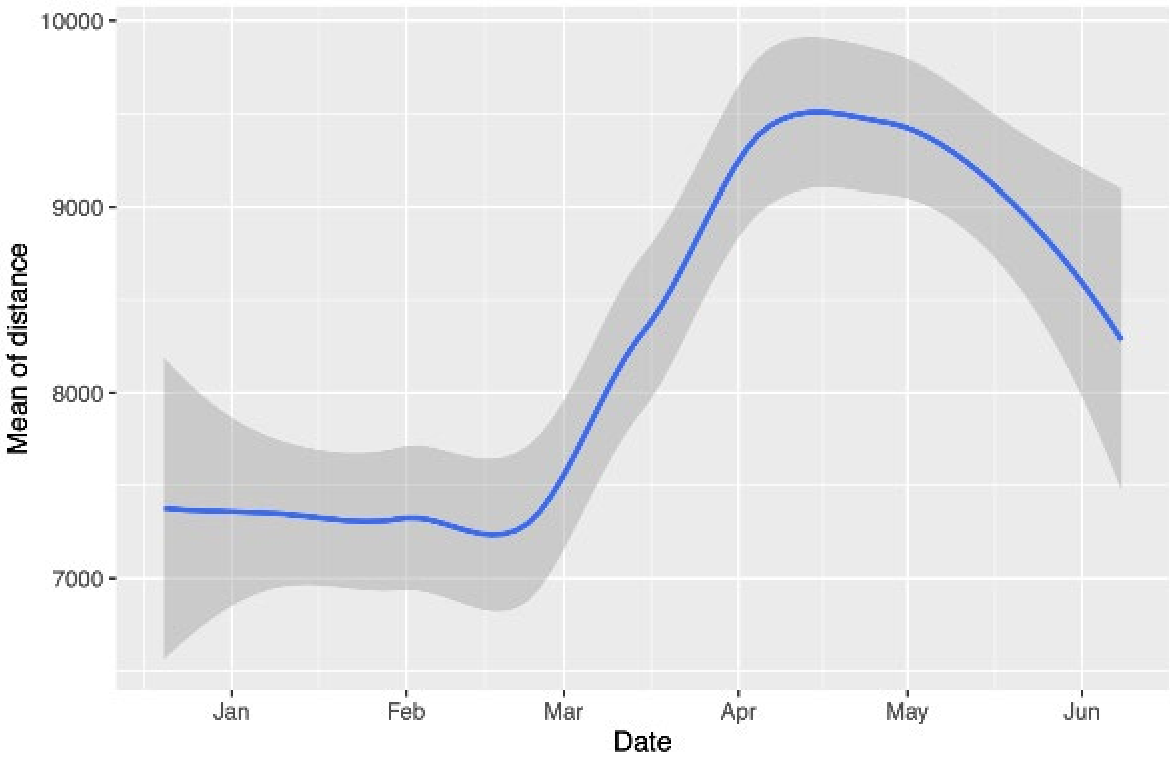


Figure 73. Average distance travelled (metres) by GNSS collared cows in Connell's 4 paddock at Brunette downs during the deployment period from December 2022 to June 2023.

The average minimum distance to permanent water sources by Connell's 4 cows was 1.2 ± 0.3 km (Figure 74). This tended to remain similar month to month, which would be expected in a well watered paddock.

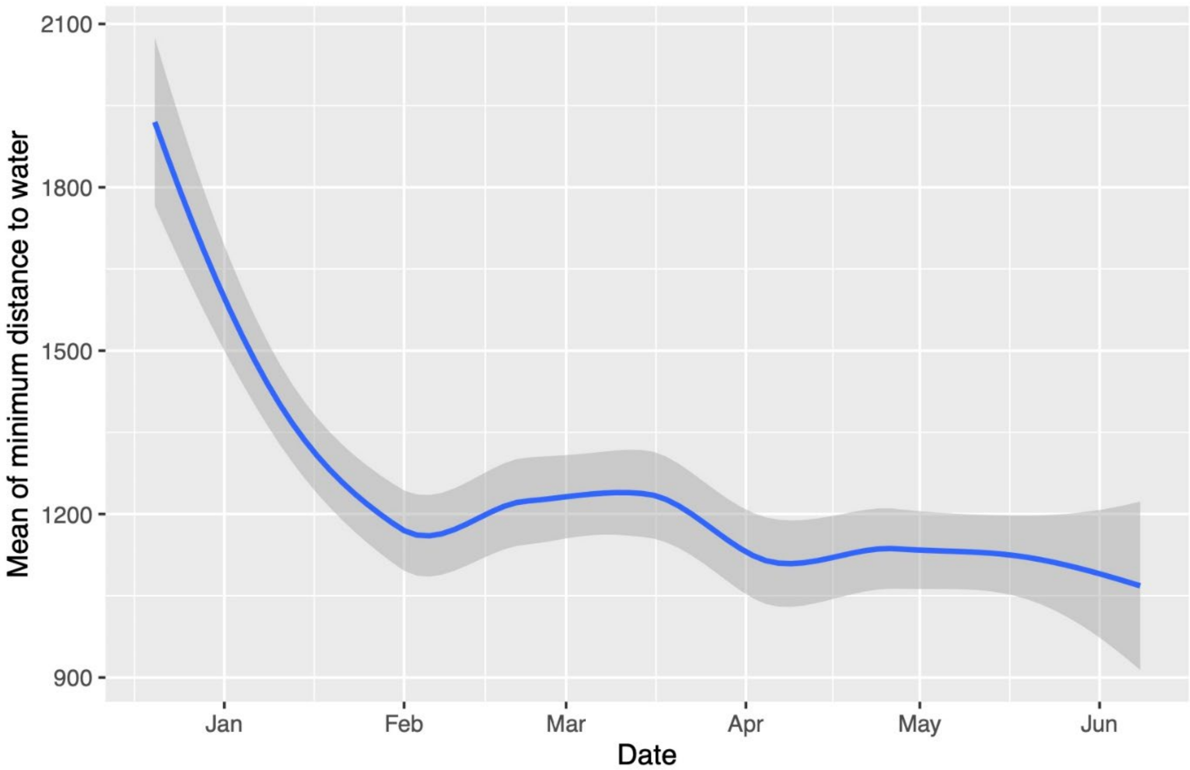


Figure 74. Minimum average distance to water (metres) for GNSS collared trial cows grazing Connell’s 4 Paddock during the deployment period from December 2022 to June 2023 at Brunette Downs Station, Northern Territory.

Animals inducted to Connell’s 4 paddock were due to calve in the 2 months following the GNSS collaring in December. There were 706 pregnant breeder animals inducted into Connell’s 4 paddock for trial period, with GNSS collars fitted to 25 animals on the 20th of December. The average body condition of collared cows in Connell’s paddock at collaring was 3.5.

4.2.6 Home range data

GNSS collars were fitted to pregnant breeder cows in December 2022, to capture wet season spatial data for 2 paddocks selected in the initial phase of the project. Both paddocks at Brunette Downs received well above average rainfall during the wet season of 2022-2023, and both trial paddocks had significant surface water availability for the majority of the time that GNSS collars were deployed. Home range data from Connell’s paddock showed that animals utilised much larger areas of the paddock compared to those at Rocklands (Figure 75).

