Final report

The Sweet Spot: Improving breeder herd performance through optimal pasture utilisation

Project code: B.GBP.0029

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Sweet Spot project team contribution to the project and final report

Name	Organisation	Contribution to final report	Contribution to project
Robyn Cowley	NTDAF	Led generation and collated the report, Primary author of introduction, pasture utilisation, and discussion chapters. Primary author of appendices. Contributed to descriptive analysis of reproductive performance, impact of utilisation on breeder performance and bioeconomic modelling chapters	Project leader. Developed and led the project from conception, including preparation and submission of funding applications. Managed project administration, milestone reporting, and overall coordination. Designed and implemented the pasture utilisation modelling methodology, modelled pasture utilisation of all NT locations, and assisted with modelling pasture utilisation of Qld sites, collation of NT breeder dataset predictor variables, generated monthly pasture production data for Barkly representative CLEM herd, contributed to interpretation of breeder performance analyses, contributed to Barkly bioeconomic modelling assumptions and interpretation, contribution to statistical analysis approach, presenting project results to industry and conferences, collated final report
Kieren McCosker	QAAFI, UQ	Primary author of descriptive analysis of reproductive performance and impact of utilisation on breeder performance chapters; Performed general review and contributed to the writing of appendices	Contributed to project development, assisted in securing funding, determined methodology for collating animal data, processes and analytical approach; led empirical breeder data collation and generation of breeder performance measures;, descriptive summaries of breeder performance and key parameters, contributed to statistical analysis design, approach and analyses, contribution to Barkly bioeconomic modelling assumptions, conducted background analyses for project team presentations at industry events and contributed to workshops; presenting project results to industry and conferences
Lester Pahl	QDPI	Primary author of bioeconomic modelling chapter, contributed to Communications and Adoption pathways and Synthesis chapters	QDPI project leader, bioeconomic modelling of Barkly and Burdekin regions, presenting Burdekin modelling at workshops, collating management recommendations

Giselle Whish	QDPI	Contributed to pasture utilisation chapter	Modelled pasture utilisation of Qld sites, collated Qld breeder dataset predictor variables, generated monthly pasture production data for Burdekin representative CLEM herd, and contributed to Burdekin bioeconomic modelling assumption
David Mayer	QDPI	Contributed to the statistical analyses included in chapter 6, assessing the impact of utilisation on breeder performance	Statistical analysis of empirical breeder dataset
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Caroline Pettit	NTDAF		Modelling of pasture utilisation at Katherine and Sturt Plateau sites
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Trudi Oxley	Upriver		Suggested we apply for the funding, contributed to project development, provided advice re project extension, contributed to NT assumptions for bioeconomic modelling, facilitated NT producer workshop
Neil MacLeod	Karingal systems		Contributed to bioeconomic model methodology
Melissa Wooderson	NTDAF		Collated NT breeder datasets

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Abstract

Beef enterprises in northern Australia face the challenge of optimising breeder herd productivity and profitability while maintaining land condition under variable climates. A key industry issue is balancing stocking rate and pasture utilisation to maximise returns without compromising animal performance or long-term sustainability. The Sweet Spot project was undertaken to provide evidence-based guidance on this balance and to identify management strategies that improve both profitability and landscape productivity and resilience.

The project conducted a meta-analysis of historical datasets drawn from 60 research trials involving breeding female cattle, across 22 commercial and research stations. The resulting dataset summarised the reproductive performance of over 78,000 annual production cycles, and were integrated with bioeconomic modelling using the GRASP and CLEM models. Empirical analyses quantified the effects of relative pasture utilisation on reproductive performance, while bioeconomic modelling assessed long-term productivity and profitability outcomes in two representative regions, the Barkly Tablelands (NT) and the Burdekin (QLD) over 40+ years of historical climate.

Multivariable modelling demonstrated a consistent negative association between increasing pasture utilisation and four reproductive outcomes: annual pregnancy rate, pregnancy within four months, weaning percentage, and foetal/calf loss. Over the long-term optimal production and profitability was achieved at moderate utilisation rates (18–23% Barkly; 18–20% Burdekin), often below assumed safe levels, particularly in less resilient environments.

Collectively, the findings highlight that pasture utilisation, nutritional availability, and strategic management are critical determinants of reproductive performance and long-term herd sustainability. Proactive management to maintain land condition and align stocking rates with pasture availability is essential to optimise both animal productivity and enterprise profitability.

Executive summary

Background

The research addressed the critical industry problem of optimising breeder performance and production through pasture utilisation in extensive cattle herds across northern Australia. Previous studies primarily focused on grower cattle, leaving a significant gap in understanding the impact of pasture utilisation on breeder herds. Most grazing trials were too short in duration to capture the longer-term impacts of higher pasture utilisation on land condition and how this impacts productivity and profitability. We know of no research that has continued long enough to observe these feedbacks with breeding females. This creates challenges with communicating to industry, as most breeder production studies have shown that while higher stocking rates lead to more variable year to year production, they also appeared more profitable. This was because, during the project lifetimes, the seasons were relatively good and negative impacts on the pasture feedbase did not emerge yet. The main target audience is the northern Australian extensive beef cattle industry, which relies heavily on native and improved pastures where safe pasture utilisation typically ranges from 5% to 25%. The research results will be used to develop management recommendations for breeder herds, discussing trade-offs for production, environmental stewardship, methane emissions reduction, carbon market participation, and social licence. Findings will also be integrated into existing training courses like the EDGE network packages.

Objectives

The project aimed to evaluate the short-term (1-5 years) impacts of pasture utilisation on breeder performance with existing empirical breeder datasets, as well as the longer-term (multi-decadal) impacts using a bioeconomic modelling approach. Existing breeder herd datasets from commercial and research stations across northern Australia were collated and robust statistical modelling used to quantify the effects of pasture utilisation on four key reproductive performance measures. Bioeconomic modelling was used to determine optimal pasture utilisation rates for land condition and landscape productive capacity and how this flows through to herd performance, production and profitability over the long-term incorporating the impacts of climate variability for 2 different regions and land types. A further objective was to translate these findings into practical recommendations and recommend resources that could be incorporated into training packages and extension programs targeting northern beef producers.

Methodology

The Sweet Spot project employed a multidisciplined methodological approach combining empirical data analysis and bioeconomic modelling. A meta-analysis was conducted using 30 years of historical breeder datasets from 60 sites across 22 stations in northern Australia, selected for their detailed individual animal records, paddock-level data, and suitability for pasture growth modelling. Pasture growth and utilisation were estimated using the GRASP model, calibrated with site-specific pasture and grazing data, and expressed as relative utilisation against safe thresholds to enable comparison across land types for 350 site years. The starting dataset summarised individual annual production year outcomes, including: 78,601 annual pregnancy, 30,552 foetal and calf loss, 28,534 pregnancy within four months and 49,029 weaning records. Statistical analyses, including mixed and generalised linear models, were applied to quantify the effects of pasture utilisation on four key reproductive outcomes. Bioeconomic modelling integrated GRASP and CLEM to simulate the long-term impacts of varying utilisation rates on land condition, herd performance and dynamics,

productivity, and enterprise profitability over four decades of historical climate in two representative regions, the Barkly Tablelands and the Burdekin. Industry workshops were held to refine modelling assumptions and scenarios, ground-truth findings, and co-develop practical recommendations for adoption and future research.

Results/key findings

- Pasture growth and utilisation were retrospectively modelled for 350 site-years in 60 paddocks for the breeder herd datasets (Chapter 4, page 35). Estimated paddock level safe pasture utilisation rates varied between 9 and 30%. Simulated annual pasture utilisation of annual pasture growth varied from very low to very high (0.5% to 114%). The ratio of annual to estimated safe utilisation - relative pasture utilisation, varied from 0.03 to 7.4. This provided a wide range of pasture utilisation to model the short-term (1-10 years) impacts of relative utilisation on breeder performance.
- This is the largest pasture growth and utilisation modelling exercise ever undertaken in northern Australia. This led to methodological advancements including the refinement of existing modelling methodology to facilitate modelling at the paddock scale across multiple land types, with the incorporation of satellite green cover data to guide model calibration for research site years. This methodology can and should be applied to all cattle research trials in extensive rangeland systems to help estimate and adjust for pasture utilisation in research paddocks, which could be influencing herd performance in addition to any other treatment being tested / researched
- Descriptive analyses summarised typical levels and variation in performance for beef breeding females in four regions across northern Australia, including Northern NT, Central NT, Southern NT and North East Qld, using standardised reproductive measures (Chapter 5, page 76). Beef breeding females in the Southern NT showed moderate to high performance, comparable to or exceeding Central NT, but with substantial variability reflecting management and environmental differences within this arid region. This analysis provides new insights, as the Southern NT was not included in the North Australian beef fertility project and previous studies have focused on specific animal classes or were conducted on research stations. Overall, regional differences and levels of performance were consistent with existing literature, with lower performance in northern NT.
- Multivariable modelling findings (Chapter 6, page 92) demonstrated that high relative pasture utilisation significantly reduced individual animal performance across all reproductive and weaning outcomes. Pregnancy within 4 months of calving was predicted to decline by approximately 33% from low to high relative utilisation in low *Bos indicus* content cattle while a lesser response was observed in higher *Bos indicus* breed content. Foetal/calf loss increased by about 2.3% per incremental step in relative utilisation. Critical nutritional factors, such as pasture growth, available green pasture, and pasture percent nitrogen around calving and in the early dry season, were vital for reproductive success and calf survival. Body condition score at pregnancy testing was also strongly linked to calf loss, decreasing from 22.7% at BCS 1.5 to 8% at the recommended score of 3.5 at calving.
- Bioeconomic modelling (Chapter 7, page 118) highlighted a trade-off between individual animal performance and herd-level productivity. In both regions the utilisation rates that maintained land condition were the most productive and profitable over the longer-term. This was primarily

due to feedback of higher pasture utilisation leading to reduced land condition and pasture growth which led to decreased climate resilience, needing to destock sooner and more often during dry periods, and increased costs with more destocking and rebuilding required to maintain herd numbers. In the Barkly, the optimal median annual utilisation rate for profitability was 18-23%, aligning with its safe rate of 20%. In the Burdekin, with lower land resilience and more periods of successive years with below-average rainfall, highest profitability was achieved at 18-20% utilisation, which is lower than its assumed safe rate of 25%. This underscored the importance of maintaining high land condition as a buffer against climatic variability, often requiring conservative utilisation rates. Bioeconomic modelling indicated that the most profitable breeder herds were those which were able to maintain productive stocking rates in good years and still get through the next dry period without needing to destock. They achieved the most productive and profitable long-term balance between pasture offtake and pasture growth – essentially the sweet spot of breeder herd performance.

- For both regions the most profitable and sustainable utilisation rates were those that maintained good land condition. They had the maximum stocking rate possible without causing appreciable long-term reductions in land condition, or as Ian McLean describes "*run as many as you can, but no more than you should*." Trying to achieve higher stocking rates in wetter years led to subsequent overutilisation and land condition decline when drier years returned. The short-term opportunity cost in not utilising occasional large amounts of forage available during periods of high rainfall, was more than repaid by the land condition buffer that limits or even prevents crashes in herd production when the next drought was encountered. Without this buffer, costly periods of drought feeding, destocking or high mortality rates were more frequent, and additionally, they limited future herd productivity and profitability. Hence the conservative risk adverse approach to manage the unpredictable and variable climate risk was the most profitable and sustainable over the longer term.
- Anecdotal evidence from producers who have reduced pasture utilisation to increase breeder performance was collated incidentally as part of the project. Although not part of the project objectives, producers would often share their experiences with the project team after hearing about the Sweet Spot project. This provided a lot of insights into the potential ways to implement optimal pasture utilisation, and the flow on effects to other parts of the business, including more options for pasture management, improvement in land condition, enhanced breeder performance and consistent paddock production with lower supplement and other costs with the same or higher profits. Producers in the Victoria River District at the 2024 Kidman Springs BeefUp Forum (see transcript Chapter 14.8, page 441) discussed how after the dry years in 2019 reductions in stocking rates on their stations led to 20-30% increases in weaning rates, reduced mortalities, higher growth rates, shorter turnoff times, with similar paddock level production, reduced supplementation costs, and enhanced profitability, better pasture growth response to rainfall, recovering land condition, and enhanced their flexibility to manage stock to incorporate wet season spelling and fire for vegetation management. Furthermore, they anticipated that the improved land condition would lead to enhanced carrying capacity so that additional stock may be sustainably carried in the future. Similarly, a large Barkly station increased the watered area to reduce stocking rates which enabled them to get through the very dry years of 2018-2020 without having to destock, with the lower pasture utilisation rates leading to increased production / head, making their herd numbers and production more

resilient to drier years, and allowing them to wet season spell without overgrazing other paddocks.

Benefits to industry

The findings provide clear evidence that pasture utilisation, nutritional availability, and strategic management, such as management of body condition score and lactation, are critical determinants of reproductive performance and long-term herd sustainability in northern Australian beef systems. This report provides an evidence base for economic evaluations of different pasture utilisation rates, enabling more balanced management decisions that consider both short-term productivity and long-term sustainability, optimising overall long-term enterprise profitability and resilience.

Future research and recommendations

Producers at bioeconomic modelling feedback workshops recommended:

- expanding the regional scope of bioeconomic modelling of the economics of pasture utilisation to additional production environments, such as Katherine and the Victoria River District
- using CLEM to model case studies Sweet Spot in action where of commercial enterprises have successfully adjusted stocking rates to enhance breeder performance, while maintaining or enhancing land condition, herd production and profitability, to see if CLEM can replicate what they found and to develop producer case studies for use in extension materials
- in regions where there is little empirical data on safe utilisation rates for different land types, such as Alice Springs, work with producers with good land condition and stocking rate records to retrospectively model safe utilisation rates for different land types
- Industry stakeholders also highlighted the need to improve data accessibility and decision-support tools, including the development of user-friendly versions of CLEM and the release of regional baseline herd files for other users
- using CLEM to examine the economics of herd management and infrastructure development options such as weaning and mating, segregation by calving date, number of musters, supplementation, waters and fencing

Further bioeconomic modelling is advised to test the sensitivity of the CLEM bioeconomic modelling findings to:

- assumed rates of land condition change and thresholds of safe and upper and lower levels of utilisation that promote land condition recovery and decline
- varying the climate windows used

Extension and adoption materials should be developed:

- Producer case studies showcasing successful implementation of better pasture utilisation to enhance breeder performance and profitability
- How to guides to assist producers to identify if they could improve breeder performance through management of stocking rates including:
    - Minimum herd data collection and monitoring requirements and methods to determine breeder herd performance
    - Published easily accessible regional benchmarks of potential breeder performance

- Potential approaches to enhance breeder performance through managing pasture utilisation
- Published easily accessible safe levels of utilisation for different land types, equivalent stocking rates and how this varies with percentile rainfall

Glossary of terms and acronyms used in this report

Term / acronym	Description
AE	Adult equivalent. Measure of pasture intake of a standard animal - 450 kg, 2.25-year-old Bos taurus steer with zero weight (W) change and walking 7 km/day on level ground
Aged cow	Cow with diminishing ability to forage or diminishing fertility. Start usually ranges from 8 years of age where environments cause early wearing, fracture and loss of teeth, to 13 years of age when stores of ova become depleted in some cows. Cows older than 9 years were considered aged
Annual pregnancy rate	Percentage of cows in a management group (mob) that became pregnant within a one-year period. For continuously mated herds, this included cows that became pregnant between September 1 of the previous year and August 31 of the current year
Barkly Tablelands	The Barkly Tablelands comprises extensive Mitchell Grass Downs located in the central east of the NT, from the Northern Territory / Queensland Border region west to Tennant Creek and north to Elliot
Bioeconomic modelling	Computerised analytical framework which integrates biophysical and economic models. In this project, GRASP and CLEM models were integrated to predict whole-of-property outcomes of interactions between land, cattle, pastures, finances and climate
BCS	Body condition score. Subjective assessment of the body tissue (fat and muscle) reserves of an animal. Five-point scale (1=poor 2= backward 3=moderate 4=forward/good 5=fat)
Bos indicus	Sub-species of cattle originating in tropical southern Asia. Brahmans are derived predominately from *Bos indicus* cattle.
Bos taurus	Sub-species of cattle originating in Europe, and includes British and continental breeds
Breeder	Synonym for cow in a breeding herd
Burdekin region	Dry Tropics natural resource management region of north Queensland. Includes the catchment of the Burdekin River and the coastal streams in the Townsville-Bowen area
Carrying capacity	The safe number or safe stocking rate that can be carried on average over the long-term while maintaining or improving the underlying resource base
CashCow	Northern Australia Beef Fertility Project: https://www.mla.com.au/contentassets/6428c467b1904744b287e539b50f17e7/b.nbp.0382_final_report.pdf
CLEM	Crop livestock enterprise model
CCI	Comprehensive climate index: a heat load index that is applicable to wide range of environmental conditions. This index includes adjustments for ambient temperature, relative humidity, wind speed and solar radiation. Described in full by Mader et al. (2010)

Controlled mating	Non-continuous mating. The longest controlled mating is 7 months. Five months may allow mating after first weaning. Three months enables most calving to be complete before the next mating. Six weeks enables a maximum pregnancy rate of 90% in healthy cycling beef heifers and cows
Cool Calves	Reducing calf loss from exposure project: https://www.mla.com.au/contentassets/4ee7b12dbd3f4f50b72ea09906262780/b.gbp.0031-final-report-deliverables-december-2024-deidentified.pdf
Drought feeding	Feeding molasses with 8% urea (M8U) during droughts to limit or prevent mortality due to inadequate forage supplies. Only used for the Burdekin herds
Empirical dataset	The field derived cattle performance data and related simulated pasture growth and utilisation data
First-lactation cow	Cow during the period when the majority of her cohort is experiencing their first lactation
Foetal and calf loss	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
GBA	Grass basal area
GRASP	Pasture growth model, used to simulate grazing systems, including pasture growth, intake by grazers and pasture utilisation
GRASP Calibrator	Software that runs the pasture growth model GRASP and allows easy visualisation of model versus observed outputs to enable calibration of the model to observed datapoints
Gross profit	Annual income from cattle sales minus costs of purchasing cattle plus the difference in the value of cattle present at the end and beginning of the financial year
Gross profit margin	Gross profit minus annual variable costs
HB	Hold breeder numbers relatively constant in bioeconomic modelling
Land condition	Condition of pasture, woody plants and soil, an indicator of ecological function and potential productivity. A = Pristine to D = Very poor (severe erosion or scalding, weed predominance)
Maiden heifer	Heifer prior to first mating
Mature cow	Cow after the time when her cohort has weaned their second age group of calves
Mineral supplementation	Mineral addition to the diet to balance primary deficiencies, speeding up digestion, thereby increasing the rate of pasture or hay consumption, thus energy intake
Mortality rate	Cattle that have died as a percentage of the number known to be alive at a previous time
Overhead costs	Annual fixed costs, such as wages of permanent staff, rates and insurance, not directly related to individual animal expenses (i.e. variable costs)
Pasture growth	Annual pasture growth between October 1 and September 30

Pasture utilisation	Annual pasture utilisation between October 1 and September 30 = estimated intake / simulated growth
PB	Purchase breeders post drought to rebuild breeder numbers in bioeconomic modelling
Pregnant within 4 months of calving while lactating (P4M)	Lactating cows that became pregnant within four months of calving
Profit	Gross profit margin minus overhead costs
Relative utilisation rate	The actual annual utilisation rate divided by the safe utilisation for that land type
Safe utilisation rate	The utilisation rate of pasture that maintains or improves land condition over the long-term. It varies with land type. In northern Australia for native pastures it usually varies between 10 and 25% of annual pasture growth. It can be as low as 0-10% for spinifex (low palatability) or inaccessible pastures
SS	Sell (destock) 1- to 3- year-old pre-market age steers in response to forage shortages in bioeconomic modelling
Stocking rate	The number of animals or adult equivalents per unit area. Expressed here as AE/km^2
Sweet Spot	The pasture utilisation rate that optimises animal production and profits over the long-term
THI	Temperature Humidity Index. Environmental comfort index calculated from ambient index (THI) temperature (T) and relative humidity (H) THI = 0.8T + H * (T - 14.4) + 46.4.
TSDM	Total standing dry matter
Uncontrolled mating	Breeding females are exposed to entire males year-round so mating occurs whenever cows cycle.
UR	Pasture utilisation rate
Variable costs	Per-individual animal expenses incurred for activities such as mustering, weaning, castration, tags, supplementation, husbandry treatments and the transport and marketing costs associated with selling and purchasing cattle
VRD	Victoria River District, south west of Darwin, west of Katherine to the WA border
Watered area	The area within a paddock within a defined distance from a water source where animals can access drinking water
Weaning rate	Cows weaning a calf as a percentage of those mated the previous year. Usually difficult to calculate as herd restructures and culling during pregnancy often prevents accurate information being available. Can be derived from multiplying annual pregnancy rate by (1-foetal and calf loss rate)

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1. Background

1.1 Industry problem research is addressing

Much of northern Australia's beef cattle production is based on the grazing of rangelands. These production systems are predominantly breeding operations and are characterised as extensive, low-input grazing systems relying on the utilisation of native pastures, with some areas augmented by introduced legumes. Substantial knowledge exists regarding the effects of biophysical traits, nutrition, breed characteristics and environmental conditions on reproductive performance (Burns et al. 2010;Fordyce et al. 2022; McCosker et al. 2023b; Bell and Sangster 2022). However, the specific impact of pasture utilisation rates on breeding cows remains poorly quantified. Instead, insights are often extrapolated from studies on growth performance in steers or non-breeding females (O'Reagain *et al.* 2011). Diet quality declines as pasture utilisation increases, leading to decreased intake (White 2011) and poorer nutritional outcomes for cattle. Most research on the impacts of pasture utilisation has been based on grower cattle. The Sweet Spot project sought to collate evidence that pasture utilisation could be optimised to enhance breeder performance and production in these extensive rangeland systems.

1.2 What is pasture utilisation?

Safe pasture utilisation is usually used in a pasture sustainability context as the level of offtake that will maintain the underlying resource base (e.g. McKeon *et al.* 1994, Johnston *et al.* 1996, Hall *et al.* 1998, Hunt 2008, Walsh and Cowley 2011) and is defined as the proportion of annual pasture growth that can be consumed by domestic livestock while maintaining or improving the underlying pasture resource base (Walsh and Cowley 2011). But pasture utilisation also affects animal performance and production through short-term and longer-term feedbacks on the pasture feedbase (Figure 1-1). What is optimal for long-term pasture sustainability may not be optimal for animal production from a paddock over the short term.

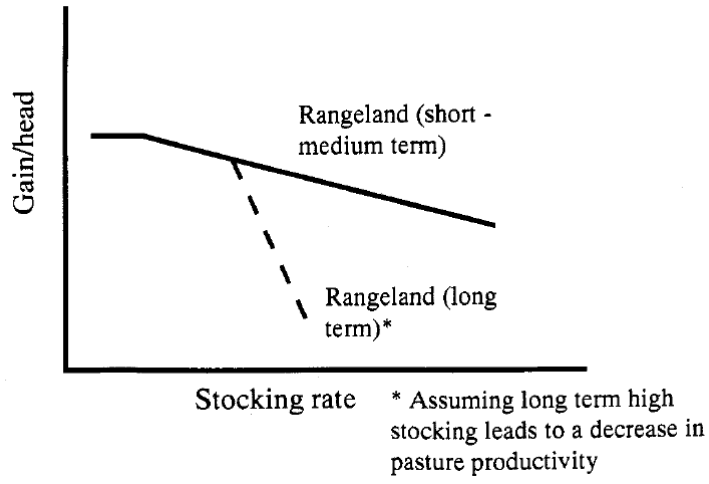


Figure 1-1: Hypothesized short and long-term relationship between stocking rate and animal production in rangelands. From Ash and Stafford Smith 1996

1.2.1 Short-term effects of pasture utilisation on animal performance

In the short-term (during a season, and the carryover effects to the following year) higher levels of pasture utilisation reduce diet quality (Ash *et al.* 1995, White 2011) as the more nutritious parts are selectively grazed from the pasture across a season (Andrew 1986, White 2011). Quantity of forage can also become limiting under high pasture utilisation (Ash and Stafford Smith 1996). Most studies have looked at the *short-term* impacts of pasture utilisation on *grower* animals (e.g. reviewed in Ash and Stafford Smith 1996, Hunt *et al.* 2014). Limiting diet quality and quantity act to reduce the intake of forage leading to lower liveweight gains (Ash *et al.* 1995, Ash and Stafford Smith 1996, Fynn and O'Connor 2000, Cowley *et al.* 2007).

Empirical studies on the impacts of stocking rates and pasture utilisation on *breeder* herds though fewer in northern Australia, have also detected short-term performance responses to pasture utilisation (e.g. Smith *et al.* 2001, Cowley *et al.* 2007, Hunt *et al.* 2013), reflecting the short-term impacts of diet quality and quantity on breeder weight (Smith *et al.* 2001, Gillen and Sims 2002, Cowley *et al.* 2007) and body condition score (Hunt *et al.* 2013), time to fall pregnant (Cowley *et al.* 2007), pregnancy and weaning rates (Jayawardhana *et al.* 1992, Cowley *et al.* 2007), weaner weight (Smith *et al.* 2001, Gillen and Sims 2002, Hunt *et al.* 2013) and breeder mortality (Jayawardhana *et al.* 1992, Smith *et al.* 2001). Lower breeder performance at higher stocking rates has been extensively demonstrated elsewhere (e.g. Winder *et al.* 2000, Gillen and Sims 2002).

However, the lower herd performance resulting in lower LWG produced / breeder, is usually offset by the increased number of cows at higher stocking/utilisation rates so that highest production of LWG / ha is found at highest stocking or utilisation rates (Smith *et al.* 2001, Gillen and Sims 2002, Hunt *et al.* 2014).

However, performance is more affected by high stocking rate / utilisation in drier years, so that production fluctuates more year to year at higher utilisation (Smith *et al.* 2001, Gillen and Sims 2002, Hunt *et al.* 2013). In drier years there can be no (Gillen and Sims 2002) or greatly reduced (Hunt *et al.* 2013) additional calf production at higher stocking rates. In these studies, reduced livestock performance at higher stocking rates was purely due to short-term differences in pasture due to competition between too many mouths, rather than due to longer term changes in pasture composition and growth. These breeder studies were all relatively short-term – 4 to 9 years in duration and there was no effect of high pasture utilisation on pasture condition, pasture growth and carrying capacity during those studies. Rangeland systems are resilient to high utilisation during wetter periods (Milchunas *et al.* 1994) until extended multi-year drier periods lead to declines in pasture and soil condition (Ash *et al.* 2002, O'Reagain *et al.* 2022).

1.2.2 Short-term effects of pasture utilisation on pastures

In the short-term high utilisation can lead to low end of season ground cover and residual TSDM (Ash *et al.* 1997, Hunt *et al.* 2013), leading to higher runoff (McIvor *et al.* 1995b, Scanlan *et al.* 1996, Bartley *et al.* 2010), lower infiltration (Roth 2004, Fraser and Stone 2016) higher soil evaporation and lower rainfall use efficiency and pasture growth the following growing season (Ash and McIvor 1998). High utilisation over the growing season is particularly damaging for native grasses and can lead to reduced pasture growth the following growing season (Ash *et al.* 1997, Ash and McIvor 1998, Ash *et al.* 2011) due to removal of growing points and depletion of reserves from continually regrowing following repeated grazing (Mott *et al.* 1992), reducing plant survival (Hunt 2008). While there was little effect of *dry* season utilisation on native pasture on a Eucalypt woodland tallgrass

savanna at Katherine (Ash and McIvor 1998), high utilisation in the *dry* season reduced grass basal area the following wet season on an alluvial grassland in the VRD (White 2011).

1.2.3 Long-term effects of pasture utilisation on pastures

Despite studies all finding highest animal production at the highest stocking rate, they recommended more conservative stocking to protect the pasture resource over the longer term (Smith *et al.* 2001, Sims and Gillen 2002, Hunt *et al.* 2013). In the longer-term (over multiple years or decades) high pasture utilisation leads to declines in land condition (Tothill and Gillies 1992, Shaw *et al.* 2007, Karfs *et al.* 2009,) characterised by reduction in grass basal area (McKeon *et al.* 1990, Ash *et al.* 2011) and changes in pasture composition to fewer preferred decreaser palatable perennial grasses and more less preferred increaser perennial grasses, legumes, forbs and annual grasses (Ash *et al.* 1995, Ash and McIvor 1995, McIvor *et al.* 1995b, Ash *et al.* 2011, O'Reagain *et al.* 2022). The higher proportion of forbs and annual grasses in poorer condition pastures can be associated with higher pasture quality (Ash and McIvor 1995) driving higher liveweight gains in B than A condition pastures with low to moderate levels of utilisation (Ash *et al.* 1995). But poorer condition pastures have lower pasture growth (Ash and McIvor 1995, McIvor *et al.* 1995b) and combined with higher detachment rates (Cowley 2017) contribute to lower end of season yields (implied in Ash *et al.* 1995) lower ground cover and more bare exposed soil (Ash *et al.* 1995, Hunt *et al.* 2013). This can drive the formation of physical soil crusts on bare patches with lower infiltration and higher runoff and erosion (Bridge *et al.* 1983, Mott *et al.* 1979, Roth 2004) and in extreme cases severe erosion and gullying (Lewis 2004, Bartley *et al.* 2006, McCloskey *et al.* 2016). The lower pasture growth and higher detachment rates also contributes to less available forage, that disappears faster through the season, both factors compounding to reduce carrying capacity. This can be accompanied by increases in unpalatable plants, weeds, exotic grasses (Tothill and Gillies 1992, Shaw *et al.* 2007, O'Reagain *et al.* 2022) and both native and exotic woody plants (Shaw *et al.* 2007) through the effect of less competition from the pasture layer and the reduced fire incidence due to lower fuel loads.

1.2.4 Long-term effects of pasture utilisation on animal performance

Poor land condition resulting from long-term overgrazing reduces rainfall use efficiency, potential pasture growth and carrying capacity. Poorer condition pastures can have higher diet quality and providing pasture quantity is not limiting can drive higher liveweight gains (Ash *et al.* 1995) albeit for fewer cattle due to reduced carrying capacity. In high rainfall years at higher utilisation LWG/ha is highest on poor condition country but in poor rainfall years LWG/ha is lowest (Fynn and O'Connor 2000, Ash *et al.* 2002). This increases the variability in animal production from poor land condition compared to good land condition. In low rainfall years poor condition pastures require more drought feeding (MacLeod *et al.* 2004) or destocking and receive discounted prices for poor condition cattle (Wilson and MacLeod 1991, O'Reagain *et al.* 2011, O'Reagain *et al.* 2022).

Even if cumulative production from poor condition pastures is higher with high utilisation, as was with the case for steers at Wambiana grazing trial and breeder production in Gillen and Simms (2002), the additional costs and reduced prices received meant that the highest utilisation treatments were less profitable at Wambiana. There was little additional profit gain at high stocking rates in Gillen and Simms (2002), but a more variable annual return and more risk to the resource base. The pasture utilisation for optimal production / ha (Figure 1-2) will change as land condition declines over the longer term and the relationship between stocking rate and performance per head gets steeper (Figure 1-1).

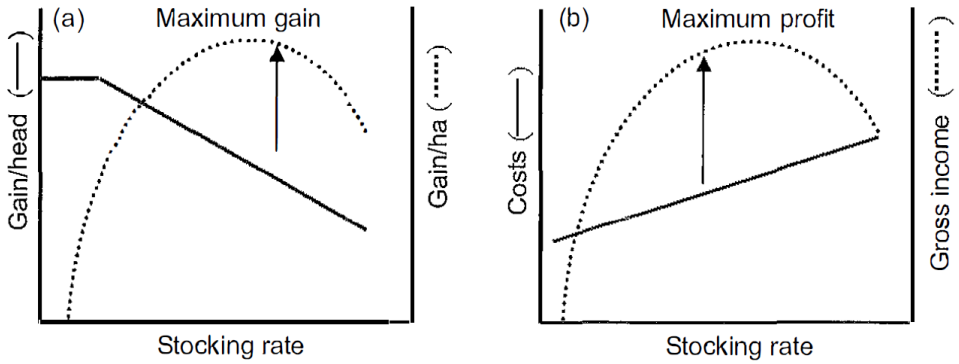


Figure 1-2: Effect of increasing stocking rate on animal gain per head and per ha (a) and on economic performance (b) based on the model of Jones and Sandland (1974). In (a) the solid line represents liveweight gain per head and the dashed line liveweight gain per ha. In (b) the solid line represents the costs of production and the dashed line gross income. From Ash *et al.* 2002

We know of no breeder trial that has continued long enough for longer-term feedbacks of pasture utilisation on the productive capacity of a system. This has been problematic for messaging to industry when most breeder production studies showed higher stocking rates although more variable in production year to year, were more profitable, because during the project lifetimes the seasons were relatively good and there were few effects on the pasture feedbase (e.g. Smith *et al.* 2001, Gillen and Sims 2006, Hunt *et al.* 2013). The slow, imperceptible changes in rangelands year to year, make the impact of stocking rates on rangeland condition and production difficult to detect by managers, because there is relatively limited short-term feedback from their management. This is compounded in regions dominated by corporate pastoral operations that regularly move managers between locations (every 5 to 10 years), so they don't have an understanding of the long-term variability in local rainfall and pasture growth and never see the feedbacks of their management on rangeland condition and animal production.

The Wambiana grazing trial, although with steers, is an exception to this. Its' longer duration through multiple dry periods allowed declines in pasture condition, palatable perennial grasses and potential pasture growth to develop under higher stocking rates. Because it takes multi year periods of consecutive below season rainfall to see longer-term impacts on pasture growth, studies have taken a space for time substitution approach to examining the long-term impacts of high utilisation, by comparing the performance of livestock grazing pastures in different land condition (Ash *et al.* 1995, Fynn and O'Connor 2000). Modelling approaches have also been recommended to help understand and test the longer-term impacts of grazing (Ash *et al.* 2004). These field studies were then used to populate modelling assumptions used to model the economic impacts of long-term high utilisation and resulting poor land condition (MacLeod *et al.* 2004). It is only recently that a model can simulate the long-term utilisation impacts of pasture utilisation on land condition as well as individual animal performance based on available diet. The Crop Livestock Enterprise Model (CLEM, https://www.apsim.info/clem) can be used to explore the impacts of multi-decadal climate variability, on pasture condition and growth and how that impacts diet quality, intake, individual animal performance, reproduction, mortality, herd dynamics and production / ha, costs, returns and profits.

1.3 Project questions

The Sweet Spot project investigated if breeder performance and production could be optimised through better pasture utilisation in extensive northern Australian breeder herds. This study addressed this question through multiple approaches that addressed both short and longer term direct and indirect impacts of pasture utilisation on breeder performance and production.

1. We collated and reanalysed breeder herd datasets from across northern Australia to look for trends in retrospectively modelled pasture utilisation with breeder *performance*. There were many pre-existing breeder herd datasets in northern Australia where pasture utilisation was not explicitly examined as a factor potentially influencing performance. Stand-alone they provide little insight, but combined with other datasets they could contribute to a meta-analysis of pasture utilisation impacts on breeder performance across northern Australia. Some of the pre-existing breeder datasets were explicitly designed to look at stocking rate or utilisation impacts, but this was the first time that pasture utilisation was more accurately estimated through simulation of pasture growth and intake was more accurately calculated based on measured performance.
2. To examine pasture utilisation rates for optimal breeder *production* that included multi-decadal climate variability and feedbacks on land condition we used a bioeconomic modelling approach using the CLEM model.
3. We sought feedback from cattle producers about the modelling and broader project results, and the implications for recommended herd management practices to enhance breeder performance and production, as well as potential adoption pathways and next steps.

1.4 Target audience

The northern Australian extensive beef cattle industry relies on both the native and improved pasture feedbase. The NT and WA feedbase includes relatively unmodified natural ecosystems, with low levels of tree clearing, although exotic pasture species such as *Bothriochloa pertusa* in North Queensland and *Cenchrus ciliaris* in central Australia are naturalising large areas. Native pastures are not adapted to high levels of grazing and can sustain only relatively low levels of pasture utilisation between 5 to 25% of pasture growth (Johnston *et al.* 1996, Hall *et al.* 1998, Ash *et al.* 1997, Hunt *et al.* 2013, Walsh and Cowley 2011).

1.5 How will research results be used?

Results will feed into management recommendations for extensive breeder herd management in northern Australia.

2. Objectives

The participant will deliver:

- A meta-data database of breeder production data collated from a mixture of research and commercial herds from northern Australia (see additional details for example data sources) containing:
    - Reproduction indices recalculated using a consistent methodology across all datasets, and related seasonal, environmental and herd management records

    - Pasture utilisation data that permits comparison and analysis.
- An estimation of the impact of pasture utilisation on reproductive performance and body condition score at pregnancy diagnosis, after accounting for the effects of other factors such as seasonal conditions.
- An analysis of pasture utilisation resulting in high long-term breeder reproductive performance, breeder herd productivity and modelled profitability for particular regions and pasture types. A lead indicator should be developed that flags when production may be compromised and hence supplementation required.
- Algorithms that predict reproduction based on grower LWG and utilisation that are validated for regions and land types and incorporated into bioeconomic models.
- Bioeconomic analysis of management practices that will achieve the desired pasture utilisation, breeder herd productivity and enterprise profitability.
- Content relating reproductive performance to stocking rate management for regions and pasture types for incorporation into training courses such as the EDGE *network* packages—Grazing land management, Breeding, Business, Nutrition and Grazing fundamentals.
- Recommended extension and adoption program - including consideration of links to the Bred Well Fed Well program.
- Records of producer consultation, engagement and networking.
- Final report.
- Scientific publications – Utilisation impacts on reproduction performance and bioeconomic scenario modelling of pasture utilisation on herd economics.

3. General Methodology

3.1 Study components and approach

The Sweet Spot project took two broad approaches to investigating utilisation impacts on breeder performance. The first was a meta-analysis of previous breeder study empirical datasets from across northern Australia. This investigated the short-term effects of pasture utilisation on breeder herd performance per head. The second was through bioeconomic modelling of the longer-term implications of pasture utilisation on land condition, breeder production per area and profits (Figure 3-1). The bioeconomic modelling enabled the exploration of the longer-term impacts of pasture utilisation and climate variability on land condition and carrying capacity, herd dynamics, animal production, and consequent income, costs and profits.

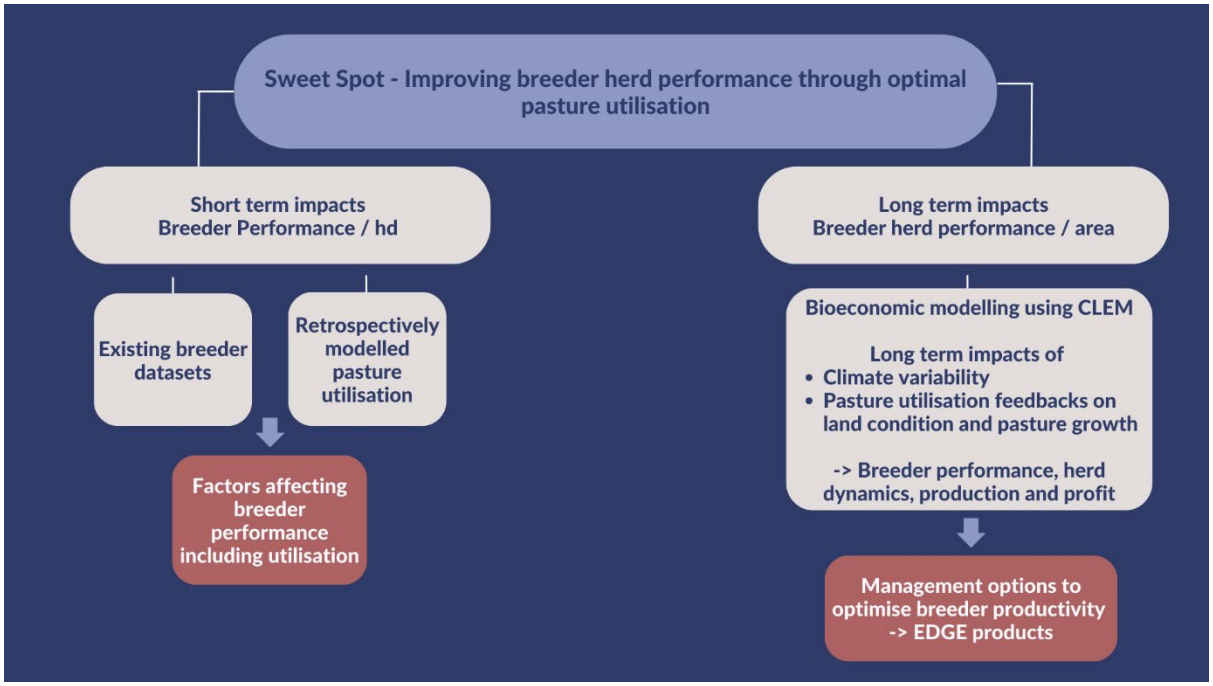


Figure 3-1: Sweet Study approach to examining the impacts of pasture utilisation on breeder performance in the short and longer term

3.1.1 Empirical data selection

3.1.1.1 Dataset selection criteria

Data sets from across northern Australia were assessed for their suitability for inclusion in the project, based on predefined criteria. A complete list of considered datasets is presented as an appendix to this report (Appendix 14.1, page 300).

All available breeder herd datasets were evaluated according to the availability and reliability of site-specific individual cattle and paddock records (required to calculate intake and breeder performance), as well as the presence of relevant land type models to support pasture growth and utilisation modelling.

The minimum requirements for dataset inclusion were:

- Individual animal data available (not just herd summaries) enabling the consistent calculation of reproduction indices using a standardised method across all datasets.
- Known numbers by class of all cattle present in each paddock, to enable the calculation of stocking rates, and class- and paddock-scale intake.
- Paddock infrastructure and mapped land types available to calculate land type watered area for deriving stocking rates and paddock scale safe utilisation rates.
- Pasture growth models available for the land types in herd paddocks.
- Animals were not production supplemented.
- Data for at least two years (preferably three years or more) to cover the range of seasonal conditions, and a greater likelihood of experiencing a range of utilisation rates for the herd.

In addition to the above, datasets which had the highest level of confidence in derived utilisation rates contained the following information:

- Total standing dry matter (TSDM) measured in the paddocks for use in validation of simulated pasture growth.
- Locally calibrated land type models (SWIFTSYND sites).
- No within-year paddock movements; mobs were continuously grazed in individual paddocks.

For datasets that met the inclusion criteria, supporting datasets for pasture and utilisation modelling and cattle metadata analysis were sought. Supporting datasets included:

- GIS analysis of paddock land type watered area, including area of paddocks within different distances from water, which was used to weight paddock observations of TSDM before use in calibration of simulated paddock growth
- Supplementation records
- Faecal NIRS records
- LWG data from grower animals in the same paddocks or nearby at the same time
- Location and timing of fire
- Available soil phosphorus (Zund 2022)
- Provision of paddock or 5km watered area shapefiles to the Queensland Department of Environment, Science and Innovation (QDESI) for satellite woody, ground and green cover extraction.

3.1.1.2 Description of herd dataset – table of variables

To identify datasets suitable for inclusion, researchers across northern Australia were contacted to identify what data they were willing to share with the project. The review process assessed the availability of the required animal performance records and site-specific stocking records, which were both necessary for calculating intake and breeder performance. Only datasets that met these criteria were selected, ensuring confidence in the accuracy and comprehensiveness of the subsequent analysis.

Approximately 166 sites from 25 breeder herd datasets were reviewed. Of these, 80 sites from 21 breeder herd datasets were found to be suitable for modelling pasture utilisation (Figure 3-2). In some studies, only had a subset of sites that were suitable for modelling pasture growth and utilisation, such as North Australian Beef Fertility Project (McGowan *et al.* 2014) and the NT Heifer Study. The cattle datasets spanned over a 30-year period from 1991 to 2021, with the number of years represented in each dataset varying from 2 to 14, averaging 5.7 years per site.

The main reasons datasets were excluded was a lack of records in animal numbers by class in the paddocks, or where paddocks were rotationally grazed but it was unknown if other animals also grazed the paddocks at the same or other times (Table 3-1). The 80 sites identified as suitable were located on 22 different stations from 4 broad regions (Table 3-2). Some sites were used for more than one study (Table 3-3). Of the 80 suitable sites we modelled pasture growth for 60, and 59 of these were combined with cattle data for analysis of factors affecting the reproductive performance of females (Table 3-3). The Kidman Springs dataset was not included in the analysis due to time constraints but is still considered suitable. Kidman Springs has multiple studies from the 1990s to current day, on a range of land types not represented in the current dataset, and for these reasons it is recommended that it be collated and modelled at a future date.