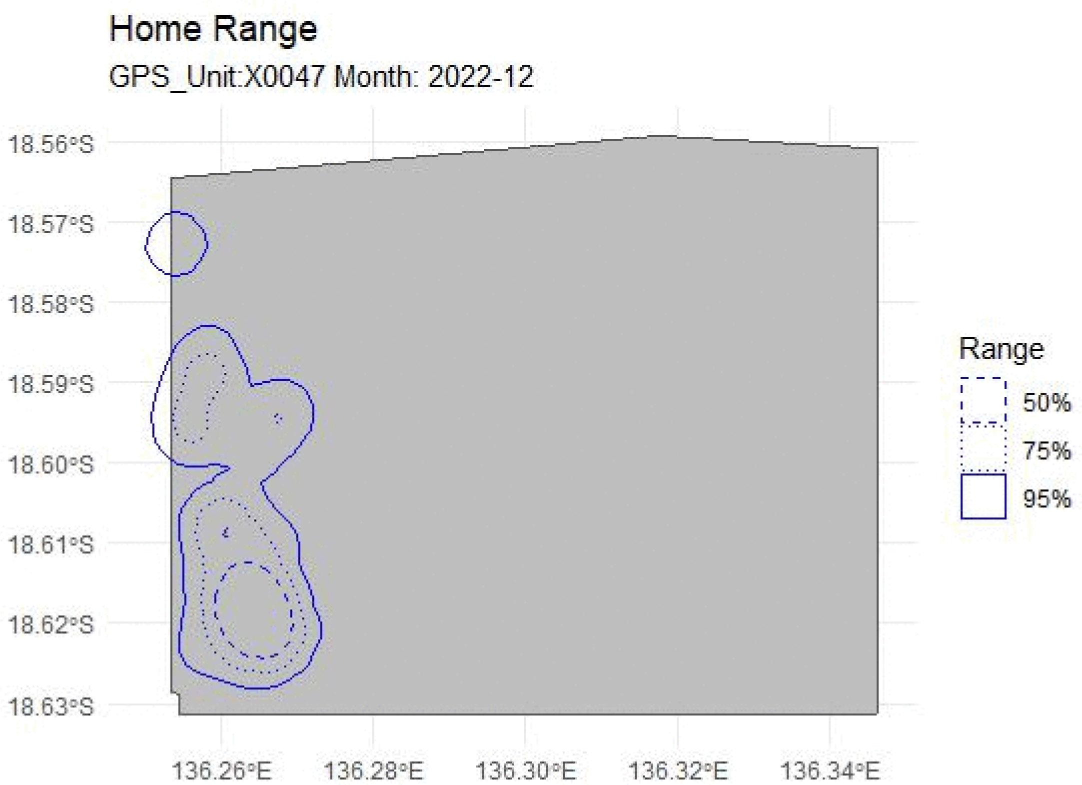


Figure 75. GIF image showing the monthly changes in home range of a single animal grazing in Connell’s 4 paddock at Brunette Downs from December 2022 to June 2023.

Paddock utilisation by animals grazing in Connell’s 4 paddock appeared to be more evenly distributed across water points (Figure 76), when compared to the home range trends at Rocklands Station. The home range data for December 2022 only shows 10 days of data in that month, so this should be taken into consideration when interpreting the data.

Land type and land type preferences and grazing behaviours of animals is an important factor to consider in the subdivision and development of paddocks, and this area of research needs further investigation to better understand what impacts this may have on productivity and reproductive performance, as well as land condition and pasture utilisation.

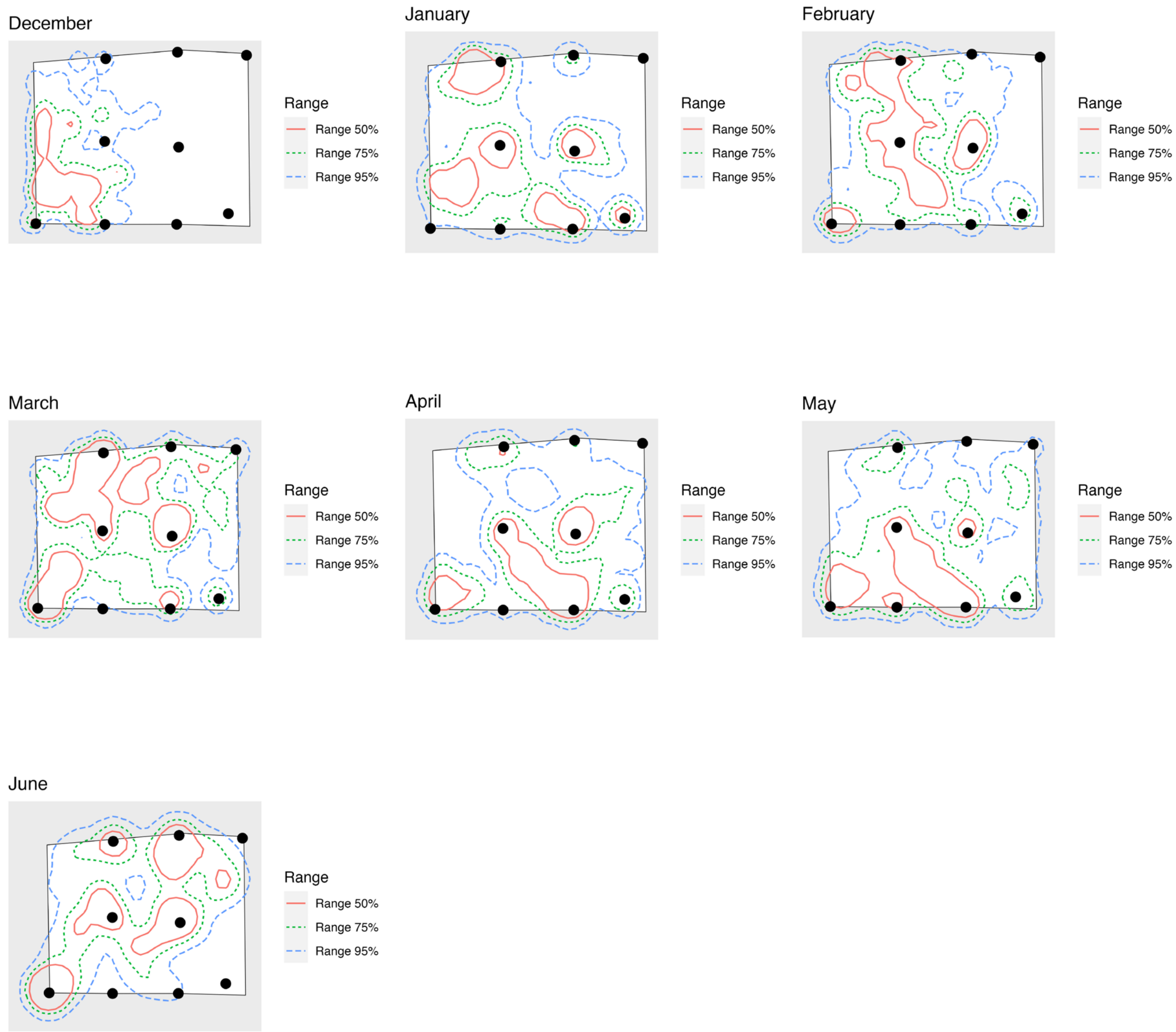


Figure 76. Home range of trial cows in Connell’s 4 paddock on a monthly basis during the deployment period from December 2022 to June 2023 showing the 50, 75 and 95% home range area.