The sites included two department-operated, government owned research stations (Old Man Plains and Swans Lagoon) and commercial stations. Some of the commercial herd datasets used in this project may not be representative of commercial herd performance because they were closely managed research herds often in smaller than commercial sized paddocks. These included Mt

Sanford, Pigeon Hole and Thalanga. The datasets were not chosen for their representativeness of commercial herd performance, but rather to get a broad range of pasture utilisation rates across as broad an area as possible to test the impact of pasture utilisation on breeder performance.

Table 3-1: Datasets found to be unsuitable for inclusion in the Sweet Spot Project

Study	Location	Reason excluded
Beef CRC	Brian Pastures, Brigalow, Toorak	Uncertainty re stocking rates, or if other animals were also moving through multiple multi-grazed paddocks
Spyglass	Spyglass Research Station, Charters Towers	
Cash Cow sites	142 mobs from across northern Australia, modelled 10/72 sites	
Heifer Trial sites	10 sites across the NT, modelled 3/10 sites	

Table 3-2: Regional distribution of sites with suitable data for inclusion in the Sweet Spot Project

Region	Count of Stations	Count of Sites
North East Qld	5	11
South NT	4	9
Central NT	5	15
North NT	8	45
Grand Total	**22**	**80**

Table 3-3: Study datasets meeting assessment criteria and included in the Sweet Spot Project

Study	Years	No. of sites	No. of years	No of cattle	Study Source / related publications
Paddock Power	2020-22	2	6	1620	Internal NT DAF, UQ; Pearson *et al.* 2023
Reducing calf loss from exposure (Cool Calves)	2019-22	2	8	1478	Internal NT DAF, UQ; McCosker 2023
Katherine Research Station lease Senepol and Calf Watch	2012-22	2	19	4117	Internal NT DAF; Schatz *et al.* 2022
OMP Quality Graze	2011-22	5	55	5685	Internal NT DAF
Validation and demonstration of a diagnostic tool for phosphorus status of beef cattle	2011-13	1	3	1605	Quigley *et al.* 2015
North Australian Beef Fertility Project – 'Cash Cow'	2009-11	9*	29	17007	UQ; McGowan *et al.* 2014
NT Heifer study	2004-12	3	11	10683	Schatz and Hearnden 2008, Schatz 2013, Internal NT DAF
Pigeon Hole Project	2003-07	12	60	10306	Hunt *et al.* 2013
Lake Nash Breeder Herd Efficiency	2000-02	2	7	1486	NT DPIFM 2007
Narweitooma Water medication	1998-01	2	6	1366	Hill 2003

Alexandria Nutrition effect on breeders	1997-01	4	16	6696	Savage 2004
Swans Lagoon Stocking Rate Demo	1994-99	4	24	7036	Smith *et al.* 2001
Thalanga Stocking Rate Demo	1994-99	3	18	3957	Smith *et al.* 2001
Mt Sanford Stocking Rate & Utilisation Demonstrations	1993-00 2001-06	8	82	6326	Cowley *et al.* 2007, Hunt *et al.* 2013
Mt Riddock Benchmarking	1991-96	1	6	6839	Coventry 2013, Coventry *et al.* 2007
Grand Total		**60**	**350**		

* Note only 8 of the 9 Cash Cow sites were included in the reproductive performance analyses and chapters, but data from all nine sites is included in Chapter 4 and Appendices 14.2 and 14.3.

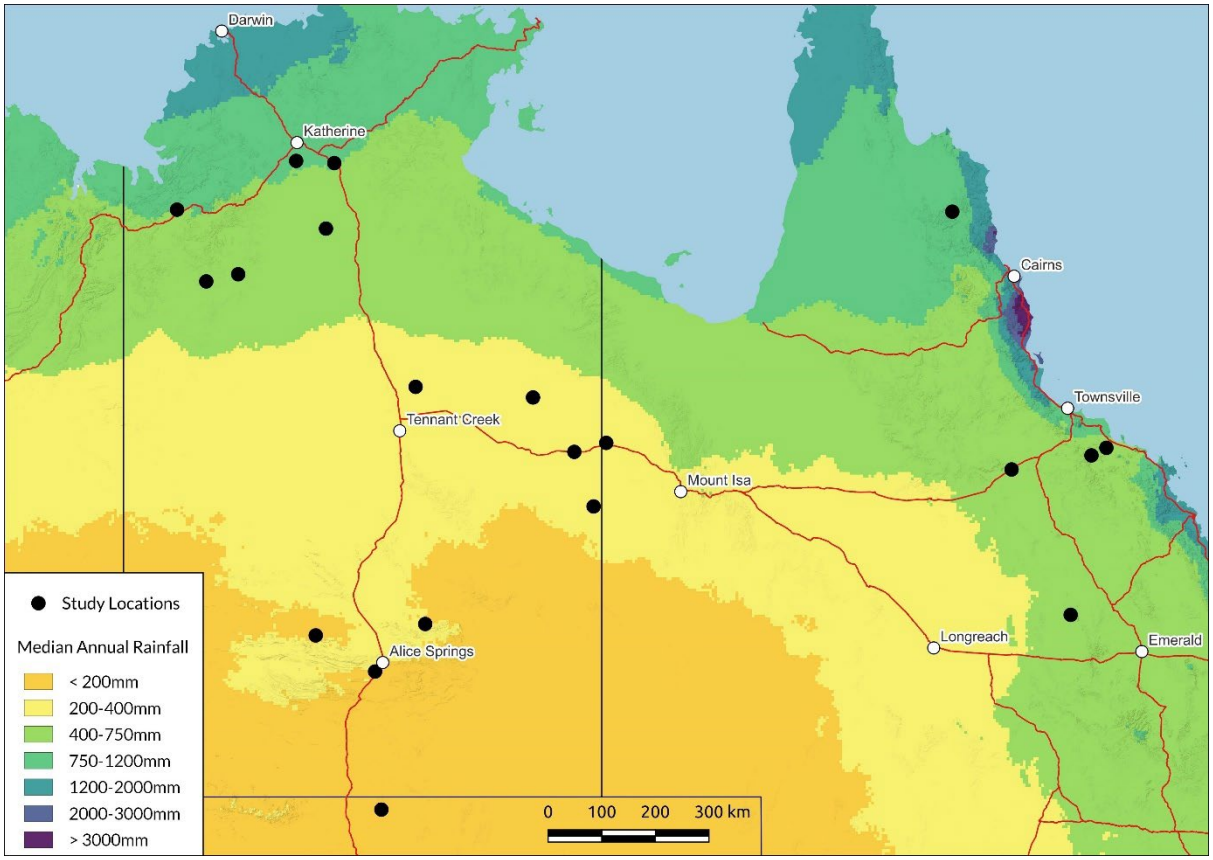


Figure 3-2: Locations of the 60 Sweet Spot sites across northern Australia. These sites represent datasets that met assessment criteria and were included in the Sweet Spot Project analyses.

3.1.2 Statistical analysis of empirical datasets

Statistical analyses of the breeder datasets from across northern Australia were performed to identify the main factors which influenced rates of annual pregnancy, lactating cows pregnant within four months of calving, annual weaning and foetal and calf loss. As per Appendix 14.4, there were many possible factors which potentially affected these rates. The data sets were analysed with mixed (random-effects) models (Robinson 1987), and generalised linear models (McCullagh and Nelder 1989) with the Binomial distribution and logit link, all using Genstat (2024).

3.1.3 Bioeconomic modelling

A bioeconomic modelling framework, consisting of the GRASP pasture and animal production model (Littleboy and McKeon 1997) and the Crop Livestock Enterprise Model (CLEM), was used to quantify the outcomes of a range of pasture utilisation rates on land condition, herd productivity and enterprise finances, over approximately forty years of historical climate. This was done for two very different breeding herds. One was a large breeding property typical of the Barkly Tablelands of the Northern Territory, and the other was a much smaller breeding property typical of the Burdekin region of north-east Queensland.

3.1.4 Industry feedback and input

Industry workshops were built into the project to get feedback and input into the project results and bioeconomic modelling, as well as interpretation of the project results to derive relevant herd management recommendations.

4. Pasture utilisation modelling

4.1 Methodology

4.1.1 GRASP pasture growth model

The point-based GRASP model (Littleboy and McKeon 1997, McKeon *et al.* 2000, Rickert *et al.* 2000) was developed for modelling pasture growth of northern Australia pastures and has been used successfully to simulate pasture growth and pasture utilisation in Queensland (Day *et al.* 1997) and the Northern Territory (Cobiac 2006, Walsh and Cowley 2011).

For the 'Sweet Spot' project, pasture utilisation was defined as the proportion of annual pasture growth eaten by livestock, determined on a growing season basis (October 1 to September 30).

GRASP Calibrator (version 1.33 Build 7177) was used to calibrate pasture growth through the adjustment of parameter values to match each site TSDM and satellite derived green ground cover. Once predicted TSDM and green ground cover matched site observations, Cedar GRASP (GRASP CEDAR version 2.1.02 date 11/3/2021) and cedar default parameter file (cedardefault_v_2_1_02.prv dated 3/4/2020) was then used to simulate daily, monthly and annual pasture growth, intake and utilisation for each study time period.

The methodology for modelling pasture utilisation builds upon seminal work by Day *et al.* (1997) and Stone *et al*. (2008). Further refinements were made while modelling sites for the Sweet Spot project that considered large, sometimes poorly watered and variable land type paddocks (see Cowley *et al.* 2019, Cowley and Walsh 2023).

A standardised approach was developed and used for pasture utilisation modelling for Sweet Spot breeder herd sites. A template Sweet Spot base GRASP model parameter file SweetSpot.mrx" specified parameter values that were consistent across all sites, and a CEDAR control file template specified simulation outputs were developed and used for all sites. Documentation of the modelling approach and assumptions for each site was inputted into a template 'Calibration Notes' spreadsheet.

The excel spreadsheet 'Calibration notes' was used to capture the data used, logic for the selection of site-specific parameter values, and the calibration and modelling outcomes. This documentation

included trial design and herd information, stocking rate AE calculations, rainfall, land types, safe utilisation weighted for land type composition, watered area, woody cover, TSDM, pasture composition, satellite cover, fires, faecal Near Infrared Spectroscopy (NIRS) data, modelling assumptions, confidence measure of modelling, simulation outputs and estimation of long-term safe carrying capacity with the final model. The available supporting datasets varied between sites, but satellite derived ground and woody cover was averaged across the total paddock or watered area, for all sites for each available date. Of the 60 sites modelled, six datasets which included 35 of the 60 sites had calibrated TSDM and detailed pasture composition data.

Data was arranged into the format required for entry to a standardised Sweet Spot GRASP management records Importer file. The Sweet Spot Importer file read in the site data and exported the site management records in the format required to be copied at the end of the base SweetSpot.mrx file for use for site calibration and modelling.

4.1.2 Pasture utilisation components

4.1.2.1 Watered / grazed area

Modelling of pasture utilisation was done at the scale of the breeder herd, the paddock scale or where paddocks were poorly watered, the scale of grazed area within a paddock. The grazed area was assumed to be the accessible watered area of the paddock, in the land types the cattle grazed.

The watered area was calculated as all the area within 3 km from permanent water and half the area between 3 and 5 km from permanent water (Cowley *et al.* 2020, Queensland Government 2024). Semi-permanent waters such as dams, waterholes, creeks and streams were also included in the calculation of watered area for a paddock. Satellite images and anecdotal knowledge from producers were used to estimate the proportion of the year semi-permanent waters were available. The area within 3 km and 5 km from semi-permanent waters was included as for permanent waters but discounted by the proportion of the year they were available.

Some sites (8 in the VRD and 2 in the Barkly) had areas of spinifex that were assumed to be ungrazed and were excluded from the paddock area when calculating stocking rates, intake per area, and when modelling pasture growth.

4.1.2.2 AE and Intake calculation

Number of head for each class of animals by date were collated for each paddock of each study. The AE Calculator (McLean and Blakeley 2014, version 14.63) was used to calculate AE for each class of animals by date. Inputs to calculate AE included breed, start and end weight, age, weaning and pregnancy rates and weaning weight. Intake was calculated per AE based on paddock herd class performance measured at each site by date. An AE was assumed to eat 8 kg/day in moderate productivity zones, 8.5 kg/day in low productivity zones and 7.5 kg/day in high productivity zones (McLennan *et al.* 2020).

GRASP settings for potential liveweight gain in summer, autumn, winter and spring parameters (parameters 145-148) and subroutines were parameterised so that cattle ate the desired 7.5 to 8.5 kg/AE/day averaged over a year depending on productivity zone. All sites assumed 8 kg/AE/day. The exception was the Far North Queensland site where intake was assumed to be 8.5 kg/AE/day for a lower productivity zone (McLennan *et al.* 2020). Cattle stocking rate was entered into GRASP as the calculated AE based on paddock animal performance calculated with the AE Calculator. Changes in stocking rates were accounted for in the changing AE calculations for the paddock. The animal model p120 was set to 0 so simulated cattle did not grow between changes in stocking rate. The calculated

AE based on cattle performance represented a set intake per day. GRASP parameters (144, 214 = 50 or 100 kg/ha and 143=0) were set to ensure intake was not restricted. Despite this intake was sometimes still restricted to less than 7.5 kg/AE/day due to very low TSDM values in dry years (7 out of the 350 site years).

Intake by other herbivores (e.g. horses) was considered and where known were included in AE calculations. Macropods were not a large component of the total grazing pressure at modelled sites. However, there may have been low levels of intake by macropods such as wallabies and kangaroos, although their density is generally low across northern Australia. Macropod and invertebrate grazing will contribute to a background low level of utilisation that was not modelled.

4.1.2.3 Pasture Growth

Climate files were downloaded for each site from https://www.longpaddock.qld.gov.au/silo/ and combined with local/site rainfall where available.

Candidate land type models were selected based on land type composition of each site. Land type model was chosen based on fit with field and satellite derived observations of yield and green ground cover for each site. The parameters of the relevant land type were added to the end of the template SweetSpot.mrx to create a site mrx file. All paddock relevant observations were added as management records to the bottom of the site mrx and were used to calibrate pasture growth against site derived observations.

Average satellite derived ground and persistent green cover was provided by DESI for all available dates. Green ground cover was averaged across each paddock or within the 5km watered area in large poorly watered paddocks. Green ground cover and paddock TSDM where available were used to calibrate pasture growth for each study site.

Where there was no site data on woody cover, foliage projective cover (FPC) and Landsat derived persistent green cover was used as a proxy for woody foliage projective cover to drive woody plant competition with the pasture layer. At Queensland sites, State of Queensland FPC composite spatial data (1998-2001, Thalanga and Swan's Lagoon; 2008-2011, Cash Cow sites) was used to provide woody cover. This FPC data was converted to tree basal area (TBA) m^2ha^{-1} using the Armston equation developed for Queensland woody cover (Armston *et al.* 2009). In the NT, the Landsat derived persistent green cover was converted to tree basal area (TBA) following Staben *et al.* 2016. FPC and TBA were reset in the management records on April 15 every year.

Where there was field data on woody cover at the site, it was either used instead of Landsat derived values, or used to validate Landsat derived values. Growth was both calibrated and modelled with the same woody cover.

Field data on TSDM, ground cover, grass basal area and species composition were also used to parameterise and calibrate GRASP if available for each site. The locations of field monitoring sites were not always representative of the whole paddock due to varying land type proportions or distance from water. Where enough representative locations of field data were available, paddock averages were weighted to account for distance to water and land type proportion so that it was representative of the whole paddock before being used to calibrate TSDM and growth.

To supplement field TSDM data or where there was no field TSDM data, photos from monitoring sites in the paddocks were used to visually estimate yield, by experienced observers referring to yield photo-standards. Producer visual estimates of yield in the paddocks at the time of faecal NIRS sample collection were also used.

Landsat derived green ground cover was used to calibrate simulated green cover and optimise the death rate of green yield parameters p10 and p51.

Field observed grass basal area was used to calibrate changes in basal area (p288) so that dynamic basal area was realistic for that location. Grass basal area was set to either a constant value or dynamic, depending on which approach led to the best fit between observed and simulated green cover and TSDM. Usually, dynamic grass basal area provided the better fit. The main goal of the modelling was to simulate pasture growth for each year of the study as accurately as possible. To this end, grass basal area was occasionally reset to better fit observed TSDM and green cover for a particular year. This occurred for some sites at Mt Sanford when TSDM and green cover was initially overestimated by the model in 2003 after a late start to the wet season (Appendix 14.3.8, page 361).

Detachment (p128 to p131), trampling (p15), nitrogen uptake and dilution (p99, p101, p102), and pasture growth (p6 and p7) parameters were then adjusted to provide the best fit to weighted field TSDM and green ground cover. Pasture structure parameters (p45 to 46, p271, p5) were based on the land type values or derived from field observations of yield, ground cover and grass basal area, if available, Land types of Queensland parameters (Zhang and Carter 2018, State of Queensland 2022) and satellite derived cover observations.

Where twice-annual TSDM data was available, dry season detachment was able to be calculated and adjusted annually. The trampling parameter (the proportion of pasture available for grazing, p15) was set at 1 for low stocking rates (no trampling effects on pasture), decreasing to 0.7 for high stocking rates. Wet season detachment was adjusted to match observed TSDM once green cover was adequately simulated.

Where there was a good understanding of the site characteristics, soil water holding capacity and deep soil evaporation rates or tree rooting depth, relevant parameter values from multiple related land type parameter sets were also sometimes adjusted to better fit satellite derived green cover.

Fire scars were downloaded from NAFI https://firenorth.org.au/nafi3/. The proportion of the paddock burnt by date was added to management records to reduce TSDM to adjust for fire effects on TSDM, green cover and standing ground cover.

4.1.2.4 Pasture utilisation and relative pasture utilisation

Once each site was calibrated, the calibrated GRASP site model was then used to simulate pasture growth, intake and utilisation for the time period of the breeder herd datasets.

Additionally long-term pasture growth using the full SILO climate file from 1889 or 1900 to date of download which varied from 2020 to 2022 was used to characterise site long-term safe carrying capacity which was calculated using the following equation

Safe stocking rate = median pasture growth x safe utilisation rate / intake (2920kg/AE/year).

For the purposes of this report, pasture utilisation refers to the utilisation of annual pasture growth between the 1st of October and 30th of September each year. This roughly coincided with breeder performance timeframes. However, monthly growth, TSDM and intake were provided for analysis of factors affecting breeder performance so that utilisation could be calculated over any timeframe to statistically find which was most relevant to breeder productivity.

The safe utilisation rate assumed for each land type is derived from grazing trials, retrospective analyses of utilisation on benchmark properties where grazed pastures are still in good condition and expert opinion (reviewed in Hunt 2008, Stone *et al.* 2021). For Queensland sites, safe pasture

utilisation for all land types are published in 'Land types of Queensland' (State of Queensland 2022). In the Northern Territory there was no specific publication of safe utilisation rates for all land types and the following assumptions were used (Table 4-1).

Table 4-1: Safe utilisation assumptions for NT land types

Land type	Safe Utilisation (%)	Evidence base
Improved pastures	30-50	Arthur Cameron unpublished data
High productivity / clay soils	20-25	Cowley *et al.* 2007, Hunt *et al.* 2013, Walsh and Cowley 2011, Johnston *et al.* 1996
Moderate productivity soils	15	Ash and McIvor 1998, Ash *et al.* 1997; Johnston *et al.* 1996
Low productivity or erodible soils	10	Ash *et al.* 1997, Johnston *et al.* 1996
Spinifex	0-5	Adjusted based on proportion and palatability of spinifex in pastures

Because safe utilisation rates vary between land types, absolute utilisation level is not the best way to compare the effect of utilisation on breeder performance across different sites. For example, 20% utilisation would be within the safe utilisation level on alluvial or basalt derived vertosols, but more than double the safe rate for a calcareous oatgrass community in central Australia. For this reason, we used a simple index of utilisation; relative utilisation = modelled utilisation/safe utilisation. An index of 1 indicates that modelled utilisation = safe or recommended levels for that site. Where there was more than one land type in a paddock and the land types had different safe utilisation rates, a paddock level safe utilisation rate was calculated by weighting safe utilisation according to the proportion of paddock area for each land type. The average safe utilisation assumed for each site is listed in Table 14-2 in Appendix 14.2 page 305.

Cattle land type preference in multi land type paddocks was not accounted for, except for excluding avoided areas. Hence pasture utilisation and relative utilisation is reported for the average paddock watered area, even though cattle may have grazed the landscape unevenly.

4.1.3 Statistical analysis of pasture utilisation

Pearson correlation was used to test for correlation between variables using Statistica version 12.0 (StatSoft Inc., 2013). To compare whether stocking rate or pasture growth was the greater influence on pasture utilisation in the different regions, analyses were performed in R (R Core Team, 2024). Data from properties in each region was used for a linear model to assess the relationship between annual percent pasture utilisation and the explanatory variables of log(annual pasture growth) and stocking rate. Partial correlation coefficients for each explanatory variable were generated using the ppcor package (Kim 2015a, Kim 2015b).

4.2 Results

Across the entire 350 site years the average modelled pasture utilisation was slightly higher than the average safe level of pasture utilisation at 23 vs 20% (Table 4-2). However, the average utilisation

was skewed by a few very high utilisation years (Figure 4-1), and the median modelled pasture utilisation was slightly less than the median safe level at 19%. Slightly more than half (180 out of the 350) site years had relative utilisation within safe levels at ≤ 1 (Figure 4-2).

Table 4-2: Pasture utilisation statistics across the entire Sweet Spot dataset

	Valid N	Mean	Median	Minimum	Maximum
Safe utilisation (%)	350	20.4	22.0	9.0	30.0
Annual utilisation (%)	350	23.0	19.2	0.5	113.8
Relative utilisation	350	1.2	1.0	0.0	7.4

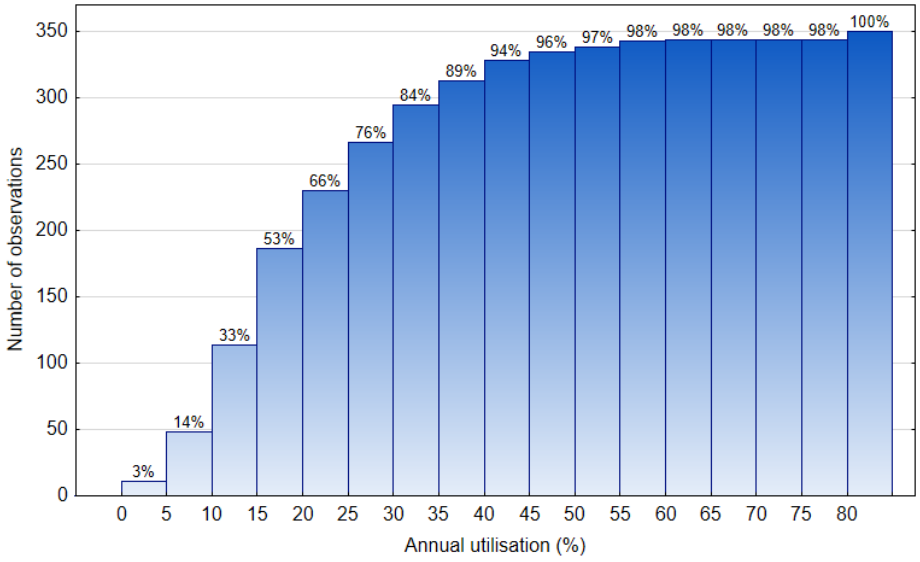


Figure 4-1: Histogram of annual pasture utilisation at Sweet Spot sites

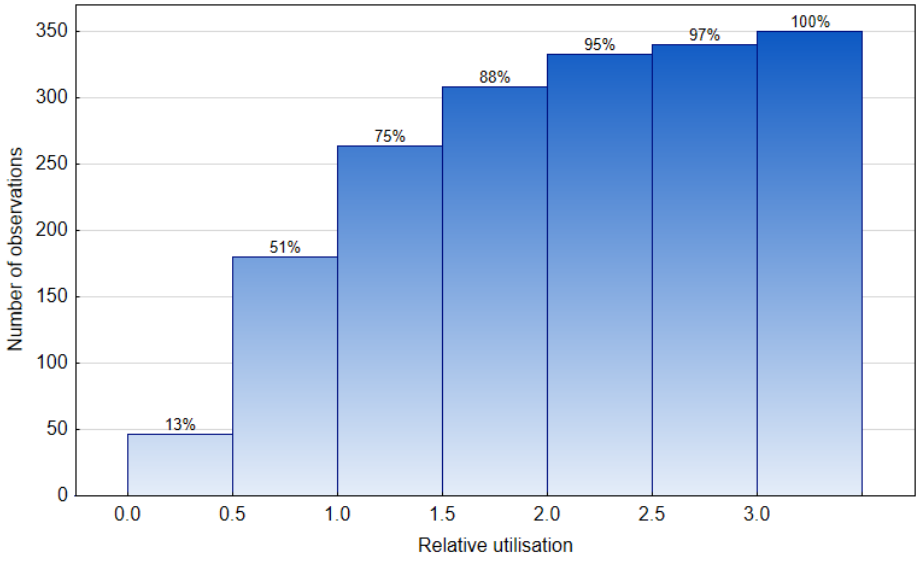


Figure 4-2: Histogram of relative pasture utilisation at Sweet Spot sites

4.2.1 Average region by site results

The regional groupings used to report regional differences in site characteristics in this section vary from those used to summarise breeder performance. This reflects the exploratory nature of the initial dataset assessment, which informed the subsequent regional groupings used to report breeder performance statistics. The groupings presented here can be regarded as subregions of the broader regional groupings used elsewhere in this report.

Table 4-3: Regions and subregions represented in Sweet Spot study

Regional grouping (used to report breeder performance)	Subregion	Number of Stations	Number of Paddocks	Number of paddock years
North East Queensland	Central Queensland	1	1	3
	Far north Queensland	1	1	3
	North Queensland	3	9	48
Northern NT	Katherine	1	2	22
	Sturt Plateau	2	2	6
	Victoria River District	3	21	144
Central NT	Barkly Tablelands	5	15	50
Southern NT	Alice Springs	4	9	74
Total		20	60	350

Confidence in pasture growth modelling outputs varied between sites from 50 to 94% (Table 4-4). Grazing trials where total standing dry matter (TSDM) was collected at multiple locations and dates, had the highest level of modelling confidence. Sites from commercial properties tended to have lower modelling confidence (Cash Cow, Heifer study, Water Medication studies), because less data was available on TSDM, and paddock intake calculations had uncertainty due to lack of information on bull number and weights. The exception to this was for sites on the Barkly because multiple breeder herd, fire and grazing trial studies across the region over the 25 years to current day contributed to pasture yield datasets that informed modelling assumptions, including GRASP model calibration SWIFTSYND sites (Day and Philp 1997) and historical calibrated TSDM estimates for the same Mitchell grass land type close to or within the sites.

Table 4-4: Confidence in modelling pasture utilisation at Sweet Spot sites by subregion and study

Subregion	Study	Confidence in utilisation modelling
Alice Springs	Benchmarking	81%
	Heifer study	50%
	Quality Graze	81%
	Water medication	54%
Barkly Tableland	Breeder Herd Efficiency	86%
	North Australian Beef Fertility	82%
	Reducing Calf loss from exposure	79%
	Heifer study	81%

	Nutrition effect on breeders	86%
	Paddock Power	69%
	Phosphorus	71%
Central Queensland	North Australian Beef Fertility	57%
Far north Queensland	North Australian Beef Fertility	56%
Katherine	North Australian Beef Fertility/Senepol	72%
	Senepol	72%
North Queensland	North Australian Beef Fertility	72%
	Stocking rate Demonstration	77%
Sturt Plateau	North Australian Beef Fertility	71%
Victoria River District	North Australian Beef Fertility	69%
	Pigeon Hole Project	90%
	Mt Sanford Stocking Rate/Utilisation	93%

4.2.1.1 Site characteristics

Sweet Spot sites covered a broad range of the rainfall, tree cover (Figure 4-3) and pasture growth that is found across northern Australia (Figure 4-7). Tree basal area ranged from 0 (Alice and Barkly) to 9 m^2 per hectare (Far North Queensland). Grassland sites were found in the 100 to 600mm rainfall zone, and woodland sites at higher rainfall. Tree basal area increased linearly with rainfall between 500 and 1000mm median rainfall (Pearson's r=0.80, r^2=0.64, P<0.00001).

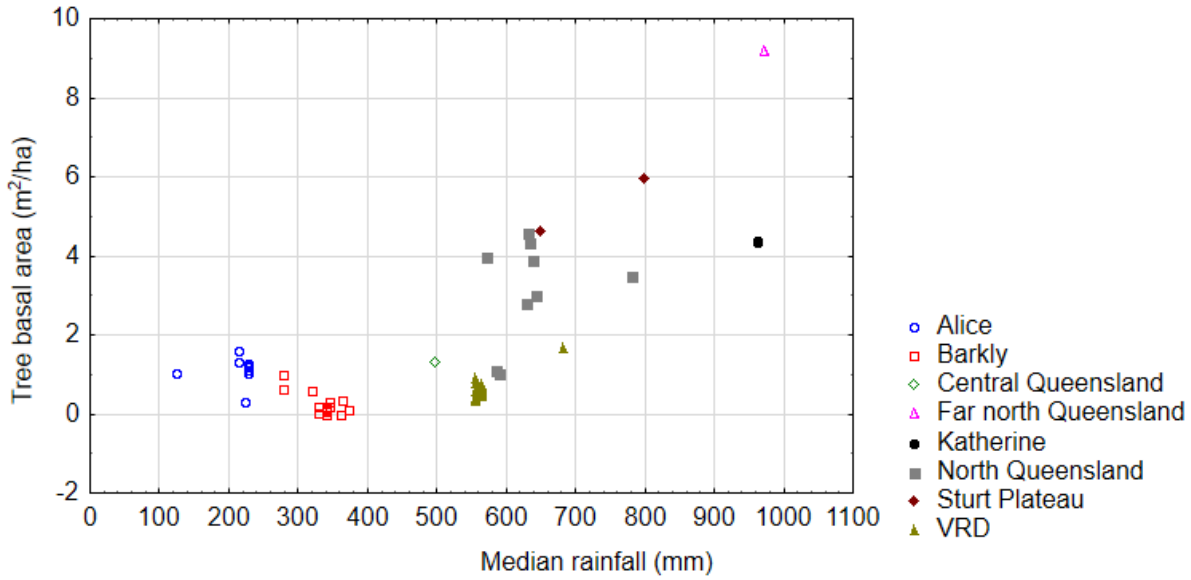


Figure 4-3: Tree basal area vs. long-term median rainfall at modelled Sweet Spot sites, by region

Lower rainfall sites (Alice and Barkly) also had highest rainfall variability, whilst the wetter, more northerly Katherine, Sturt, VRD and Far north Queensland sites had the lowest rainfall variability (Pearson correlation, r=-0.87, P<0.0001) (Figure 4-4).

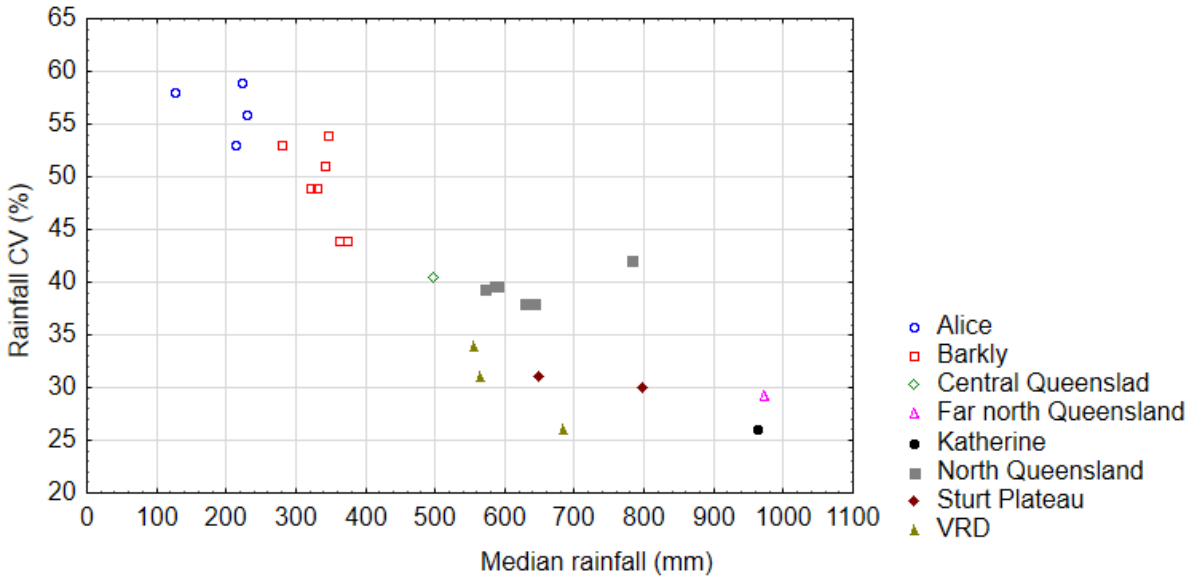


Figure 4-4: Variability in rainfall vs. median long-term rainfall at Sweet Spot sites, by region

Average characteristics of the Sweet Spot sites and how they vary regionally are shown in Table 4-5 to Table 4-7. Sites on average had higher rainfall during the studies compared to the site long-term median rainfall. Sites with median rainfall less than 500mm had higher pasture growth during the study period than the long-term median pasture growth, reflecting the impact of wetter than average years on pasture growth in those regions. The average regional relative utilisation was always higher than 1 except for the Barkly region where it was 0.7.

The Sturt Plateau and Katherine sites had the lowest available phosphorus (Figure 4-5) while the central Australian sites had the highest soil phosphorus.

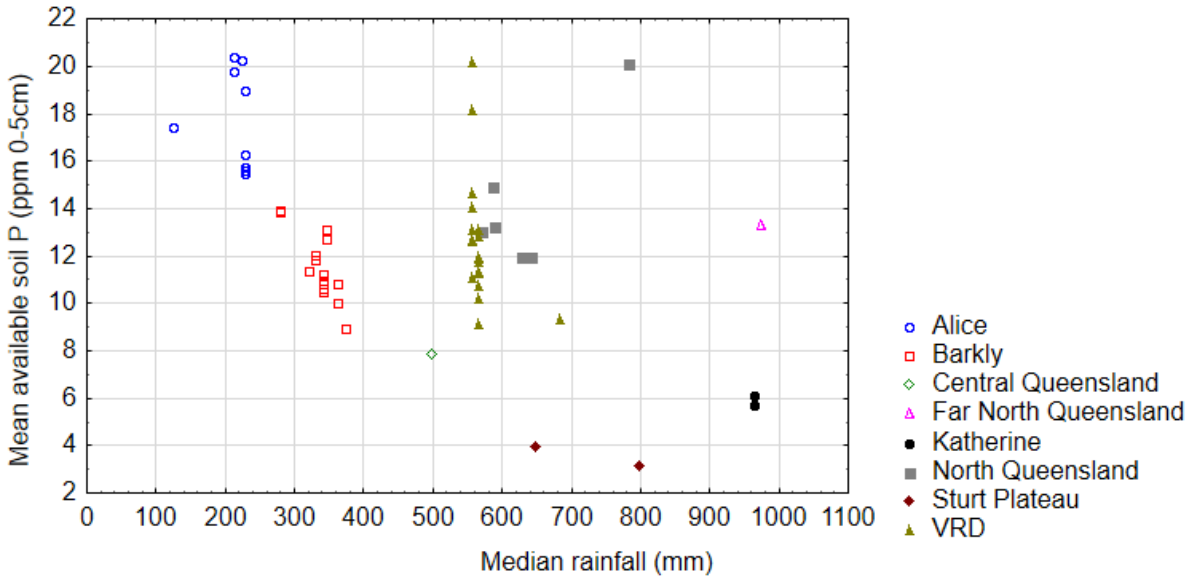


Figure 4-5: Phosphorus availability vs. median long-term rainfall at the Sweet Spot sites by region

The assumed safe utilisation varied between Queensland and NT Eucalypt woodland dominated regions. This was not explained by median rainfall or variability in rainfall (Table 4-6). However, the Queensland sites had more than double the soil available P of the NT sites, which could explain the lower safe utilisation of NT Eucalypt woodland sites.

Table 4-5: Location and characteristics of Sweet Spot sites ordered by median long-term rainfall

Region	Sub-region	Number of sites	Median rainfall (mm)	Average rainfall during study (mm)	Rainfall CV (%)	TBA (m^2/ha)	Average available soil phosphorus (ppm 0-5cm)	Safe utilisation (%)	Long-term median pasture growth (kg/ha)	Pasture growth average during study (kg/ha)	Stocking rate average (AE/km^2)	Average utilis. (%)	Relative Utilis.
Southern NT	Alice	9	217	279	56	1.1	18	15.0	686	1100	5	19	1.3
Central NT	Barkly	15	334	571	50	0.3	12	22.0	1249	2079	10	15	0.7
North East Qld	Central Queensland	1	498	941	40	1.3	8	23.0	1507	2929	32	32	1.4
Northern NT	VRD	21	561	781	29	0.6	12	21.9	1895	1993	15	24	1.1
North east Qld	North Queensland	9	624	666	26	3.1	13	26.8	2544	2130	22	36	1.4
Northern NT	Sturt Plateau	2	724	1234	39	5.3	4	13.8	2176	2082	11	16	1.2
Northern NT	Katherine	2	963	1011	31	4.4	6	12.5	1971	1829	14	23	1.8
North east Qld	Far north Queensland	1	972	1468	32	9.2	13	15.0	2094	2093	11	17	1.3

Table 4-6: Variation in estimated safe utilisation for Eucalypt woodland land types in different regions

Subregion	Median rainfall (mm)	Coefficient of variation of rainfall (%)	Average available soil phosphorus (ppm 0-5cm)	Safe utilisation lower (%)	Safe utilisation mid (%)	Safe utilisation upper (%)
Far north Queensland	972	29	13	10	15	20
Katherine	963	26	6	10	12.5	15
North Queensland	633	39	13	22	27	31
Sturt Plateau	724	31	4	11	14	16

4.2.1.2 *Relative rainfall and pasture growth*

The breeder dataset was skewed towards wetter years, with between only 6 to 39% of total study years with rainfall lower than median in the different regions (Figure 4-6) and 35% across the entire dataset.

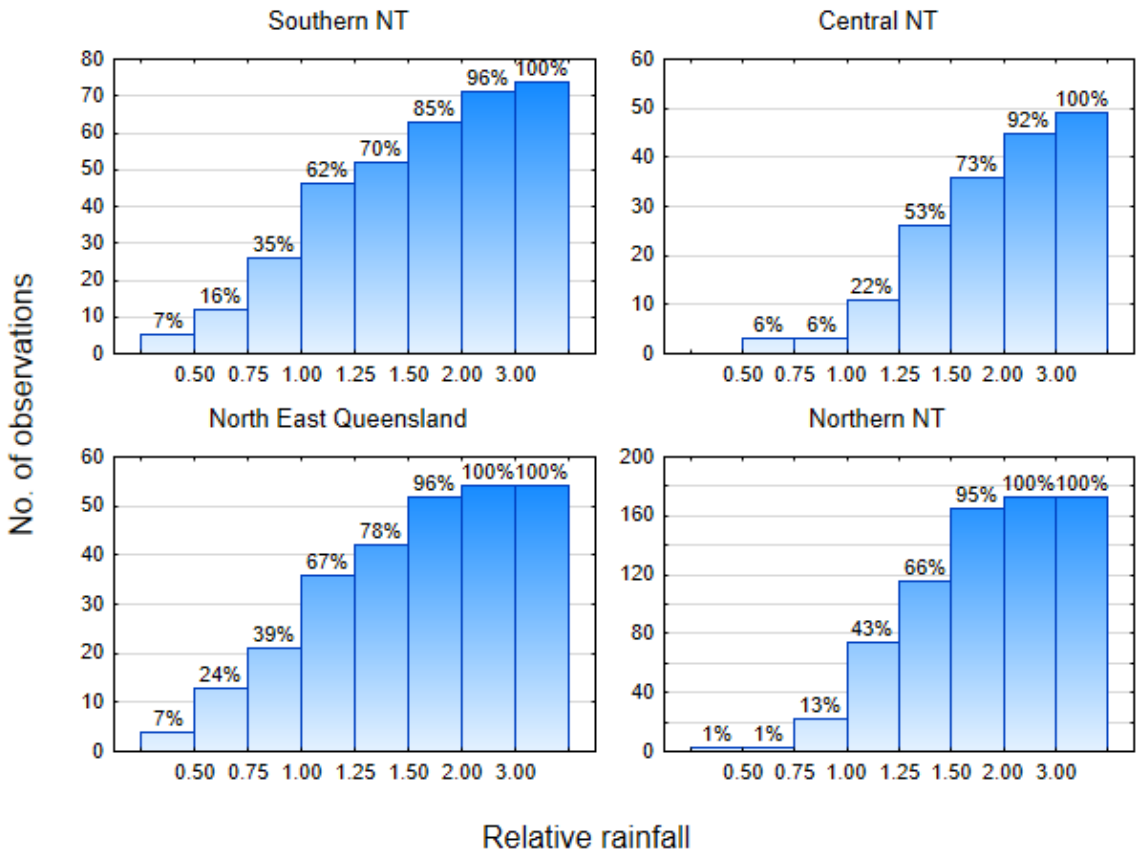


Figure 4-6: Relative rainfall across the empirical Sweet Spot data set by broad region

4.2.1.3 *Pasture growth and carrying capacity*

Simulated annual pasture growth at Sweet Spot sites increased with rainfall up to 600mm (Figure 4-7). Generally, both tree cover and pasture growth increased with rainfall across Sweet Spot sites (Figure 4-8). The highest pasture growth was found at high rainfall with intermediate tree cover.

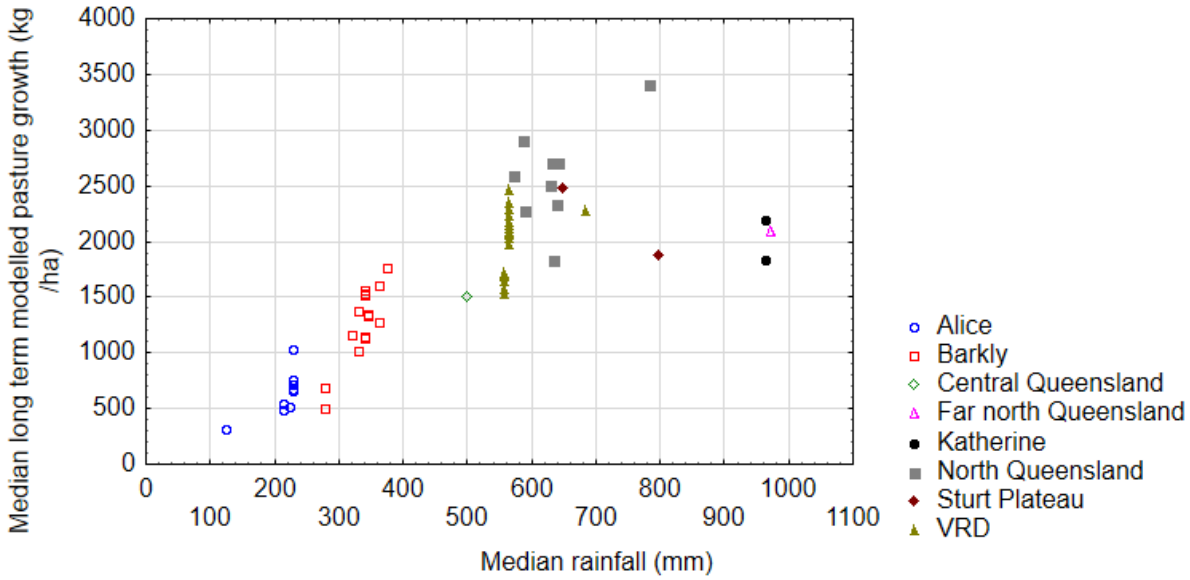


Figure 4-7: Long-term median simulated annual pasture growth vs. long-term median rainfall at modelled Sweet Spot sites by region

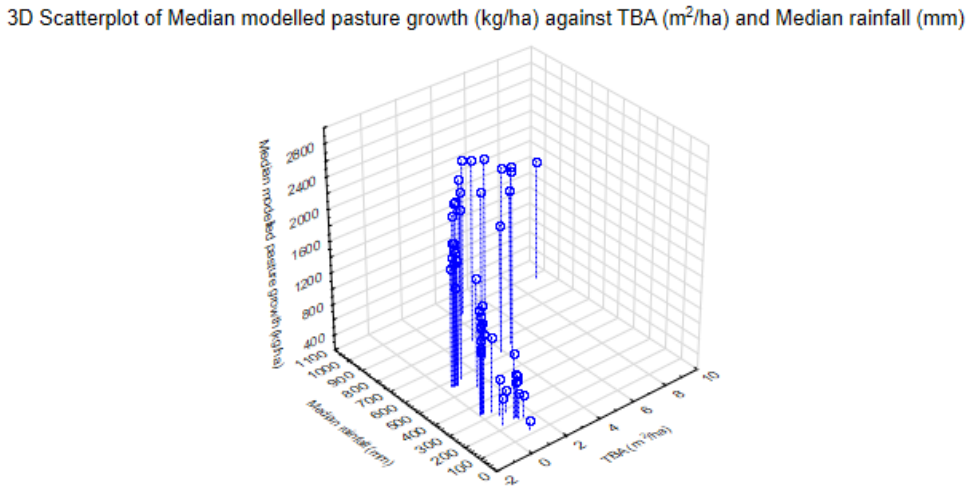


Figure 4-8: Simulated pasture growth by rainfall and tree cover at Sweet Spot sites

An outcome of the Sweet Spot modelling was a pasture growth model parameter set that represented each site and enabled calculation of the long-term carrying capacity of all sites. Long-term safe carrying capacity varied from 1.4 to 29 AE/km^2 (Figure 4-9). The carrying capacity broadly follows the same trend as pasture growth. However, there are slight differences as safe utilisation levels also contribute to safe stocking rates (Figure 4-9). At very high rainfall (around 800mm+) safe carrying capacity was limited by lower safe utilisation rates.