While the home range data from Connell’s paddock showed generally uniform distributions, it would be important to remember that this data was collected over the wet season, during a 95th percentile rainfall year. Further data around grazing behaviour and its interaction with land type is needed to better understand how and why certain grazing behaviours occur.

5. Paddock Power Mapping Tool and Investment Calculator

5.1 Introduction

Infrastructure development delivers some of the best returns on invested capital for under-developed properties in northern Australia (Petty *et al*. 2013). Producers understand this and often nominate development as one of their highest priorities in industry surveys (Cowley *et al*. 2015). However, water points and fencing are expensive to install and maintain in northern Australia and low profitability has constrained the rate of development for many businesses (Rolfe *et al*. 2016). Northern beef producers regularly confide that they feel uncomfortable about making such important decisions based on "gut-feel" (Dionne Walsh pers. comm.). Furthermore, property owners, shareholders and financiers are increasingly requesting evidence-based business cases for capital expenditure projects.

To service these industry needs, the project undertook to develop some simple digital tools so that producers and their advisors can confidently assess the costs and benefits of infrastructure development. Importantly, the Paddock Power tools are the first of their kind to present this information in the context of the producer's own cost base, land types, stocking rates and animal productivity. The tools encompass scientifically backed concepts related to sustainable grazing land management and farm economics, including safe carrying capacity, liveweight production, ABCD land condition, watered area analysis and discounted cash flow analysis.

5.2 Methodology

5.2.1 Tool development

Prior to this project, Dr Dionne Walsh (formerly NT DITT) had developed a prototype spreadsheet tool that showed promise for evaluating the economic merits of infrastructure development projects. It was envisaged that during this project the prototype would be further tested and refined to ensure that it was robust and credible before being released more widely to industry. Furthermore, there was a need to develop a digital mapping tool to support the spreadsheet tool.

Early in the project, NT DITT built some prototype mapping tools for use within the open-source mapping software QGIS (see QGIS website here). However, after about 18 months of development and trialling, it became apparent that a more sophisticated approach to the mapping tool was required. A software programmer was subsequently engaged to custom-build a dedicated QGIS "plugin". The resulting Paddock Power plugin houses all the necessary mapping functions within an intuitive user interface. The Paddock Power plugin is freely available via the QGIS plugin repository and is supported by a User Manual and training workshop developed by Range IQ.

The original spreadsheet tool was also substantially re-developed during the project. Dr Phil Holmes (Holmes and Company) was engaged to review the initial prototype and recommended that a simple 10-year discounted cash-flow approach be taken. This recommendation was endorsed by the project leader and the Paddock Power Investment Calculator tool was subsequently built by Holmes and Company with the assistance of Bush AgriBusiness and Range IQ. A benefit of the collaboration with Holmes and Company and Bush AgriBusiness has been that the Paddock Power Investment Calculator aligns perfectly with the theory and concepts taught in the MLA Business EDGE™ workshops.

The Paddock Power Investment Calculator is intended to be used as a simple "go-no go" tool to help users identify development options that can be excluded immediately and those that are worthy of further investigation. The best performing options (from an economic perspective) are typically those that sustainably increase carrying capacity, increase per head productivity and/or reduce enterprise costs.

The Calculator requires users to set up a "Baseline" for the target paddock/property by entering the current carrying capacity, watered area, typical livestock productivity, typical enterprise costs, livestock value and typical price received. Using data from the Paddock Power Mapping Tool and their own records, users then input the capital costs of their proposed infrastructure development/s, anticipated enterprise costs and any change in overheads that might occur as a result of the development. The Calculator output shows how the development option/s compare to the Baseline (and to each other, if more than one option is being considered) on the basis of four metrics: Net Present Value, Years to Break Even, Benefit to Cost ratio and Internal Rate of Return. Recommended benchmarks for these metrics are provided to allow users to evaluate the economic merits of the development being considered. Sensitivity tables are also included so that users can assess how different combinations of livestock productivity, herd size and costs would influence the results. These sensitivity tables show at a glance whether superior results could be achieved by tweaking the design of the development (and/or the management of stock numbers and their productivity). They also allow users to recognise and manage business risk by showing how the investment might perform if their assumptions about carrying capacity and livestock productivity were not met (e.g. during an extended dry period). We recognise that economic performance may not always be the primary factor influencing some developments and that sometimes producers will decide to build infrastructure that doesn't "stack up" economically in order to improve logistics, staff health and safety and animal welfare.

Both tools are supported by a comprehensive User Manual. A webinar recording showcasing the tools and their features can be found on the FutureBeef website.

5.2.3 Industry training workshops

The project undertook to train at least 20 producers to use the Paddock Power tools via face-to-face workshops in the NT, Qld and WA. A one-day workshop has been designed to be very "hands-on", with attendees required to bring a computer in order to practise using the tools in a supportive learning environment. A PowerPoint presentation has been developed for use in the workshops, together with a generic "demonstration property" file for use in the Mapping Tool. Producers with excellent existing property mapping are encouraged to bring their own data to workshops for loading into the Mapping Tool. It is anticipated that agency extension staff and consultants will deliver training workshops after the project ends.

At the end of each of the four pilot workshops, feedback was captured from participants via a printed evaluation form as well as a verbal review session (see Results section below). Any technical feedback received about the Mapping Tool was provided to the software programmer for further refinement.

5.3 Results

The project team made a deliberate decision to keep the two tools separate despite the temptation to integrate the Investment Calculator with the QGIS plugin. We recognised that keeping the Investment Calculator as a standalone tool in Excel will reduce barriers to adoption for users who wish to evaluate investment options, but may not have the need or desire to download QGIS and the Mapping Tool plugin.

A comprehensive Paddock Power User Manual has been written and covers the following topics:

- What to organise before using the tools (e.g. computing requirements, map files and data);
- Guidance on minimum mapping standards needed for Paddock Power and where to source on-line mapping data for the NT, Qld and WA;
- How to install QGIS and the plugin;
- A recommended workflow for using the tools;
- Detailed step-by-step instructions on how to use all the features of the Mapping Tool and Investment Calculator;
- Understanding the four economic measures used in the Investment Calculator; and
- A set of practice exercises for use in the Investment Calculator.