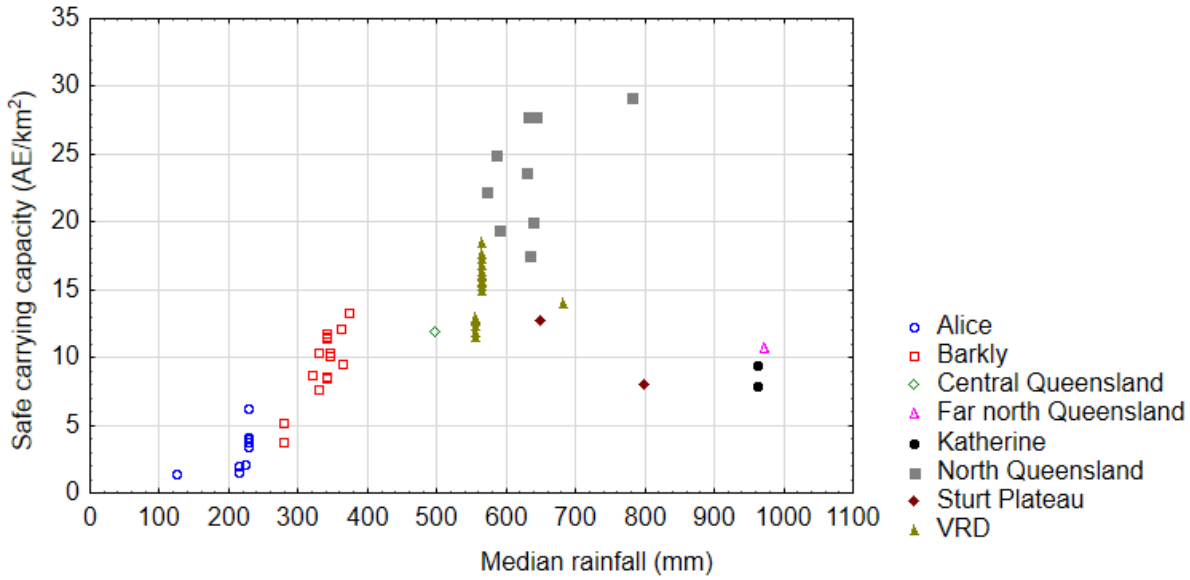


Figure 4-9: Safe long-term carrying capacity at Sweet Spot sites vs. median long-term rainfall, by region

4.2.1.4 Infrastructure development

There was a broad range in intensity of infrastructure development across the sites and particularly within the central and southern NT regions. There was a hundred-fold range in paddock size from more than 500 km^2 to less than 5 km^2. Paddocks ranged from very poorly watered to fully watered (all paddock within 3 km from water). Larger paddocks tended to be more poorly watered (Figure 4-10, Pearson correlation, r^2=0.34, p<0.0001). Larger, poorly watered paddocks were more likely at more arid sites with less than 400 mm median rainfall and lower pasture growth sites (Table 4-7, Figure 4-11 - Figure 4-13). Queensland sites were mostly fully watered. The VRD and Katherine sites were dominated by smaller better watered research trial paddocks. The smaller paddocks in the southern and central NT were research station paddocks at Old Man Plains and more recently developed paddocks in the Barkly.

Table 4-7: Infrastructure development of Sweet Spot sites

Region	Subregion	Number of sites	Paddock area average (km^2)	Watered area average (% all area within 3km and half area between 3-5km from water)	Maximum distance to water average (km)
Southern NT	Alice	9	156	56%	8.8
Central NT	Barkly	15	152	73%	7.3
North east Qld	Central Queensland	1	14	96%	4.0
Northern NT	VRD	21	17	95%	3.1
North East Qld	North Queensland	9	14	100%	2.8
Northern NT	Sturt Plateau	2	136	56%	11.0
Northern NT	Katherine	2	25	88%	6.5
North East Qld	Far North Queensland	1	48	100%	2.5

Three of the four regions had both research and commercial herds represented. In the Southern and Northern NT datasets the commercial station paddock sizes were larger, and the proportion of the paddock watered was lower than on the research sites (Table 4-8).

Table 4-8: Variation in infrastructure development between commercial and research paddocks in the Sweet Spot dataset

Region	Research / Commercial	Number of sites	Paddock area average (km^2)	Watered area average (% all area within 3km and half area between 3-5km from water)
Central NT	Commercial	15	157	72%
North East Qld	Commercial	3	25	99%
	Research	8	14	100%
Northern NT	Commercial	5	82	63%
	Research	20	19	95%
Southern NT	Commercial	4	291	54%
	Research	5	79	57%

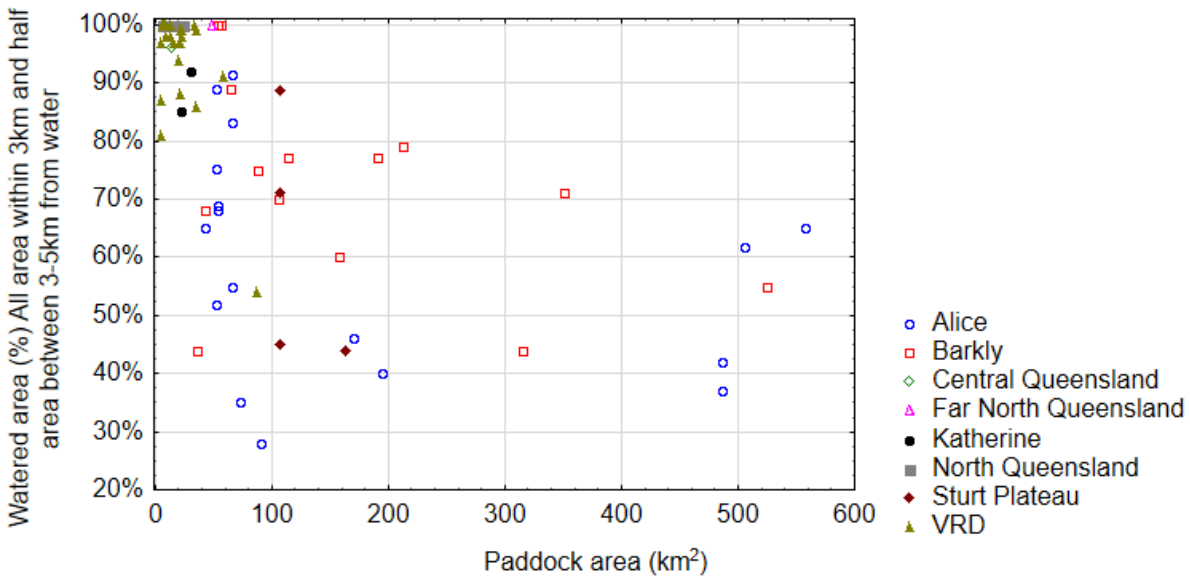


Figure 4-10: Percent of paddock watered vs. paddock size at Sweet Spot sites by region

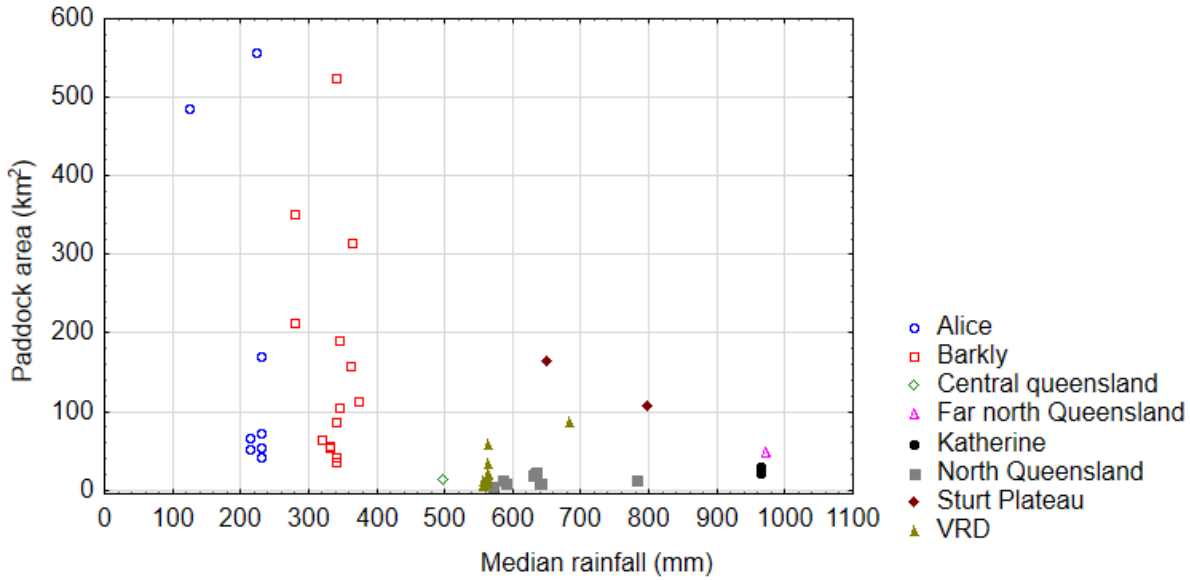


Figure 4-11: Paddock area of Sweet Spot sites vs. median long-term rainfall by region

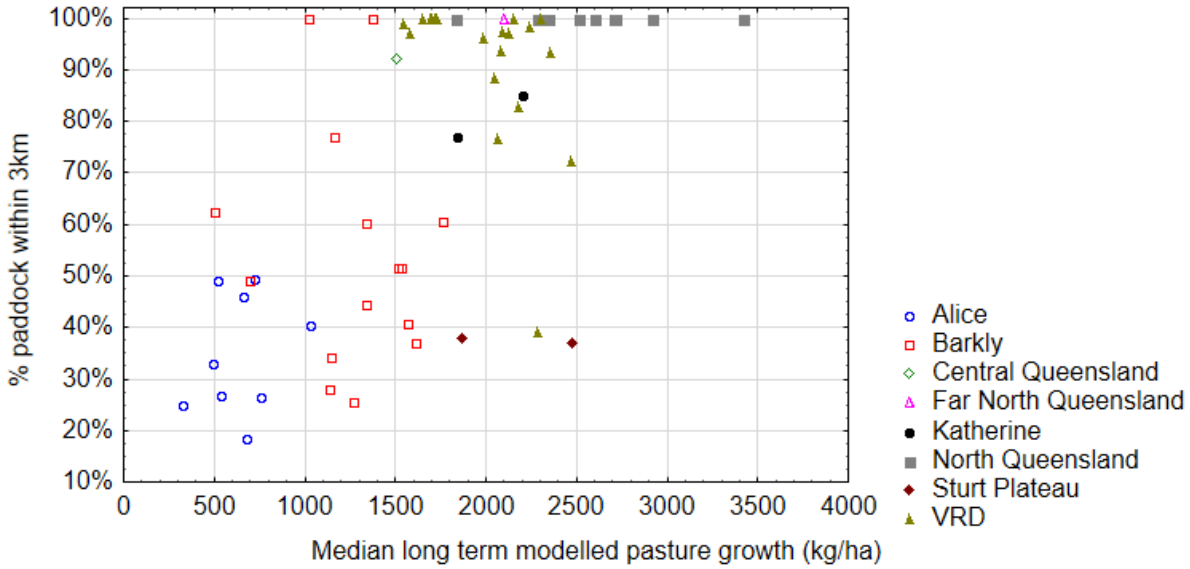


Figure 4-12: Percent of paddock area within 3km from water vs. median long-term pasture growth at Sweet Spot sites by region

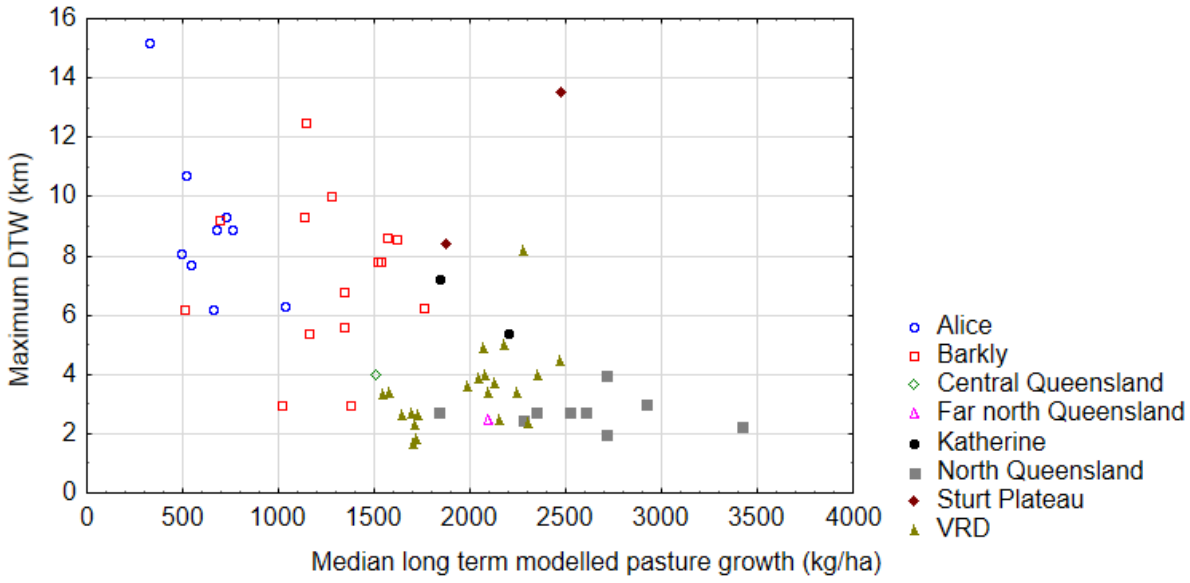


Figure 4-13: Maximum distance to water vs. long-term median pasture growth at Sweet Spot sites by region

4.2.1.5 Stocking rate

Average stocking rate at sites during the study years within the watered area (area within 3 km and half the area between 3 and 5 km from water) varied tenfold across sites from 3 to 33 AE/km^2 (Figure 4-14). Stocking rate generally increased with rainfall up to about 600 mm (Figure 4-14 - Figure 4-15), but was more closely correlated with long-term median simulated pasture growth, (Pearson correlation, r=0.65, P<0.0001), and average pasture growth during the site study years (Pearson correlation, r=0.61, P<0.0001) (Figure 4-16 - Figure 4-17).

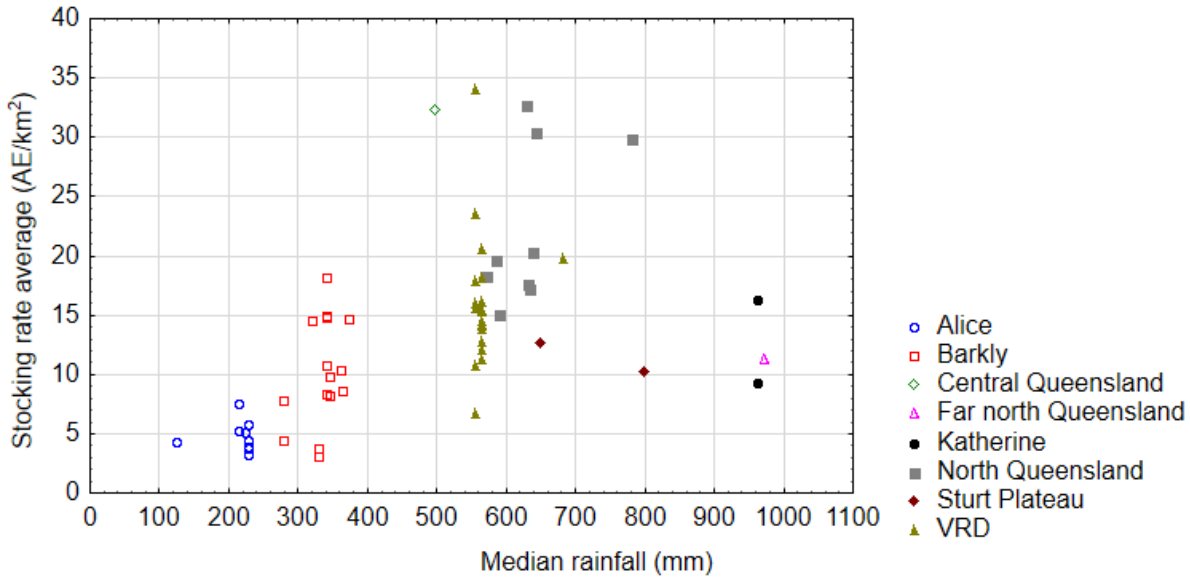


Figure 4-14: Average stocking rate at Sweet Spot sites vs. long-term median site rainfall by region

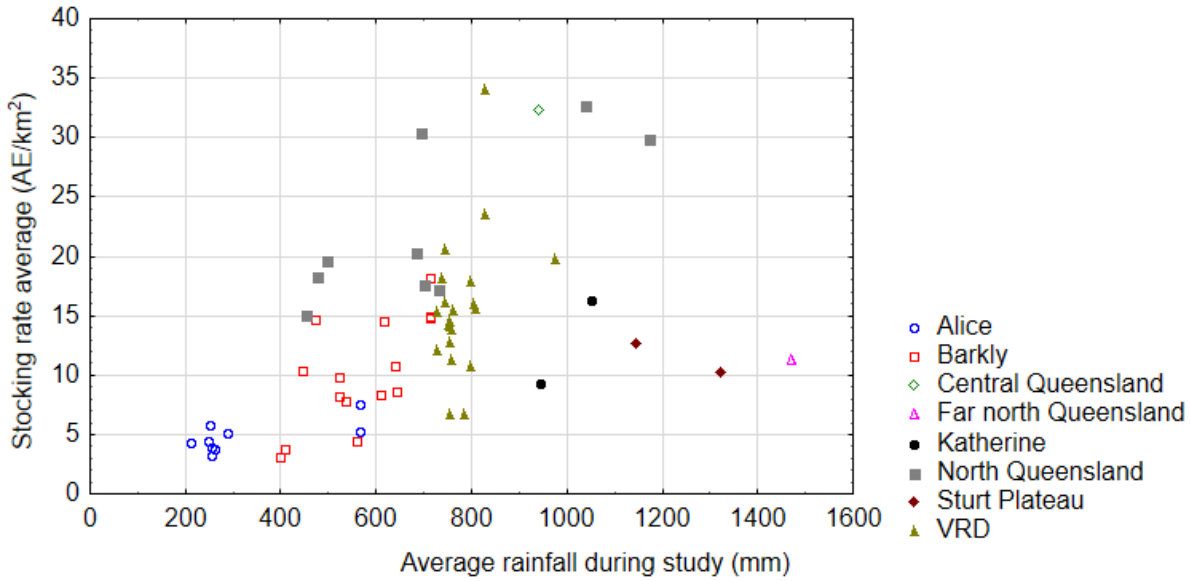


Figure 4-15: Average stocking rate at Sweet Spot sites vs. average rainfall during study site years by region

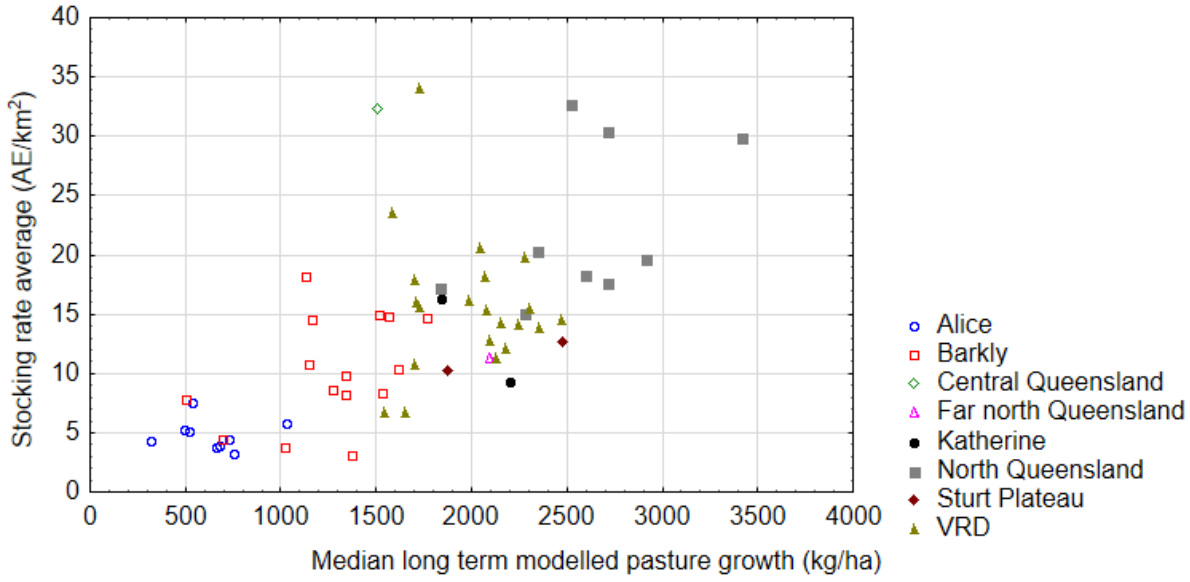


Figure 4-16: Average stocking rate at Sweet Spot sites vs. long-term median annual simulated pasture growth by region

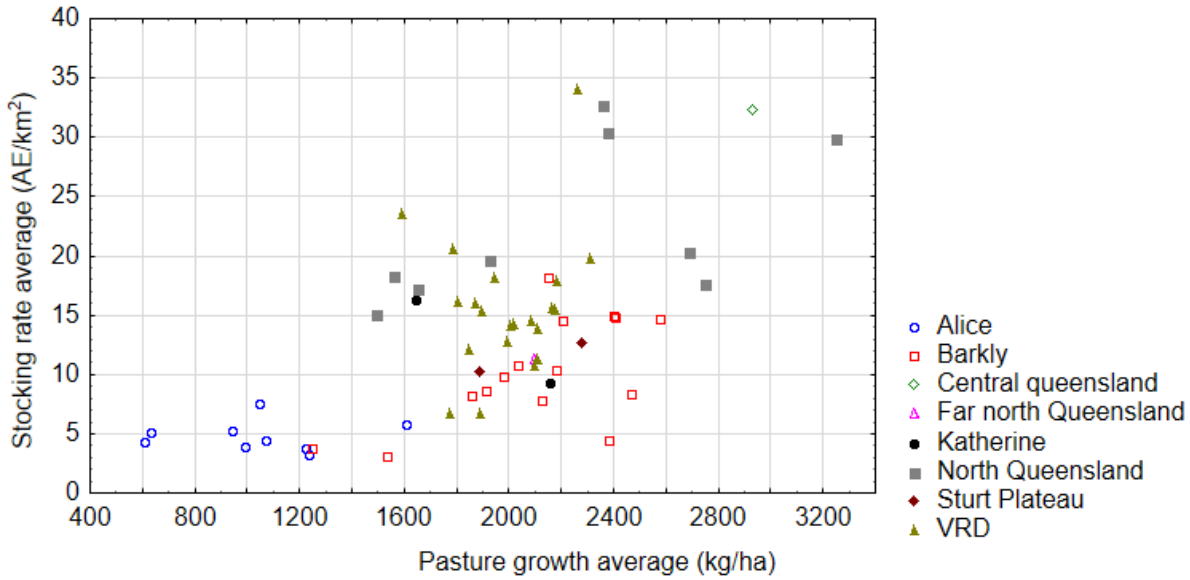


Figure 4-17: Average stocking rate at Sweet Spot sites vs. average simulated annual pasture growth during site study years by region

Although correlated (Pearson's correlation r^2=0.41, P<0.0001), stocking rate during the study was sometimes quite different from the long-term safe carrying capacity (Figure 4-18). This was sometimes because sites were part of grazing trials deliberately trialling lower and higher than safe stocking rates (e.g. in the VRD and North Queensland regions), or due to the study period being wetter or drier than average. An example of this is the central Queensland site which had a long-term safe carrying capacity of 11.9 AE/km^2 (Figure 4-9), but average stocking rate during the study was 32 AE/km^2 (Table 4-5, Figure 4-14), because the study for that site was during a La Nina period when rainfall and pasture growth was much higher than the long-term median.

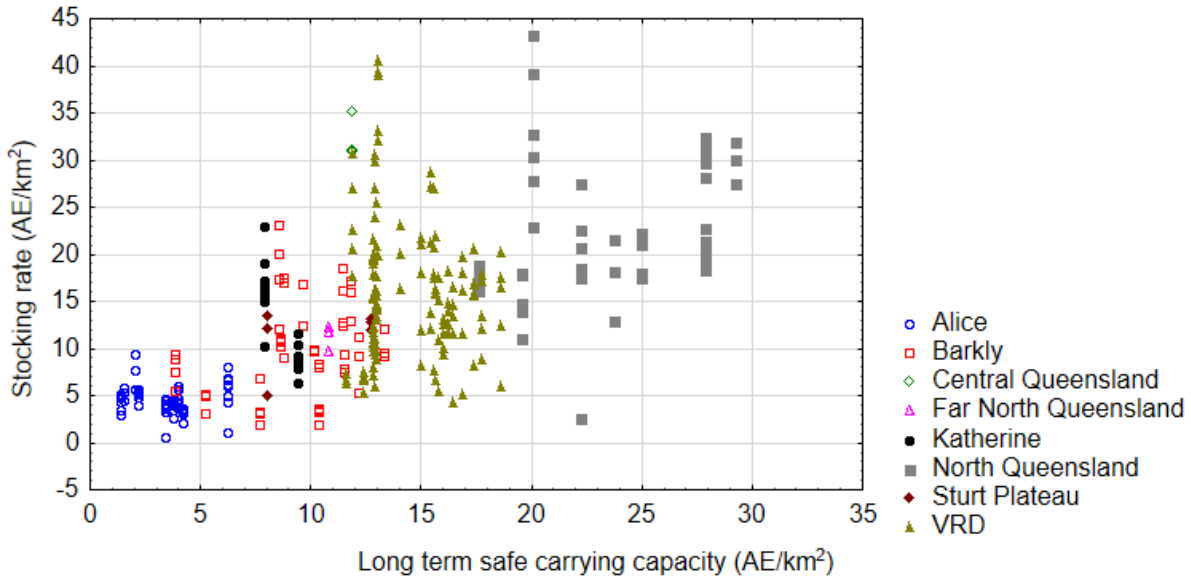


Figure 4-18: annual stocking rate vs. estimated long-term safe carrying capacity at Sweet Spot sites by region

Stocking rates were higher in smaller paddocks (less than 50 km^2) and there was a trend for lower stocking rates in more poorly watered paddocks (Figure 4-19 - Figure 4-20).

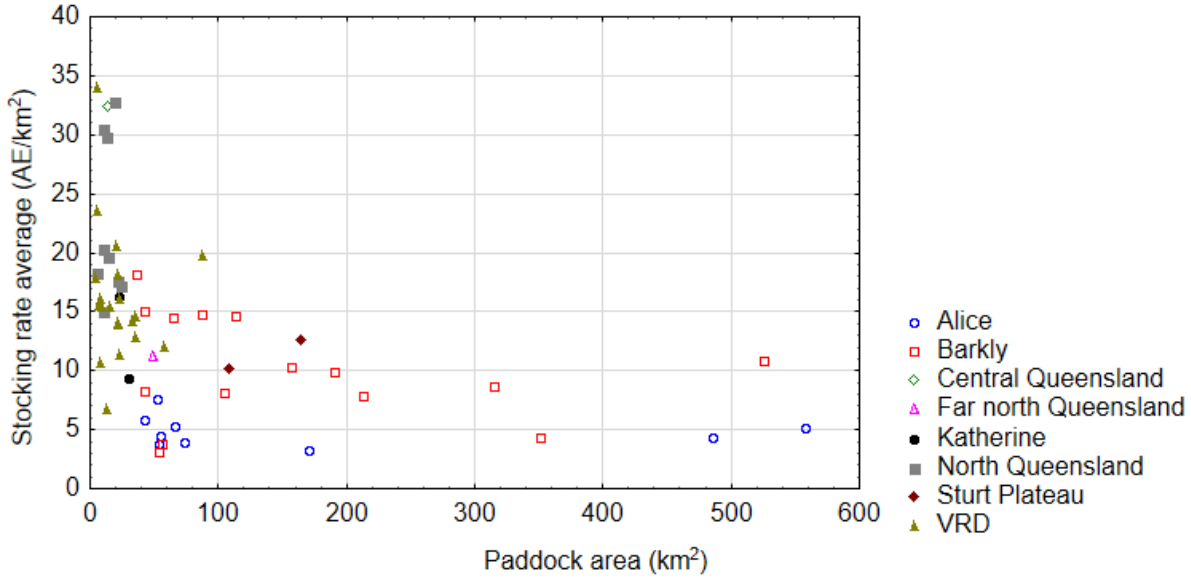


Figure 4-19: Average stocking rate at Sweet Spot sites vs. total paddock area, by region

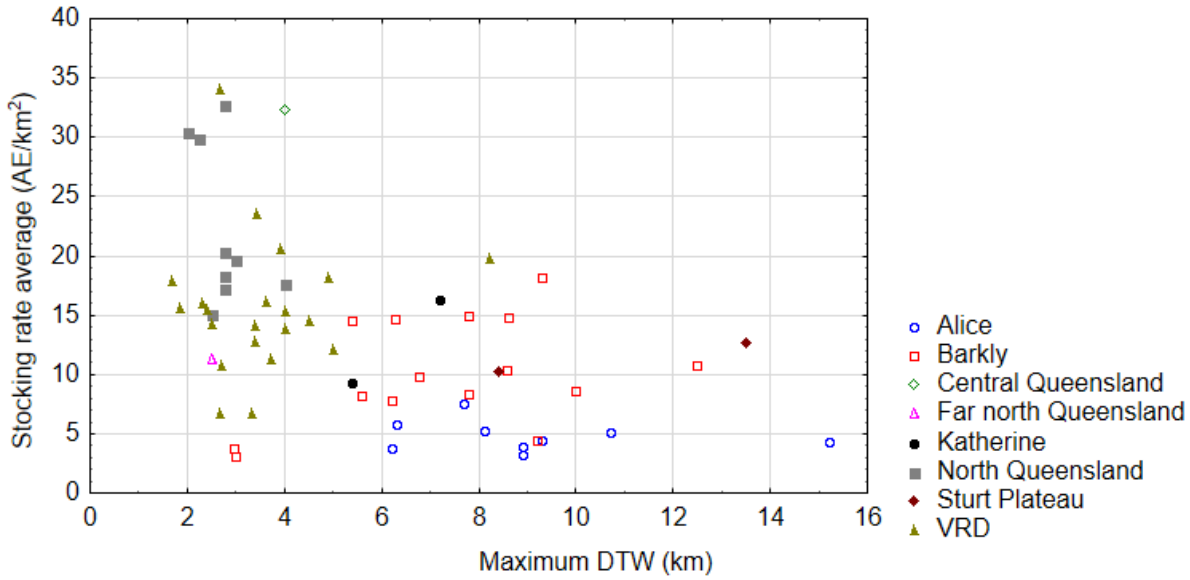


Figure 4-20: Average stocking rate at Sweet Spot sites vs. maximum distance to water, by region

4.2.2 Individual site by year results

The previous section looked at the average across all years for each site, to describe broad trends in datasets. Each site was represented by a single point. This section examines annual outputs to examine the range in stocking rates and pasture utilisation found in each region, each land type, and at different pasture growths and rainfalls. Here each site will have multiple points, depending on the number of years the dataset represented (ranging between 2 and 14 years).

4.2.2.1 Stocking rate

Table 4-9 shows average stocking rates by region and by whether or not the study was part of a grazing trial or on a research station (research), or from a commercial cattle station run according to station management (commercial). This separation was made to distinguish whether results are likely to be representative of the broader cattle industry. The breakdown varied by region. For example, the Barkly (Central NT) region were all commercial stations, whereas the Southern NT, Northern NT and NE Queensland datasets were dominated by grazing trial data. In NE Queensland and Southern NT, stocking rates were higher on commercial stations, but differences were only significant in the Southern NT (ANOVA P=0.007). The variation in stocking rates was greatest in the Queensland and Northern NT sites (Figure 4-21). There was a wide range in stocking rates with rainfall and pasture growth for most regions (Figure 4-22 to Figure 4-24).

Table 4-9: Variation in stocking rate in the Sweet Spot dataset with region and whether from commercials stations or as part of a research project testing stocking or utilisation rates

Region	Research/ Commercial	Number of site years	Stocking rate (AE/km^2) Average	Stocking rate (AE/km^2) Median
Southern NT	Commercial	19	5.3	5.2
Southern NT	Research	55	4.2	4.2
Central NT	Commercial	49	10.2	9.6
Central NT	Research	0		
Northern NT	Commercial	9	14.2	13.2
Northern NT	Research	164	15.1	14.8
North East Qld	Commercial	9	24.5	30.0
North East Qld	Research	45	21.7	20.2

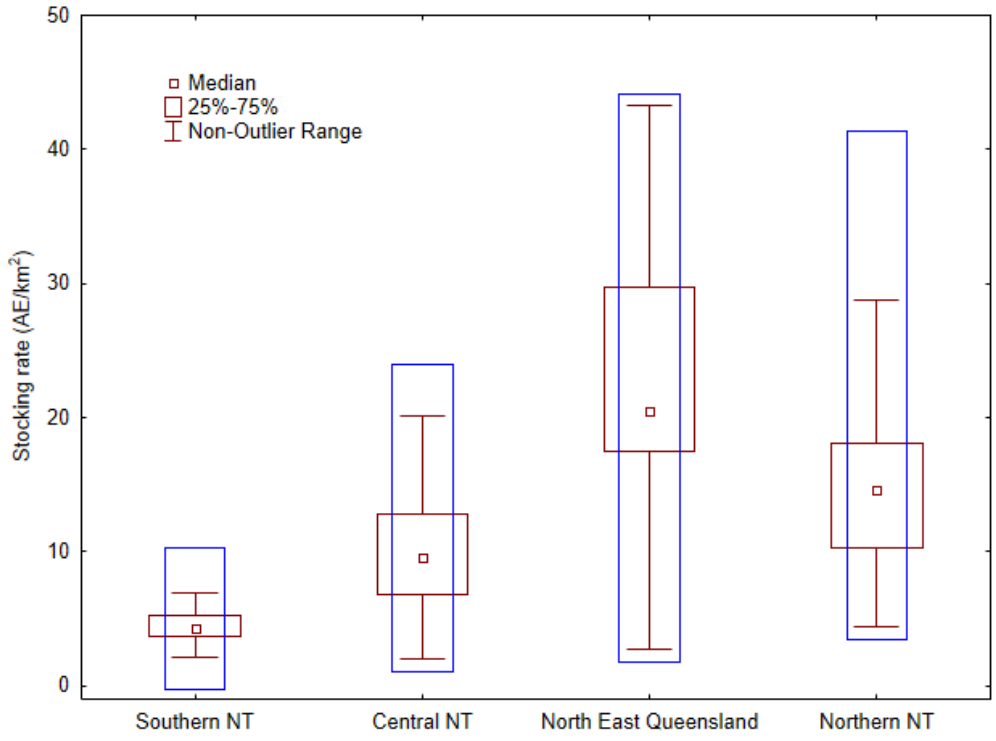


Figure 4-21: Variation in stocking rate across all sites and years by broad region. Blue box = full range of data

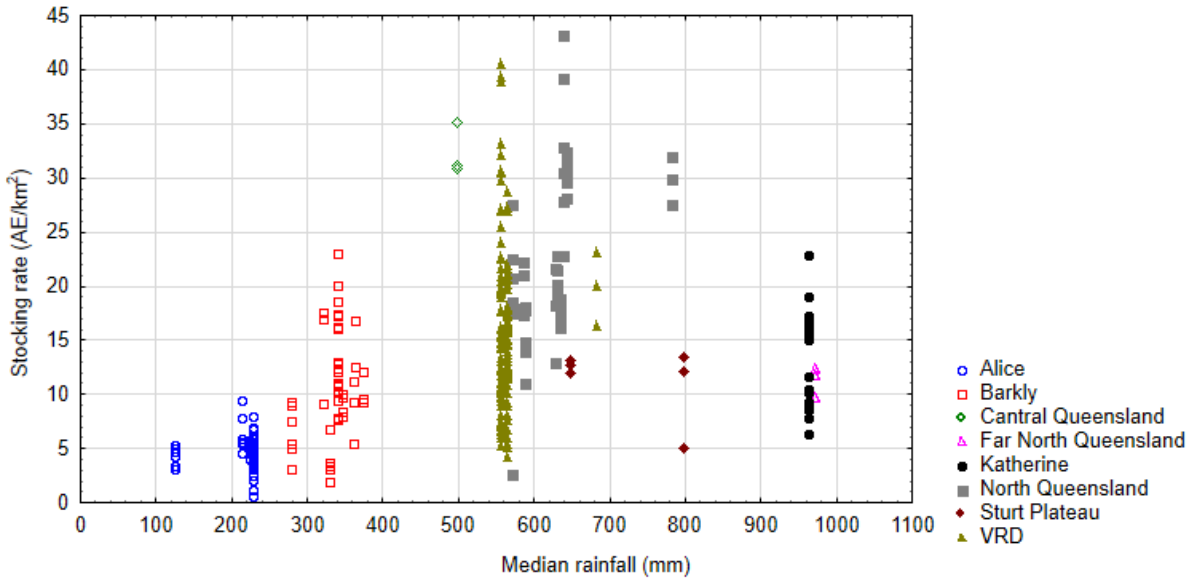


Figure 4-22: Annual stocking rate vs. long-term median rainfall for each year and site by region

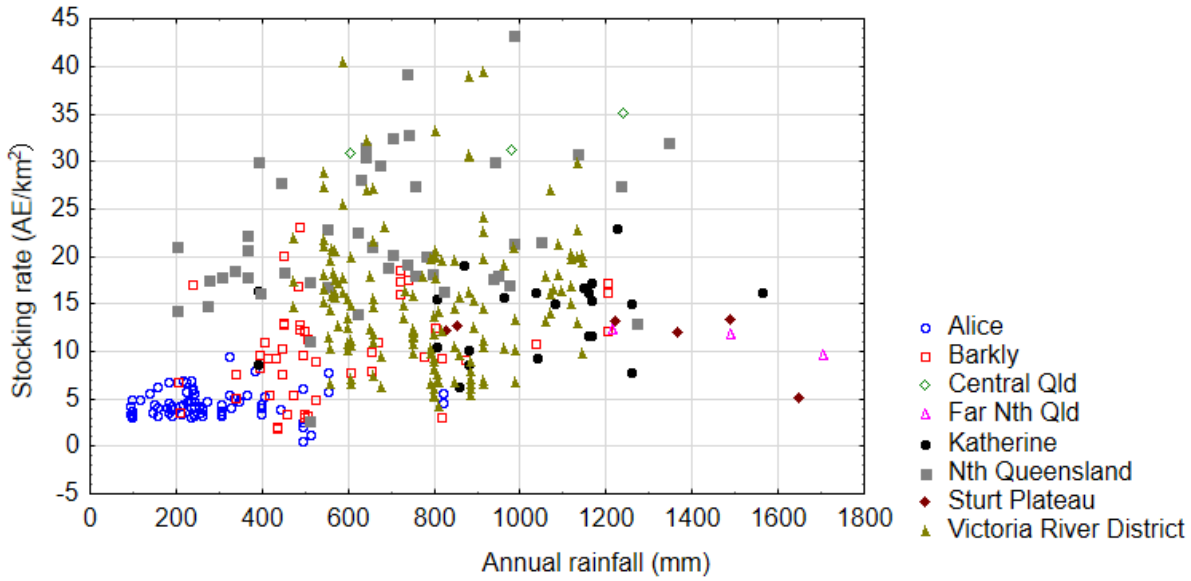


Figure 4-23: Annual stocking rate vs. annual rainfall for each year and site by region

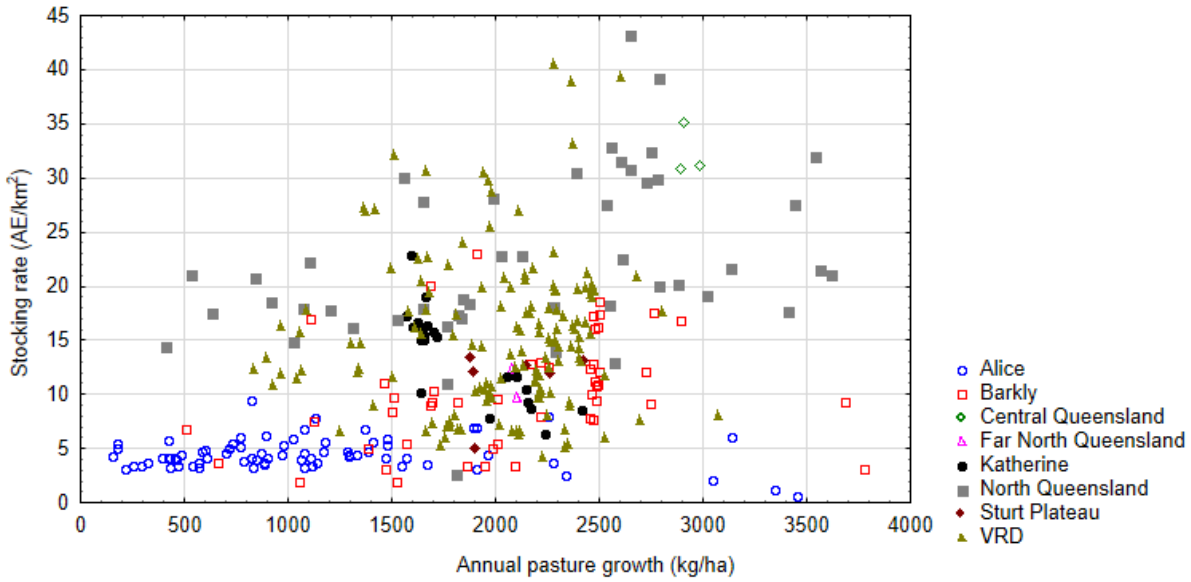


Figure 4-24: Annual stocking rate vs. pasture growth for each year and site by region

On average, over all years and sites, the average number of AE per waterpoint (including both permanent and semi-permanent waters) was 152. However, this varied within and between regions (Figure 4-25 – Figure 4-26). There was a larger range in number of head per water point in the Barkly and VRD regions (Figure 4-26).

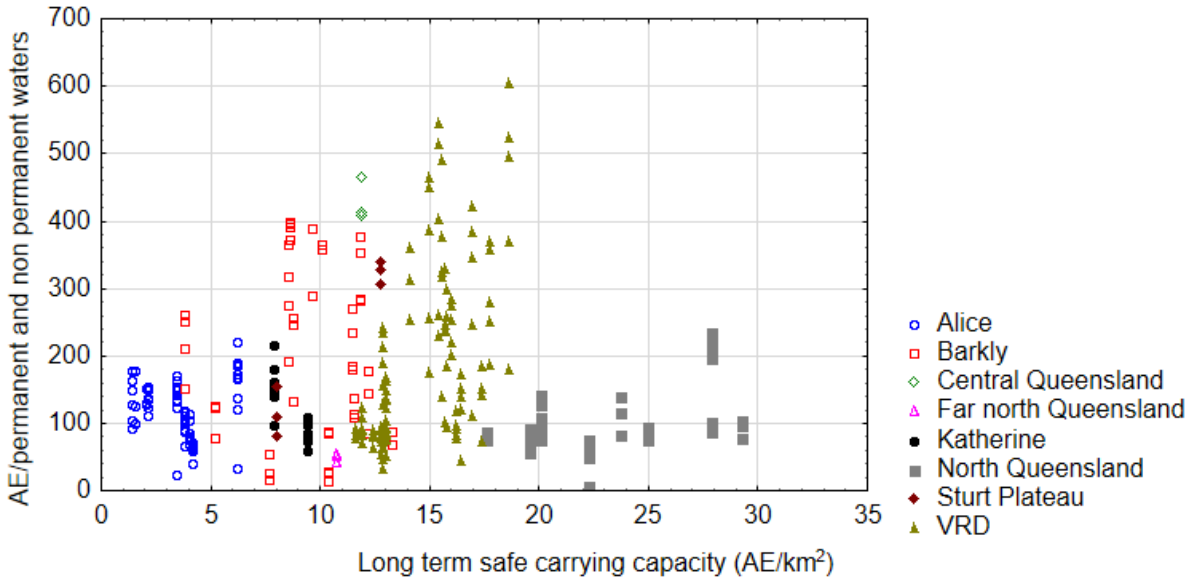


Figure 4-25: Annual adult equivalents per water point vs. safe carrying capacity for each site by year by region

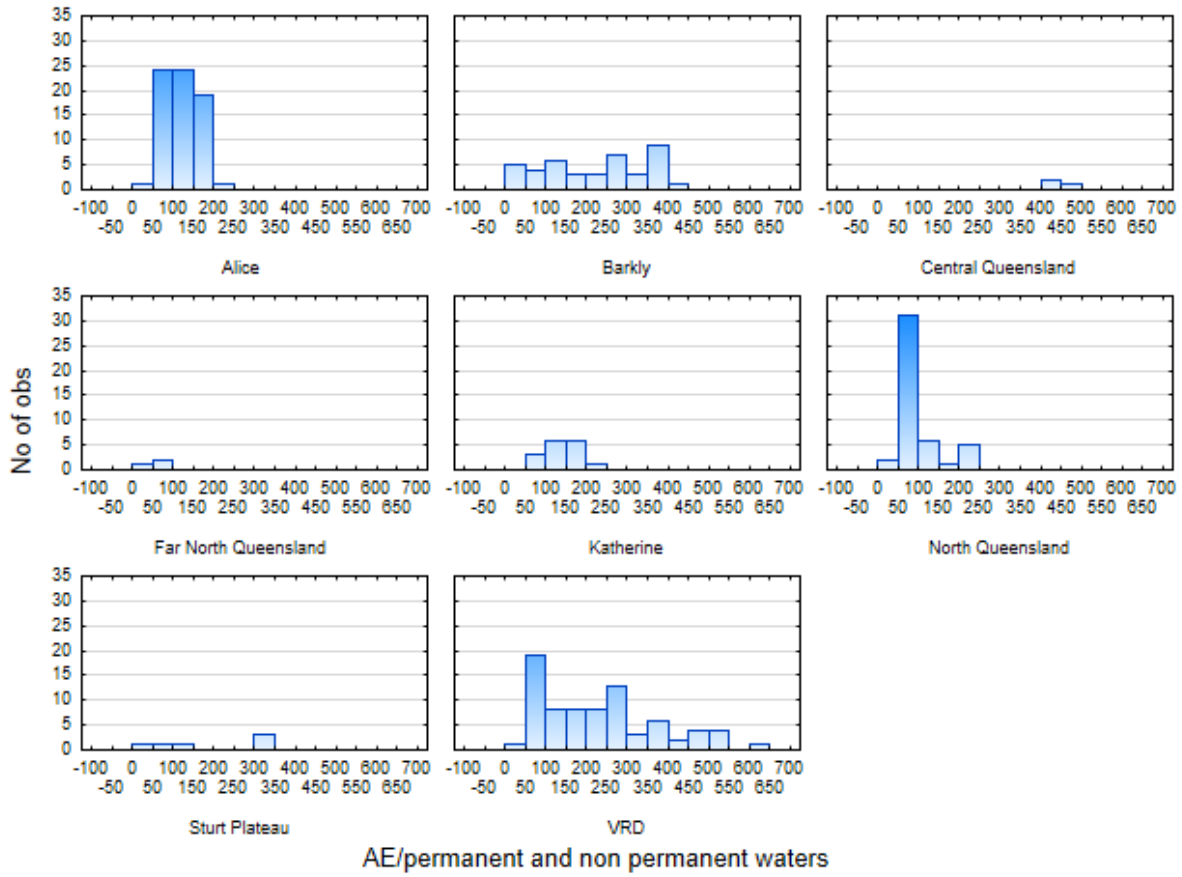


Figure 4-26: Variation in AE per number of permanent and non-permanent water points in the different regions

4.2.2.2 Annual rainfall and pasture growth

NE Queensland rainfall (Mann-Whitney U test $p<0.0001$), and annual pasture growth were higher on the commercial stations than during the research trials (Mann-Whitney U test $p=0.01$, Table 4-10). In the Alice region pasture growth was lower on the commercial station studies than on OMP (Mann-Whitney U test $p=0.01$, Table 4-10), despite higher rainfall (ns).

Table 4-10: Variation in rainfall and pasture growth in the Sweet Spot dataset with region and whether from commercials stations or as part of a research project testing stocking or utilisation rates

Region	Research/ Commercial	Number of site years	Rainfall (mm) Average	Rainfall (mm) Median	Pasture growth (kg/ha) Average	Pasture growth (kg/ha) Median
Southern NT	Commercial	19	348	324	737	766
Southern NT	Research	55	255	241	1226	1075
Central NT	Commercial	49	571	493	2079	2170
Central NT	Research	0				
Northern NT	Commercial	9	1147	1142	2158	2260
Northern NT	Research	164	807	798	1965	2067
North East Qld	Commercial	9	1177	1233	2757	2895
North East Qld	Research	45	632	638	2056	2024

Median rainfall increased from 241 mm at Alice to 802mm in the Northern NT, but the median growth was similar across the three more northern regions at around 2000 kg/ha (Figure 4-27, Figure 4-28). There was a greater range in rainfall in the Queensland and Northern NT sites (Figure 4-27), but the Northern NT site had the smallest range in simulated pasture growth (Figure 4-28). Despite having the smallest range in rainfall, the Alice region sites had a wide range in pasture growth similar to the Barkly and Queensland regions.

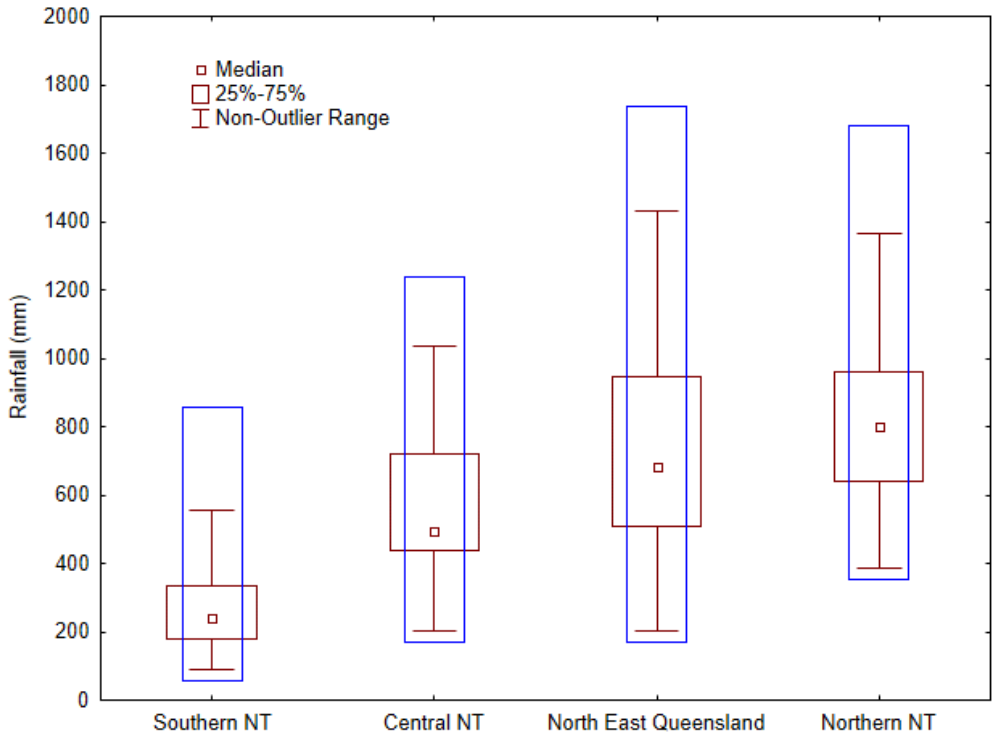


Figure 4-27: Variation in rainfall across all sites and years by broad region. Blue box = full range of data

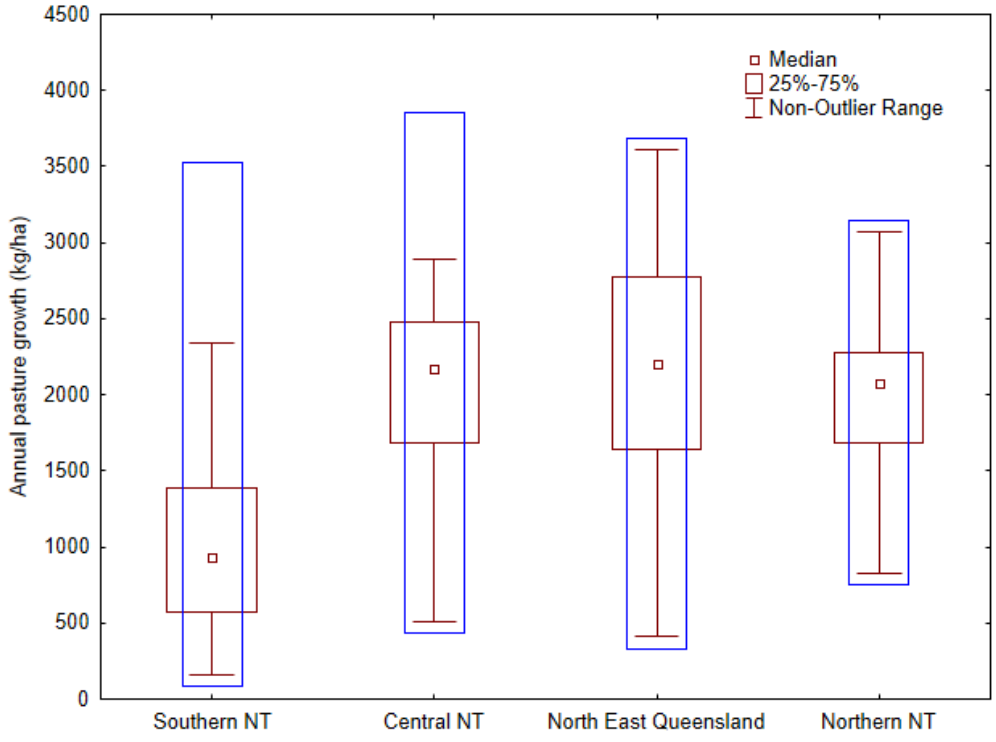


Figure 4-28: Variation in pasture growth across all sites and years by broad region. Blue box = full range of data

Pasture quality (% nitrogen in the standing pasture) varied between sites and years. Katherine, Sturt Plateau and the Far North Queensland sites had the lowest pasture quality reflecting high nitrogen

dilution in these high rainfall areas (Figure 4-29), while Alice Springs had amongst the highest % N in pasture, reflecting lower rainfall and pastures dominated by forbs and annual grasses.

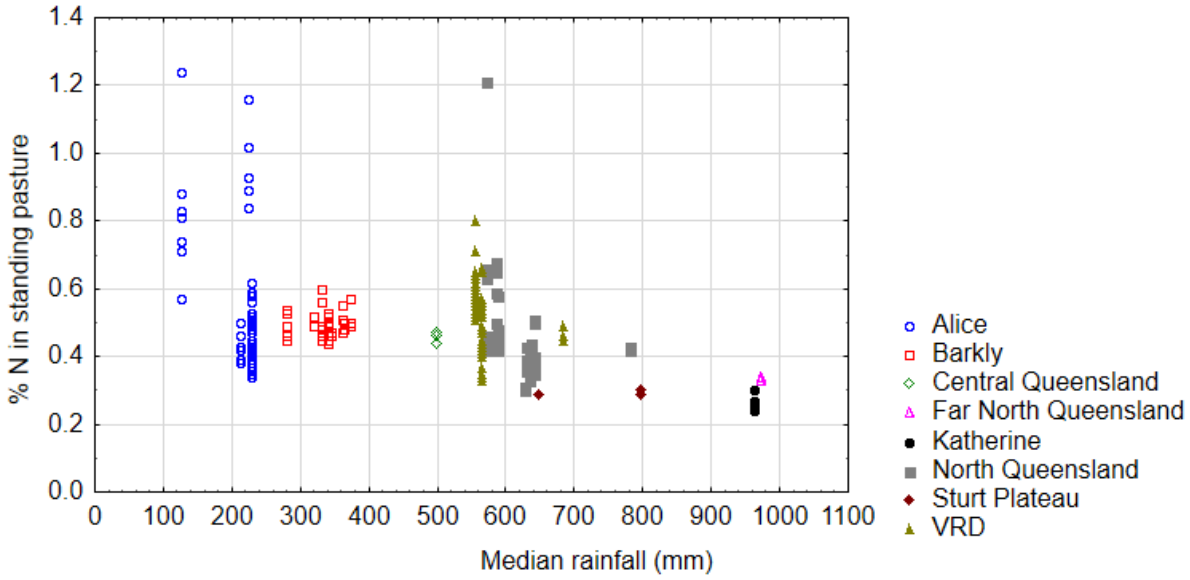


Figure 4-29: Average % N in standing dry matter vs. median long-term rainfall at the Sweet Spot sites by region

4.2.2.3 Annual pasture utilisation

In the Alice region pasture utilisation on commercial stations was double that on OMP (Mann-Whitney U test P=0.0003, Table 4-11). The pasture utilisation on NE QLD commercial stations was lower than in the grazing trials, but differences were not quite significant (Mann-Whitney U test, P=0.07).

Table 4-11: Variation in annual pasture utilisation in the Sweet Spot dataset with region on commercial stations vs. as part of a research project testing stocking or utilisation rates

Region	Research/ Commercial	Number of site years	Pasture Utilisation (%) Average	Pasture utilisation (%) Median
Southern NT	Commercial	19	31.0	21.6
Southern NT	Research	55	14.6	11.8
Central NT	Commercial	49	15.3	14.7
Central NT	Research	0		
Northern NT	Commercial	9	19.1	18.9
Northern NT	Research	164	23.9	21.8
North East Qld	Commercial	9	25.4	26.2
North East Qld	Research	45	36.2	31.9

The Alice and Queensland regions had the widest range in simulated pasture utilisations (Figure 4-30, Figure 4-31). The median pasture utilisation was less than safe in the Barkly and higher than safe in Queensland, possibly reflecting the stocking rate trials in the Queensland dataset.

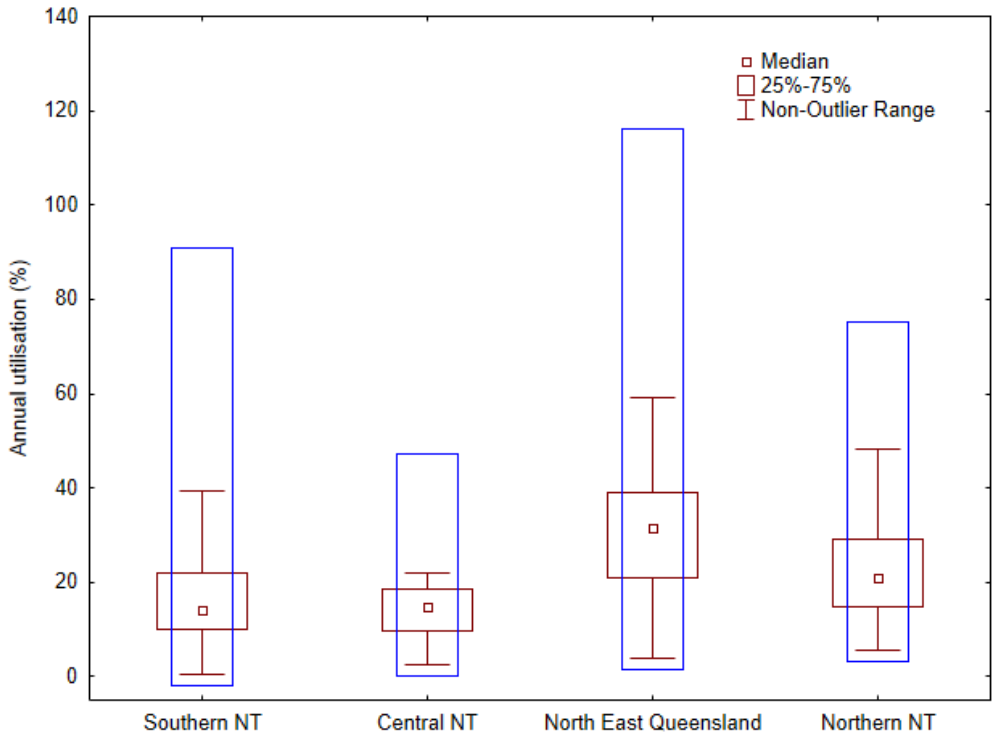


Figure 4-30: Variation in pasture utilisation across all sites and years by broad region. Blue box = full range of data

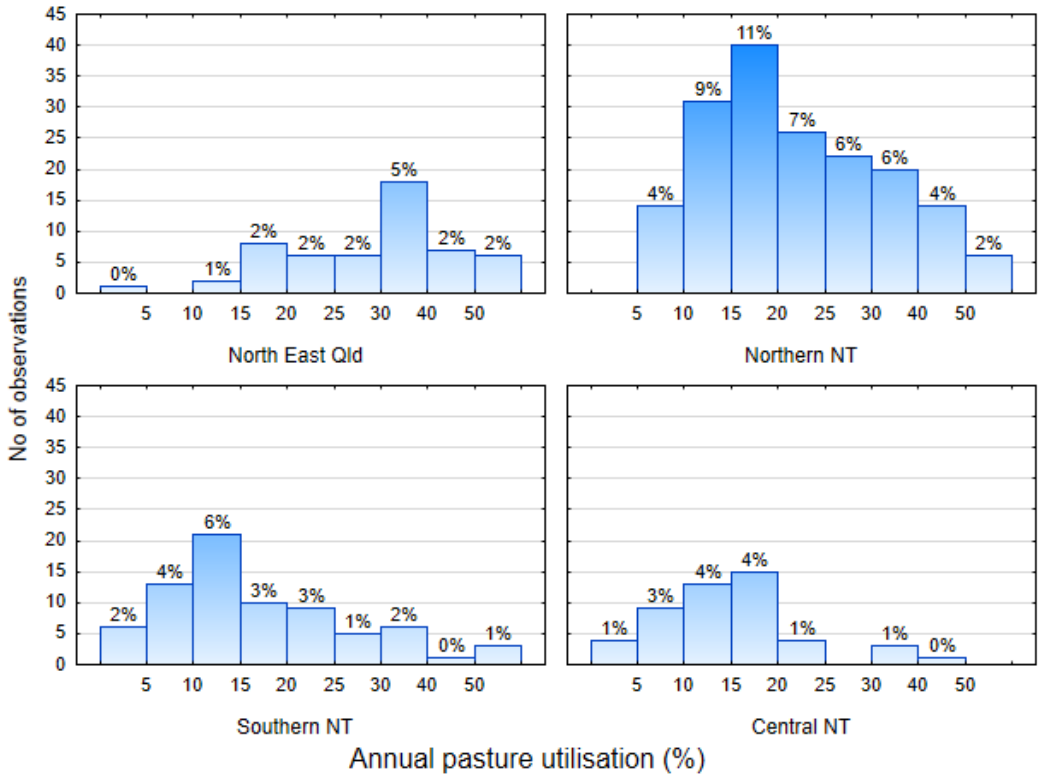


Figure 4-31: Histogram of the distribution of annual pasture utilisation values in each region of the Sweet Spot dataset

The combined effect of varying annual stocking rates and pasture growth provided a wide range in pasture utilisation found for each region across a range of rainfall and rainfall variabilities (Figure 4-32 to Figure 4-35). Very high pasture utilisation occurred when all of the annual pasture growth was utilised in low rainfall years (Figure 4-34 and Figure 4-35), but there was a wide range in utilisation for each region. Exceptions were the Cash Cow sites in far north and central Queensland which each only had 1 site by 3 years between 2009 and 2011, which happened to be high to very high rainfall years overlapping the 2010-2012 La Nina, and hence there was less variation in utilisation in these regions. They were subsequently combined with the North Queensland region for all breeder performance summaries.

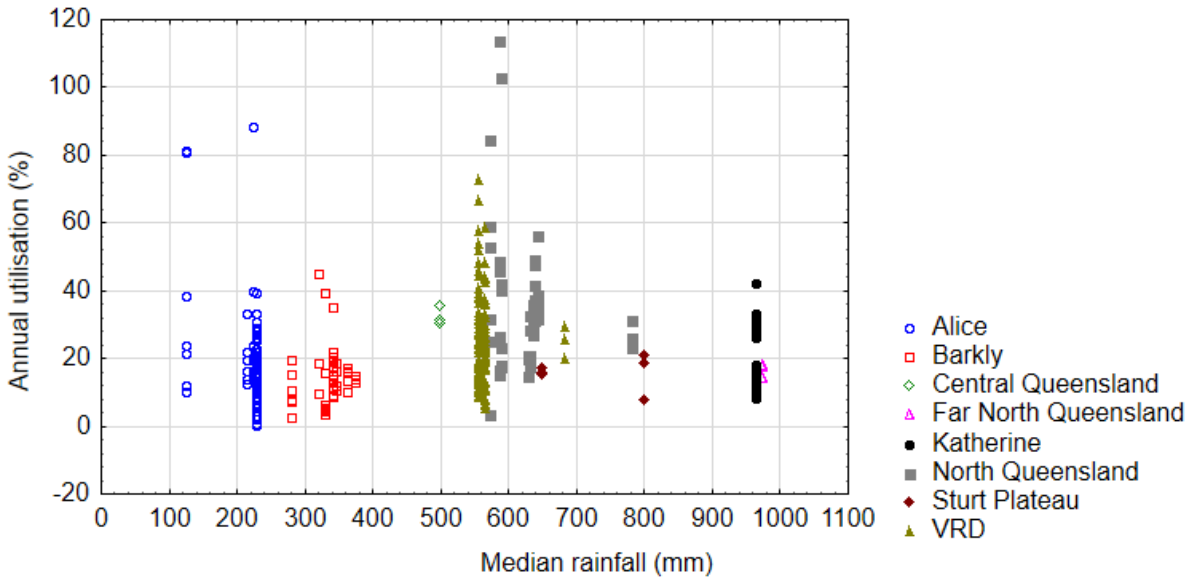


Figure 4-32: Annual pasture utilisation for each year and site vs. long-term median rainfall by region

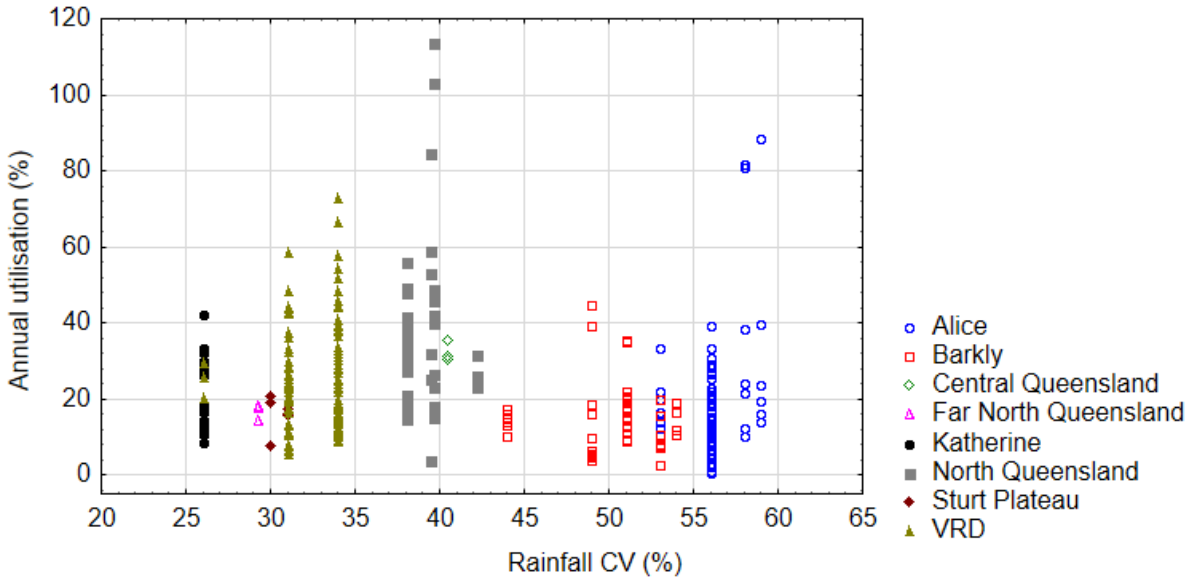


Figure 4-33: Annual pasture utilisation for each year and site vs. rainfall coefficient of variation by region

The highest pasture utilisations (>70%) occurred in low rainfall years (Figure 4-34 and Figure 4-35) at sites with both high and low long-term median growth (Figure 4-36), but when growth was less than 500kg/ha (Figure 4-37) and in both small and large paddocks (Figure 4-39).

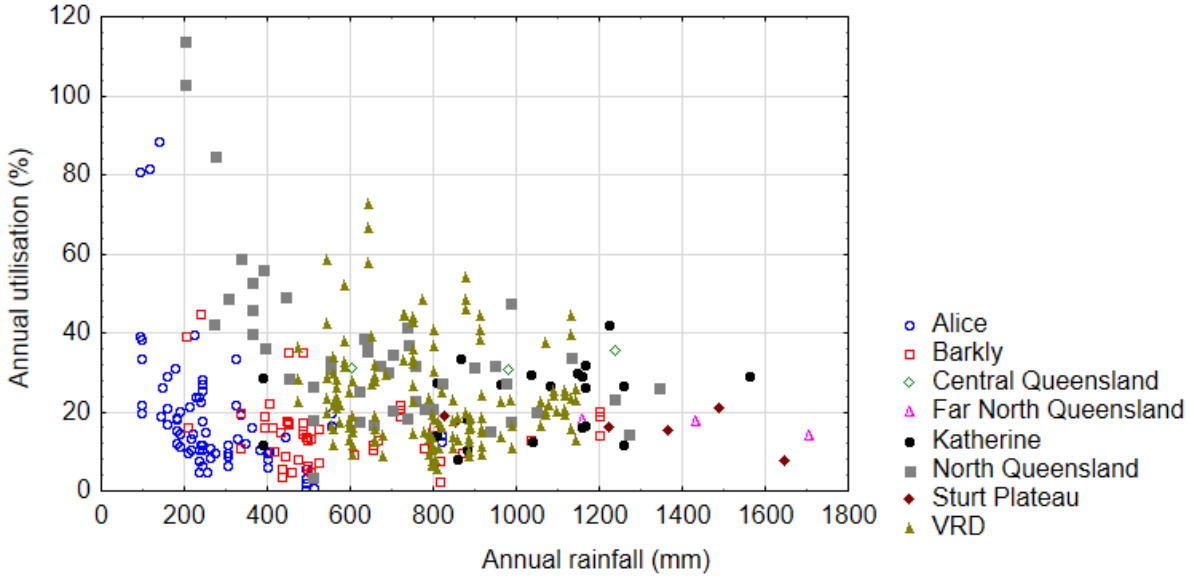


Figure 4-34: Annual pasture utilisation for each year and site vs. annual rainfall during each study by region

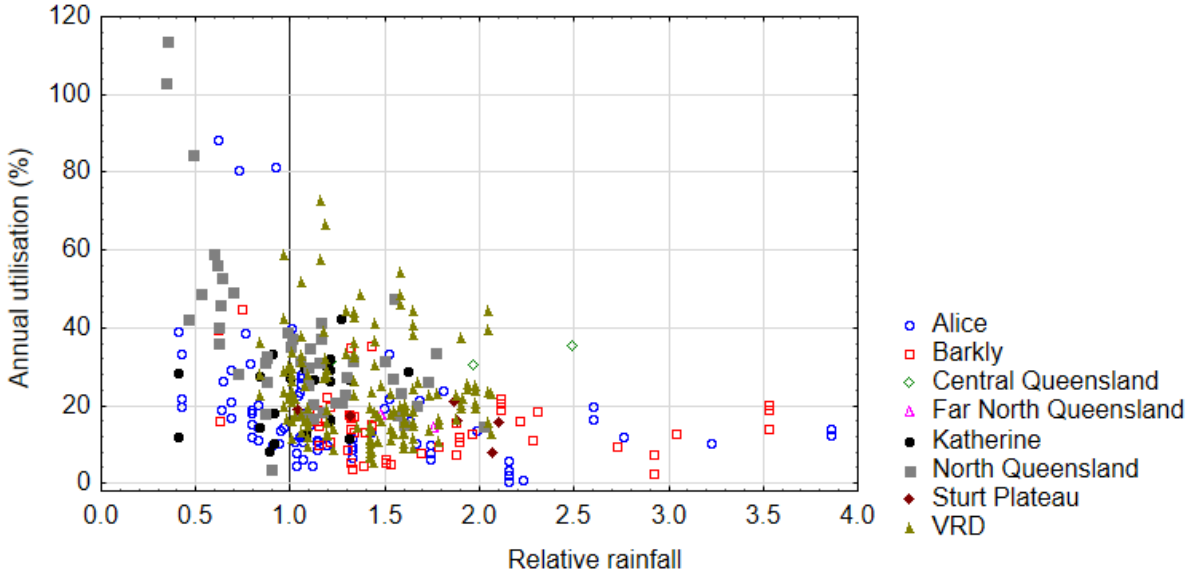


Figure 4-35: Annual pasture utilisation vs. relative rainfall (annual/median rainfall) by region. Relative rainfall <1 = less than median rainfall, >1 = greater than median rainfall, = 1 = median rainfall

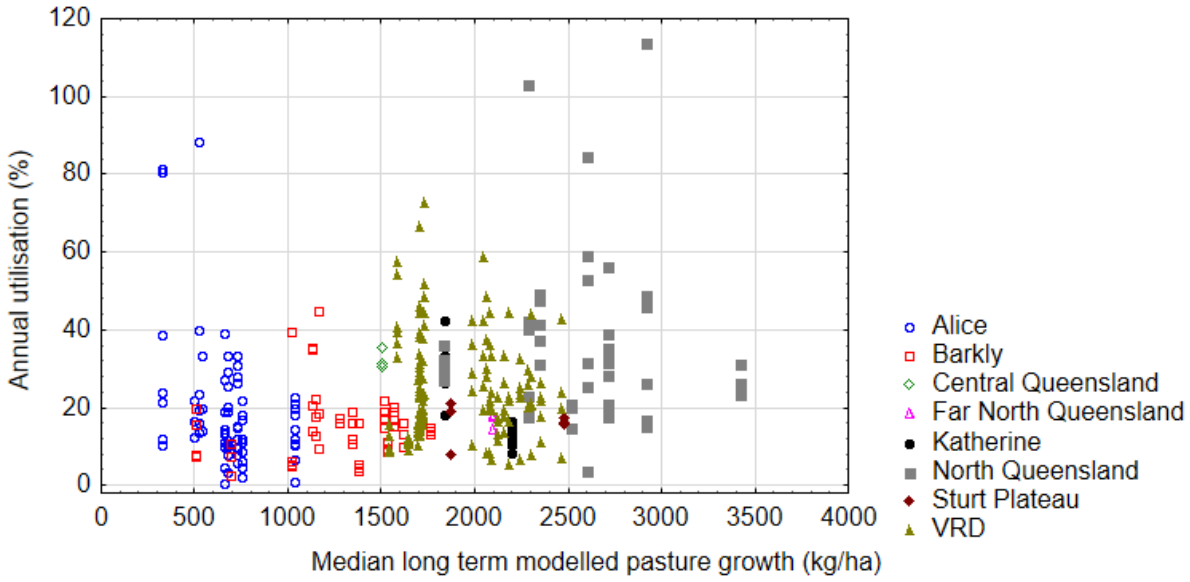


Figure 4-36: Annual pasture utilisation for each year and site vs. long-term median pasture growth by region

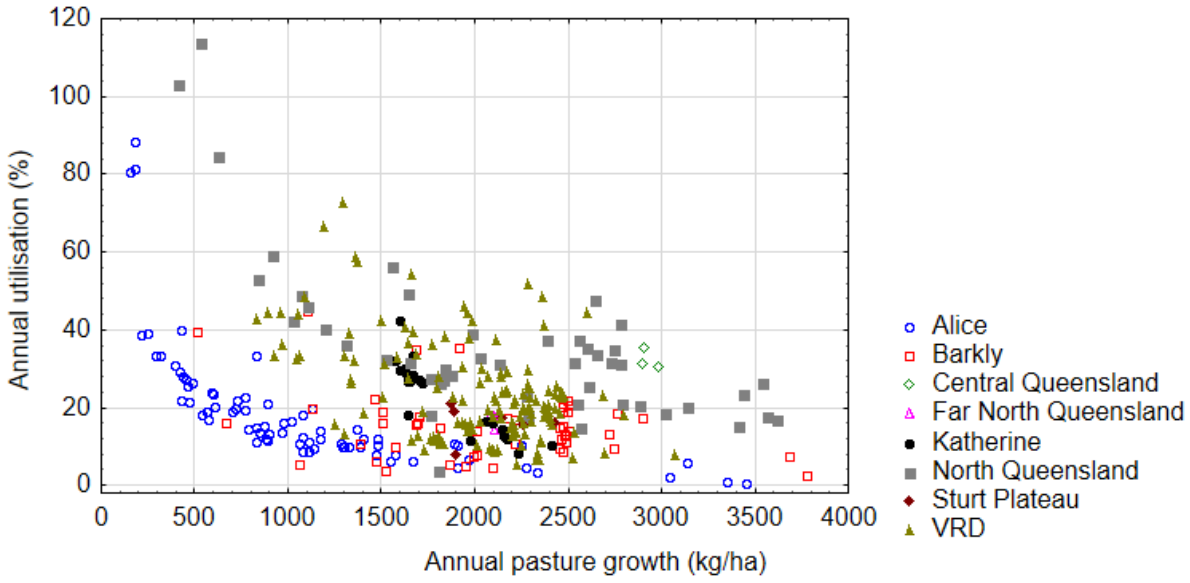


Figure 4-37: Annual pasture utilisation for each year and site vs. annual pasture growth by region

Stocking rate explained more of the variation in annual pasture utilisation in the Northern NT and Barkly regions (Table 4-12) and pasture growth explained more of the variation in pasture utilisation in the Southern NT and NE Queensland regions (Figure 4-38, Table 4-13).

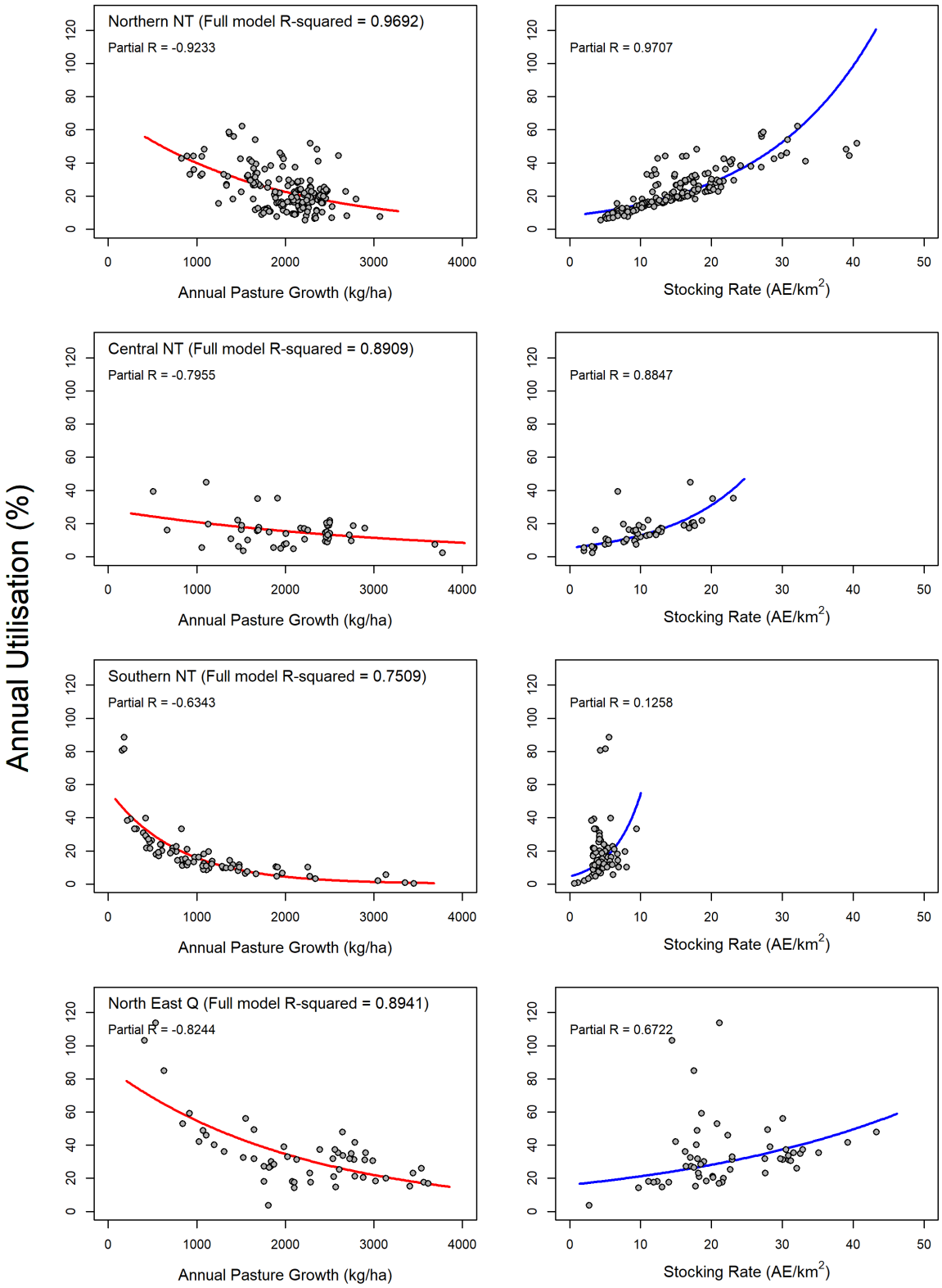


Figure 4-38: Relationships between pasture utilisation and stocking rate and pasture growth for each broad region

Table 4-12: Coefficient of regression between annual pasture utilisation and annual stocking rate for Sweet Spot broad regions * P<0.05 P<0.01*** P<0.00001**

Region – Sub-regions	df	Intercept	Slope	r^2	P
Southern NT - Alice	72	9.5	2.05	0.03	ns
Central NT - Barkly	47	3.2	1.18	0.48	***
Northern NT - Katherine / Sturt Plateau / VRD	171	1.3	1.46	0.70	***
North East Qld – Central, North and Far North Qld	52	24.2	0.46	0.03	ns

Table 4-13: Coefficient of regression between annual pasture utilisation and log annual pasture growth rate for Sweet Spot broad regions * P<0.05 P<0.01*** P<0.00001**

Region – Sub-regions	df	Intercept	Slope	r^2	P
Southern NT - Alice	72	153	-45.6	0.72	***
Central NT - Barkly	47	82.7	-20.5	0.15	**
Northern NT - Katherine / Sturt Plateau / VRD	171	217	-58.9	0.26	***
North East Qld – Central, North and Far North Qld	52	282	-75.2	0.62	***

Paddock size was not correlated with pasture utilisation with high utilisation in both very large commercial paddocks in the Alice region and with smaller research paddocks in the VRD and North Queensland (Figure 4-39).

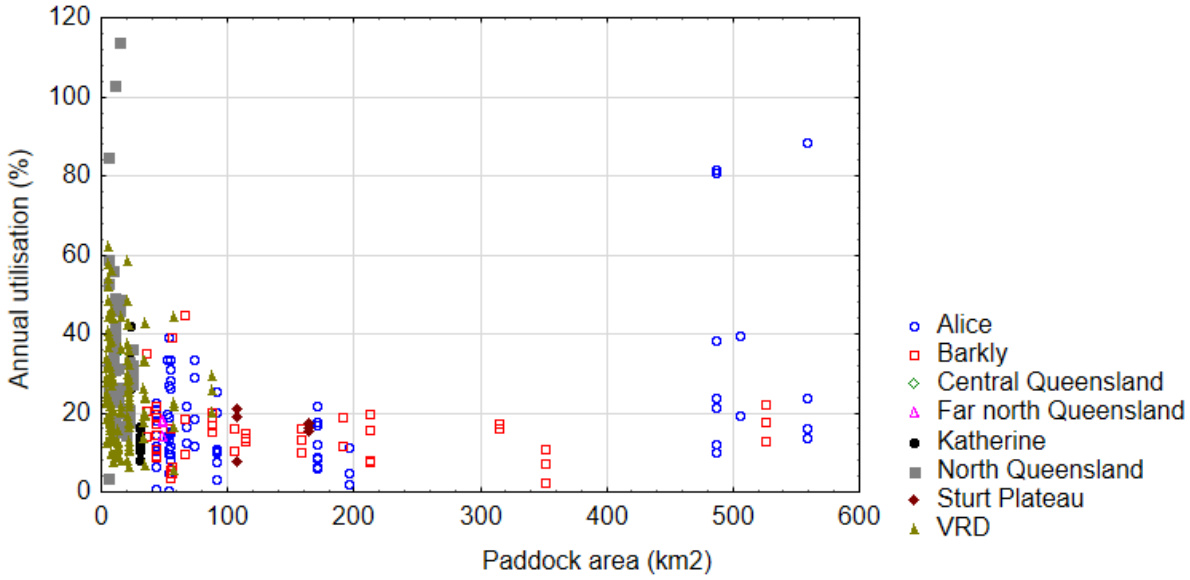


Figure 4-39: Annual pasture utilisation for each year and site vs. paddock area by region

For detailed site descriptions and GRASP calibration and modelling results of each site see Appendix 14.3, page 308.

4.2.2.4 Relative pasture utilisation

In the Alice region relative pasture utilisation on commercial stations was more than double that on OMP (Mann-Whitney U test P<0.0001,Table 4-14), but there was no difference in median relative utilisation in Northern NT and NE QLD between research trials and commercial stations, which were all between 1 and 1.3.

Table 4-14: Variation in annual pasture utilisation in the Sweet Spot dataset with region on commercial stations vs. as part of a research project testing stocking or utilisation rates

Region	Research/ Commercial	Number of site years	Relative Pasture Utilisation Average	Relative Pasture Utilisation Median
Southern NT	Commercial	19	2.6	1.8
Southern NT	Research	55	0.9	0.7
Central NT	Commercial	49	0.7	0.7
Central NT	Research	0		
Northern NT	Commercial	9	1.3	1.2
Northern NT	Research	164	1.2	1.0
North East Qld	Commercial	9	1.3	1.3
North East Qld	Research	45	1.4	1.1

The Alice region had the widest range in relative pasture utilisation (Figure 4-40, Figure 4-41) and the Barkly region had the smallest. In the Alice Springs region, median pasture utilisation was 1.8 x higher than recommended levels on commercial stations compared to the utilisation rate on the research station where it was 0.7 x recommended levels, despite higher relative rainfall for the commercial herd studies. In contrast, in the Barkly the median utilisation on commercial stations was lower than recommended levels (0.7 x recommended) possibly reflecting the high relative rainfall during those studies. On commercial stations in northern NT and NE Queensland regions, median utilisation was 1.2 and 1.3 respectively x recommended levels of pasture utilisation, but this was for years with rainfall 1.6 and 1.7 times the long-term median respectively.