The resources developed during this part of the project will have ongoing industry benefit and include:

- The Paddock Power Mapping Tool (digital tool)
- The Paddock Power Investment Calculator (digital tool)
- Comprehensive User Manual
- A generic demonstration property file to use in the Mapping Tool
- A training workshop PowerPoint presentation
- Training workshop evaluation templates
- A webinar recording that demonstrates the use of the tools

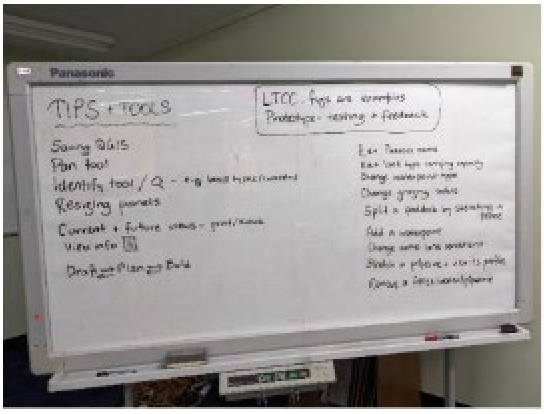
5.3.1 Industry training workshops

A total of 21 producers and 6 industry advisors/extension staff attended the four pilot training workshops:

Date	Location	Number of producers	Number of advisors/extension staff
3 May 2023	Arid Zone Research Institute, Alice Springs, NT	7	2
9 May 2023	Katherine Research Station, Katherine, NT	3	2
13 June 2023	Gregory Jockey Club, Gregory, Qld	8	2
4 July 2023	Frank Wise Institute, Kununurra, WA	3	0
	Totals	21	6

The promotion of the four pilot workshops was deliberately kept "low key" to ensure a positive experience for a small number of attendees at the early stage of the roll-out. Unfortunately, unseasonal heavy rainfall and consequent road closures prevented a further six registered participants from attending the Kununurra workshop. A western-Qld producer received one-on-one training on their property, bringing the total number of producers trained to 22.

Small group size at this stage allowed the presenter (Dionne Walsh) to provide a high level of technical assistance to each attendee. As confidence in the functionality of the Paddock Power tools grows, it is envisaged that larger numbers of attendees will be able to be accommodated at workshops, particularly if there is a second trained presenter available to provide technical assistance.



Workshop 1 – Arid Zone Research Institute, Alice Springs, 3 May 2023

Workshop 2 – Katherine Research Station, Katherine, 9 May 2023


Workshop 3 – Gregory Jockey Club, Gregory, 13 June 2023


Workshop 4 – Frank Wise Institute, Kununurra, 4 July 2023

5.3.2 Workshop evaluation data

A printed feedback questionnaire was provided to participants at the end of each workshop. Twenty-two out of a potential 27 questionnaires were returned. The shortfall reflects that a joint questionnaire was completed by a family of three, and two attendees had to leave to attend urgent business before the questionnaires were circulated.

The results show that the tools and the workshop were highly valued and there was a measurable increase in knowledge, skills and confidence as a result of attending (Table 21):

Table 21. Feedback by workshop participants regarding the Paddock Power workshops.

Questions	Average Score (out of 5)
Overall, how beneficial was the workshop to you for planning paddock development?	4.6
How would you rate the general presentation of the workshop?	4.5
How would you rate the communication leading up to the workshop?	4.4
How would you rate the help you received at the workshop?	4.6
How was the venue – e.g. comfort, facilities and location?	4.7
How was the catering?	4.6

Participants were asked about which aspects of using these tools might be most beneficial to them and their business (or to their client's businesses). Multiple answers were allowed (Figure 77):

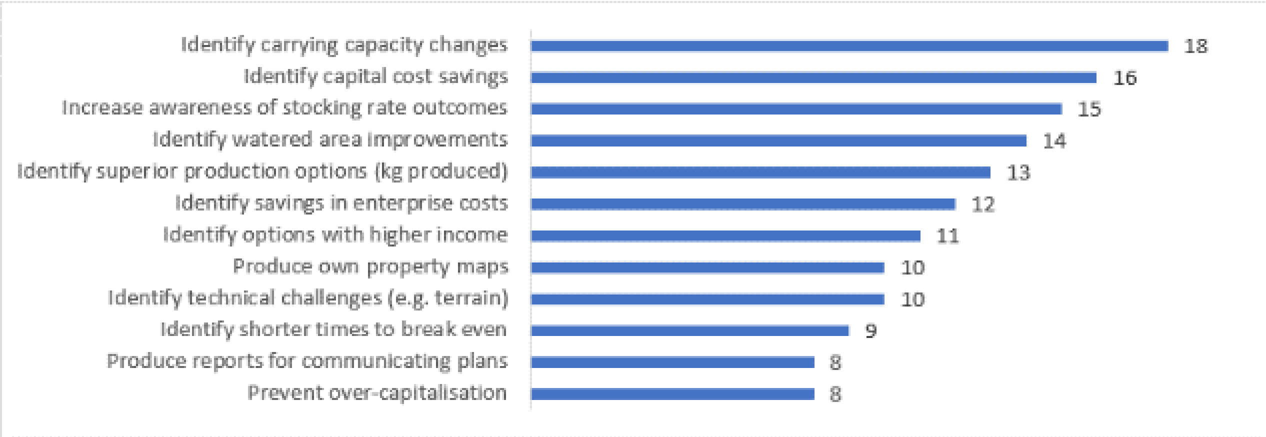


Figure 77. Paddock Power workshop participant's responses about how use of the tools may benefit them and their business (or their clients businesses).

Participants were asked how their knowledge, skills, confidence and ability had changed as a result of attending the workshop (Figure 78):

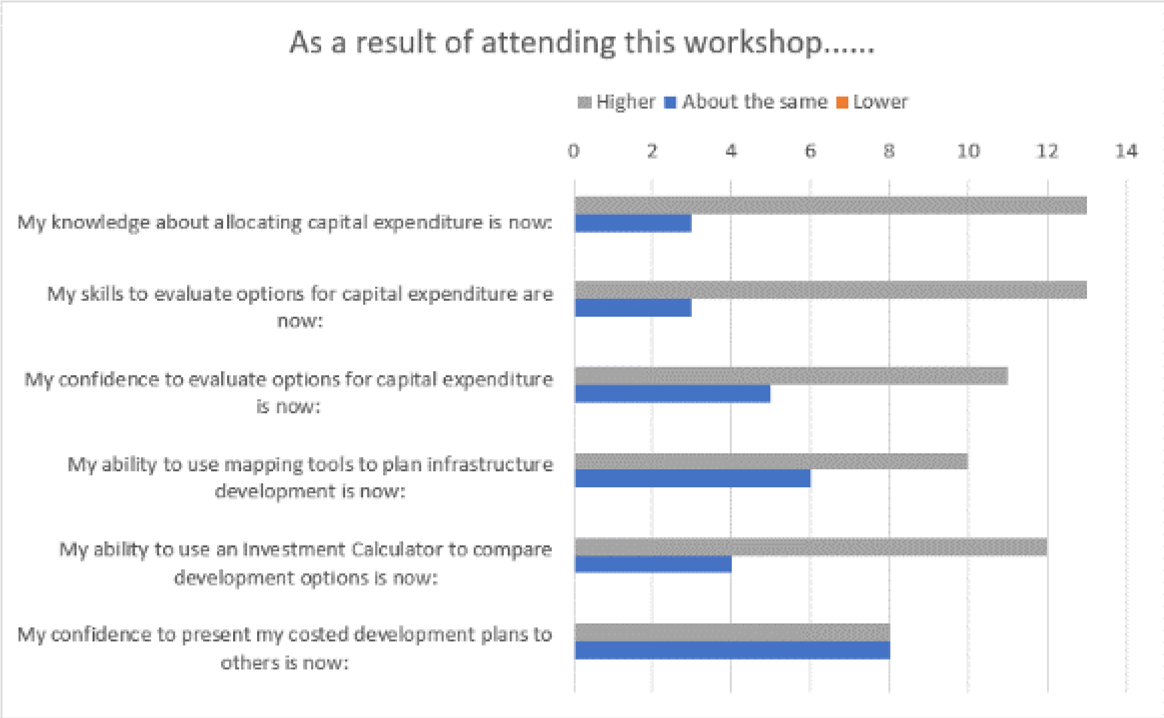


Figure 78. Paddock Power workshop participant's responses regarding how their knowledge, skills and confidence changed as a result of attending the workshop.