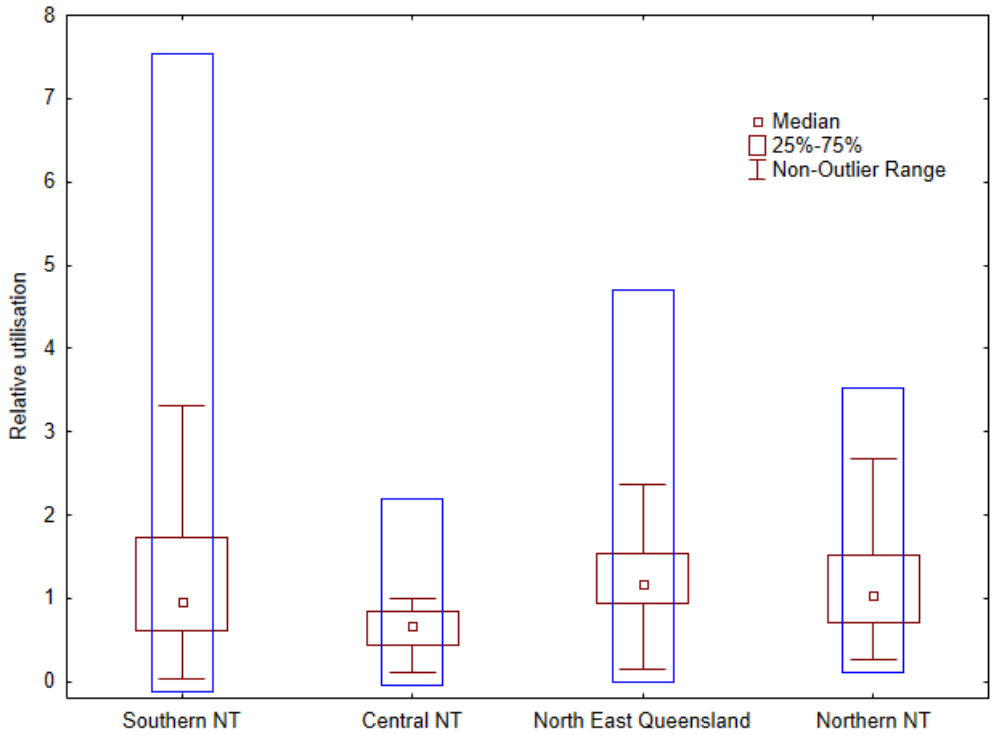


Figure 4-40: Variation in relative pasture utilisation across all sites and years by broad region. Blue box = full range of data

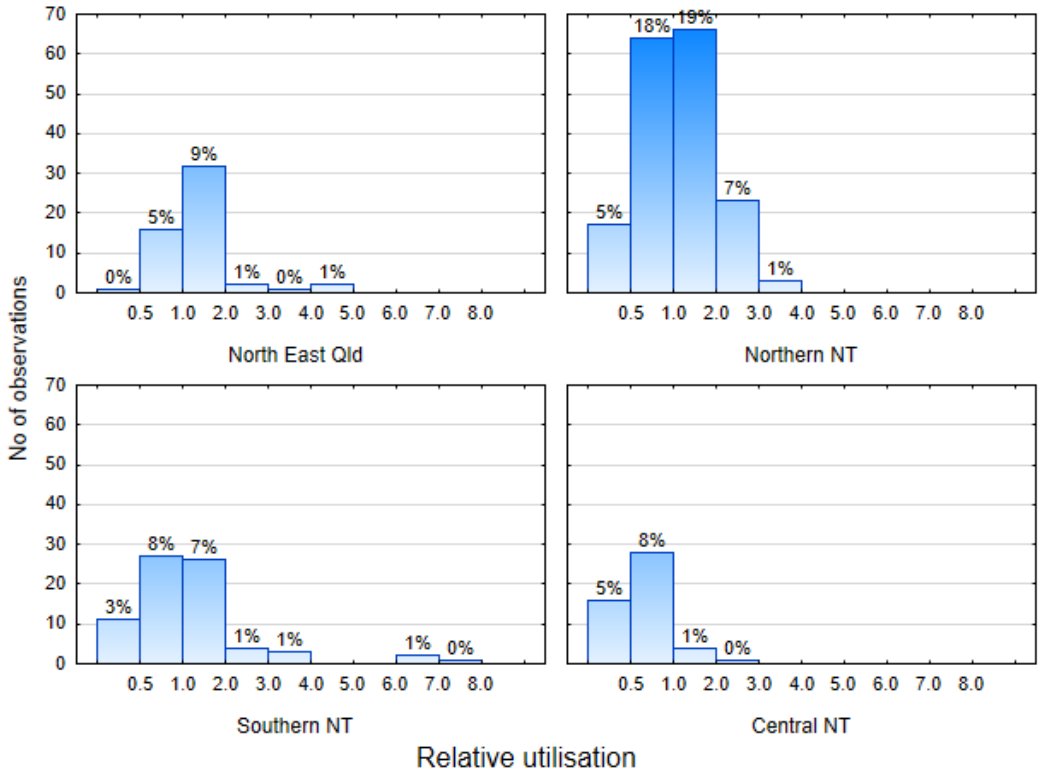


Figure 4-41: Histogram of the distribution of relative utilisation values in each region of the Sweet Spot dataset

Relative utilisation did not significantly vary with median long-term rainfall or rainfall variation (Figure 4-42, Figure 4-43), although the highest relative utilisation was in low rainfall high rainfall variability sites in the Alice region.

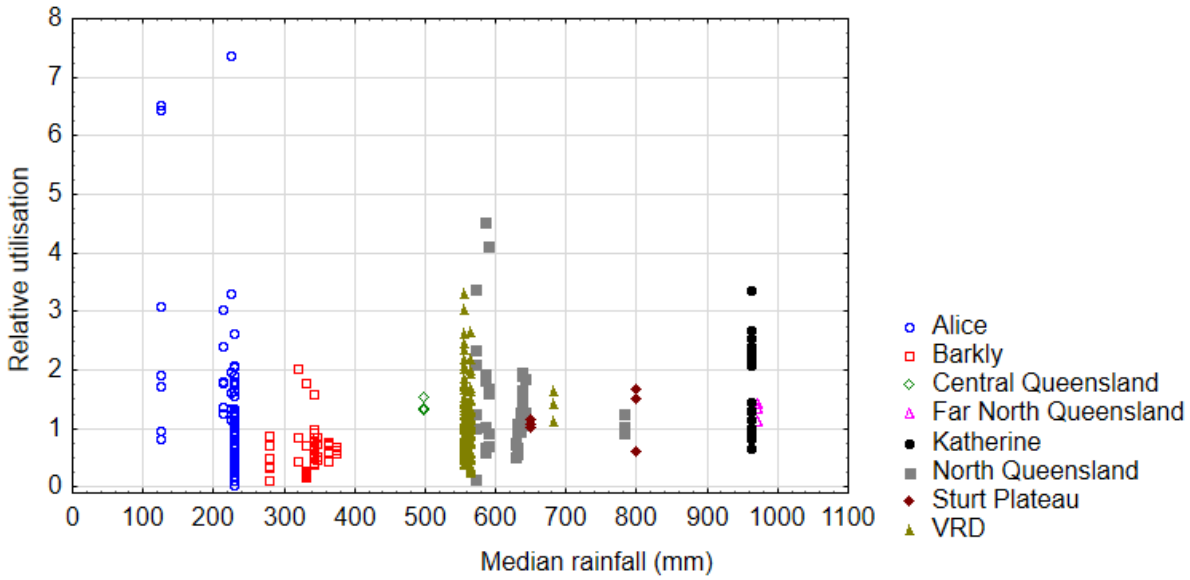


Figure 4-42: Relative pasture utilisation (modelled/safe utilisation) vs. median long-term rainfall

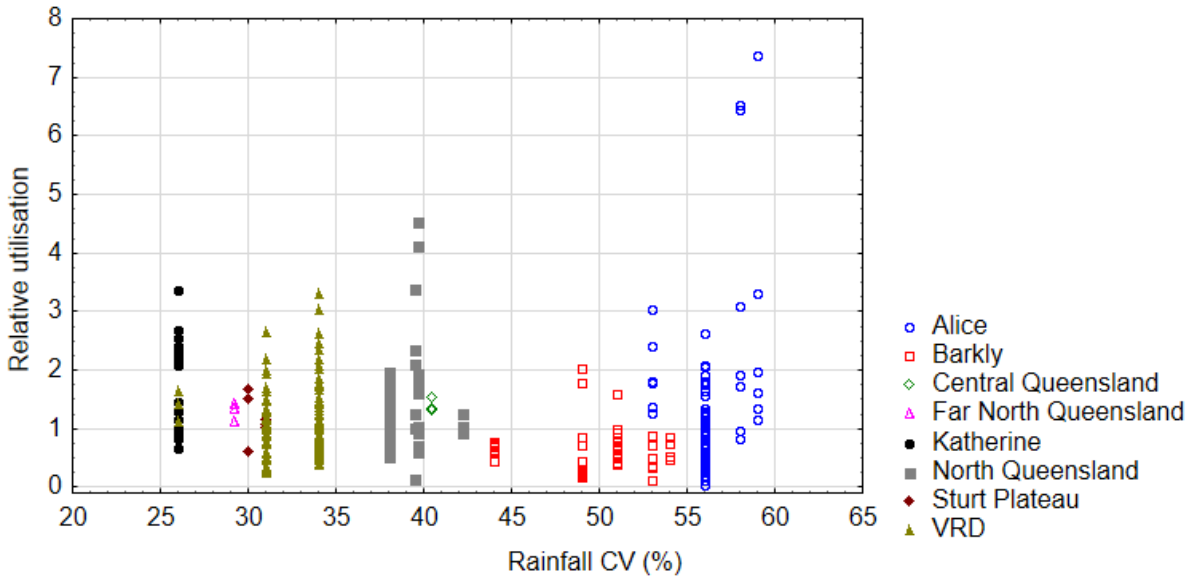


Figure 4-43: Relative pasture utilisation (modelled/safe utilisation) vs. rainfall variability

Relative pasture utilisation was more likely to be high with lower than median rainfall (Figure 4-44) and lower with higher than median rainfall. Relative utilisation was highest when annual pasture growth was around 500kg/ha or less (Figure 4-45).

The Barkly region had the lowest relative pasture utilisation (Table 4-5), and only exceeded recommended levels in 4 out of 49 site years (Figure 4-45).

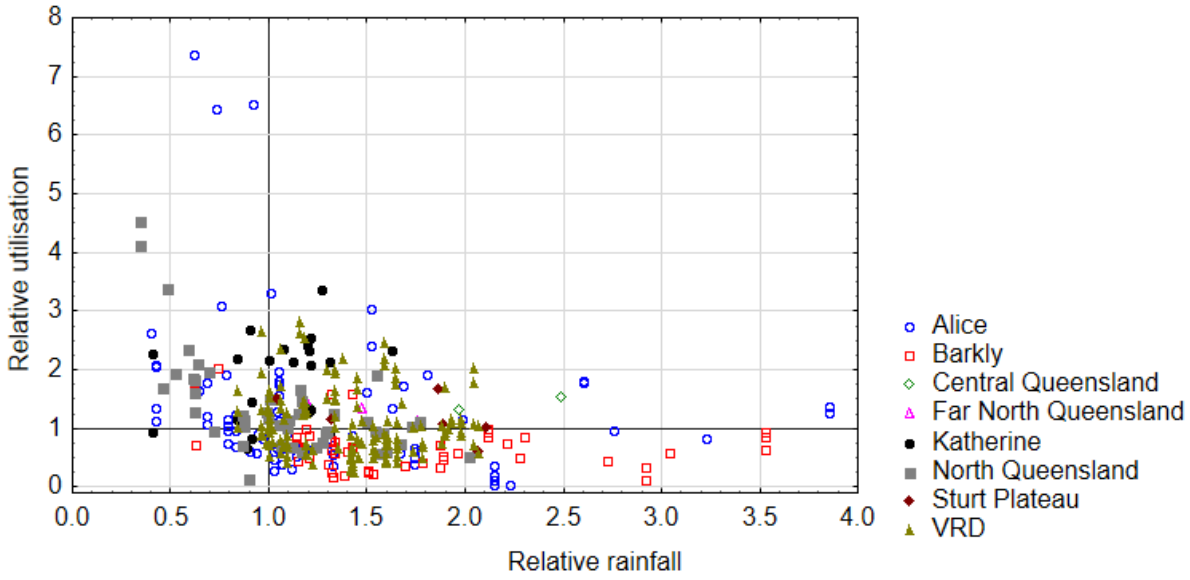


Figure 4-44: Relative pasture utilisation (modelled/safe utilisation) vs. relative rainfall (annual/median rainfall)

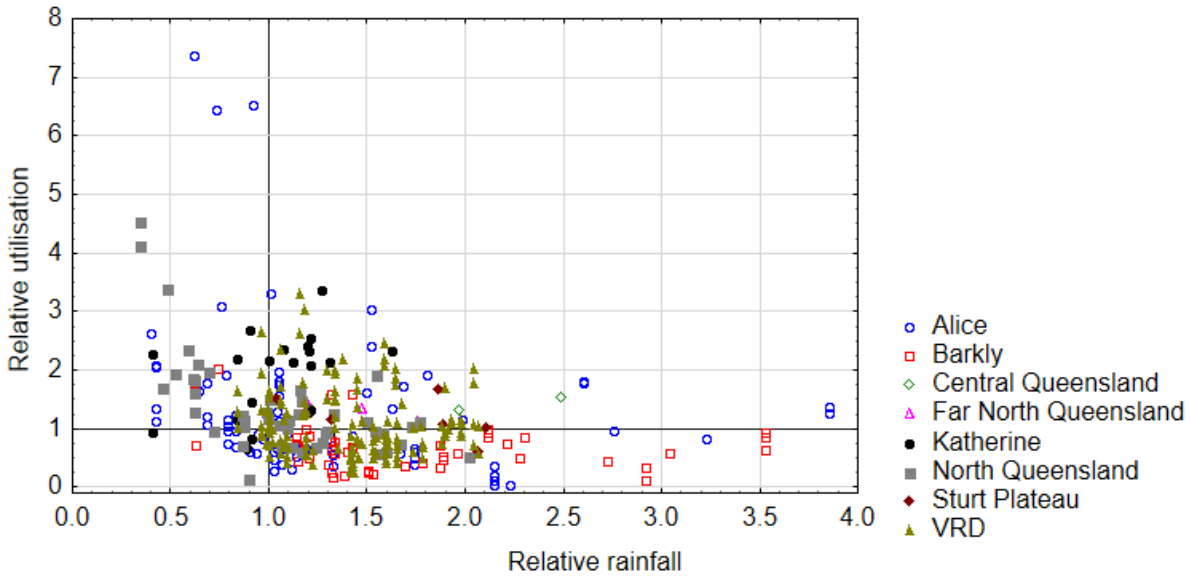


Figure 4-45: Relative pasture utilisation (modelled/safe utilisation) vs. annual pasture growth

4.3 Discussion

4.3.1 Infrastructure development

The infrastructure development in the dataset is unlikely to be a good representation of industry scale of development for a number of reasons. The paddock infrastructure collated for this study represents the levels of development at the time of each study and may not be as representative of current infrastructure development. Additionally, this dataset is skewed by smaller research paddocks in the Alice (Old Man Plains) and VRD regions (Mt Sanford and Pigeon Hole) where paddocks were deliberately reduced in size for grazing trials. Despite this, some patterns are probably reflective of industry trends. Larger less well watered paddocks tended to be found in more arid areas with lower carrying capacity, possibly reflecting the lower cost effectiveness of development at low carrying capacity. All Queensland sites were fully or nearly fully watered, reflecting the higher intensity of development in Queensland.

4.3.2 Modelled pasture growth

Tree cover varied between 0 and 2 m^2/ha up to about 500mm long-term median rainfall, and increased linearly with higher rainfall consistent with observations of woody cover along a rainfall gradient in the Northern Territory (Williams *et al.* 1996). Simulated pasture growth was strongly linearly responsive to median long-term rainfall up to about 600mm, where upon growth had much greater variation with increased rainfall reflecting the greater effect of increasing tree cover and land type fertility on pasture growth when nutrients can become limiting to growth at higher rainfall (Mott *et al.* 1985, Cobiac 2006).

This dataset is skewed towards wetter years. This is manifest in the drier regions (median rainfall <500mm) having higher pasture growth during the study timeframes than the long-term median pasture growth for those sites. This is because pasture growth is usually rainfall limited in drier regions, whereas for wetter regions there is less variability in growth year to year, because growth is often nutrient limited at higher rainfall locations (Mott *et al.* 1985).

The lower range in pasture growth in the wettest region of Northern NT also reflects the greater likelihood of pasture growth being limited by nitrogen at higher rainfall. You can see with the modelled growth at the individual sites (Appendix 14.3) that growth often topped out with nitrogen limitations in the higher rainfall years.

Stocking rate was more closely correlated with median long-term simulated pasture growth than average simulated growth during the study years. This suggests a tendency for stocking rate to be strategically set to match long-term expected conditions rather than tactically adjusted to follow seasonal variations., It was of course both as some datasets were explicitly trialling adjusting stocking rates to reduce fluctuations in pasture utilisation (Mt Sanford and Pigeon Hole utilisation trials), and others such as Old Man Plains were set to the long-term safe carrying capacity.

In the sites with frequently measured paddock TSDM there was little evidence that pasture growth was less than potential growth at higher utilisations unlike suggested in Day *et al.* 1997. Evidence of this would be if the final site models of higher utilisation paddocks (that were otherwise similar in land type and productive capacity) had lower long-term simulated pasture growth than paddocks with safe or low utilisation. A possible example of this was at Pigeon Hole where there was a tendency for lower simulated pasture growth at higher average pasture utilisation even though the maximum utilisation tested was only 36%. Higher pasture utilisation years can lead to lower rainfall use efficiency the following year through lower ground cover and TSDMs leading to higher soil evaporation and runoff. High utilisation particularly over the wet season can also lead to reduced pasture growth the following wet season (Mott *et al.* 1992, Ash *et al.* 1996, Ash and McIvor 1998, Ash *et al.* 2011) through impacts on perennial grass basal area. This was possibly observed in the 2002/2003 wet season at the Mt Sanford and Pigeon Hole grazing trials when the wet season was delayed after a false start and the model overestimated growth for that season (Appendix 14.3.8, page 361). The model was adjusted to better predict growth that year by reducing grass basal area for that year. It is possible that the delayed start to the wet season after a false start caused high defoliation early in the wet season which reduced grass basal area. At other grazing trials in this dataset with calibrated TSDMs - OMP, Thalanga and Swans Lagoon, there was no evidence that growth was overestimated following high utilisation years.

4.3.3 Safe carrying capacity

The long-term safe carrying capacity calculated here in AE / km^2 varied almost 30 fold between sites, due to the variation in long-term median simulated pasture growth and assumed safe level of utilisation for different land types. The safe carrying capacity calculated here is relevant to the land condition and the land types within the watered area at the study sites at the time of the studies. Usually carrying capacity is calculated assuming A condition and may assume all the paddock is watered – more a potential carrying capacity. Here we wanted to know the actual rather than potential pasture growth during the study, so carrying capacity here may vary from other assessments of safe carrying capacity for those sites if land condition or infrastructure has changed since the time period of each dataset.

4.3.4 Pasture utilisation modelling approach

The modelling of pasture utilisation for 60 breeder herd sites was a massive undertaking. Four modellers from NTDAF (Robyn Cowley, Chris Materne and Caroline Pettit) and QDPI (Giselle Whish) modelled the sites and a further two modellers from QDESI (John Carter and Grant Fraser) provided coding for GRASP model adjustments and feedback and advice regarding modelling design and

parameterisation. Data collation alone to model each site took at least a week, with considerable lead times, collaboration and coordination across research groups required to source supporting datasets. The methodology to calibrate pasture growth at sites was continually updated with new learnings as new site-specific challenges were identified and resolved. Calibration and modelling of a site took up to several days, depending on the availability of supporting datasets, knowledge of and familiarity with the site. Up to two modellers worked on each site. As new methods were developed, sites were often rerun to incorporate new learnings to increase the accuracy and reliability of model outputs. The process of modelling these sites from breeder herd trials over the last 30 years has greatly increased the modelling experience and capacity for northern Australian grazing systems research.

Pasture utilisation has previously been modelled for grazing trials in Queensland (Day *et al.* 1997, Stone *et al.* 2008) and the Northern Territory (Cowley and Walsh 2023). This is the first time it has been done for the purposes of explaining the variation in cattle breeder performance that the authors are aware of, particularly at sites where pastures were not monitored as part of the original animal production study. The Sweet Spot dataset includes both intensive research datasets designed explicitly to investigate stocking rate or utilisation impacts on breeder performance (Cowley *et al.* 2007, Hunt *et al.* 2013, Smith *et al.* 2000), as well as paddocks on commercial stations where herds were monitored for performance, but little to no accompanying vegetation data was recorded as part of the study. Our approach combined various sources of supporting datasets including Landsat satellite derived green ground cover, calibrated yield estimates from other studies in those paddocks at other times, uncalibrated yield estimates from study paddocks, and from historical photos from permanent monitoring sites on NT stations which were used to estimate historical TSDM (by Robyn Cowley and Chris Materne comparing photos to yield photo-standards) to help calibrate the paddock pasture growth for each site. The monitoring site photos were not available outside of the NT, which reduced the confidence we had in the modelling outputs for those sites. The availability of satellite derived ground cover indices extracted for each site greatly enhanced the ability to model sites where little other vegetation data was collected in the paddocks, and without which we would not have attempted to model many of these sites on commercial stations in outside of the NT.

Where TSDM was regularly collected, and especially where it was collected twice yearly, there was some evidence that parameters that are usually left constant for a land type may be changing over time due to seasonal variation in species composition and grazing. These were the pasture structure parameters p45 and p46 (green yield at 50% green cover), total yield at 50% total cover (p271) and detachment rates (p128 - p131). Accompanying trial field data on species composition at Mt Sanford, Pigeon Hole, Thalanga, Swans Lagoon and Old Man Plains indicated that the proportion of annuals and forbs and perennial grasses sometimes shifted gradually over time (Mt Sanford), and sometimes fluctuated quite a lot annually with different seasons (Pigeon Hole, Thalanga, Swans Lagoon, Old Man Plains). We know that detachment rates are higher for forbs and annuals and cover-yield relationships vary with different structured species such as tussocky grasses vs. more prostrate forbs and annual grasses. These parameters were sometimes changed through the simulation based on evidence where TSDM, green cover and species data suggested it was logical to do so. This is not something that is dynamically simulated in GRASP, so required manual resets through the management records. It is also not something that we would try to achieve for long-term modelling of pasture growth for carrying capacity purposes where the median over the long-term is the outcome of interest rather than in this study where we tried to simulate pasture growth (and hence pasture utilisation) as accurately as possible for each year. Hence the modelling approach of each site varied depending on the available supporting datasets.

Given the potential variability in yield across paddocks with multiple land types and through the uneven distribution of grazing with distance from water, the use of TSDM estimates from a few permanent monitoring sites seems potentially fraught. Where possible the TSDMs were weighted for distance from water and proportion of land type in the paddock. Large paddocks sometimes had multiple monitoring sites which were either averaged or included individually as a visual comparison but not explicitly calibrated to, if the relevance of the monitoring site to the broader paddock yields was uncertain (e.g. at Station 6, page **Error! Bookmark not defined.**). Estimates of grazing intake were based on cattle performance data from the study period. Despite the many potential sources for error, the GRASP model was able to simulate the observed paddock level yields well (e.g. at Mt Riddock, page **Error! Bookmark not defined.**).

The calculation of relative pasture utilisation required an assumption of the safe level of utilisation for each paddock. Safe/recommended utilisation levels have been developed from the perspective of what will maintain land condition, rather than what is economically profitable, and varied between sites and regions. The safe utilisations assumed for the dataset varied from 9 to 30% with most between 20 and 22%. This compares with 25% for the north American rangelands (Smart *et al.* 2010, Galt *et al.* 2000). For the eucalypt woodland regions, estimated safe utilisation levels were higher for Queensland regions (15 - 30%) than for NT regions (10-15%) (Table 4-6). This may reflect inherent differences in land type fertility and/or resilience because the Queensland sub-regions had more than double the available soil P levels of the NT sub-regions. Differences were not explained by rainfall, because the region with the lowest median rainfall and the highest inter-annual variation in rainfall, which could be expected to reduce safe utilisation rates, had the highest 'safe' utilisation rate.

Research into the safe utilisation rates of northern Australian pastures from a resource sustainability perspective has been ongoing since the 1990s (McKeon *et al.* 1994, Day *et al.* 1997, reviewed in Hunt 2008). Safe pasture utilisation varies with land type and regionally. It is lower with poorer soil fertility (Hall *et al.* 1998, Johnston *et al.* 1996), higher rainfall variability (Hall *et al.* 1998) and shorter growing seasons (fewer days with pasture growth, Hall *et al.* 1998). Where possible we referred to published estimates of safe utilisation for each study site land types based on grazing trials (Ash and McIvor 1998, Ash *et al.* 1997, Cowley *et al.* 2007, State of Queensland 2022), and retrospective modelling of utilisation in benchmark paddocks with good or improving pasture condition (Cowley and Walsh 2011, Johnston *et al.* 1996). In Queensland all land types have published descriptions including the safe level of pasture utilisation derived through a combination of modelling and expert opinion. This is not the case for the Northern Territory. In the Alice region there was no locally derived research evidence for safe land type utilisations, so we referred to recommended safe utilisation levels from similar land types in south west Queensland (Johnston *et al.* 1996, Walsh *et al.* 2014).

The Alice sites had the highest rainfall variability, which generally reduces safe utilisation rate, but also amongst the highest available soil phosphorus which generally increases safe utilisation rate. The utilisation rates we assumed were safe for Alice sites varied from as low as 9% in a paddock with a dominated by spinifex land types to 17.5% in a paddock with alluvial sandy soil dominated by buffel. This compares with an average 15% safe utilisation estimated for central Australia previously (Hall *et al.* 1998). However, there was some evidence from one of the Alice region sites that the safe level of utilisation may be higher than we assumed (see the Mt Riddock utilisation results, page **Error! Bookmark not defined.**). This was in a large paddock that anecdotally (but supported by our modelling) had improving land condition, where in most years the utilisation in the watered area was in the order of 20% when we assumed safe utilisation would be closer to 12% due to the

presence of rocky hills and gravelly soils. Hence it is possible that the safe levels of utilisation are underestimated for some of the Alice sites. The use of benchmark good condition sites on commercial stations with good cattle records to retrospectively model safe pasture utilisation rates for more land types is planned for future research in the Alice region.

Alternatively, cattle may also be accessing browse which typically makes up to 20% of the cattle diet in good years, and up to 40% in drier years (e.g. Low *et al.* 1973, Squires & Low 1987, Squires and Siebert 1983). There is a greater availability of palatable browse species in central Australia than in the Barkly and Northern NT regions (Walsh *et al.* 2014), including mulga, other Acacia species and chenopod shrubs. This was only accounted for in our modelling by allowing cattle to graze down to lower TSDM levels (50kg/ha), which will effectively increase the potential simulated utilisation of these pastures. It is likely that the proportion of browse varied by site and seasonally, so it was not possible to accurately adjust for browse intake in this study. However, if for example, 20% of the cattle diet in the Alice region sites was browse, then the simulated utilisation rates in this study would overestimate pasture utilisation and relative pasture utilisation by 25%.

Pasture utilisation was always calculated within the accessible area which excluded rugged terrain, spinifex sandplains that were unutilised and areas far from water (>4km). However, cattle spend more of their time further from water as the number of head per waterpoint increases (Cowley *et al.* 2020), or as pasture utilisation increases (Materne *et al.* 2025) and in drier years (Hodder and Low 1976). Hence in the very high pasture utilisation cases in this study the pasture utilisation experienced by cattle may have been lower than modelled because cattle would have walked further from water, at least in the large poorly watered paddocks where unwatered areas and land types can act as a drought refuges. In Queensland where paddocks are usually fully watered, this is not an option, and for the Swans Lagoon study, resulted in destocking in the high utilisation years. Although cattle can access pasture beyond 4km, it is anticipated that the additional walking would have had an energy cost (McLean and Blakely 2014) and potentially a calf loss cost, when breeders have to spend more than 1 day from water to access forage.

4.3.5 Factors related to pasture utilisation in this dataset

Unsurprisingly very high utilisation occurred in drier than median years when pasture growth was in the order of 200-500kg/ha. The three occasions when pasture utilisation exceeded 6 times the safe level of utilisation were on commercial stations in the Alice region in large paddocks in drier than median rainfall years when annual pasture growth was less than 250 kg/ha. Breeders would have relied on carryover feed from previous years, walking further than 4km to find forage and supplementing their diet with browse to meet forage requirements. Cattle tend not to walk further than 4km from water unless forage has been grazed out within 4km such as in in very dry years (Hodder and Low 1976). Between one to two thirds of these large paddocks was beyond 4km from water, where there would have effectively been a drought refuge of forage. One of these paddocks had two consecutive very low growth years, and photos from the site showed there was no available forage within the watered area. Hence it is likely those cattle walked further in the drier years to access forage. At the other site with very high relative utilisation, it followed a high growth year, so it is likely the previous year's growth may have also contributed to the breeder diet, as well as the 'drought haystack' of the one third of the paddock beyond 4km from water. Although the assumed safe levels for the above Alice sites were low 11-13% due to the presence of spinifex and/or rocky hills, even if we assumed the safe level was 20%, the relative utilisation of those sites would still have been ≥4 times the safe level.

The seven instances where relative utilisation was between 3- and 6-times safe levels included three instances where stocking rates were much higher than recommended and four instances where pasture growth was much lower than median:

- one year in the Alice region in a dry year when pasture growth was less than 250kg/ha
- two years in the Alice region when stocking rate was 2 to 4 times recommended levels in average and above average rainfall and pasture growth years, possibly a case of overestimating the impact of higher rainfall on pasture growth and carrying capacity
- three instances in North Queensland when pasture growth was in the bottom 5 percent of all years and less than 650kg/ha
- one instance in the Katherine region when the stocking rate was nearly 3 times the recommended level in a slightly below median growth year.

The Barkly region had lower relative pasture utilisation than other regions, with the average relative utilisation being less than 1. This possibly reflects the lack of specific stocking rate or utilisation research trials (where a range of stocking / utilisation rates from low to high are tested and compared) in the Barkly dataset. All sites were on commercial stations in commercial herds. Of the 4 (out of 49) years when safe levels of utilisation were exceeded in the Barkly, only one of those years was a dry year, hence the high utilisation years were due to high stocking rates per watered area. Two of those occasions were in high rainfall years in a paddock that was poorly watered (only 44% of the paddock was within 4km of water), and is possibly a case of where cattle were stocked to total paddock area rather than watered area, possibly because it was assumed cattle could access semipermanent waters elsewhere in the paddock (although there was no satellite evidence that there were other semi-permanent waters) and / or where the impact of higher rainfall on pasture growth was overestimated.

An analysis of which factor - pasture utilisation or stocking rate had the greatest influence on pasture utilisation for each region (Cowley *et al.* 2025) found that in the North Queensland and Alice regions variation in pasture growth influenced pasture utilisation more than stocking rate. This was despite deliberate stocking rate trials being the major component pf the North East Queensland dataset. In contrast in the Barkly and Northern NT regions variation in stocking rate had a bigger influence on pasture utilisation. In the Northern NT this probably reflects the large portion of the dataset being represented by deliberate stocking rate and pasture utilisation research sites, where stocking rate was deliberately varied between paddocks to achieve varied pasture utilisation.

5. Reproductive performance of females

5.1 Methodology

This section presents descriptive summaries of the reproductive performance of females by region and class.

Because the breeder herd datasets were limited to those that were suitable and available across northern Australia, they were not balanced by region, class or whether from commercial stations or stocking rate and pasture utilisation research trials that deliberately tested across a range of grazing intensities. Sometimes there were only a few or no representative mobs of breeder classes for regions. Despite this they provide a useful additional comparison to complement existing breeder herd performance statistics in northern Australia, particularly as this adds the southern NT region, which was not included in the North Australian Beef Fertility project (McCosker *et al.* 2020).

5.1.1 Establishment of database

The combined animal dataset was created by collating multiple available animal performance datasets into a single, standardised format. Source data originated from both commercial cattle stations and research projects across multiple regions and typically varied in its structure, terminology, and level of detail.

A standardised data template captured all relevant animal performance information in a single row for each animal-year combination. The template was developed based on a number of data inclusion rules and information requirements. Standardised column headings were used to capture information about the individual animal, including their electronic and visual ID, year brand, breed, and station they resided on. Columns to capture management group information, such as age class and paddock details, were also included. Muster event information was captured, such as body condition score, lactation status, pregnancy status and foetal age, as well as the date the muster was performed and any recorded live weights.

Generally, animal data was provided as single excel worksheets containing animal performance information for a management group at an individual muster or year. Also, there were differences in methods and presentation of recording data. The data template not only captured all necessary animal performance data but also standardised the presentation of that data, which included using a 1 to 5 body condition score rather than 1 to 9. This standardisation streamlined the process of data collation and allowed multiple datasets to be seamlessly merged into a cohesive and easily manageable format. The template ensured that all relevant information was collated consistently and accurately, resulting in a dataset that provided a comprehensive view of animal performance over time. Overall, the use of the data template improved the efficiency and accuracy of data collection and enabled meaningful analysis and insights to be derived from the collated data.

5.1.2 Generating breeder performance indices

All measures of performance (outcome variables) were calculated from standardised individual animal records (). The primary measures used in this project were Annual pregnancy rate, pregnancy within four months of calving while lactating, foetal and calf loss and contributed a weaner. The calculation methods were based on the methodology fully described in McCosker *et al.* (2020).

Performance measures were calculated by for each animal-annual production cycle. An annual production cycle was defined as the period between the pregnancy testing muster in one year to the pregnancy testing muster the following year. Variables that did not align with this period have been defined specifically. While it is recognised that an annual production cycle is not exactly equal to one year on all occasions, this cycle is pragmatic and aligns well with the annual management for most

northern Australia beef properties.

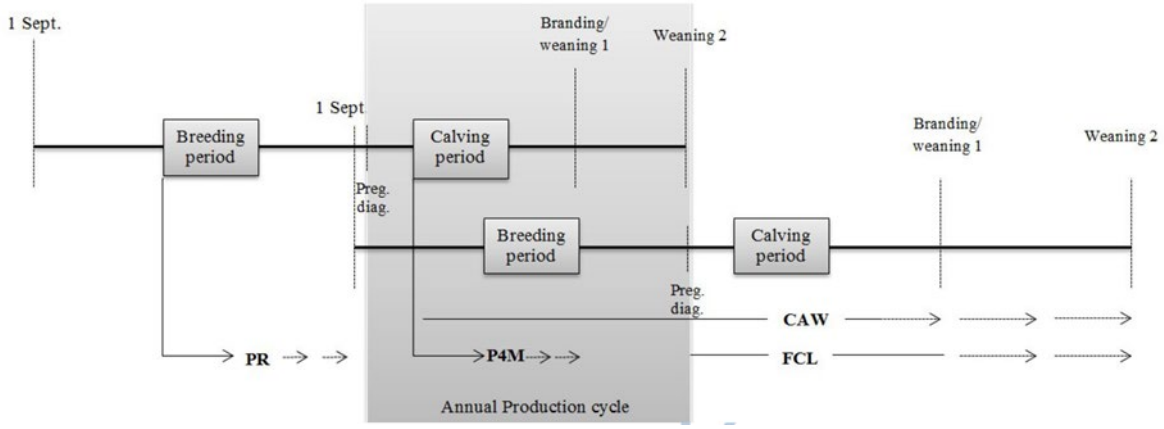


Figure 5-1: Schematic of periods represented by outcome variables: Annual pregnancy (PR), pregnant within 4 months while lactating (P4M), foetal and calf loss (FCL) and contributed a weaner (CAW)

Annual pregnancy status

Annual pregnancy indicated 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.

Pregnancy status of animals was generally determined by pregnancy diagnosis and foetal aging. If foetal aging was conducted late in the year, conceptions occurring after September 1 were attributed to the next annual production cycle. On the other hand, advanced pregnancies detected early in the following year (weaning/branding muster) were attributed to the current annual production cycle.

Pregnant within four months of calving (P4M)

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/calf loss

To determine 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.

Annual lactation status for each animal was determined by summarising the lactation status records from each mustering occasion during an annual period. Females that were recorded as wet at either one or both mustering occasions during the annual period were identified as having lactated. In contrast, females that were recorded as dry at both musters, or were recorded as dry at the first muster and culled were identified as not lactating.

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.

Contributed a weaner

The binary variable "contributing a weaner" indicated whether an exposed female contributed a weaner in the following year. This variable was used to generate summaries of animal-level data, such as weaning rates for properties by year.

To be recorded as having successfully weaned a calf, females needed to be diagnosed as pregnant in the current year and recorded as lactating in the following year. Conversely, females were recorded as having failed to wean a calf if they failed to become pregnant in the current year or were recorded as having experienced foetal or calf loss in the following year.

5.1.3 Data summary

Descriptive summaries for annual pregnancy, pregnancy within four months of calving, contributed a weaner and foetal and calf loss are presented. The data were summarised using two methods, a boxplot and a summary table. The boxplots were produced by calling the boxplot function within R (R Core Team, 2025), showing the median, interquartile range (IQR), whiskers extending to values within 1.5 times the IQR from the quartiles, and individual points indicating outliers beyond this range. Data have been presented by region and by each cow age class (‘heifers’, ‘first-lactation’ and ‘mature and aged’ cows). Heifers have been defined as a cohort of female cattle up to when the majority should have calved, after which the cohort was categorised as first-lactation females. A mature cow was defined as being less than 9 years of age. Breeding females that were of an unknown age were defined as mature cows. Aged cows were defined as great than or equal to 9 years of age. Mature and aged cows were combined for summary descriptions in this chapter, due to the low number of mob-level observations in the dataset.

Outcome measures for different cow age classes have been derived by aggregating animal-level performance data by cow age class and year for each management group. For analysis, mature and aged cows were combined, as the relatively small numbers of aged cows often led to unstable estimates and fluctuations in the summary statistics when treated as a separate group.

5.2 Results and discussion

5.2.1 Descriptive summary of breeder performance

Annual pregnancy

The outcome of annual pregnancy status used in this analysis refers to pregnancies where conception occurred in the 12 months ending September 1 of the current year.

Performance of heifers

Due to the data inclusion rules of annual pregnancy, data were only available for heifers in the South NT region. Data from heifers inducted at the time of their pregnancy test were excluded from the analysis, as their complete reproductive status was unknown; specifically, heifers may have been removed prior based on their reproductive status. Only heifers that were followed prior mating to a bull are reported. The age at which heifers were first mated varied between properties. The median pregnancy rate for this group of heifers was 76.4% (Figure 5-2, Table 5-1).

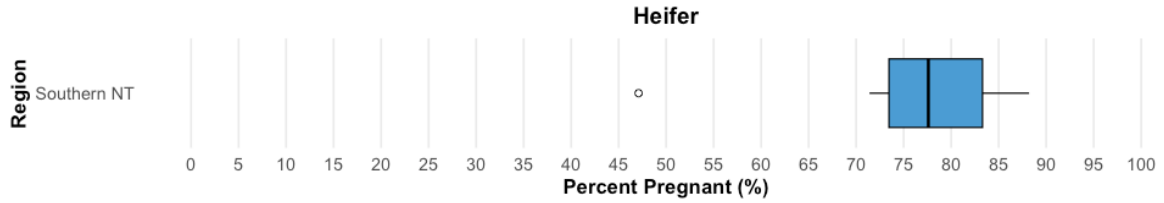


Figure 5-2. Boxplot showing the distribution of annual pregnancy rates for heifer mobs in Southern NT. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Table 5-1: Descriptive summary of recorded annual pregnancy rates for heifer mobs in each region, including the number of mobs contributing data, the median, and the 25th and 75th percentiles

Region	No. of mobs	Annual pregnancy (%)		
		25th percentile	Median	75th Percentile
North East Qld	0	-	-	-
Southern NT	11	73.4	77.6	83.3
Central NT	0	-	-	-
Northern NT	0	-	-	-

Data were available from only three properties within the Southern NT region, comprising 11 mob-years. Variation in annual pregnancy rates between properties was similar to the variation within properties across years. This region was not included in the Cash Cow report, which defined an achievable level of performance as that attained by 75% of the dataset. Applying this definition to the current dataset suggests an achievable annual pregnancy rate for heifers of 83%. These results indicate that heifer performance in the Southern NT is comparable to that observed in the Central Forest region in the Cash Cow project (McGowan *et al.* 2014).

Performance of 1st lactation cows

Animal class–management group rates for annual pregnancy in first-lactation cows have been summarised and presented below. These results relate specifically to cows that were experiencing lactation for their first time. The median pregnancy rates for 1st lactation cows in Central NT, South NT and North East Qld were similar, at between 83 and 89% (Figure 5-3, Table 5-2). In contrast to this, the median pregnancy rate of 1st lactation cows in the North NT was much lower at only 50%.

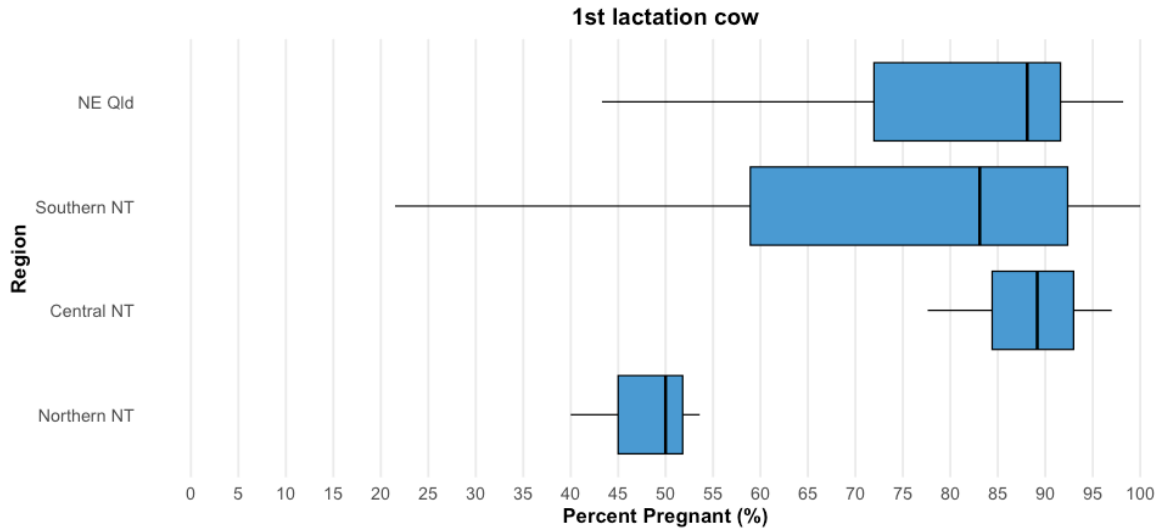


Figure 5-3. Boxplot showing the distribution of annual pregnancy rates for 1st lactation cow mobs across regions. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Table 5-2: Descriptive summary of recorded annual pregnancy rates for 1st lactation cow mobs in each region, including the number of mobs contributing data, the median, and the 25th and 75th percentiles

Region	No. of mobs	Annual pregnancy (%)		
		25th percentile	Median	75th Percentile
North East Qld	24	72.0	88.1	91.6
Southern NT	20	59.0	83.1	92.4
Central NT	16	84.4	89.2	93.0
Northern NT	3	45.0	50.0	51.8

With the exception of the observed performance in the Northern NT, which is comparable to the Northern Forest region reported by McCosker *et al.* (2020), the results in this dataset are generally slightly higher. Several factors may account for these differences, including variations in timelines, potential seasonal effects, and the inclusion of government-owned and department-operated research stations in the current dataset. Research stations are generally characterised by industry as being associated with more conservative stocking rates, smaller management group sizes, and higher levels of management and intervention, which is associated with higher levels of performance and could be responsible for inflating the average performance estimates. Very large variation was observed for the Southern NT, possibly reflecting the extreme seasonal variability present in arid regions, but also the differences between the commercial (median 42%) and OMP research station herds (median 89%) (See Appendix 14.5, page 394). These lower medians from the Northern NT are likely related to the nutritional challenges of growing heifers while lactating, which can reduce reconception rates. For example, one of the three commercial herds in the Northern NT was in the Sturt Plateau, with the lowest available soil P of all sites (<4ppm, Table 4-5, Figure 4-5), the lowest minimum simulated %N in end of season standing pasture (Figure 4-29, 0.29%N) in a large poorly watered paddock (Table 4-7, Figure 4-10), all factors that provide nutritional challenges, reducing the chances of heifers meeting their nutritional demands.

Performance of mature and aged cows

Animal class–management group rates for annual pregnancy in mature and aged cows has been summarised and presented below. Median pregnancy rates for mature and aged cows in South NT and Central NT were similar at 89.4 and 91.4% respectively (Figure 5-4, Table 5-3). Mature cows in North NT and North East Qld had lower median pregnancy rates of 73.6 and 78.7% respectively.

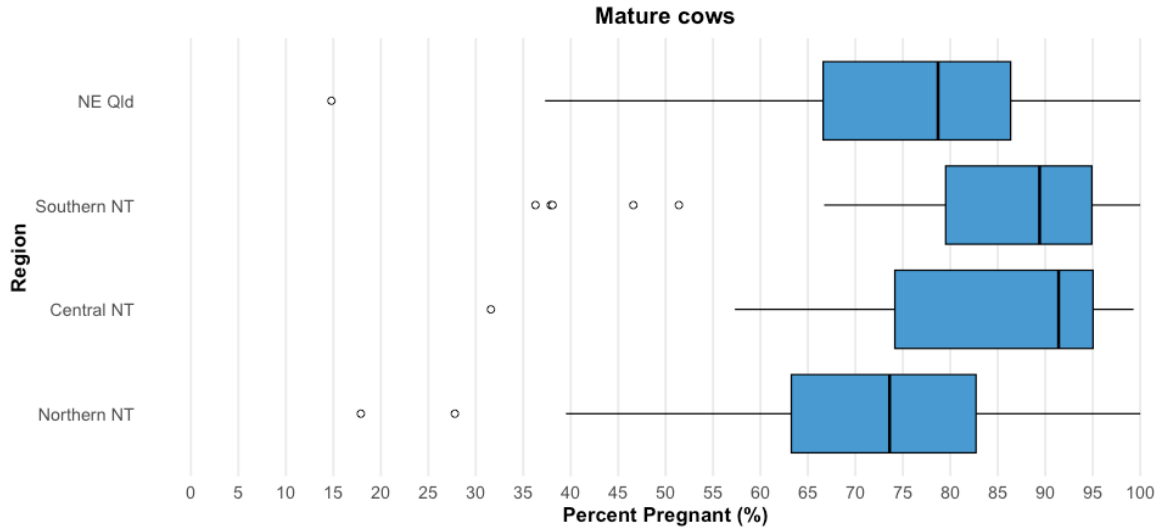


Figure 5-4. Box plot of annual pregnancy for mature and aged cow mobs in each region

Table 5-3: Descriptive summary of recorded annual pregnancy rates for mature and aged cow mobs in each region, including the number of mobs contributing data, the median, and the 25th and 75th percentiles

Region	No. of mobs	Annual pregnancy (%)		
		25th percentile	Median	75th Percentile
North East Qld	43	66.6	78.7	86.3
Southern NT	57	79.5	89.4	94.9
Central NT	30	74.1	91.4	95.0
Northern NT	167	63.2	73.6	82.7

These results suggest that beef herds in the Southern NT and Central NT generally achieve high reproductive performance in mature and aged cows, with median annual pregnancy rates approaching or exceeding 90%. In contrast, herds in the Northern NT and North-East Queensland exhibit notably lower median pregnancy rates, in the mid-to-high 70% range. Both these regions were dominated by research trials that specifically were testing a range of stocking and pasture utilisation rates. This reduced performance may partly reflect the impact of higher utilisation being tested as part of these trials but may also reflect regional differences in management and nutritional constraints. For herd management, these findings highlight the importance of region-specific strategies to attain high conception rates in mature and aged cows in northern regions.

Pregnant within four months of calving

The measure pregnancy within four months while lactating (P4M) can be generally considered as the proportion of cows that will contribute weaners in two consecutive years. Determination of the percentage P4M was restricted to only those cows that reared their calf. This means that cows that

did not rear their previous pregnancy were not included in performance analyses, nor included in the derived achievable levels of performance.

Performance of first lactation cows

The cow age class, heifers, have been used in this section but as these heifers were experiencing lactation for their first time, they are first-lactation cows. Percentage P4M varied greatly between regions (Figure 5-5, Table 5-4). By far the highest median P4M of 76.2% occurred for heifers in Central NT. P4M of heifers in North East Qld was approximately 20% less at 57.1%, followed by Southern NT at 28.7%, and P4M for heifers in Northern NT was only 15.8%.

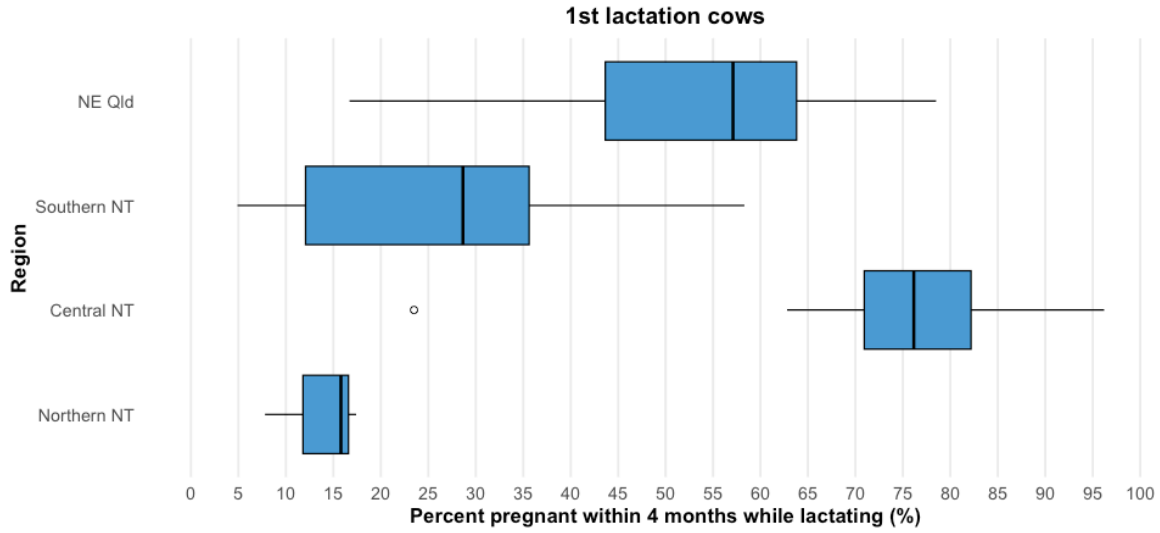


Figure 5-5. Boxplot showing the distribution of percent pregnant within 4 months while lactating for heifer mobs across regions. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Table 5-4: Descriptive summary of recorded percent pregnant within 4 months while lactating for 1st lactation cow mobs in each region, including the number of mobs contributing data, the median, and the 25th and 75th percentiles

Region	No. of mobs	P4M (%)		
		25th percentile	Median	75th Percentile
North East Qld	19	43.7	57.1	63.8
Southern NT	6	12.1	28.7	35.6
Central NT	16	70.9	76.2	82.2
Northern NT	3	11.8	15.8	16.6

The much lower rates observed in the Northern NT are likely attributable to regional differences in nutrition and environmental conditions. The low performance in the Northern NT is consistent with the well-recognised challenge of rebreeding in first-lactation cows, where the combined demands of lactation and continued growth under nutritional constraints often result in prolonged lactational anoestrus, preventing cows from cycling and reducing reconception rates. In contrast, the substantially higher performance observed for the North East Qld region compared with the Northern NT is likely influenced by the high results recorded at the Swans Lagoon Research Station (Smith *et al.* 2001), which contributed a large proportion of the data for this region for this performance measure. The high performance observed for the Central NT region is not easily

explained but generally is much higher than rates previously recorded for this region (McCosker *et al.* 2020; Schatz *and* Hearnden 2008). In the Southern NT and North East Qld regions, large variation was evident, likely reflecting seasonal differences.

Performance of 2nd lactation cows

Animal class–management group rates for pregnancy within four months of calving in 2nd lactation cows has been summarised and presented below.

Median P4M for 2nd lactation cows was again very low in Northern NT at only 15% (Figure 5-6, Table 5-5) P4M for these cows was again highest in Central NT, at 82.2%, followed by 60.8% for cows in Southern NT and 51.7 for cows in North East Qld.

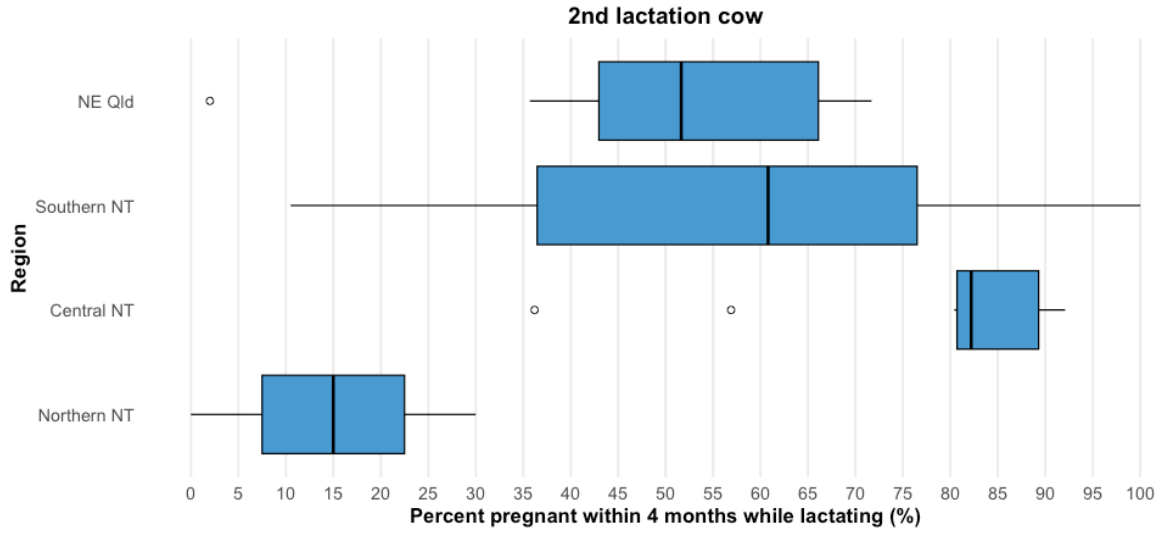


Figure 5-6. Boxplot showing the distribution of percent pregnant within 4 months while lactating for 2nd lactation cow mobs across regions. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Table 5-5: Descriptive summary of recorded percent pregnant within 4 months while lactating for 2nd lactation cow mobs in each region, including the number of mobs contributing data, the median, and the 25th and 75th percentiles

Region	No. of mobs	P4M (%)		
		25th percentile	Median	75th Percentile
North East Qld	16	43.0	51.7	66.1
Southern NT	12	36.5	60.8	76.5
Central NT	10	80.7	82.2	89.3
Northern NT	2	7.5	15.0	22.5

Performance of mature and aged cows

Animal class–management group rates for pregnancy within four months of calving in mature and aged cows has been summarised and presented below (Figure 5-7, Table 5-6). Rates of medium P4M for mature and aged cows were higher compared with those of younger cows in the regions of NE Qld, Southern NT and Northern NT, ranging from 37.6 to 70.2%. In contrast to this, P4M for mature cows in Central NT of 59.2% was lower than those of younger cows in that region. This result is not easily explained and suggests that some data attributed to heifers was collected under different

seasonal conditions or properties represented in this region, potentially affecting the observed performance.

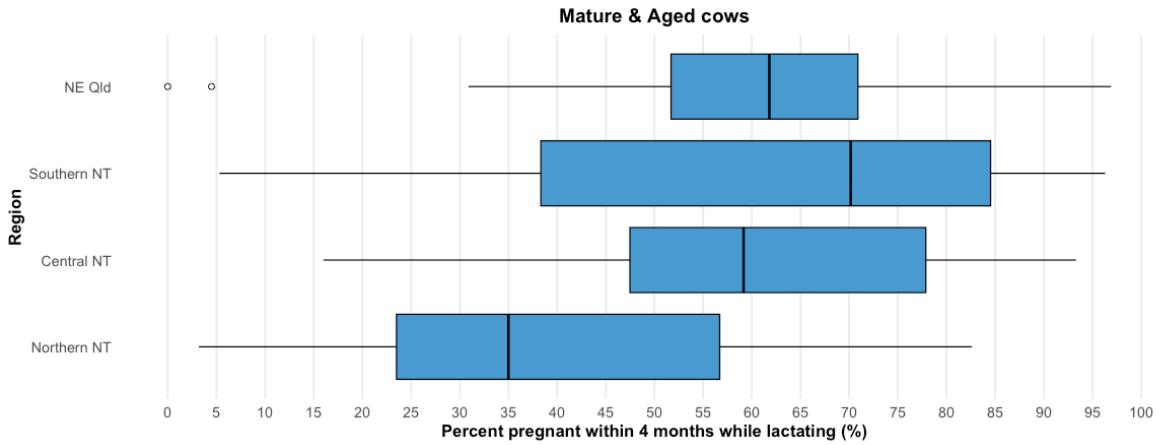


Figure 5-7. Boxplot showing the distribution of percent pregnant within 4 months while lactating for mature and aged cow mobs across regions. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Table 5-6: Descriptive summary of recorded percent pregnant within 4 months while lactating for mature and aged cow mobs in each region, including the number of mobs contributing data, the median, and the 25th and 75th percentiles

Region	No. of mobs	P4M (%)		
		25th percentile	Median	75th Percentile
North East Qld	29	51.7	61.8	70.9
Southern NT	28	38.3	70.2	84.5
Central NT	22	47.5	59.1	77.9
Northern NT	145	23.5	35	56.7

These results highlight significant regional differences in the ability of mature and aged cows to re-conceive within four months of calving. In the Northern NT, this occurred across both research and commercial mobs. Where median P4M rates for mature cows are around one-third, this means that only about one in three cows will produce calves in two consecutive years. From an industry perspective, such low rebreeding rates make it impractical to adopt strict culling policies for non-pregnant cows and maintain a stable herd size. The large variability in P4M in Southern NT is possibly reflecting the differences between the research and commercials herds (Appendix 14.5, page 394) as for annual pregnancy.

Foetal and calf loss

The results in this section relate to descriptive analyses of paddock–age class–year foetal or calf loss rates. Outcomes are presented separately for each cow age class.

Foetal/calf loss from a confirmed pregnancy was recorded when a heifer or cow diagnosed as pregnant in one year was observed as dry (non-lactating) at least one month after the expected calving month in the following year. Cows observed lactating during the subsequent year were considered to have successfully reared their pregnancy.

Because the foetal/calf loss outcome combines information from two consecutive production cycles (pregnancy and calf survival), fewer observations were available for this analysis compared with other derived outcomes such as annual pregnancy rate.

Performance of heifers

Animal class–management group rates for foetal or calf loss in heifer mobs is presented below (Figure 5-8, Table 5-7). Median foetal and calf loss for heifers was highest at around 18% in Cent. and Northern NT, followed by 10.5% in Southern NT and 4.3% in North East Qld.

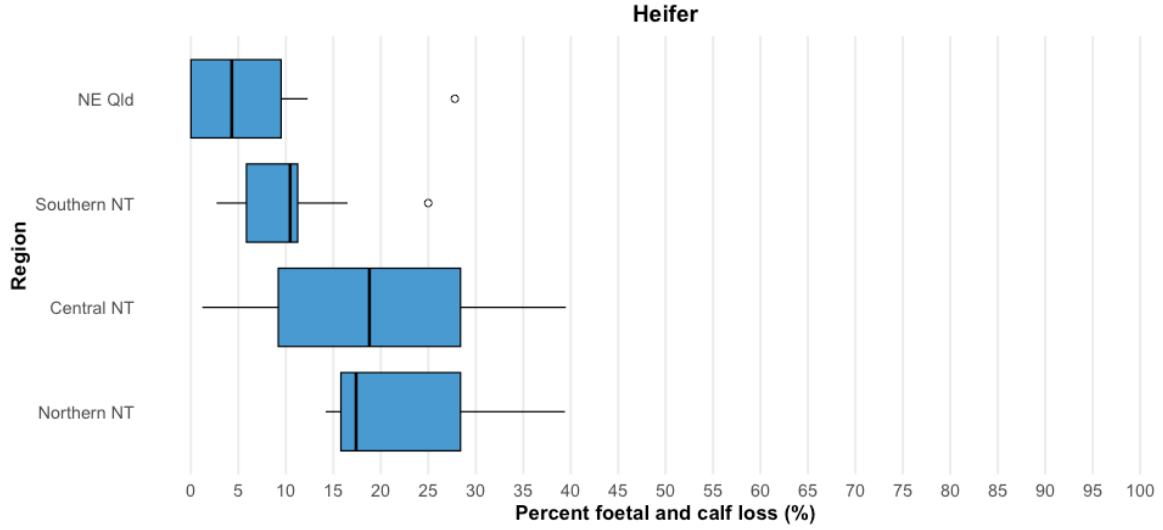


Figure 5-8. Boxplot showing the distribution of foetal and calf loss percentage for heifer mobs across regions. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Table 5-7: Descriptive summary of recorded percent foetal and calf loss for heifer mobs in each region, including the number of mobs contributing data, the median, and the 25th and 75th percentiles

Region	No. of mobs	Percent foetal and calf loss (%)		
		25th percentile	Median	75th Percentile
North East Qld	19	0	4.3	9.5
Southern NT	10	5.9	10.5	11.3
Central NT	17	9.2	18.8	28.4
Northern NT	3	15.8	17.4	28.4

These results highlight that substantial losses between confirmed pregnancy and weaning are common in heifers, particularly in the Northern and Central NT, where rates of near 40% were observed. More than a quarter of mobs in these regions recorded loss rates above 25%, with the more typical losses around 18% commonly observed. Such levels of foetal and calf loss represent a significant inefficiency in northern beef breeding businesses. The high foetal and calf losses in heifers has been found previously in northern Australia (Schatz and Hearnden 2008, Burns 2010, McCosker *et al.* 2020).

Performance of 1st lactation cows

Animal class–management group rates for foetal or calf loss in 1st lactation cow mobs is presented below (Figure 5-9, Table 5-8). These 1st lactation cows had lower foetal and calf loss compared with heifers, with rates ranging from 1.5 to 7.3%.

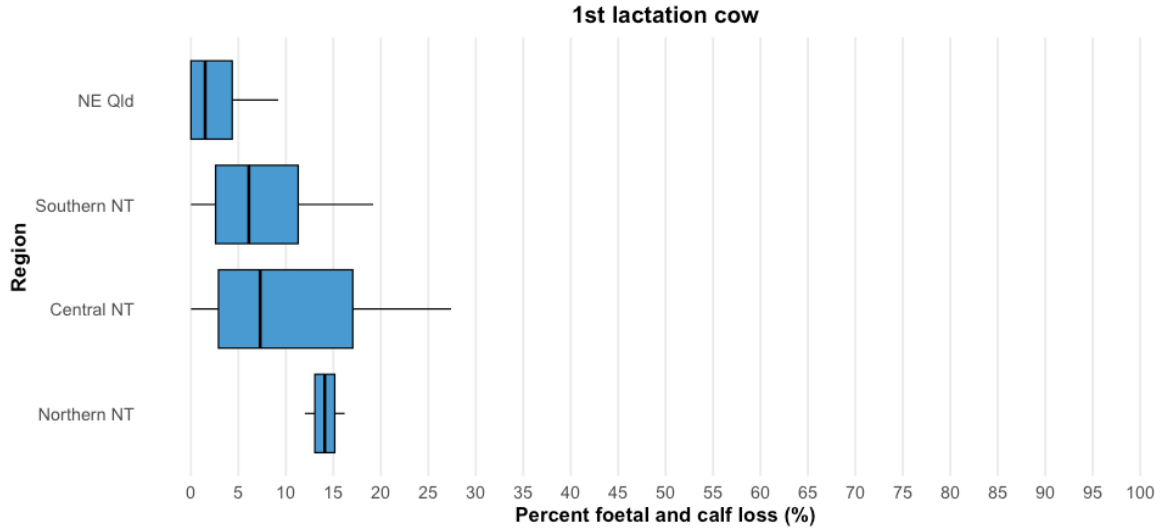


Figure 5-9. Boxplot showing the distribution of foetal and calf loss percentage for 1st lactation cow mobs across regions. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Table 5-8: Descriptive summary of recorded percent foetal and calf loss for 1st lactation cow mobs in each region, including the number of mobs contributing data, the median, and the 25th and 75th percentiles

Region	No. of mobs	Percent foetal and calf loss (%)		
		25th percentile	Median	75th Percentile
North East Qld	16	0	1.5	4.3
Southern NT	13	2.6	6.1	11.3
Central NT	11	2.9	7.3	17
Northern NT	2	13.1	14.1	15.1

Overall, first-lactation cows generally exhibited lower foetal and calf loss rates compared with heifers. High rates of loss were observed in most regions; however, the rates recorded in North East Qld were notably lower than those observed elsewhere and comparative lower than previously reported rates for this region (McCosker *et al.* 2020). This difference may reflect the substantial contribution of data from the Swans Lagoon Research Station for this region, compared with typical commercial operations in this region. The markedly higher foetal and calf loss observed in first-lactation cows in the Northern NT region was based on only a small sample, with data drawn from two commercial properties, one each located in the Victoria River District and Katherine region, for a single year.

Performance of mature and aged cows

Animal class–management group rates for foetal or calf loss in mature and aged cow mobs are presented below (Figure 5-10, Table 5-9). Foetal and calf loss varied considerably across regions. The lowest median losses were recorded in North East Qld (5.8%) and Southern NT (4.7%), with North

East Qld also showing the narrowest range between the 25th and 75th percentiles (4.5–7.6%). Central NT recorded the highest median loss at 11.1%, with the upper quartile reaching 15.8%, indicating that a substantial proportion of herds experienced very high losses in their older-animal class mobs. Northern NT also had relatively high losses, with a median of 7.2% and an upper quartile of 11.8%. This was despite most of those mobs coming from relatively small paddocks in grazing research trials in the Victoria River District on high productivity basalt derived mixed grasslands. These results highlight that while some regions achieve low loss rates, others—particularly Central and Northern NT—face persistent challenges in reducing foetal and calf mortality.

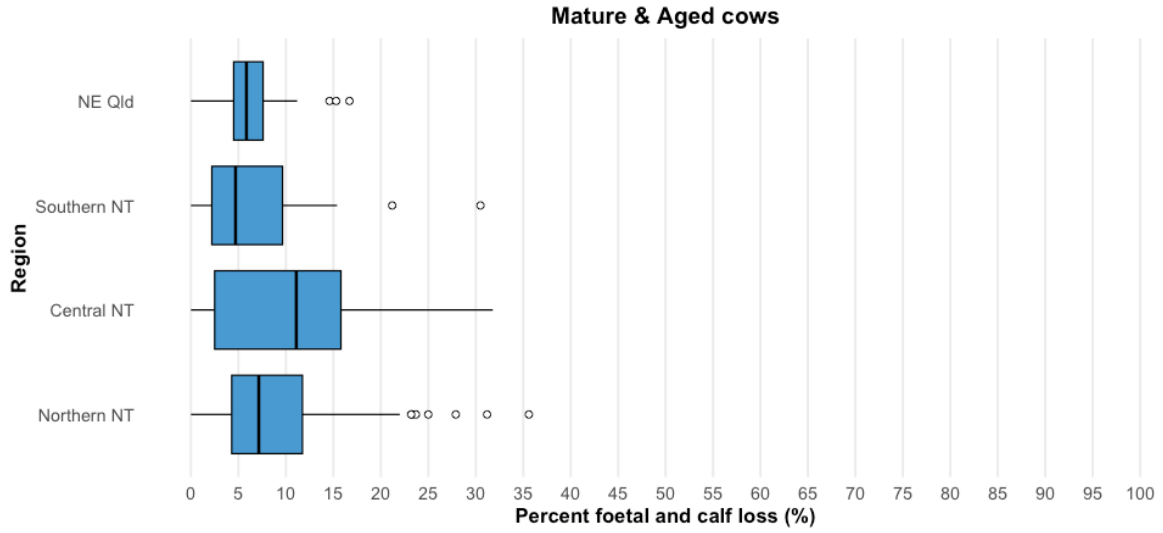


Figure 5-10. Boxplot showing the distribution of foetal and calf loss percentage for mature and aged cow mobs across regions. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Table 5-9: Descriptive summary of recorded percent foetal and calf loss for mature and aged cow mobs in each region, including the number of mobs contributing data, the median, and the 25th and 75th percentiles

Region	No. of mobs	Percent foetal and calf loss (%)		
		25th percentile	Median	75th Percentile
North East Qld	34	4.5	5.8	7.6
Southern NT	31	2.2	4.7	9.7
Central NT	25	2.5	11.1	15.8
Northern NT	150	4.3	7.2	11.8

Weaned a calf

Weaning performance was assessed at the individual animal level based on whether a female successfully weaned a calf in the current year. A female was classified as having weaned if she had been diagnosed pregnant in the previous year and was recorded as lactating (wet) at an observation after the expected calving date. Failure to wean was recorded if the female had not been pregnant in the previous year or if she experienced foetal or calf loss during the current year. These data were aggregated to generate property- and year-level weaning rate estimates for analysis.

As this outcome combines two consecutive annual production cycles—first achieving pregnancy, then successfully rearing the calf to weaning—it inherently requires data from two successive years. Consequently, the number of mobs contributing to the analysis varied, depending on the availability of complete records across both years. These data were aggregated to generate mob- and year-level weaning rate estimates for descriptive analysis.

It should be noted that, the direct calculation of weaning rates by simply combining annual pregnancy rates and calf loss percentages may not be directly aligned. This is because pregnancy rate and foetal/calf loss are measured in separate, discrete annual cycles, while the "weaning rate" outcome spans both and the mobs contributing data to each measure may differ due to incomplete or missing records across years. As a result, calculated weaning rates derived by combining these two independent measures may differ slightly to those presented below. Weaning rates in this analysis were derived from direct records of cows diagnosed pregnant in one year and confirmed to have weaned a calf in the next, ensuring best estimate of actual weaning rates.

Performance of heifers

Due to the data inclusion rules of weaning data for management groups of heifers weaning was only available for the Southern NT region. Two commercial properties within this region were represented. The median weaning rate for region was 68.8% (Figure 5-11, Table 5-10).

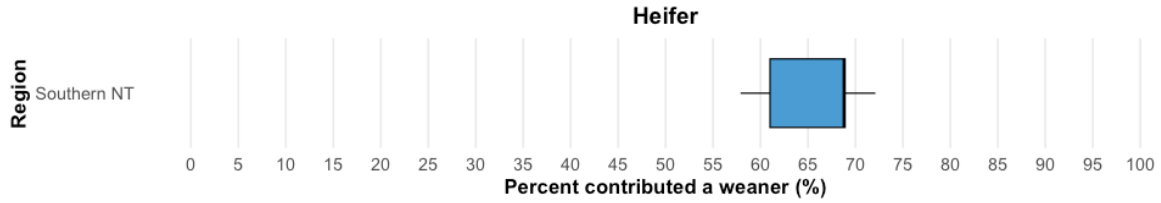


Figure 5-11. Boxplot showing the distribution of weaning percentage for heifer mobs across regions. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Table 5-10: Descriptive summary of recorded weaning percentage for heifer mobs in each region, including the number of mobs contributing data, the median, and the 25th and 75th percentiles

Region	No. of mobs	Contributed a weaner (%)		
		25th percentile	Median	75th Percentile
North East Qld	0	-	-	-
Southern NT	5	61.0	68.8	68.9
Central NT	0	-	-	-
Northern NT	0	-	-	-

These findings suggests that approximately 2/3 of heifers exposed to a bull in southern NT contributed a weaner, highlighting a sizeable production gap and possible opportunity for improvement given the significant investment in growing and mating heifers.

Performance of 1st lactation cows

Weaning rates for first-lactation cow management groups varied widely across regions (Figure 5-12, Table 5-11). The highest median rate was recorded in North East Qld (87%), followed by Southern NT (80.4%) and Central NT (79.5%). While North East Qld showed consistently high performance, Southern NT exhibited much greater variability, with some mobs achieving excellent results while others performed poorly. This is partly due to the wide disparity in weaning rates in Southern NT

between commercial and research mobs, with Old Man Plains research station cattle run at the safe long-term carrying capacity in smaller paddocks having a median weaning rate of 81% vs. 33 % for the commercial herds (Appendix 14.5, page 394). There was also a large variation in weaning rate within the Southern NT commercial herds (16-80%) vs. a fairly tight range for the research herds (79-93%) (Appendix 14.5, page 394). Central NT showed a relatively smaller variation, suggesting more consistent performance across years and properties. In contrast, Northern NT recorded a markedly lower rate of 18.6%, based on data from a single mob located on a commercial property in the VRD.

Across all regions, at least some mobs recorded very low weaning rates, with minimum values below 50%. Southern NT had the widest range, from less than 16% to over 90%. Even in the higher-performing regions of North East Qld and Central NT, some mobs fell well below 50%, highlighting that low weaning rates can occur in any production environment despite overall regional trends.

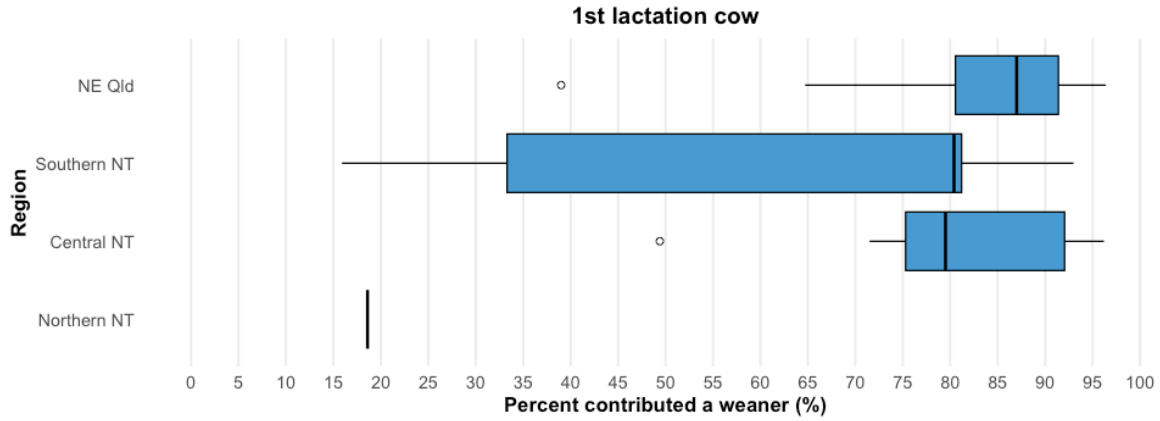


Figure 5-12. Boxplot showing the distribution of weaning percentage for 1st lactation cow mobs across regions. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Table 5-11: Descriptive summary of recorded weaning percentage for 1st lactation cow mobs in each region, including the number of mobs contributing data, the median, and the 25th and 75th percentiles

Region	No. of mobs	Contributed a weaner (%)		
		25th percentile	Median	75th Percentile
North East Qld	16	80.6	87	91.4
Southern NT	13	33.3	80.4	81.2
Central NT	7	75.3	79.5	92.1
Northern NT	1	-	18.6	-

Performance of mature and aged cows

Weaning rates for all cow management groups showed substantial variation between and within regions (Figure 5-13, Table 5-12). Southern NT recorded the highest median weaning rate at 84.9%, with a wide spread from a minimum of 20.4% to a maximum of 100%. Again this variation came largely from differences between commercial and research herds, with a much wider variation in commercial herds (median 56%, range 20-86%), vs research (median 89%, range 68-100%) (Appendix 14.5, page 394).North East Qld followed with a median of 77.6% and a narrower range (52–93.3%), suggesting more consistent performance. Central NT had a median of 72.3%, but also a broad range (32.4–96.3%) indicating both high- and low-performing mobs. Northern NT recorded the lowest median at 67.5%, with a range from 23.6% to 90.6%.

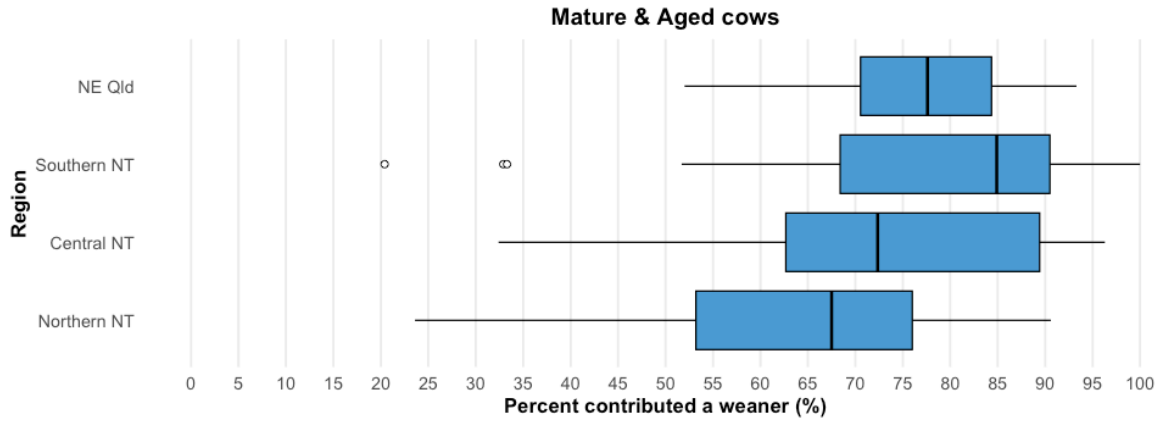


Figure 5-13. Boxplot showing the distribution of weaning percentage for 1st lactation cow mobs across regions. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Table 5-12: Descriptive summary of recorded weaning percentage for 1st lactation cow mobs in each region, including the number of mobs contributing data, the median, and the 25th and 75th percentiles

Region	No. of mobs	Contributed a weaner (%)		
		25th percentile	Median	75th Percentile
North East Qld	23	70.6	77.6	84.3
Southern NT	29	68.4	84.9	90.5
Central NT	16	62.7	72.3	89.4
Northern NT	121	53.2	67.5	76

The results demonstrate that high weaning performance is attainable across all regions; however, substantial variability is evident, particularly in Southern NT and Central NT, where performance ranged from exceptional to markedly below average. In contrast, North East Qld exhibited comparatively uniform weaning rates, higher than considered typical for the region (McCosker *et al.* 2020) which may reflect the data used in this analysis are predominantly derived from research stations. The modest median performance observed for Northern NT, despite the large proportion of mobs coming from research grazing trials is likely attributable to the nutritional and environmental constraints characteristic of the region, which inherently limit productive potential.

5.3 Conclusion

The present study analysed performance across commercial and research herds in northern Australia, representing varied regions, management practices and seasonal conditions, and found several important regional differences in reproductive productivity and calf loss. These findings illustrate both challenges and productive opportunities for northern beef enterprises.

Observed performance in this study was broadly consistent with past research, but slightly elevated compared to datasets from commercial stations alone, especially in north eastern Queensland where research stations contributed much of the data. Management groups in northern NT recorded lower reproductive rates than other regions, with a typical weaning rate of 66%. In contrast, southern N, and region previously underrepresented in published literature, was found to have a typical weaning rate of 85%, though with much greater variability reflecting seasonal

changes. Central NT and north eastern Queensland showed similar weaning rates, generally ranging from 72–77%.

Calf loss rates observed in this study highlights its' major impact on productivity and profitability for northern enterprises. In most regions except north eastern Queensland, rates exceeding 30% were not uncommon. Central NT, for mature and aged cows which form the bulk of most enterprises herd, had the highest typical loss for these groups at 11%, compared to less than 7% in other regions.

Reducing calf loss and improving reproductive performance represents a key avenue for boosting herd profitability and productivity across northern Australia. The large variability between management groups within region suggest substantial opportunities for improvement.

6. Quantifying the impact of pasture utilisation on breeder performance

Much of northern Australia's beef cattle production is based on the grazing of rangelands. These production systems are predominantly breeding operations and are characterised as extensive, low-input grazing systems relying on the utilisation of native pastures, with some areas augmented by introduced legumes. Forage availability and quality in these systems is strongly influenced by regional rainfall patterns, soil characteristics and land condition (Pahl *et al.* 2016)

Substantial knowledge exists regarding the effects of biophysical traits, nutrition, breed characteristics and environmental conditions on reproductive performance(Bell and Sangster 2022). However, the specific impact of pasture utilisation rates on breeding cows remains poorly quantified. Instead, insights are often extrapolated from studies on growth performance in steers or non-breeding females (O'Reagain *et al.* 2011). This reliance stems, in part, from the complexity of accounting for variation in calving distribution, lactation management and reproductive management. This challenge is further compounded by pasture utilisation generally calculated on an annual basis at a paddock level, with cattle managed in mobs and often grazed through multiple paddocks over an annual production cycle. This complexity requires robust analytical approaches capable of handling the hierarchical nature of northern breeder performance data, where individual animals are nested within management groups, paddocks, and production years.

Given this context, the current project aimed to address the identified gap by subjecting the retrospective dataset established in this project to robust statistical procedures, including mixed effects modelling where inherent variability between individual animals within management groups and paddocks were accounted for. This methodology was designed to examine the association between pasture utilisation and measures of reproductive performance after accounting for other major factors that may confound the results. The analysis focused on four key measures of reproductive success: annual pregnancy rates, pregnancy within four months of calving while lactating, weaning success, and calf mortality. Each analysis was performed individually for each outcome, and the results are presented separately below. The following sections outline the effects in the final models for each reproductive outcome.

6.1 Methodology

6.1.1 General Statistical approach

This section presents the findings from the final multivariable models used to identify important explanatory variables that influence the four key reproductive performance outcomes: annual pregnancy rate, pregnancy within four months, weaning rate, and calf mortality rate. For each factor (variable) and interaction term included in the final multivariable models, the following sections provide the predicted mean reproductive performance of cows at the referent level for all other factors in the model.

The reproductive outcomes were binary responses and were therefore analysed using generalised linear models (McCullagh and Nelder 1989) with a binomial distribution and logit link. Analyses of annual pregnancy rate, pregnancy within four months of calving, and weaning rate were performed at the cohort level in Genstat (2024), where a cohort was defined as the animals in each breed and animal-class within each paddock and year, with cohort size (number of animals) used as the weighting factor. Random-effects mixed models (Robinson 1987) were fitted using restricted maximum likelihood (REML), with fixed effects as detailed below and random effects of years and paddocks within stations. In contrast, foetal and calf loss were analysed at the individual-animal level in R, using multivariate modelling to account for animal-specific factors, with adjustment for cohort and property-level random effects.

The purpose of the multivariable modelling process is to identify the major drivers of reproductive performance and to explain the effect of each factor after adjustment for all other factors in the model. All candidate factors were initially considered for inclusion in the multivariable model building process, and all factors with significant and biologically plausible associations with each outcome were retained in the final models.

There were many possible terms and factors which potentially affected these four measures of cow reproductive performance. A full list of variables available at the commencement of the analysis is presented in Appendix (page 389, Appendix 14.4). Partial aliasing and considerable levels of correlations amongst these independent terms confounded the modelling process. We adopted a targeted modelling process – first fitting ‘known and well-established animal-level effects’ (animal-class and breed). Whilst body condition score fitted this description and was highly-significant ($P<0.001$), it was deliberately excluded as it was obviously dependent on the subsequent environmental and management terms that were of interest. Step-forward modelling was then adopted, seeking common terms across the four reproductive measures which were the most significant as well as ‘made biological sense’. It is acknowledged that alternate models which are similarly ‘biologically feasible’ would likely achieve about the same degree of fit. Note that factors that are not in the final models were screened out because they were either non-significant, or their influence was represented by other variables or combination of variables already specified in the model.

The continuous terms were initially screened as linear and polynomial contrasts (to test for curvature), and then also categorised into factor-levels (with approximately equal numbers in each class). This facilitated testing for different response patterns (such as broken-stick or asymptotic), as well as allowing visualisation of the actual data averages across the ranges of each term. Finally, all two-way interactions between the selected independent terms were screened for significance and interpretability. Fortunately, few interactions were retained, as they generally proved to be relatively unimportant.

In all analyses, the adjusted mean proportions (i.e., adjusted for all other terms in the model) and their standard errors were estimated for each fitted effect. Note that the performance reported in this section may be different to that presented in the descriptive summaries of performance

presented in Section 5.2, as the mean performance is predicted from the multivariable models and considers the impacts of all other major factors included in the final models.

It is important to be aware that when comparing the predicted differences between reproductive performance of cows for each factor, the absolute difference is expressed in terms of percentage points increase or decrease i.e., the difference between 50% and 55% is 5 percentage points.

A description of the breeder herd dataset *Bos indicus* content and calving distribution are shown in Appendix 14.6, page 398 to aid interpretation of the results presented below.

6.2 Results

6.2.1 Factors influencing pregnancy and weaning outcomes

Analyses of annual pregnancy rate, pregnancy within four months of calving, and weaning rate were conducted at the cohort level. A cohort was defined as all animals of a given breed and animal class within a paddock in a particular year, with cohort size (number of animals) used as a weighting factor. The number of observations contributing to each model varied: 572 mob-years for annual pregnancy rate, 428 units for pregnancy within four months of lactation, and 547 units for weaning rate. The difference in the number of units contributing to the pregnancy within four months and weaning rate analyses is that mobs without an expected month of calving could still contribute data for weaning rate, whereas pregnancy within four months could not be calculated for these mobs.

The multivariable analyses indicated that reproductive performance in northern beef herds was influenced by a combination of animal, management, and environmental factors. Among these, breed, relative utilisation rate, animal class, and pasture growth around calving emerged as the major drivers of variation, highlighting their dominant effect on production (Table 6-2). Early dry season pasture growth and soil phosphorus were also important contributors for some reproductive outcomes.

Region was not included in the final models, as its effects were largely accounted for by other terms that vary regionally, such as breed, mating strategy, and soil phosphorus levels.

The impact of each factor on the pregnancy and weaning outcomes is presented individually below.

Table 6-1: Factors identified in the final multivariable models influencing cohort-level reproductive outcomes in northern beef herds. Wald statistic and significance levels (P) are shown for annual pregnancy rate, pregnancy within four months of calving, and weaning rate.

	Annual pregnancy		Preg. (4 months)		Weaning rate	
Term	Wald stat	P value	Wald stat	P value	Wald stat	P value
Animal class	47.93	<0.001	11.69	0.01	27.29	<0.001
Bos indicus content	2.22	0.335	2.57	0.28	1.04	<0.001
Relative utilisation rate	97.2	<0.001	60.16	<0.001	47.99	<0.001
Pasture growth ±3 months around calving	20.78	<0.001	omitted		omitted	
Prop. Green ±3 months around calving	omitted		56.27	<0.001	omitted	
Perc. N ±3 months around calving					16.25	<0.001
Growth (Jan–Mar)	omitted		omitted		0.96	0.33
Growth (Apr–Jun)	omitted		omitted		34.26	<0.001
Soil phosphorus (0–5 cm)	2.39	0.13	0.65	0.42	omitted	
Mating system	0.129	0.70	8.13	<0.001	0.32	0.57
Interaction: Utilisation × B. indicus content	81.32	<0.001	75.25	<0.001	49.34	<0.001

Impact of relative pasture utilisation rate and Bos indicus content

Relative pasture utilisation rate had a significant influence on all reproductive and weaning outcomes (P<0.001), and its effect was moderated by *Bos indicus* content category for all reproductive outcomes (P<0.001). Trends across relative pasture utilisation rates, particularly for herds with <50% *Bos indicus*, were highly variable and not easily explained by biological mechanisms alone (Figure 6-1, Table 6-2, Figure 6-2, Table 6-3, Figure 6-3, Table 6-4). This variability may reflect differences in management intensity, or other region-specific factors not accounted for in the model.

Annual pregnancy rates showed a marked decrease with increasing relative pasture utilisation rate, declining from approximately 80–90% at very low utilisation (<0.5) to around 70% at high utilisation (>1.7). Pregnancy within four months was particularly sensitive to pasture utilisation in herds with lower *Bos indicus* content. In herds with <50% *Bos indicus*, the proportion of cows pregnant within four months declined from 75–88% at moderate utilisation rates (0.5–1.06) to 44–66% at high utilisation rates (1.4–2.2), a reduction of approximately 33%. Herds with 50–75% *Bos indicus* showed smaller declines (58–62% to 13-35%). In contrast, herds with >75% *Bos indicus* appeared to be comparatively resilient, with pregnancy within four months ranging 43–57% and annual pregnancy remaining around 68–76%. Substantially lower occurrences were predicted under extreme pasture overutilisation (>2.3), with annual pregnancy and weaning percentage predicted at 46% and 20%, respectively. These predictions are associated with large confidence intervals, reflecting the limited number of data points supporting this observation. In reality, such extreme overutilisation would be rare and likely reflects exceptional conditions, such as prolonged dry periods or drought-like situations when animals have not been removed.

Increasing the relative pasture utilisation rate from around 1 to 2 was predicted to result in an estimated 33% decline in weaning rate for herds with <50% *Bos indicus* and a 16% decline for herds with 50–75% *Bos indicus*, whereas herds with >75% *Bos indicus* showed little change.