All four advisors who returned evaluations agreed that these tools and training workshops have the potential to:

- Increase producer's knowledge about allocating capital expenditure;
- Increase producer's skills to evaluate options for capital expenditure; and
- Increase producer's skills to use an Investment Calculator to compare development options.

All but one advisor agreed that the tools and training workshops have the potential to:

- Increase producer's skills to use mapping tools to plan infrastructure development;
- Provide a mechanism for producers to present costed development plans to others.

One advisor felt that the tools might be a bit too complex for some producers to use, so nominated that they were "not sure" if the above two aspirations would be met.

Finally, all participants were asked about their future intentions and whether they would endorse the workshops to others. Every respondent said that they would recommend the workshop to others. All but two said that they would use the Mapping Tool again. One respondent said that they weren't sure if they would use Investment Calculator again because she already had other tools to do this in her business. Another respondent said that she wasn't sure if attending the workshop had influenced plans for future development because her partner typically made these decisions in their business.

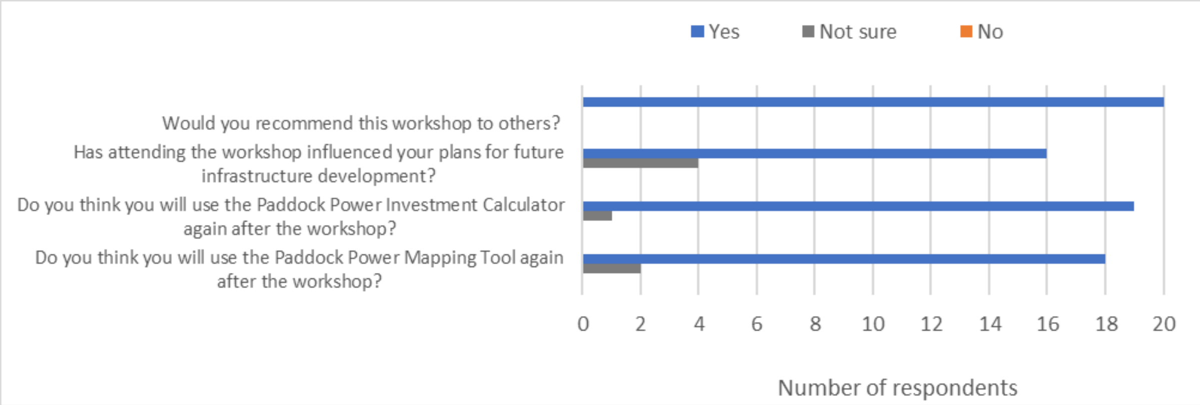


Figure 79. Paddock Power workshop participant’s responses about their future intentions and whether they would endorse the workshop to others.

Participants were also asked to provide general feedback for technical refinements, workshop delivery and future follow up and the responses are summarised below:

General feedback for technical refinements:

- Be able to drag/move/toggle fences, pipes and water points rather than delete and redraw
- Optional intro to QGIS workshop for people who haven't seen it before (how to use basic functions)
- Issues with crashing (on QGIS 3.28) but please continue development. I think this could be a great tool, particularly for partner who likes to look at development ideas
- Be able to pinpoint elevation on a pipeline
- Add roads to access infrastructure development (and to include in costings)
- Add a tip to the manual on how to account for increased appetite and forage demand in Option 3 of the practice exercise (e.g. by reducing the number of "additional AE" by a percentage.

General feedback about tools and workshop delivery

- Easy to follow along and covered everything needed
- I thought it was quite straightforward to use
- Investment calculator is powerful but simple
- A very complex tool - for service providers
- Financial and map = very good tool
- The Investment Calculator is a very useful tool
- The elevation tile would be useful to use
- Good workshop
- Good tool
- Very informative and personalised, learnt a lot
- Was really well run with very useful information

General feedback regarding future follow up:

- Phone support available over next 12 months

- Send updates of tools when complete or notification of when available online
- Assistance with using the Paddock Power tool
- If I was to support people using it, I'd need access to someone with more experience
- I would still require further assistance to set up my property
- A map of [property name] that will work on QGIS
- Mapping will take some practice

Several of the technical suggestions above were subsequently incorporated into the final release of the Mapping Tool or were added to the list of “future features”. Suggested future features (if further funding can be sourced) include:

Both tools:

- A user-registration system to track who is using the Tools and for version management
- User guides embedded within the tools as tips or call-outs
- A dedicated on-line dashboard design; increased sophistication of delivery and operation

Mapping Tool:

- Geometry validation and repair at layer import stage
- Single-step import window for importing layers
- Auto-snapping of water points to pipelines (and vice versa)
- Easily move the vertices of lines to re-map fences and pipelines
- Pinpoint the location of a specific elevation on a pipeline
- Paddock merging functionality (e.g. remove fences to merge paddocks)
- Editable carrying capacity discount value to account for increased pasture intake related to urea and phosphorus supplementation
- Make the “working”/”processing” stages more visually obvious to reduce QGIS crashes caused by task overloading

Investment Calculator:

- A digitally-signed macro to allow users without computer administration rights to use the full functionality of the tool

6. Project Communications

6.1 Communications summary

Overall project communications targets and activities are shown in the table below (Table 22). The two webinars for the project focussed on the two broad sections, the Mapping and Investment tools in the first webinar and the commercial property data results in the second webinar. Field day presentations focussed on how producers may benefit from using the tools and give an overview of results and how to use the Mapping Tool and Investment Calculator. Due to the complexity and fluidity of the tools and their associated software updates, NT DITT will provide support for producers who are using the tool for any technical issues that producers may encounter as the uptake of the tool increases within the industry. There has been significant industry engagement and interest in the tools and their usefulness across a wide variety of producers making infrastructure development plans.

The project has presented two webinars, with strong engagement from industry. Webinar 1 was held online through FutureBeef on the 11th of July 2023, and the recording can be found here: **Paddock Power – a new computer tool for planning your paddock development.** The first webinar attracted 214 registrations and 78 people attended the live session. The live audience comprised 35% producers, 32% agribusiness consultants, 32% government officers and 2% education providers. Sixty-five percent of the live audience were QLD based, 17% were WA based, 7% were from the NT, 7% from VIC/SA/TAS, and 4% were from NSW/ACT.

Webinar 2 was held online through FutureBeef on the 25th July 2023 and can be found here: **Paddock Power – a new computer tool for planning your paddock development.** The second webinar attracted 106 registrations and 42 people attended the live session. The live audience comprised 35% producers, 32% agribusiness consultants, 32% government officers and 2% education providers. Seventy-nine percent of the live audience were QLD based, 7% were WA based, 7% were from the NT and 7% from VIC/SA/TAS.

Table 22. Paddock Power Project communications targets and progress.

Communication Product	Timing	Target (Whole Project)	Progress (End project)
Industry targeted newsletter and e-newsletter articles published	From March 2019	6	13
Producer facing social media updates	From June 2019	15	39
Attendance at industry events to communicate the outcomes of the project	From June 2019	6	7
Industry and researcher facing press articles published	From June 2019	3	3

[Project team to engage with the NTCA & KPCA Innovation & Adoption Managers to discuss communication to their respective memberships]			
At least 20 NT, QLD and WA producers using the Paddock Power Calculator by the completion of the project. User locations by state and region to be provided to MLA.	From July 2020	20	22
Producer field days held (1 NT, 1 QLD)	August 2020	2 NT/ 1 QLD	3 (BarklyBeefUp and VRDCA) (Field Day at Rocklands Station/Mt Isa 7-9th Nov 2023)
Webinars hosted for producers and other stakeholders to communicate the outcomes of the project and to train producers to use the Paddock Power Calculator	Nov 2020 Apr 2021	2	2
Hard copy producer information booklet designed and delivered detailing key project outcomes and where to go for further information.	Feb 2021	1	1

Other measures of outreach from the project and its associated tools are shown in Table 23. There was significant industry engagement about the use of the tools and how this will be rolled out and supported, as producers begin to adopt the Mapping Tool and Investment Calculator.

Table 23. Other communications activities and their impact.

Measure	**Number**
Number of unique producers exposed to project (increased Awareness - Category A)	340 from 163 businesses
Total producer "exposures" (i.e. includes repeat exposures to the same audience – e.g. same newsletter distribution list over time)	At least 500
Producers with increased KASA (Category B)	25
Producers who Changed Practice/s (Category C)	0
Area of land represented by Category A, B & C producers	137,003 km²

Producer-initiated enquiries about the project	20
Number of non-producers exposed to project (e.g. industry advisers, agency staff, NRM officers)	At least 490
Number of people reached by broad-scale or media activity (Project material has been published on: LinkedIn, Beef Central, Central Station podcast, the North Qld Register, Range Management Newsletter, and various social media channels managed by FutureBeef, Rangelands NRM and the NT Cattlemen's Association)	~ 50,000

Paddock Power's social media presence has given opportunity for various other social media pages and groups to integrate and communicate more openly about the tools, their usefulness to the industry, and how they may assist various types of businesses. The Paddock Power Facebook group has over 300 followers, and the recent webinars have sparked renewed interest in the Paddock Power project and associated tools (Table 24).

Table 24. Outward facing social media and project engagement activities with industry and the number of associated activities.

Activity	Number
Project management contact with collaborators	39
Radio interviews and podcasts	3
Field days/paddock walks	2
Events/conferences attended	4
Subscribers to the Paddock Power Facebook Group*	Started at 0, currently at 300
Social media posts (multiple platforms)	45
Social media views (as at one week after posting)	3289
Social media reactions (likes and shares)	714
Newsletter & on-line articles	14
Industry committee briefings	7
Webinars	2
Paddock Power training workshops	4
Formal publications	2 (NBRUC one page papers)

7. Discussion and Conclusion

The hypothesis of this study was that the larger less watered paddocks at the collaborating properties would have higher calf loss, lower reproductive performance measures (eg. cows pregnant within four months of calving, and wet/pregnant animals), and also that cows would need to travel further to access feed and water. Due to climatic conditions beyond the project's control, factors such as stocking rate and utilisation rate were not similar between the two paddocks for most of the trial duration. Comparisons between the two paddocks at Rocklands based on reproductive performance indicators should be interpreted with caution, as other factors such as stocking rate reductions in Grassy Paddock would have impacted the performance of animals in that paddock. Also, Brunette Downs experienced one of their biggest wet seasons on record during the deployment of GNSS collars and data collection for this property. This meant that for the majority of the time animals were involved in the study, both trial paddocks would have had substantial areas of surface water, and therefore animals would not have been reliant on the permanent water points in the paddock.

The trial paddocks at Brunette Downs had a larger difference in 3km watered area than those at Rocklands (35% difference compared to 11%). Due to multiple dry years in the lead up to the trial, and the flooding that occurred in early 2023, the opportunity to assess the difference between the two Brunette paddocks occurred only over the wet season, so variability in spatial behaviours was not possible to see throughout a dry season. This would be of significant interest in future studies, where the true impacts of smaller paddocks and more watered area could be seen where cattle were completely reliant on man made water points.

The on-property research highlighted the difficulties in measuring spatial behaviours in animals at a commercial scale, and the various factors that may contribute to herd performance, including stocking rate and utilisation rate. While there were no major differences in the reproductive performance between the trial paddocks at Rocklands, the large variation in stocking rate and low utilisation rate may have been a substantial contributing factor to these results.

7.1 Animal data and paddock challenges

Collar retention

Data was successfully downloaded from ~90% of devices over the three deployments at Rocklands Station and one deployment at Brunette Downs. As the GNSS units deployed in this project were store-on-board (i.e. no data was communicated in real time) a lost collar meant that all the data on the collar was also lost as there was no way of knowing where the collar fell off in the paddock to retrieve it. Collar retention was a major reason for failure to obtain data from GNSS units. A second issue incurred was devices not successfully downloading data after the device was retrieved, although this only occurred in around 2% of cases.

Collar retention varied year to year with the lowest retrieval rate at Rocklands in the third deployment from June 2022 to May 2023 only retrieving 48% of collars. Some reasons for the low retrieval rate may be the length of time collars were on, with large weight changes in animals increasing the chance of collars coming off. Another reason may be that there were more animal movements over the wet season when a lot of the area received significantly high rainfall amounts, and some animals may have escaped the trial paddocks so they were not seen at the following muster when collars were retrieved. In the Brunette Downs collar deployment from December 2022 to June 2023, 80% of collars were retrieved in the Connell's paddock, and all collared animals remained inside the trial paddock for the duration of the collaring period. Collar design is constantly evolving and new ways to secure collars for extended deployments and increase battery life is a priority for future research projects.

GNSS data

During the three GNSS collar deployment periods at Rocklands Station, there were over 350 collars fitted to animals in the trial paddocks. There were numerous cases where paddocks assigned to animals did not match up with paddocks that animals appeared to be in according to the GNSS data. There were many cases of animals swapping between trial paddocks during each of the deployment years. While missingness is common in extensively managed herds (McCosker et al., 2020), GNSS data presents the jarring reality that animals move often, between paddocks, and this factor should be considered when interpreting the results. For the purposes of this research, calculations such as the distance to water and distance travelled by animals was done using data points that were clipped to a respective paddock. For example, if an animal assigned to one paddock ended up in another paddock, the data from that animal was assigned to the paddock that the GNSS fixes were in, and calculations made accordingly.