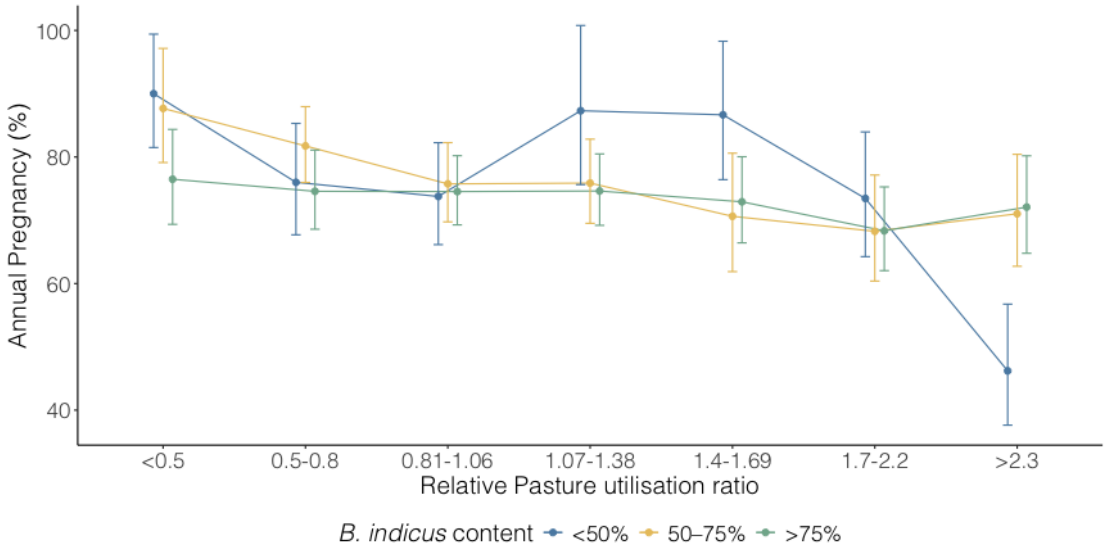


Figure 6-1. Predicted annual pregnancy across levels of *Bos indicus* content and relative utilisation rate. Points and lines represent model predictions for each breed group, while error bars indicate approximate 95% confidence intervals calculated from standard errors on the log scale

Table 6-2. Adjusted mean annual pregnancy percentages for each relative pasture utilisation rate category, by *Bos indicus* content category. Note approximate confidence limits (CL) are presented at the 95% level

Relative Utilisation Rate	*Bos indicus* content								
	<50%			50-75%			>75%		
	Mean	Lwr.CL	Upr.CL	Mean	Lwr.CL	Upr.CL	Mean	Lwr.CL	Upr.CL
<0.5	90	81.5	97.2	87.7	79.1	99.4	76.5	69.4	84.4
0.5-0.8	76	67.7	88	81.8	76	85.3	74.6	68.6	81.1
0.81-1.06	73.8	66.2	82.3	75.8	69.7	82.3	74.5	69.3	80.2
1.07-1.38	87.3	75.6	82.8	75.9	69.5	100	74.6	69.2	80.5
1.4-1.69	86.7	76.4	80.6	70.6	61.9	98.3	72.9	66.4	80
1.7-2.2	73.4	64.3	77.2	68.3	60.4	84	68.3	62	75.3
>2.3	46.2	37.6	80.4	71	62.7	56.7	72.1	64.8	80.2

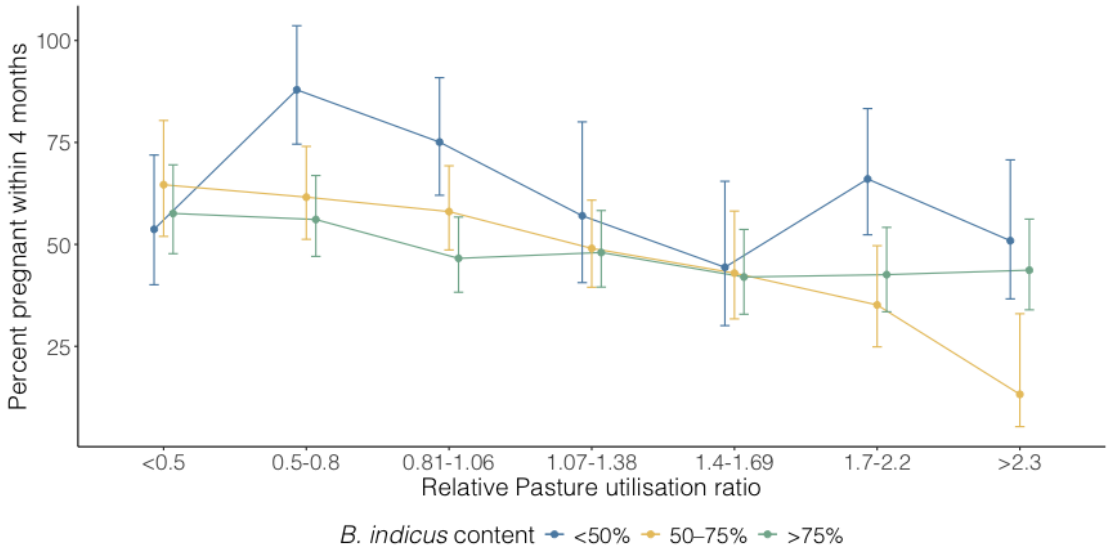


Figure 6-2. Predicted pregnancy within 4 months of calving and levels of *Bos indicus* content and relative utilisation rate. Points and lines represent model predictions for each breed group, while error bars indicate approximate 95% confidence intervals calculated from standard errors on the log scale

Table 6-3. Adjusted mean pregnancy within 4 months of calving for each relative pasture utilisation rate category, by *Bos indicus* content category. Note approximate confidence limits (CL) are presented at the 95% level

Relative Utilisation Rate	*Bos indicus* content								
	<50%			50-75%			>75%		
	Mean	Lwr.CL	Upr.CL	Mean	Lwr.CL	Upr.CL	Mean	Lwr.CL	Upr.CL
<0.5	53.7	40.1	71.9	64.6	52	80.4	57.6	47.7	69.5
0.5-0.8	87.9	74.6	103.6	61.6	51.2	74	56.1	47	66.9
0.81-1.06	75.1	62	90.9	58	48.6	69.3	46.6	38.3	56.7
1.07-1.38	57	40.6	80	49	39.5	60.9	48	39.5	58.3
1.4-1.69	44.4	30.1	65.5	43	31.7	58.2	42	32.9	53.7
1.7-2.2	66	52.3	83.3	35.1	24.9	49.7	42.6	33.5	54.2
>2.3	50.9	36.6	70.7	13.2	5.3	33	43.7	34	56.2

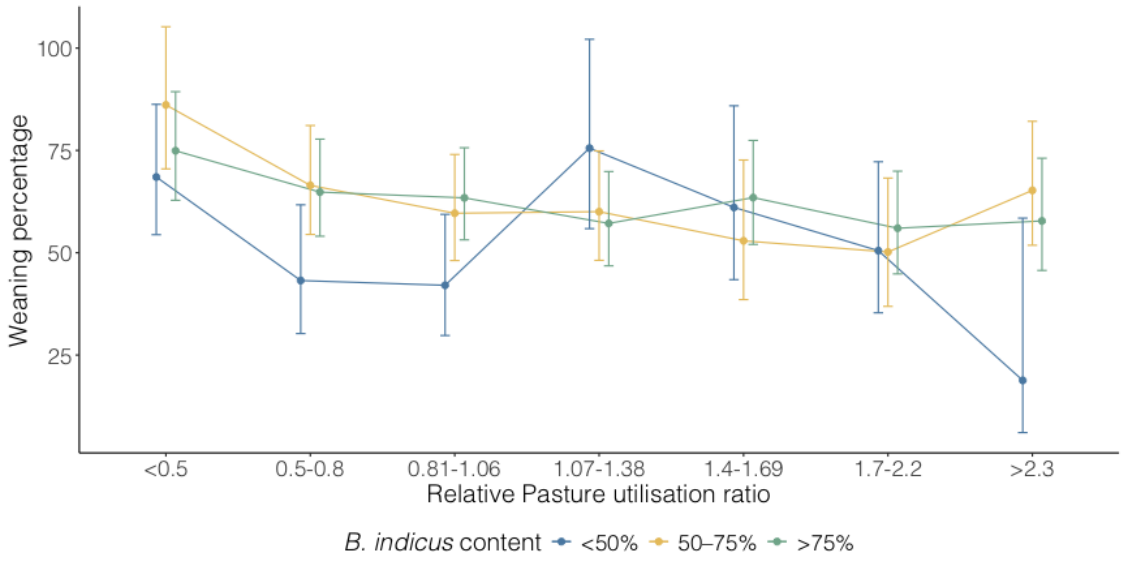


Figure 6-3. Predicted weaning percentage for levels of *Bos indicus* content and relative utilisation rate. Points and lines represent model predictions for each breed group, while error bars indicate approximate 95% confidence intervals calculated from standard errors on the log scale

Table 6-4. Adjusted mean weaning percentage for each relative pasture utilisation rate category, by *Bos indicus* content category. Note approximate confidence limits (CL) are presented at the 95% level

Relative Utilisation Rate	*Bos indicus* content								
	<50%			50-75%			>75%		
	Mean	Lwr.CL	Upr.CL	Mean	Lwr.CL	Upr.CL	Mean	Lwr.CL	Upr.CL
<0.5	68.5	54.4	86.3	86.1	70.5	105.2	74.9	62.8	89.4
0.5-0.8	43.2	30.3	61.7	66.5	54.5	81.1	64.8	54	77.8
0.81-1.06	42	29.8	59.4	59.7	48.1	74	63.4	53.1	75.7
1.07-1.38	75.6	55.9	102.2	60	48.1	74.9	57.2	46.8	69.8
1.4-1.69	61.1	43.4	85.9	52.9	38.5	72.7	63.5	52	77.4
1.7-2.2	50.5	35.3	72.2	50.2	36.9	68.2	56	44.8	69.9
>2.3	18.8	6.1	58.5	65.2	51.8	82.1	57.8	45.7	73.1

The main effect of *Bos indicus* content was significant only for weaning rate ($P < 0.001$). After adjustment for all other factors in the model, predicted weaning percentages were similar for herds with 50–75% or >75% *Bos indicus* content, averaging approximately 63% (95% CI: 52.1–73.8%), while herds with <50% *Bos indicus* had a predicted weaning rate around 10% lower (51.4%, 95% CI: 37.7–65.1%).

While these results suggest that animals with higher *Bos indicus* content are less sensitive to variations in pasture availability, *Bos indicus* content likely also reflects several regional attributes that are not explicitly captured elsewhere in the model. However, these findings highlight the importance of considering both breed and pasture utilisation when managing reproductive performance. In regions where *Bos indicus* content is low, careful management of stocking rates and pasture utilisation is critical to optimise pregnancy and weaning outcomes. In contrast, in regions with higher *Bos indicus* populations, cattle may appear less sensitive to fluctuations in pasture

availability, they are already operating close to physiological limits due to exposure to other environmental, quality of pasture, parasite burdens or management stressors that constrain performance (Bortolussi *et al.* 2005).

Impact of animal class

Pregnancy and weaning outcomes were strongly influenced by animal class, with its effect highly statistically significant for each outcome: pregnancy, pregnancy within 4 months and weaning percentage at <0.001 (Table 6-5, Figure 6-5, Figure 6-6, Figure 6-6).

Annual pregnancy rates were highest in heifers (81.9%; 95% CI 77.3–86.8) and mature cows (76.2%; 72.3–80.0), and lowest in aged cows (70.3%; 65.7–75.2). Pregnancy within four months was slightly lower in heifers (49.9%; 42.8–58.1) compared to mature cows (55.1%; 48.6–62.5), likely reflecting the additional nutritional demands on heifers that are still growing while lactating. Weaning rates were also highest in heifers (66.3%; 57.1–76.9) and lowest in aged cows (52.9%; 43.6–64.0), reflecting consistent differences in reproductive and calf survival outcomes across animal classes.

Table 6-5. Adjusted mean percentages for the animal classes, for each outcome

Animal class	Preg. (annual)			Preg. (4 months)			Weaning rate		
	Mean	Lwr.CL	Upr.CL	Mean	Lwr.CL	Upr.CL	Mean	Lwr.CL	Upr.CL
Heifer	81.9	77.3	86.8	49.9	42.8	58.1	66.3	57.1	76.9
First lactation	72.2	67.7	76.6	52.8	45.7	61	56.3	47.3	66.9
Mature cow	76.2	72.3	80.0	55.1	48.6	62.5	60.4	52.1	70
Aged cow	70.3	65.7	75.2	51.1	43.5	60	52.9	43.6	64

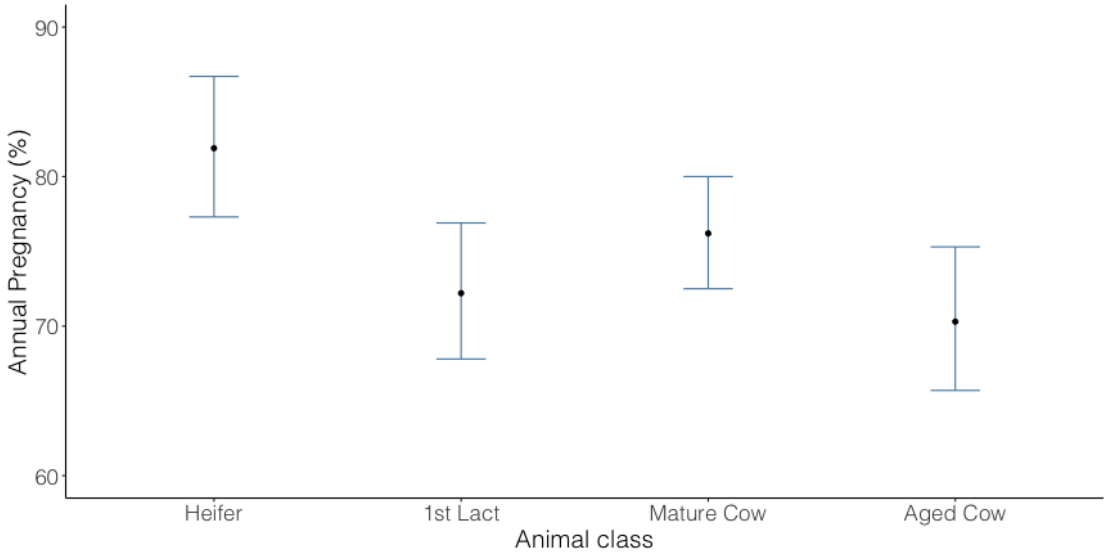


Figure 6-4. Predicted annual pregnancy for each animal age class. Points and lines represent model predictions for each animal class group, while error bars indicate approximate 95% confidence intervals calculated from standard errors on the log scale

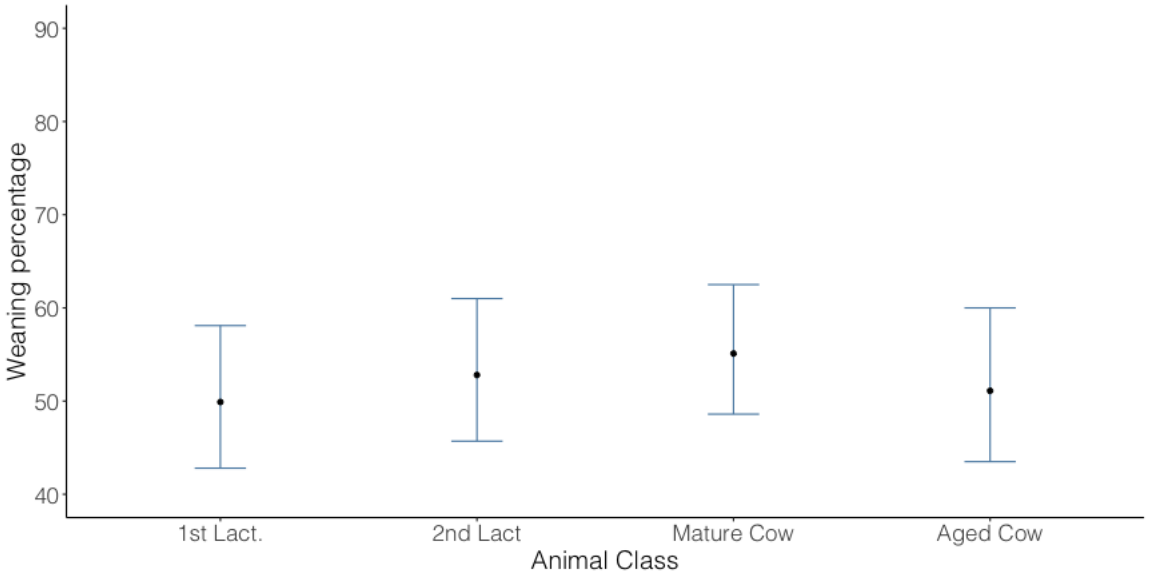


Figure 6-5. Predicted percent pregnant within 4 months of calving for each animal age class. Points and lines represent model predictions for each animal class group, while error bars indicate approximate 95% confidence intervals calculated from standard errors on the log scale

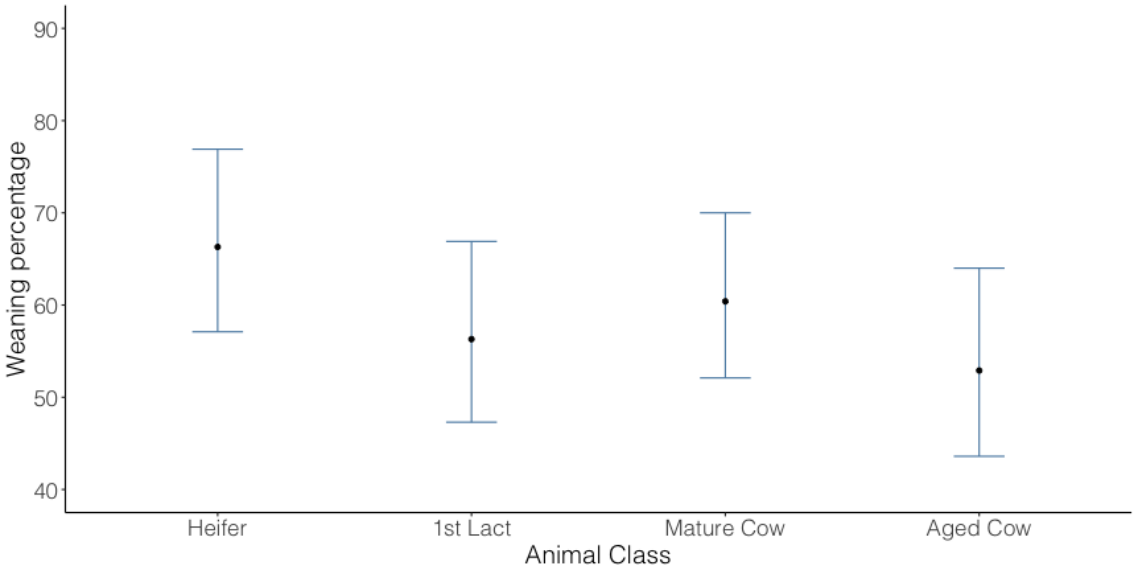


Figure 6-6. Predicted weaning percentage for each animal age class. Points and lines represent model predictions for each animal class group, while error bars indicate approximate 95% confidence intervals calculated from standard errors on the log scale

Impact of simulated pasture growth and quality around the time of calving

Reproductive and weaning outcomes were strongly influenced by simulated pasture growth and quality, and soil nutrients. Annual pregnancy was driven by pasture growth around the previous calving (±3 months; P<0.001), while pregnancy within four months depended on the proportion of

green pasture around calving (±3 months; P<0.001). Weaning rate was most sensitive to early dry season growth (April–June).

After adjustment for other factors, annual pregnancy increased with pasture growth around the time of calving, from approximately 62% at very low growth (0 kg/ha) to 83% at the highest observed growth (~3000 kg/ha; Figure 6-7). Higher growth likely reflects increased pasture quality and availability, highlighting its importance of around calving for reproductive performance in northern beef herds. As calving month was not included in the final model, pasture growth may also capture some effects associated with month of calving, with increased growth correlated to periods of high rainfall during the northern Australian monsoon (summer).

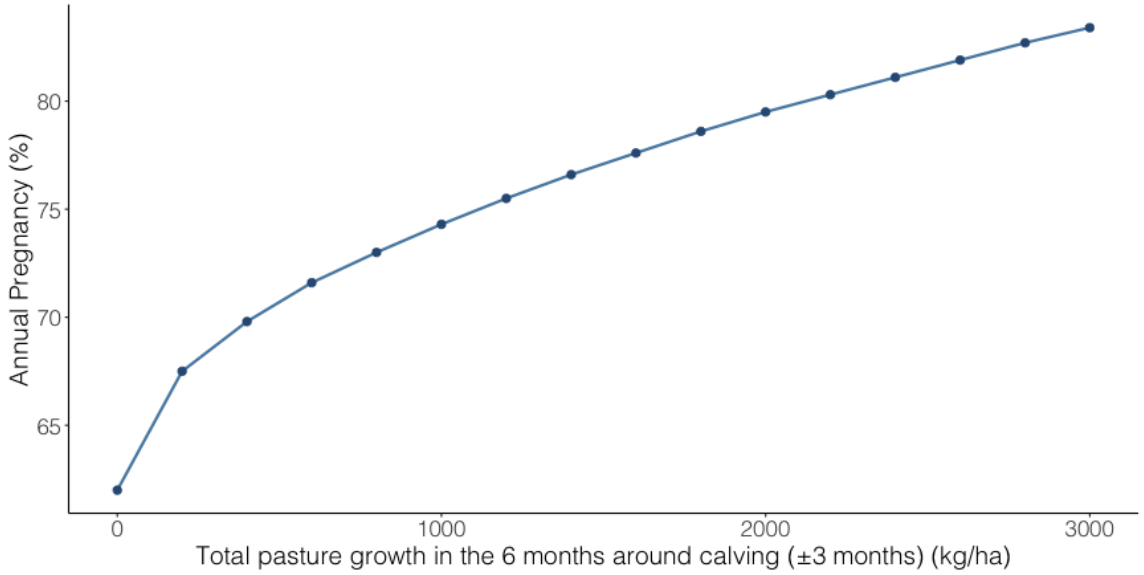


Figure 6-7. Predicted annual pregnancy percentage by total pasture growth in the 6 months around calving (±3 months of birth month)

Pregnancy within four months was positively associated with the proportion of green in standing pasture in the 3 months before and after calving (P<0.001), increasing from approximately 40% at a low proportion of green in the standing pasture (0.3) to 71% at high proportion of green (0.7) (Figure 6-8). The proportion of green pasture likely reflects forage quality and availability, ensuring that the nutritional demands of lactation are met, which supports reproductive cycling and enhances reproductive efficiency in northern beef herds.

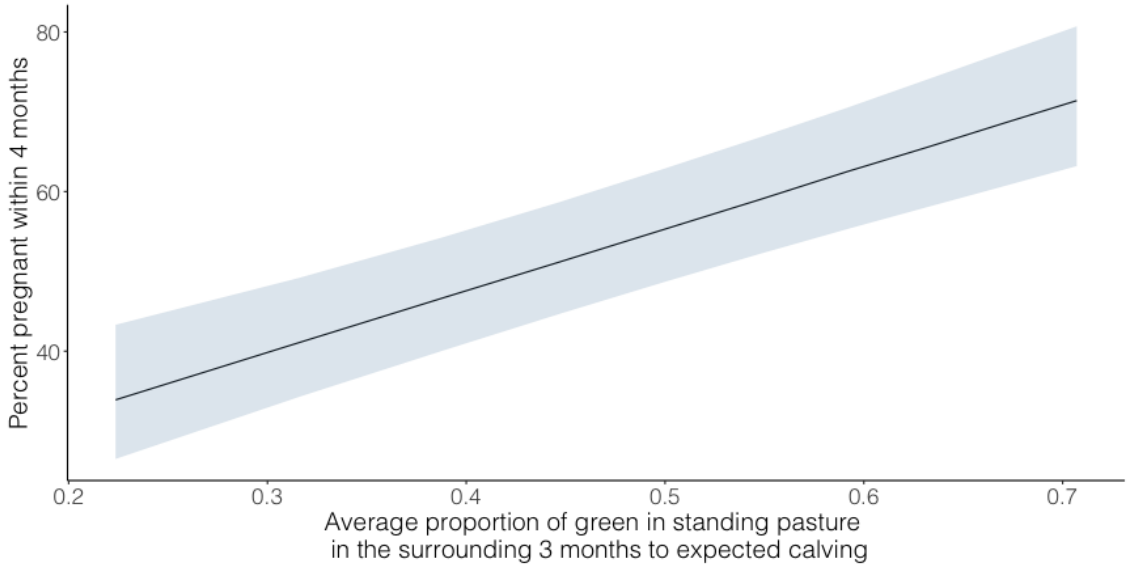


Figure 6-8. Predicted percent pregnancy within 4 months of calving by average proportion of green in standing pasture in the 3 months each side of expected calving. Line represents model predicted mean pregnancy within four months of calving, while shading represents approximate 95% confidence intervals calculated from standard errors on the log scale

Weaning rate was positively associated with both estimated pasture nitrogen content in the months surrounding calving (P<0.001; Figure 6-9) and pasture growth in the early dry season (April–June; P<0.001; Figure 6-10). Predicted weaning rates increased from approximately 40% to 80% as standing pasture nitrogen content around calving rose from 0.05 to 0.90, highlighting the importance of high-quality forage at calving in meeting the nutritional demands of lactating cows and supporting reproductive efficiency. The effect of pasture nitrogen around calving is analogous to the influence of the proportion of green pasture on pregnancy within four months. Predicted weaning rates also increased from ~52% to 68% across observed early dry season pasture growth. Growth during the early dry season indicates an extended wet season, or out of season rainfall, which is likely to extend the length of time pasture quality is higher through the season, highlighting the role of pasture quality later in the production cycle in maintaining body condition and supporting calf survival. Overall, these results demonstrate that ensuring high-quality pasture at calving and adequate forage in the early dry season is critical for reproductive success and weaning outcomes in northern beef herds.

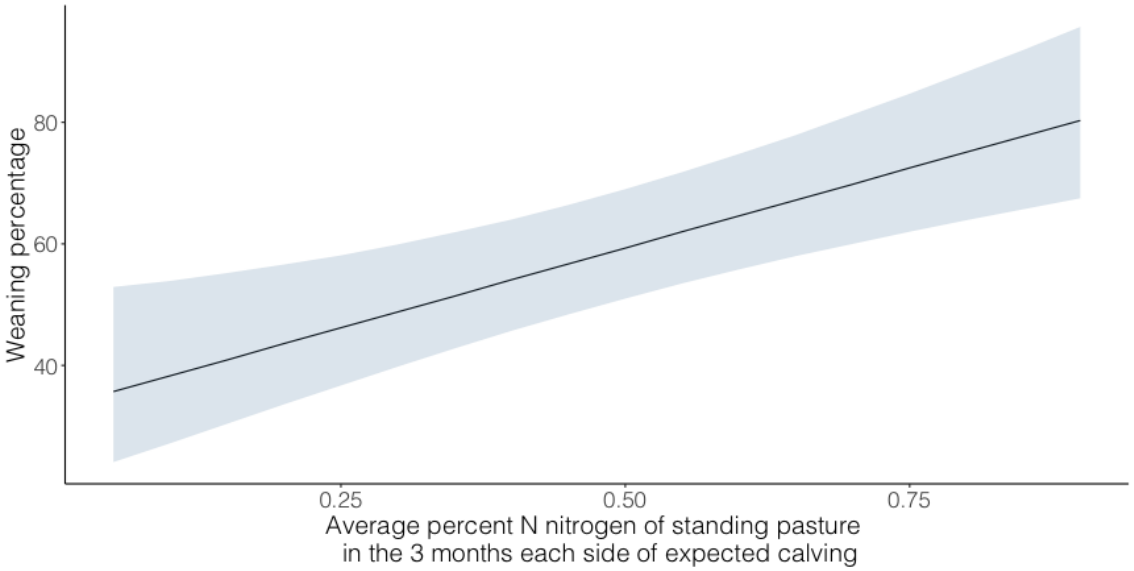


Figure 6-9. Predicted weaning percentage by average percent nitrogen of standing pasture in the 3 months each side of calving. Line represents model predicted mean weaning percentage, while shading represents approximate 95% confidence intervals calculated from standard errors on the log scale

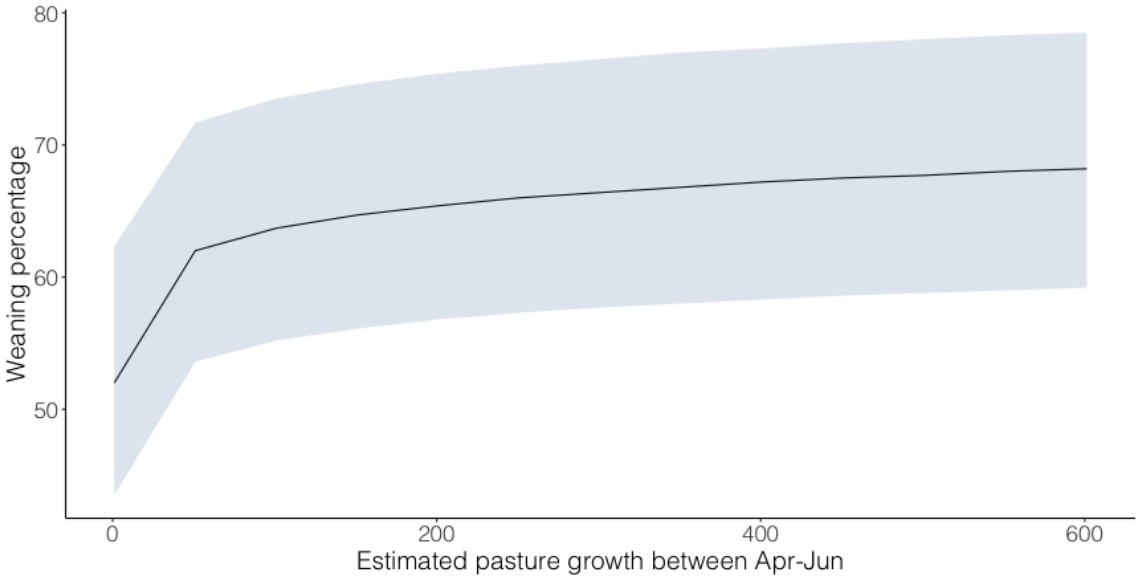


Figure 6-10. Predicted weaning percentage by simulated total pasture growth between April to June. Line represents model predicted mean weaning percentage, while shading represents approximate 95% confidence intervals calculated from standard errors on the log scale

Impact of mating management

Mating policy had a strong effect on pregnancy rate within four months, with 48% under continuous mating *vs*. 57% for controlled mating (Figure 6-11, Table 6-6). However, the factor was not found to be significant for either weaning rate (P=0.57) or annual pregnancy (P=0.70).

Although this factor is defined by management practices relating to bulls, it also likely reflects broader regional and management practices not directly measured in the model. This includes more intensive herd management, concentration of calving to optimal periods of the year for pasture quality and an improved ability to impose management practices, supplementary feeding or weaning, at the optimum time, benefiting a larger proportion of the mob compared with continuous mating systems where high variability in timing of calving exists.

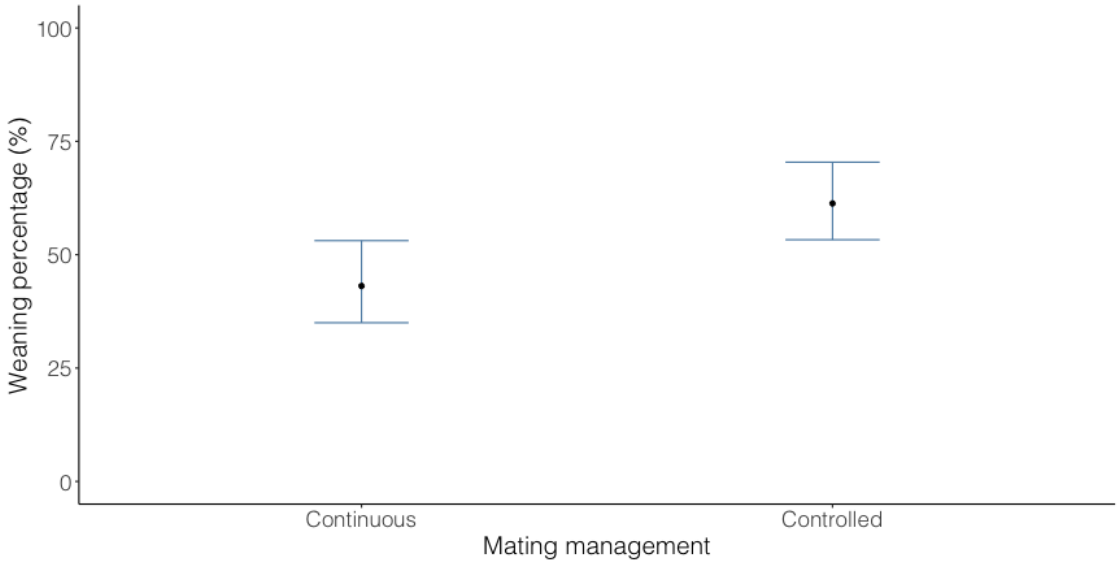


Figure 6-11. Predicted weaning percentage by mating management. Points and lines represent model predictions for each animal class group, while error bars indicate approximate 95% confidence intervals calculated from standard errors on the log scale

Table 6-6. Adjusted mean percentage pregnant within 4 months percentages for mating management

Mating system	Mean	Lwr.CL	Upr.CL
Continuous	43.1	35	53.1
Controlled	61.3	53.3	70.4

6.2.2 Predicting Other Key Factors of Interest

In addition to the primary factors retained in the final multivariable models, several other variables were explored for their potential influence on reproductive and weaning outcomes. These included factors that either did not reach statistical significance or were not retained in the final model but are biologically relevant. While these variables did not contribute meaningfully to model fit, their predicted effects were examined to understand management impacts. For example, certain environmental or management factors, although non-significant, showed directional trends consistent with expectations, suggesting potential influence under different conditions or in larger datasets.

Impact of body condition score

As previously mentioned, body condition score (BCS) is an outcome of targeted environmental and management effects, such as lactation management. For some outcomes, BCS was not included in the final models due to potential confounding and model instability. Its removal also allowed for a more direct quantification of the effect of pasture utilisation rate, which itself influences BCS. The influence of BCS on outcomes was estimated using a simplified model containing only animal class, breed, and BCS. Each incremental increase in body condition score was statistically significant (P<0.001), with higher scores consistently associated with improved breeder performance across all outcomes (Figure 6-12).

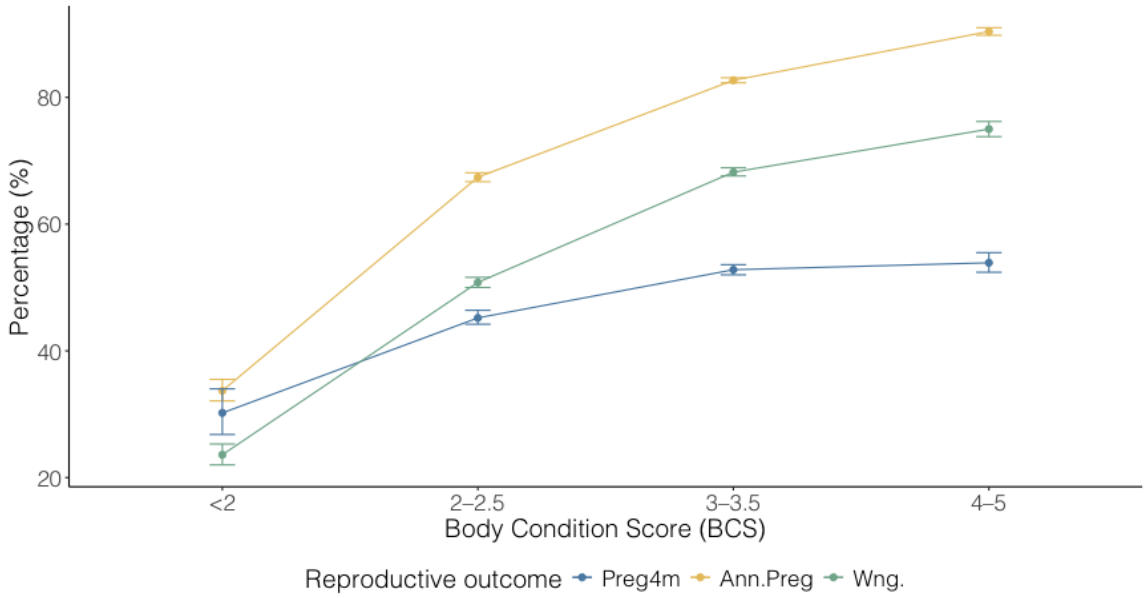


Figure 6-12: Predicted annual pregnancy, pregnancy within 4 months and weaning percentage by body condition score recorded at the pregnancy test muster in the current year. Note that this effect was predicted using a simplified model – not the final model. Line represents model predicted mean weaning percentage, while shading represents approximate 95% confidence intervals calculated from standard errors on the log scale

Soil available phosphorus

Available soil phosphorus (0–5 cm) was considered an important determinant of reproductive performance (Schatz *et al.* 2023) and was therefore included in the final models for annual pregnancy and pregnancy within four months. Although it was not statistically significant (P > 0.05; Figure 6-13), there was a general trend toward slightly higher pregnancy rates with increasing soil phosphorus. It should be noted that soil phosphorus was not specified in the final model for weaning percentage, and therefore the effect of soil phosphorus is not presented in these results.

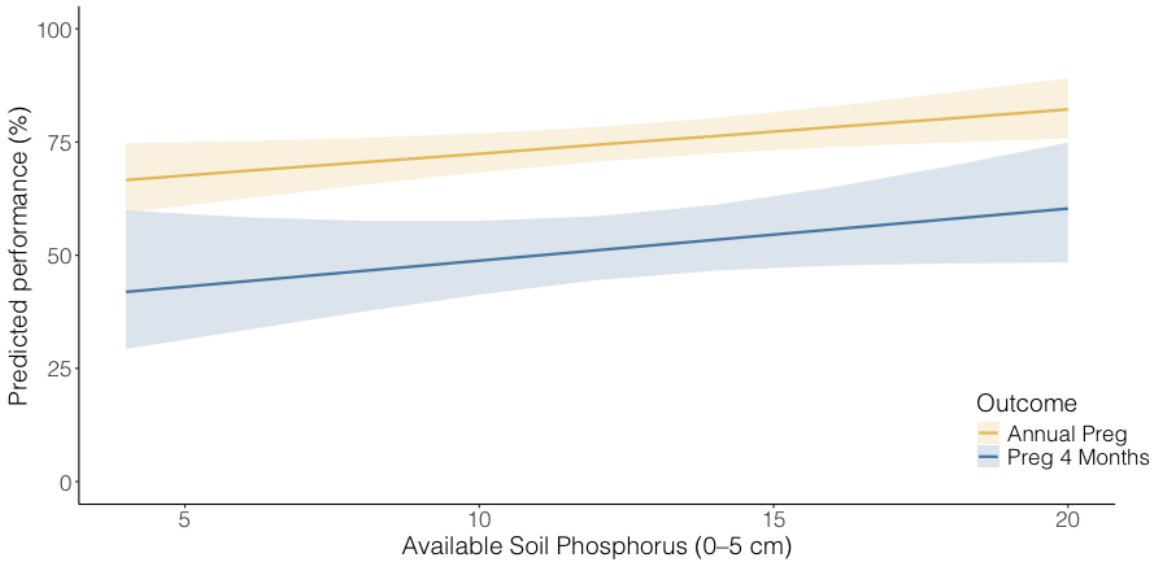


Figure 6-13. Predicted annual pregnancy and pregnancy within 4 months by estimated average available soil phosphorus for the paddock grazed by the mob in the current year. Note that these associations were not statistically significant in the final model. Line represents model predicted mean pregnancy percentage, while shading represents approximate 95% confidence intervals calculated from standard errors on the log scale

6.2.3 Factors influencing foetal and calf loss

The starting dataset comprised 26,903 annual records of individual cows, with each record representing a production year. On average, each animal contributed 1.76 (95% CI: 1.74–1.77) production years for which a valid foetal or calf loss outcome could be ascribed. Seventeen herds contributed to the analytical dataset, with a median of 1,085 (interquartile range: 500–2,387) foetal or calf loss outcomes per herd.

The final multilevel logistic regression model identified several significant and near-significant predictors of foetal and calf loss (Table 6-1). Overall, animal class, body condition score, annual lactation status, relative pasture utilisation, and the interaction between calving period and region were important contributors, whereas region and average maximum Comprehensive Climate Index (CCI) during the expected calving month were not independently significant. The magnitude of effect and predicted probabilities for each associated factor, derived from the final multivariate model, are presented individually below.

Table 6-7: Factors identified in the final multivariable model for occurrence of foetal and calf loss in breeding females. Significance levels (P) are shown

Predictor	Details	p-value	Significance
Animal class	Heifer, 1st Lactation, Mature, Aged Cow	<0.001	***
Body condition score	Quadratic	0.04	*
Calving period	6 bimonthly periods	0.09	NS
Annualised lactation status	Lactated / Didn't lactate	<0.001	***
Pasture relative utilisation	Continuous	<0.001	***
Average max comprehensive climate index	Continuous	0.59	NS
Region category	North East Qld, Southern NT, Central NT, Northern NT	0.48	NS
Interaction	Calving period × Region	<0.001	***

Relative pasture utilisation

Relative pasture utilisation rate was a significant continuous predictor of calf loss ($F = 24.90$, $p < 0.001$), with higher utilisation associated with increased risk. The predicted calf loss values rose steadily from 9.7% to 18.9% at the highest level (5.5), indicating a consistent increase in calf loss across the range of utilisation rates. On average, each incremental step in relative utilisation corresponded to an increase of approximately 2.3% in predicted calf loss.

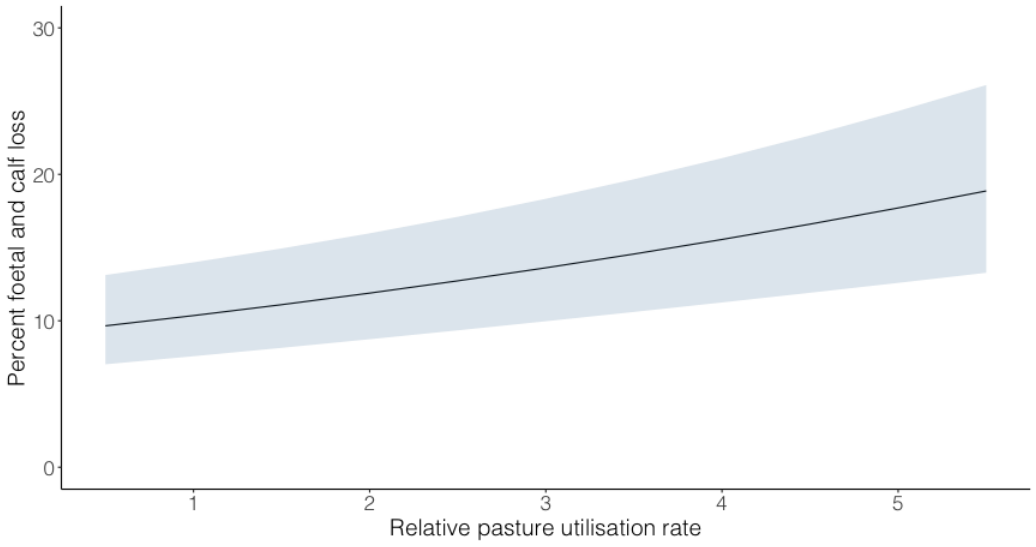


Figure 6-14. Predicted Percentage of Foetal and Calf Loss for relative pasture utilisation rate based on the Final Multivariate Model

This suggests that maintaining moderate pasture utilisation is important for calf survival. High levels of grazing pressure, reflected in higher utilisation ratios, are associated with significantly greater calf loss, likely due to reduced forage availability, increased nutritional stress, or competition among animals. Managing stocking rates and adjusting grazing to avoid excessive pasture depletion could therefore help reduce calf losses and support more consistent herd performance.

Animal class

Animal class (Heifer, 1st lactation cow, Mature cow, Aged cow) was highly significant (F = 8.78, p < 0.001), with younger and first-lactation animals generally exhibiting higher probabilities of foetal and calf loss compared with mature cows (Figure 6-15, Table 6-8). Heifers had the highest predicted loss (13.7%), followed by Aged cows (11.4%), with 1st lactation cows (9.0%) and Mature cows (9.3%) lower. Pairwise comparisons showed that Heifers had significantly higher predicted losses than 1st lactation cows (p < 0.001) and Mature cows (p < 0.001). Aged cows differed significantly from Mature cows (p = 0.02) but not from Heifers (p = 0.15) or 1st lactation cows (p = 0.08). The difference between 1st lactation and Mature cows was not significant (p = 0.79). Overall, these results demonstrate that Heifers, and to a lesser extent Aged cows, were at the greatest risk of foetal and calf loss compared with other animal classes.