GNSS battery longevity was also variable across the numerous deployments in the project. An upgraded battery (10Ah) was used in the last 2 deployments, which increased the average lifespan from 3 to 5 months, although some units only recorded data for a few weeks. The battery size and capacity is limited by the collar housing size, and further investigation into creating a larger housing should be done to achieve longer deployment periods. This would be important to capture inter-seasonal data for individuals without the need to remove collars as frequently.

Home range data was overlaid on various mapping data including TSDM, NDMI and TC in different seasons, to investigate whether there was a relationship between spatial behaviours of animals and the quantity of feed available. After investigating the GNSS data and plotting distances to water, it was of interest to see whether there was surface water present in the paddocks and what time of year this was available to animals. The mapping of NDMI showed clear areas of water throughout the river system that runs through the trial paddocks, and this was mapped with GNSS fixes from animals to see how they were using the surface water at different times of the year. Mapping the NDMI at Rocklands highlighted the challenge of identifying specific areas where surface water was present, as there were multiple sections of braided water throughout the river system which is up to 4 km wide in some sections. To achieve a more realistic picture of where animals were accessing water, the project team considered accounting for the surface water in the paddock and recalculating the distance to water results. However, as the distribution of surface water was vast, and there were many small sections of river that it was available to animals, the analysis did not attempt to include these water sources. Further to this, the distance to water based on the man made water point analysis indicated animals were further from water in the larger paddock, which is an expected result, considering animals also travelled further in the larger paddock overall.

7.2 Feedbase and animal performance data challenges

Feedbase data and associated variables including stocking rate, utilisation rate and total standing dry matter estimates from satellite derived data sources were an important part of the project. In the initial stages of the project, the collaborating properties were coming out of some challenging dry years, and decisions had to be made to lower stocking rates to account for poor conditions. The stocking rate per watered area in adult equivalents was initially similar between the two trial paddocks Big Mudgee and Grassy at Rocklands at the start of the project in 2020 (12.5 and 11.9 AE/km^2 respectively), but was lowered in Grassy Paddock in 2021, to 7.6 AE/km^2 and then 3.8 AE/km^2 by August 2021 and this was maintained until August 2022, while Big Mudgee was at 10 AE/km^2 in 2021 and 9 AE/km^2 in 2022. Further to this, the utilisation rate was at 13.5% at this time, and with a safe utilisation rate sitting at around 20%, animals did not need to go far from water to access the feed they required. The home range data shows animals with GPS collars spent most of their time well within a 3-5 km radius of permanent waters in both paddocks, especially in the third deployment during 2022-2023. This could also be the reason that the F.NIRS results were very similar between the paddocks, and animals in both paddocks were able to be very selective in their diets due to the lower utilisation rate across the paddocks.

Reproductive performance measurements were similar between paddocks across the trial at Rocklands Station, and it is suspected that this is due to the similarities in watered area and lower utilisation rates. Since the trial paddocks at Rocklands maintained a fair amount of surface water in the Georgina River system which persisted throughout the dry season, both paddocks are nearly 100% watered (within 3km), at least for a large portion of the years the trial took place. This may be the reason that little variation in reproductive performance was observed between the paddocks.

Reproductive performance at Brunette was difficult to interpret due to issues with individual animal data recording during the deployment period in 2023. Results between the two trial paddocks were unexpected, most likely due to different classes of animals being placed in each paddock, which meant that a fair comparison was challenging.

7.3 Paddock Power tools

The development of the Paddock Power Investment calculator and Mapping tool have been an important development which can enable the northern beef industry to become more profitable and achieve realistic productivity outcomes according to their own properties' characteristics and variables. One of the pathways to increasing the profitability of northern Australian beef cattle production systems is to increase infrastructure and water point development (Hunt et al., 2014). However, producers find it difficult to secure the capital and to justify spending time on infrastructure developments when they are unable to provide an accurate cost benefit. As there is a wide variability in land types, property sizes, cattle breed, and overall management of beef businesses across northern Australia, quantifying the impact of increasing infrastructure development is very difficult. To account for this, the Mapping tool and Investment calculator took into account the unique variables different to each enterprise, such as stocking rate, land type, animal productivity and cost base.

One of the biggest issues with additional developments in northern Australia has been the unknowns in relation to how decisions will impact the profitability and productivity of the herd, so the Paddock Power tools offer an objective and safe method to calculate a realistic outcome for land and animals, as well as ensuring economic viability. Widespread usage of the tools throughout northern Australia can help to optimise productivity of the beef industry, while maintaining good land condition, safe carrying capacity and making businesses more profitable. The intended outcome from adoption of these tools is taking the guesswork out of infrastructure planning and using the tools to make informed management decisions that will give producers the best return on their investments.

7.4 Key findings

- The Paddock Power Mapping Tool and Investment Calculator produced during this project can assist in decisions around the costs and benefits of increasing infrastructure according to property specific variables
- The impact of reducing stocking rate and utilisation rate may have significant positive impacts on reproductive performance in larger paddocks
- Analysis of an industry dataset comprising 58,510 individuals, each contributing an average of 2.5 production years, provided comprehensive insights into reproductive performance changes coinciding with a paddock development program. The key findings from these analyses were:
    - Concurrent improvement in pregnancy rates and occurrences of pregnancy within four months of calving (P4M) was observed with property development. However, foetal and calf loss also increased with paddock development, although it was lowest in smaller paddocks and increased with paddock size, which warrants further investigation.
    - Multivariable modelling results indicated that paddock area wasn't associated to P4M but significantly influenced annual pregnancy rates and foetal/calf loss.
    - Proximity of paddock area within 3km of permanent water was associated with P4M and annual pregnancy but not with foetal and calf loss.
    - Results of analyses reinforced the importance of various animal-level factors such as body condition score around calving, reproductive history, calving time, cow age class, and year, in relation to reproductive performance.
- Variability between seasons and properties is a large determinant of productivity, and the tools provided in this project can help to assess decisions based on multiple situations and variables

7.5 Benefits to industry

The northern Australian beef industry will benefit from the tools and outcomes this project has delivered. Providing evidence- based tools and assessment of economic investment in an objective way is critical for commercial beef businesses to increase productivity and sustainability in northern Australia. Prior to the Paddock Power project and associated tools, it was difficult for producers to ascertain at what point additional infrastructure was not leading to increases in herd productivity or overall economic value to their business. The decision-support tools enable producers to undertake an economic analysis of their plans according to their specific property characteristics and needs.

The tools will help them to understand the economic viability of their plans, and the realistic productivity that can be achieved.

More broadly, the Paddock Power tools can help producers get the most realistic and sustainable production from their businesses and take the time and guesswork out of decision making in this space. This will allow them more time to focus on other areas of the business such as genetic improvements, diversification and future planning, which has a flow on effect for industry in many positive ways.

8. Future research and recommendations

This project has significant impacts for the northern beef industry, through the development of the Mapping Tool and Investment Calculator, enabling producers to get the best ‘bang for their buck’ when it comes to increasing paddock and water infrastructure. The main challenges in this project included the development of the tool, to account for variability in enterprises and changing costs of infrastructure, and the collection of industry datasets which were comparable at a commercial scale. Future R&D could focus more on the development of further features within the tools, as well as further investigation into the impacts of paddock size, land type, watered area and utilisation rate on the reproductive performance of northern Australian cattle herds. One of the major findings in this study was the impact that utilisation rate had on the reproductive performance of animals in a large paddock. Further investigation into how this may tie in with reduced infrastructure costs, to increase productivity through lowering utilisation rate is a potential avenue for further research.

The practical applications of this project are vast, from assisting managers in subdivision of paddocks, to teaching younger people within the industry about the costs and benefits associated with infrastructure development. When the industry is becoming more and more focussed on increasing production while maintaining sustainability, the tools that this project has created are one way to ensure better efficiencies across northern Australian beef businesses. To establish adoption of the Paddock Power tools across the industry, support around their usage and assistance with troubleshooting will be provided by NT DITT and private providers into the future. Workshops with industry about using the tools and applying to specific properties and situations will also help to increase the continuation of adoption.

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10. Appendices

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10.2 Pasture and Climate data

10.2.1. Rocklands pasture assessment photos

Figure 80. The exceptionally dry season experienced in the Barkly resulted in wide contrasts in pasture conditions throughout 2019.

Figure 81. Stop 15 August 2020 and 2021 – River country, Big Mudgee Paddock, B condition (3-5 km from water)

10.2.2. Trial sites' rainfall for the duration of the trial

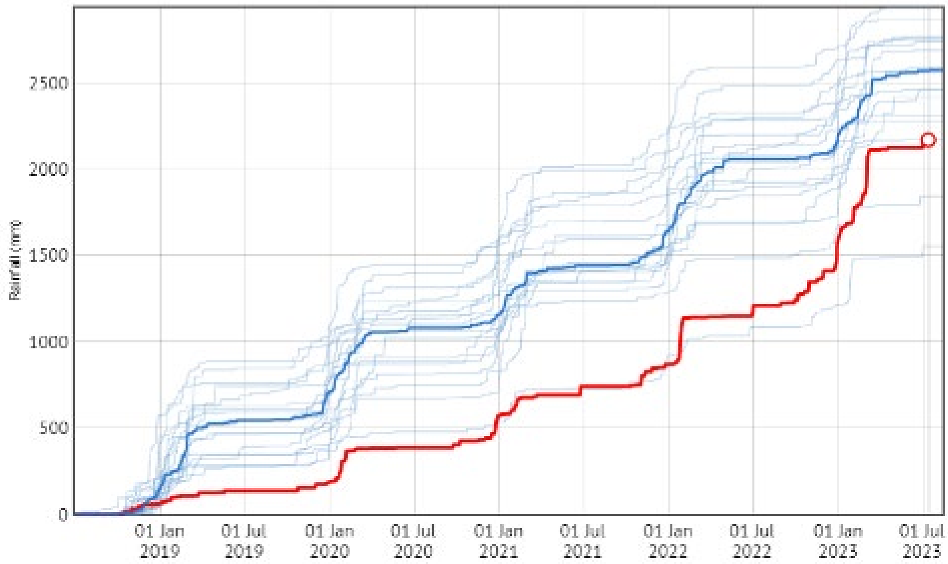

Figure 82. Brunette cumulative average (blue) and current (red) rainfall amounts from January 2019 to the end of the project in July 2023. Source: CliMate https://climateapp.net.au/A03_HowsTheSeason.

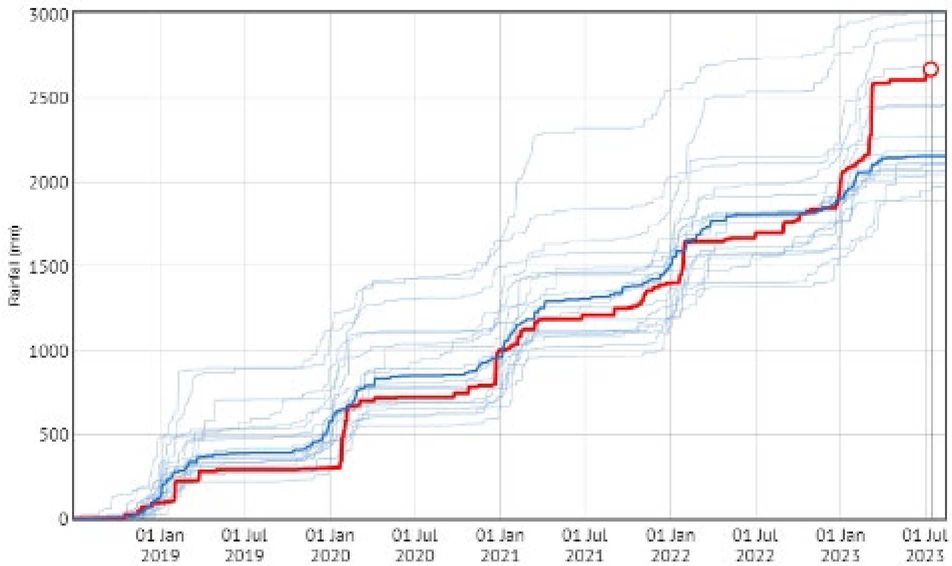

Figure 83. Camooweal average (blue) and current (red) cumulative rainfall from January 2019 to the end of the project in July 2013. Source: CliMate https://climateapp.net.au/A03_HowsTheSeason.

10.2.3. Rocklands Pasture assessment site yield estimates

Table 25: May 2023 Pasture assessment of trial paddock at Rocklands Station, Camooweal.

Site	Dominant 3 Species	Yield Estimate (kg DM/ha)	Land Condition
3	*Iseilema vaginiflorum* *Astrebla squarrosa* Forbs	1000 	B
4	*Astrebla lappacea* *Iseilema vaginiflorum* Forbs	1200 	B
5	*Astrebla lappacea* *Iseilema vaginiflorum* *Marsilea hirsuta*	1700 	B/A
6	*Astrebla lappacea* *Iseilema vaginiflorum* *Marsilea hirsuta*	900 	B/C
11	*Brachyachne convergens* *Iseilema vaginiflorum* Legume & *Dichanthium* sp.	400	B/C

Site	Dominant 3 Species	Yield Estimate (kg DM/ha)	Land Condition
			
12	*Dichanthium fecundum* *Iseilema vaginiflorum* *Brachyachne convergens*	650 	B/C
13	*Brachyachne convergens* *Dichanthium fecundum* *Iseilema vaginiflorum*	650 	B/C
14	*Dichanthium fecundum* *Iseilema vaginiflorum* *Aristida* spp	1000 	B
15	*Aristida* spp *Dichanthium fecundum* Mixed forbs & *Iseilema vaginiflorum*	800 	B

Site	Dominant 3 Species	Yield Estimate (kg DM/ha)	Land Condition
16	*Dichanthium fecundum* *Iseilema vaginiflorum* Malvaceae spp	850 	B/C
17	*Dichanthium fecundum* *Iseilema vaginiflorum* Forbs	1350 	B
19	*Eragrostis tenellula* *Iseilema vaginiflorum* *Marsilea hirsuta*	200 	C