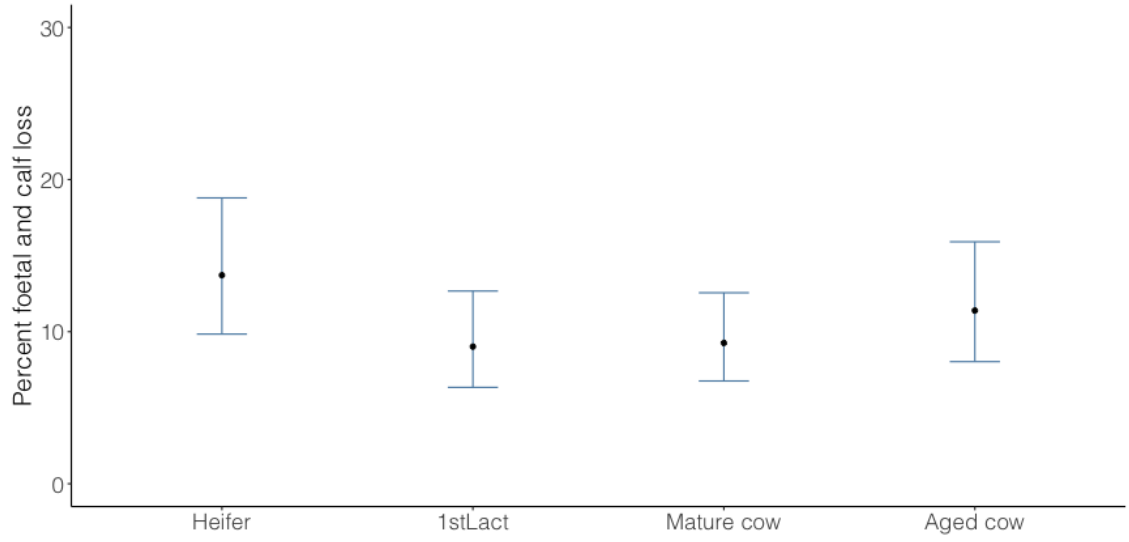


Figure 6-15. Predicted percentages of foetal and calf loss across animal classes were estimated from the final multivariate model, with whiskers representing 95% confidence limits

Table 6-8. Predicted mean occurrence of foetal and calf loss, expressed as a percentage, for each animal age class category.

Animal class	Foetal and Calf Loss %		
	Mean	Lwr.CL	Upr.CL
Heifer	13.7	9.8	18.8
1st Lactation	9	6.3	12.7
Mature cow	9.3	6.8	12.6
Aged cow	11.4	8	15.9

Body condition score

Predicted percentages of calf loss decreased steadily with increasing body condition score (BCS) at pregnancy testing (Figure 6-16, Table 6-9). Foetal and calf loss declined quadratically with BCS (F = 3.23, p = 0.04). At a BCS of 1.5, the predicted calf loss was 22.7%, falling progressively to 3.5% at a BCS of 5.0. Intermediate BCS values showed a clear gradient: 17.9% at BCS 2, 13.9% at BCS 2.5,

10.7% at BCS 3, 8.1% at BCS 3.5, 6.2% at BCS 4, and 4.6% at BCS 4.5. All pairwise comparisons between BCS categories were highly significant (p = 0.014 for all contrasts), indicating a consistent reduction in calf loss risk as condition improved.

Overall, these results provide strong evidence of a monotonic decline in foetal/calf loss with increasing BCS, reinforcing the importance of maintaining breeder cows in at least moderate condition (≥3.0) at pregnancy testing to minimise losses.

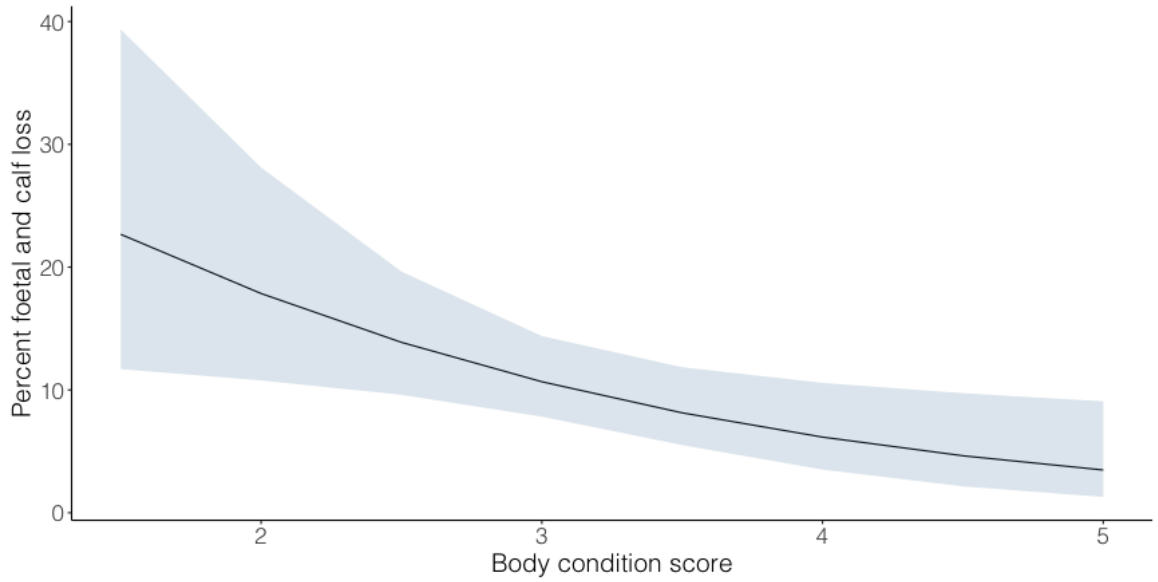


Figure 6-16. Predicted percentages of foetal and calf loss by body condition score were estimated from the final multivariate model, with shading representing 95% confidence limits

Table 6-9. Predicted mean occurrence of foetal and calf loss, expressed as a percentage, for levels of body condition score

BCS at pregnancy test muster	Foetal and Calf Loss %		
	Mean	Lwr.CL	Upr.CL
1.5	22.7	11.7	39.3
2	17.9	10.8	28.1
2.5	13.9	9.6	19.6
3	10.7	7.8	14.4
3.5	8.1	5.5	11.8
4	6.2	3.5	10.6
4.5	4.6	2.1	9.7
5	3.5	1.3	9.1

Annual lactation status

Lactation status was strongly associated with loss (Figure 6-17, Table 6-10, F = 45.18, p < 0.001). Predicted calf loss was higher in breeders that did not lactate in the previous year compared with those that did. Cows that did not lactate had a predicted calf loss of 12.8%, whereas those that lactated had a predicted loss of 8.9%.

These results indicate that failure to lactate in the previous year is associated with an increased risk of subsequent foetal or calf loss, highlighting the biological linkage between reproductive history and future performance.

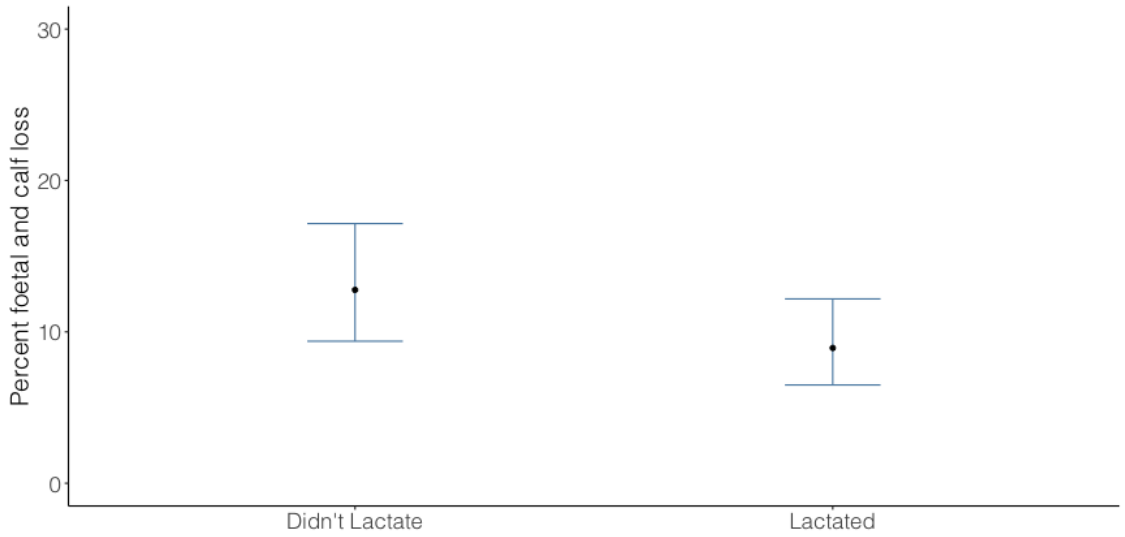


Figure 6-17. Predicted percentages of foetal and calf loss across lactation status in the previous year were estimated from the final multivariate model, with whiskers representing 95% confidence limits

Table 6-10. Predicted mean occurrence of foetal and calf loss, expressed as a percentage, for each animal age class category

Lactation status	Foetal and Calf Loss %		
	Mean	Lwr.CL	Upr.CL
Didn't Lactate	12.8	9.4	17.2
Lactated	8.9	6.5	12.2

Comprehensive climate index

Counterintuitively, heat stress indices during calving months showed no significant association with calf loss (P=0.59). Cattle are generally considered to experience severe heat stress when CCI values exceed 35 (Mader *et al.* 2010). This absence of a direct relationship may reflect limitations in the resolution of the dataset: monthly averaged CCI values could obscure short-term, acute heat stress events critical to neonatal survival. Alternatively, heat stress impacts may be indirectly mediated through correlated variables in the model, such as calving period, which encapsulates seasonal shifts in both climatic extremes and pasture conditions. Breed was not included as a factor in the current model. Given known differences in heat tolerance among breeds (Gaughan *et al.* 2010), the exclusion of breed may have influenced the observed relationships and could partially explain the absence of significant associations for some variables. Future research should integrate finer-scale heat stress metrics and direct physiological markers (e.g., colostrum IgG levels / calf vigour / actual birth events) when assessing the effects of heat stress on extensively managed beef females.

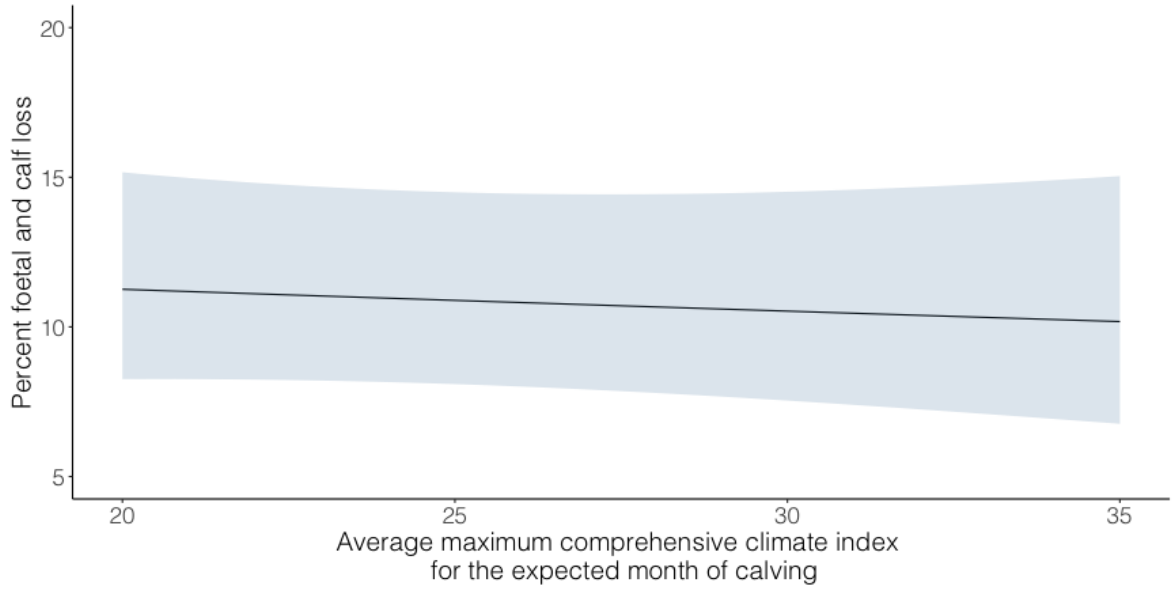


Figure 6-18. Predicted percentages of foetal and calf loss by average max comprehensive climate index during the expected month of calving estimated from the final multivariate model, with whiskers representing 95% confidence limits

Calving period and region

There was a significant interaction between region and season in calf survival (P<0.001), with clear regional differences in season of foetal and calf loss across the study areas (Figure 6-19, Table 6-11). North east Queensland stands out for its highly variable losses across the year. Losses were extremely high in May to June (~40%), which is substantially above all other regions and seasons, but were at moderate or low levels (~4–14%) in the remaining periods. This is likely due to the small number of observations in the May–June period for this region. In addition, observations from this region were dominated by records from a single research station where cows were generally managed so that this calving period was avoided.

For this dataset, most within-region comparisons between periods of calving were not statistically significant ($p > 0.05$). However, In the Northern NT, Jul–Aug was significantly higher than Sep–Oct ($p = 0.02$). Most other within-region seasonal differences were not significant ($p > 0.05$).

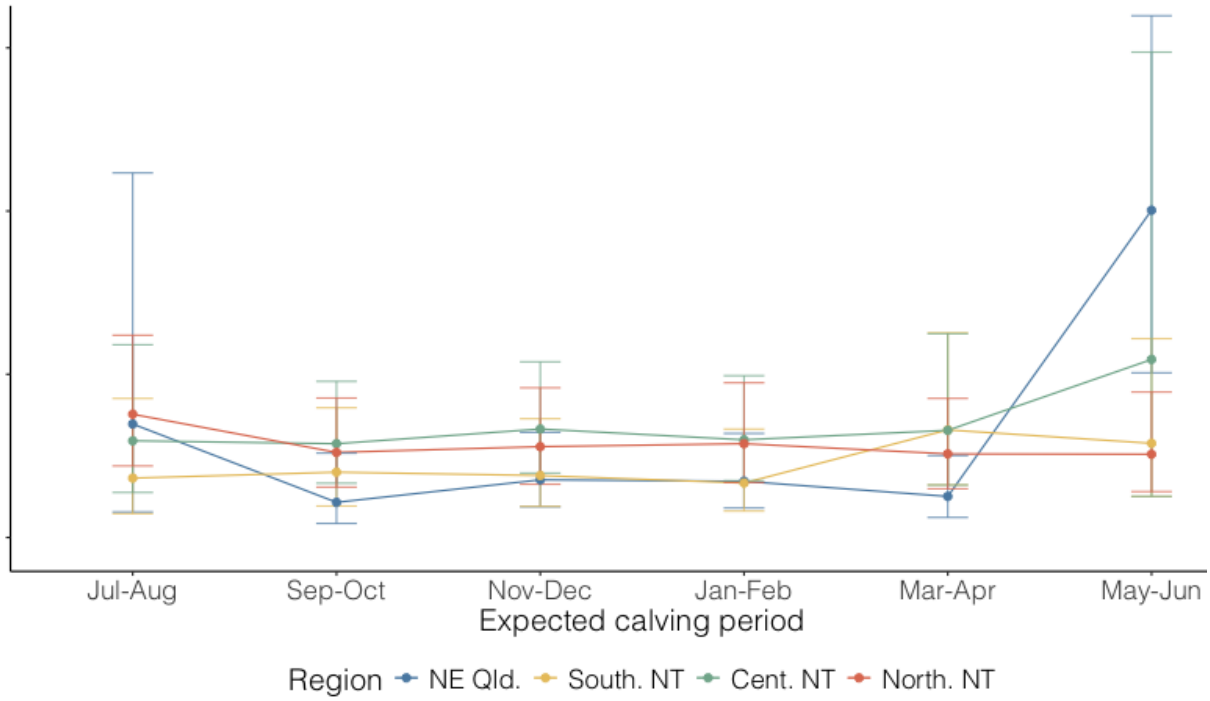


Figure 6-19. Predicted Percentage of Foetal and Calf Loss for different time periods by region based on the Final Multivariate Model

Table 6-11. Adjusted mean foetal and calf loss for each relative pasture utilisation rate category, by *region*. Note approximate confidence limits (CL) are presented at the 95% level

Relative Utilisation	Region											
	North East Qld			Southern NT			Central NT			Northern NT		
	Mean	Lwr.CL	Upr.CL	Mean	Lwr.CL	Upr.CL	Mean	Lwr.CL	Upr.CL	Mean	Lwr.CL	Upr.CL
Jul-Aug	13.9	3.1	44.7	7.3	2.9	17	11.8	5.5	23.6	15.1	8.8	24.8
Sep-Oct	4.3	1.7	10.3	8	3.9	15.9	11.5	6.7	19.1	10.4	6.2	17.1
Nov-Dec	7.1	3.8	12.9	7.6	3.8	14.5	13.3	7.9	21.5	11.1	6.5	18.3
Jan-Feb	6.9	3.6	12.8	6.7	3.2	13.3	12	7	19.8	11.5	6.7	19
Mar-Apr	5	2.5	10	13.2	6.4	25.1	13.1	6.4	25	10.2	6	17
May-Jun	40.1	20.2	63.9	11.5	5	24.4	21.8	5	59.5	10.2	5.6	17.8

6.3 Discussion

This study is one of the few to directly document the effects of relative pasture utilisation on reproductive performance in northern beef systems. Across all reproductive measures—annual pregnancy, pregnancy within 4 months, foetal and calf loss, and weaning percentage—relative pasture utilisation was identified as a significant determinant, with higher utilisation consistently associated with reduced performance.

This study addresses a key knowledge gap on the effects of pasture utilisation rates on reproductive performance of breeding females in northern Australia's rangelands. Most studies in Australia have looked at the impact of stocking rates on steers, not breeders. The few exceptions include studies incorporated into this study's dataset (Hunt *et al.* 2013, Smith *et al.* 2001).

In these and other reviews of stocking rate trials in Australian rangelands have often demonstrated that while individual animal performance is usually reduced at higher stocking rates, the larger numbers of animals still usually led to higher total beef production despite reduced individual animal performance (Ash and Stafford Smith 1996, Hunt et al. 2014). This analysis and most stocking rate trials measure the short-term impacts of pasture utilisation on breeder performance that occurs due to poorer pasture quality and lower forage availability as stocking rates increase. However, over the longer-term higher utilisation rates cause land condition decline and reduce the productive capacity of the landscape which then leads to reduced profitability (MacLeod *et al.* 2004, Hunt *et al.* 2014). This highlights the critical balance (Sweet Spot) required to optimise enterprise-level productivity and profitability while maintaining individual animal performance and long-term environmental sustainability. Overgrazing risks land degradation, soil erosion, and reduced ecological resilience, whereas underutilisation of pasture can limit potential production and profitability.

Using mixed-effects modelling on a large retrospective dataset, this study applied robust statistical methods to existing data to clarify the relationship between relative pasture utilisation and key reproductive performance metrics, specifically annual pregnancy, pregnancy within four months of calving, weaning percentage, and foetal and calf loss.

Pasture utilisation relative to the recommended safe levels was identified as a significant determinant for all reproductive measures. Higher levels of utilisation were consistently associated with reduced breeder performance. Annual pregnancy rates declining by approximately 10% from low to high relative utilisation. For pregnancy within 4 months, differences from 15 to 30% were observed and for foetal and calf loss, a predicted increase in occurrence of ~2.3% for each incremental step in relative utilisation. These results are consistent with the principle that low pasture utilisation (stocking rate) supports increased dietary selection, diet quality, greater diet quality intake, body condition score and subsequent improved reproductive performance. As pasture utilisation increases, competition for forage intensifies, reducing individual animal performance (Ash et al. 1995; White, 2011; Hunt, McIvor, et al. 2014).

The effect of utilisation was moderated by *Bos indicus* content for all reproductive measures except for foetal and calf loss. Herds classified as having lower levels of *Bos indicus* content demonstrated the most pronounced effect, while herds containing high *Bos indicus* content appearing to be quite resilient. However, as breed composition is also closely aligned with region (Bortolussi *et al.* 2005) and as region is not specified in the model, what appears as a breed-related response may include unmodelled regional differences, such as differences in management, pasture quality, environmental conditions, disease and parasite burden. The reduced performance observed in these

herds may therefore reflect animals already operating close to their physiological limits due to exposure to other stressors, leaving limited scope for further performance gains.

Notably, herds with >75% *Bos indicus* tended to respond when utilisation was below recommended levels, these herds had weaning and pregnancy rates about 10% higher than at higher stocking rates. This supports the concept that a competition response existed even at low utilisation. At low pasture utilisation, pasture quantity is not limiting and due to an increased opportunity to select cattle are able to intake a higher quality diet, leading to production gains. This suggests that high *Bos indicus* content breeder performance was limited by diet quality even when grazing at recommended utilisation, possibly reflecting the poor quality of pasture in regions with high *Bos indicus* content. The study also notes the model did not account directly for body condition score (BCS), which may contribute to these productive differences due to historical management improving BCS prior to the production year.

While this study adds further evidence that increasing pasture utilisation negatively impacts individual reproductive performance, other studies, including bioeconomic modelling in Chapter 7 Page 118, show that paddock-level outputs (e.g. total kilograms of beef produced per hectare) increase with higher pasture utilisation and stocking rates (Ash and Stafford Smith 1996, Hunt et al. 2014). This highlights the trade-off that exists between increasing grazing pressure to increase mob-level or higher production outputs, at the expense of individual animal performance, and possible environmental resilience and productive capacity. The outcomes of this study provide critical evidence base to inform economic evaluations of different utilisation rates, supporting balanced management decisions that account for both productivity and long-term sustainability.

Independent of pasture utilisation, this study demonstrated the critical importance of meeting nutritional requirements during key reproductive periods, particularly around calving. This was evident through several time-specific pasture-related factors identified as major determinants: pasture growth during the previous calving period influenced annual pregnancy; the proportion of green pasture in the 3 months surrounding the expected month of calving affected pregnancy within four months; estimated pasture nitrogen in 3 months surrounding the expected month of calving in the preceding year and early dry-season (April to June) pasture growth in the current year was positively associated with weaning percentage. The positive effects of green proportion of pasture and percent N content of pasture around the time of calving is consistent with improved dietary quality, which meets the high nutritional demand associated with lactation. This consequently reduces the duration of lactational anoestrus, reducing the time to resumption of cycling and pregnancy. Additionally, adequate pasture availability in the early dry season coincides with supporting cows to return to positive energy balance after the first annual muster. For cows that have weaned a calf but have not yet conceived, this improved nutrition supports the maintenance or improved body condition. This positive energy status is a physiological trigger than enables cows to resume ovarian cyclicity, conceive and subsequently be identified as pregnant at the second annual muster.

Furthermore, improved nutrition during this period is likely to have production benefits that extend into the next annual production cycle, allowing cows to present with improved body condition at the pregnancy test muster, and at the time of calving. Additionally, reducing the risk of cow mortality (O'Rourke, Fordyce, et al. 1995a; O'Rourke, Sullivan, et al. 1995b; Fordyce, McCosker, Smith, et al. 2022a). As reported in this section, body condition score recorded at the pregnancy test muster is a strong predictor of reproductive performance and calf survival. These results suggest Northern beef herd managers should ensure that breeding females have access to high-quality pasture at calving

and that sufficient forage is available through the early dry season to support body condition, reproductive performance, and calf survival.

This study derived the Temperature-Humidity Index (THI), Heat Load Index (HLI), and Comprehensive Climate Index (CCI) to quantify heat load, which were summarised to month and cross-referenced to the expected month of calving (Cowan *et al.* 2024). The parameter summarising CCI was identified as the most physiologically informative during the univariate model-building process and was selected for further multivariate analysis. To quantify animal heat load, this metric integrates ambient temperature, humidity, wind speed, and solar radiation into a single index. Despite the growing interest in the production consequences of northern beef herds being routinely exposed to high heat loads in northern Australia, the current study found no association between average daily maximum Comprehensive Climate Index (CCI) and foetal or calf loss. This null result likely reflects a limitation of our dataset's resolution, suggesting that monthly averages are too coarse to capture the acute heat events critical for neonatal survival. It is also possible that the effects of heat stress are indirectly mediated through correlated variables in the calf loss model, such as calving period. Additionally, the model did not account for breed, and given established differences in heat tolerance among breeds, this omission may have contributed to the lack of relationship. These findings highlight the need for future research to incorporate finer-scale heat stress metrics, such as precise birth events—to more accurately assess the influence of heat stress on reproductive performance in extensively managed beef herds.

Foetal and calf loss was 3.9% lower in cows that lactated than those that did not lactate in the previous production cycle. This latter group comprised both cows that failed to conceive and those that conceived but subsequently failed to rear a calf. These findings are remarkably consistent with the 3.6% difference reported by Fordyce *et al.* (2023a). Together, these results suggest that a cow's success in raising a calf in one year may be a lowly repeatable trait and possibly suggests that calf loss has at least a low degree of repeatability within individuals. This repeatability, albeit low, potentially warrants further research to explore the genetic variance and heritability of calf loss and maternal rearing ability.

The inclusion of available soil phosphorus in the final models was based on its well-known importance in relation to fertility and performance of northern Australia beef cattle (Schatz *et al.* 2023). As a useful indicator of pasture nutritive value and a proxy indicator for an animal’s risk of deficiency (Bell and Sangster 2022, Quigley *et al.* 2015). However, our analysis did not identify soil P as a significant predictor overall but observed an overall trend for an increase in efficiency with increasing available soil P. This finding must be interpreted with caution, as our method relied on modelled and mapped soil P data rather than direct measurements of animal phosphorus status. Consequently, the potential response could be confounded by several factors not captured in our model, including the mobilization of bodily P reserves, the heterogeneity of soil types within paddocks which has been shown to compromise some studies (Quigley *et al.* 2015), and phosphorus supplementation that may have occurred in certain herds where it wasn’t recorded. These limitations likely introduced noise, obscuring a clear signal and highlighting the complexity of quantifying phosphorus' specific contribution within extensive grazing systems.

Mating management was determined as a significant predictor of percent pregnant within four months, with 9% higher occurrence in controlled management groups. In contrast, it had no bearing on either annual pregnancy or weaning rate. While this factor describes bull management practices, the reported response may include herd management or regional differences not elsewhere represented in the model.

6.4 Conclusion

This study provides clear evidence that pasture utilisation, nutritional availability, and management practices are key determinants of reproductive performance in northern Australian beef herds. High relative pasture utilisation consistently reduced individual animal reproductive outcomes. These effects are likely to be more pronounced in herds located in environments or management systems associated with higher production potential. Independent of utilisation, access to high-quality pasture at calving and adequate forage in the early dry season was critical for supporting body condition, improving pregnancy rates, and enhancing weaning success.

Collectively, these findings underscore the importance of integrating pasture management, nutritional support, and targeted reproductive management to optimise productivity and herd sustainability in northern beef systems.

7. Bioeconomic analysis of the impacts of pasture utilisation on breeder performance, production and profit

A bioeconomic modelling (BEM) framework was used to quantify the outcomes of a range of pasture utilisation rates on land condition, breeder herd production and finances for two breeding enterprises, one typical of the Burdekin region of North East Queensland, and the other typical of the Barkly Tablelands of the Northern Territory. The BEM framework included the GRASP pasture and animal production model (McKeon *et al.* 2000, Rickert *et al.* 2000) and the Crop Livestock Enterprise Model (CLEM, https://www.apsim.info/clem).

Pasture utilisation can influence animal production in the short-term as the season's growth is consumed (White 2011), and in the long-term through feedbacks on pasture composition and land condition (Ash *et al.* 1995). Hence, the utilisation by livestock has both short- and long-term impacts on the quality and quantity of pastures (McIvor *et al.* 1995a, Ash and McIvor 1995). The bioeconomic analysis here aims to include both the short- and long-term impacts of pasture utilisation on pasture quantity and quality, and how that flows through to animal growth, fertility and mortality which determine the performance of a breeding herd. Additionally, the impact of pasture utilisation on finances are assessed at the enterprise scale.

The methods used in the bioeconomic modelling are described below, commencing with GRASP and followed by CLEM.

7.1 GRASP Methodology

The GRASP pasture growth model was used externally to CLEM to generate pasture growth. The GRASP pasture growth output was then imported into CLEM for the bioeconomic modelling.

7.1.1 GRASP pasture and animal growth model

The GRASP model was used to simulate monthly pasture growth for all possible land condition by grass basal area by stocking rate combinations over the entire climate record for each location. The GRASP generated monthly production data was imported into the CLEM model. Each year CLEM selected the relevant monthly pasture growth output based on stocking rate, grass basal area and land condition. CLEM calculated monthly diet quality and quantity based on available forage pools and specified rates of forage quality decline. The calculated available forage was used to drive animal intake and growth, which in turn influenced herd fertility, mortality, age to turnoff etc. At the end of each year, CLEM calculated the pasture utilisation rate and used this to determine the following years land condition and grass basal area. The monthly pasture growth used for the following year was that for the new combination of land condition, grass basal area and stocking rate. If land condition and grass basal area declined due to pasture utilisation, then so did the potential pasture growth and hence the availability of forage. Conversely, if pasture utilisation was below safe levels and pasture condition and grass basal area improved, so did potential pasture growth.

Intake

Feed intake and quality of diet are critical determinants of animal growth. Animal intake can be physically restricted by the rate at which animals can harvest forage e.g. on very short or sparse swards or on tall stemmy swards (O'Reagain *et al.* 1996). On tropical pastures, intake of ruminants can also be restricted by quality which can limit digestion rate and hence the rate of throughput

through the rumen. When crude protein is below eight percent (equivalent to approximately 1.28% N), rumen bacteria responsible for digesting forage cannot maintain adequate growth rates (Parish and Rhinehart 2008). Forage intake and digestibility will then decrease.

Published requirements for dietary protein relative to different growth rates in cattle have generally been derived for British or European cattle grazing temperate pastures. There is a lot of evidence indicating that the protein requirements of Brahman cattle and the various Brahman-derived breeds are less than the currently recommended requirements (Coates and Jackson 2006).

The influence of forage quality on animal growth is indirectly simulated in GRASP. The overriding seasonal effect on diet quality is captured by using potential live weight for each season (91 days) to determine potential animal intake (McKeon and Rickert 1984). Potential intake can be reduced under two possible circumstances. First, intake restriction can occur when there is reduced opportunity for diet selection with increased stocking rate or long durations of grazing e.g., year-round (McKeon and Rickert 1984). Secondly, intake can be reduced when total standing dry matter declines to a minimum threshold.

However, for this bioeconomic modelling, the GRASP parameters used did not restrict intake. Rather, GRASP settings for intake parameters (parameters 145-148) and subroutines were parameterised so that cattle ate 8 kg/AE/day for a 'medium productivity zone' resulting in long-term average annual steer growth of 110-150 kg/year (Figure 7-1, Bath *et al.* 2021; McLennan *et al.* 2020). Intake restrictions were instead simulated in CLEM, which adjusted intake based on monthly diet quality and quantity. GRASP simulations were set for a non-growing (the animal model p120 was set to 0) 450 kg cross-bred *Bos indicus* adult equivalent animal.

Detachment & trampling rates

Detachment rates often vary throughout the year, with rates of 0.005 g/g/day for summer/wet season and 0.0002 g/g/day for winter/dry season (G. McKeon *pers. comm*.). Cowley (2017), in her review of data from Northern Territory grazing trials and pasture growth (SWIFTSYND) exclosures, found dry season losses to detachment and trampling varied greatly between sites and years, with some of this variation explained by the proportion of forbs and annual grasses in the sward. Results from this study revealed a median detachment of 0.0014 g/g/day, equivalent to a monthly proportional loss of 0.042, across all grazing trials in the Barkly and VRD (Table 7-1). In Cowley's study, detachment rates of SWIFTSYND sites and grazing trials were similar, despite trampling effects in grazed paddocks that were absent in exclosed areas (Table 7-2). Cowley (2017) suggests the additional detachment due to trampling in grazed areas is possibly offset by removal of some of the more highly detachable components of the sward (palatable annual grasses and forbs) by grazing.

Detachment rates for each site were based on locally calibrated/expert derived rates for the relevant land types. Detachment in GRASP only influences growth indirectly through its effect on ground cover and hence runoff. Growth (not TSDM) was imported to CLEM and detachment was separately modelled in CLEM.

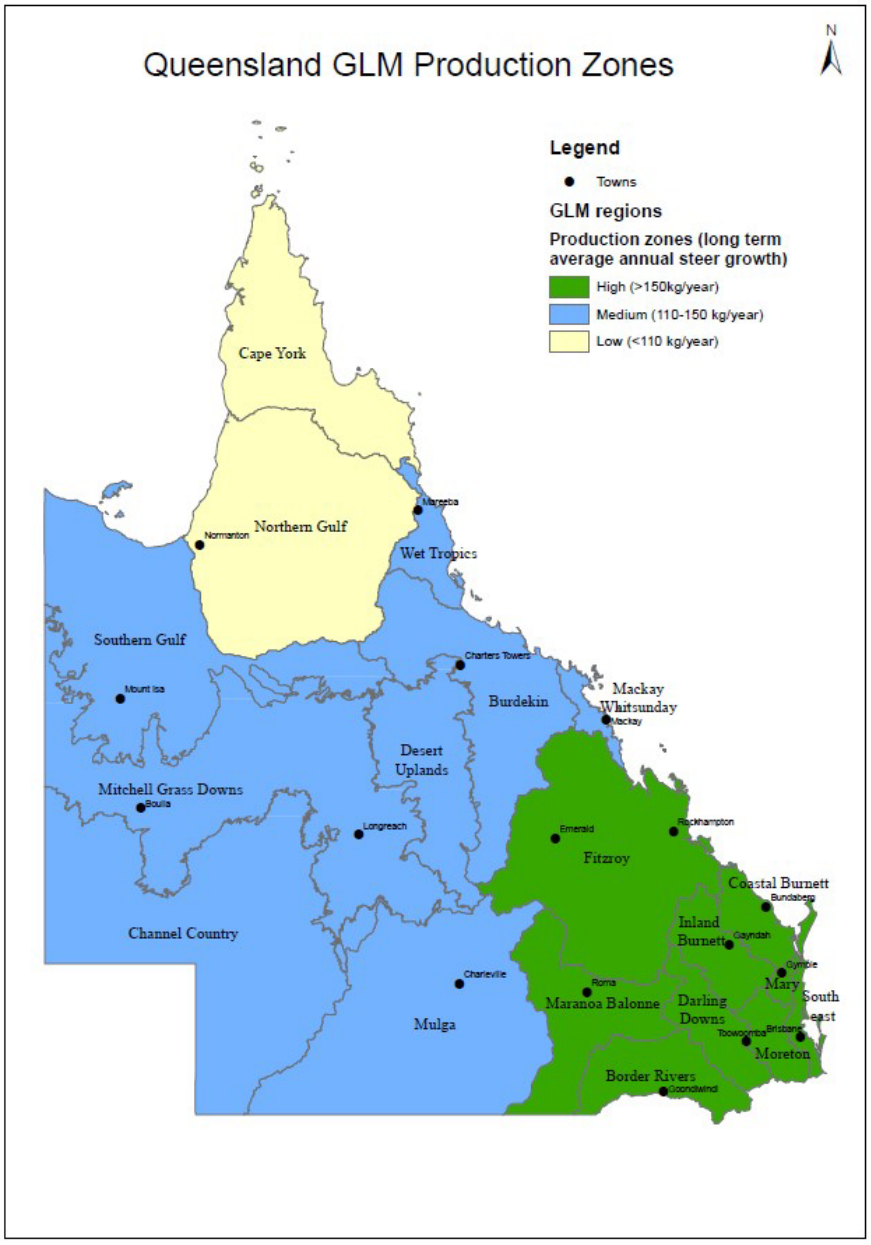


Figure 7-1: Production zones based on long-term average annual steer growth for Queensland grazing lands from Bath *et al.* 2021

Table 7-1: Average and range in dry season detachment rates across all grazing trials in the Barkly and VRD, from Cowley (2017)

	g/g/day lost n=136	3mth loss to detachment and trampling	6mth loss to detachment and trampling	12mth loss to detachment and trampling
Mean	0.0015	13%	24%	42%
Median	0.0014	12%	22%	40%
Minimum	0.0001	1%	2%	4%
Maximum	0.0050	36%	60%	84%

Table 7-2: Average and range in dry season detachment rates across all SWIFTSYND sites in the Barky and VRD, from Cowley (2017)

	g/g/day lost n=54	3mth loss to detachment and trampling	6mth loss to detachment and trampling	12mth loss to detachment and trampling
Mean	0.0021	17%	32%	54%
Median	0.0020	16%	30%	52%
Minimum	0.0001	1%	2%	4%
Maximum	0.0053	38%	62%	86%

Pasture degradation and recovery

Grazing pressure that is too high can influence pasture production by:

- reducing grass basal area
- reduction in photosynthetic area which reduces future pasture growth
- loss of perennial species and replacement by annuals with less production and faster senescence
- increased runoff due to reduced surface cover and fewer high infiltration sites e.g. areas occupied by perennial tussocks.

The productivity of native pastures in northern Australia declines with declining pasture condition (McIvor *et al.* 1995a). In GRASP, the percentage of perennial grasses is a non-linear function of pasture 'state' with pristine land at State 0 having 90% perennial grasses and degraded land at State 11 having 1% perennial grasses (Table 7-3, from Scanlan *et al.* 2014).

Table 7-3: Relationship between conceptual simulated condition state, % perennial grasses and land condition from Scanlan *et al.* (2014)

Condition state	% perennial grasses	ABCD Condition
0	90	A
1	88	A
2	84	A
3	70	B
4	50	B
5	32	B
6	20	C
7	15	C
8	10	C
9	5	D
10	2	D
11	1	D

There is a dynamic link between land condition and parameters that drive pasture growth in the GRASP model. When the pasture degradation sub-model is activated, a subset of GRASP parameters are adjusted based on pasture condition. In GRASP p180 was set to 4, so that the specified land condition (p194) and the associated adjusted parameters values were held constant for each run. The base parameter set for the land type is assumed to be the potential growth in A condition for that land type. The value of those parameters at the lowest pasture condition is also set in GRASP.

GRASP recalculates the value of the following parameters based on assigned / simulated pasture condition:

- p99 Maximum potential nitrogen uptake
- p56 Growth index for green days
- p9 Soil water index for maximum green cover
- Pasture structure
    - p45 & p46 green yield when green cover is 50%
    - p96 Height at 1000 kg/ha
- Potential nitrogen dilution in pastures
    - p101 %N at zero growth
    - p102 %N at maximum growth
- Detachment p128-p131 for leaf and stem in the wet and dry season

Grass basal area also influences pasture growth in GRASP by driving initial pasture regrowth rates and varies with rainfall and pasture utilisation. GRASP was simulated for the full range of grass basal area relevant to the land types of the representative properties in each region.

CEDAR GRASP (version 030420) with the CEDAR default parameter file (cedardefault_v_2_1_02) was run for all combinations of 12 pasture condition states, by all relevant stocking rates, all relevant grass basal areas and years.

7.1.2 Barkly-specific GRASP parameters

The Barkly station was assumed to be predominantly the Barkly land type, naturally treeless alluvial vertosol plains dominated by Mitchell grass (*Astrebla* species). The parameter set was based upon the East Ranken calibrated parameter set (Cowley and Walsh 2023).

Intake

The GRASP parameter that influences intake restrictions p143 was set to be unlimiting to intake in the pasture growth simulations as this is modelled in CLEM, and yield at which intake is restricted was set to 50 kg/ha (p144 and p214) for A condition pastures, although this increased to 300 kg/ha as land condition declined.

Detachment & trampling rates

Detachment rates can vary considerably between sites and years due to varying species composition. Average dry season detachment rates for four ungrazed Barkly land type SWIFTSYND sites was 0.003 g/g/day, and at the grazed Rockhampton Downs rotational waters trial on the Barkly land type, it was 0.0012 g/g/day (Cowley unpublished data). The Barkly land type detachment for GRASP was set at 0.002 g/g/day over the growing season and 0.0025 g/g/day over the dry season, and trampling was set at 0.75, as was calibrated for the grazed 700 km^2 East Ranken paddock (Cowley and Walsh 2023).

7.1.3 Barkly GRASP simulations

Brunette Downs climate was used as it is centrally located in the Barkly and is relevant to the land types typically found across the southern and central Barkly. For the simulation period 1977 to 2023, average annual rainfall was 462 mm, with a standard deviation of 204 mm and a coefficient of variation of 44%. Monthly pasture growth data for use in CLEM was simulated in GRASP for the

Barkly Mitchell grass land type, with a tree cover of 0 TBA m^2/ha, using an interpolated daily climate file downloaded from SILO https://www.longpaddock.qld.gov.au/silo/point-data/ for Brunette Downs (-18.64, 135.94 climate station 15085). Pasture growth was simulated for a range of land condition states (0-11), grass basal areas (1 to 5%) and stocking rates (0 to 30 AE/km^2). This created 1860 simulations of 132 years of pasture growth or 245,520 annual outputs (Table 7-4). The long-term, safe carrying capacity in A condition was 11 AE/km^2.

Table 7-4: Long-term (132 years) GRASP simulated average financial year pasture growth, June 30 TSDM and pasture utilisation for the Barkly land type using Brunette Downs climate for different land condition and grass basal area stocking rate = 6 AE/km^2

Land condition		Growth (kg/ha)	TSDM (kg/ha)	Pasture Utilisation (%)
A (p194=0, GBA=4)	Mean	1596	1908	19
	Median	1585	1860	11
B (p194=3, GBA=2)	Mean	1075	1510	42
	Median	866	1282	20
C (p194=6, GBA=1)	Mean	588	437	74
	Median	408	247	27

7.1.4 Burdekin-specific GRASP parameters

A review of the Land types of Queensland for the Burdekin GLM region (State of Queensland 2022) was undertaken to select a land type and associated GRASP parameters that aligned with the property as described by Bowen *et al.* (2023). Narrow-leaved ironbark on deeper soils (BD14) land type (State of Queensland 2022) which occurs in the Burdekin Rangelands is a *Eucalypt* dominated woodland and has an estimated long-term carry capacity of ~9 ha/AE or 11 AE/km^2in A condition, similar to that described by Bowen *et al.* (2023).

To align with the Bowen *et al.* (2023) property carrying 2500 AE in B condition, a tree cover of 3.7 TBA m^2/ha for narrow-leaved ironbark woodlands for Hillgrove climate location (Rogers *et al.* 1999) was adjusted to 3.5 TBA m^2/ha for GRASP simulations.

Intake

For the Burdekin herd, seasonal intake parameters, based on Sweet Spot Thalanga paddocks located approximately 200 km south of Hillgrove, were set to give an average daily intake of 8 kg/AE/day to align broadly with the Moderate Productivity zone. Additionally, GRASP parameters that restrict intake were set to unlimited (P143=0) while yield at which intake was restricted was set to 50 kg/ha (p144 and p214) for A condition pastures in the pasture growth simulations.

Detachment & trampling rates

Detachment rates from the Narrow-leaved ironbark land type parameters, Spyglass Research Station SWIFTSYND sites located approximately 40 km south of Hillgrove and three Sweet Spot calibrated Thalanga paddocks, were used to estimate detachment rates for the GRASP simulations. The Narrow-leaved ironbark land type detachment for the GRASP simulations was set at 0.005 g/g/day over the growing season and 0.001g/g/day over the dry season, and trampling was set at 0.75.

7.1.5 Burdekin GRASP simulations

GRASP simulations of Narrow-leaved ironbark woodlands on deeper soils pastures with tree cover of 3.5 TBA m^2/ha (9.0% Foliage Projective Cover, FPC) using historic interpolated daily climate files

downloaded from SILO https://www.longpaddock.qld.gov.au/silo/point-data/ for Hillgrove (-19.68 latitude, 145.79 longitude 30137 climate station) were run to derive monthly pasture growth data for use in CLEM. For the simulation period 1978 to 2022, average annual rainfall was 588 mm, with a standard deviation of 243 mm and a coefficient of variation of 41%. Pasture growth was simulated for a range of land condition states (0-11), grass basal areas (1 to 9%) and stocking rates (1 to 50 AE/100ha).

The long-term (131 years) average pasture growth (1701-825 kg/ha), TSDM (1938-543 kg/ha) and pasture utilisation (21.8-44.7) for Narrow-leaved ironbark on deeper soils land type, for a range of land conditions (A to C), 3.5 TBA m^2/ha, 5% grass basal area and stocking rate of 10 AE/100ha are shown in Table 7-5.

Table 7-5: Long-term (131 years) GRASP simulated average financial year pasture growth, June 30 TSDM, % perennial grasses and pasture utilisation for the Burdekin narrow-leaved ironbark land type using Hillgrove climate for A (194=0), B (194=3&5) and C (194=6) land condition, grass basal area =5%, stocking rate = 10 AE//km^2

Land condition	Growth (kg/ha)	TSDM (kg/ha)	Perennial grasses (%)	Pasture Utilisation (%)
A (194=0)	1701	1938	90	21.8
B (194=3)	1444	1419	71	25.8
B (194=5)	995	741	34	37.9
C (194=6)	825	543	19	44.7

7.2 CLEM Methodology

7.2.1 CLEM parameters

CLEM is a whole-of-property enterprise model that can test a range of property improvement strategies in both crop and livestock systems (CLEM Overview: https://www.apsim.info/clem/Content/Details/Overview.htm). To achieve this, CLEM expands upon the approaches used by its precursors, the Integrated Analysis Tool (IAT) and NABSA (Northern Australian Beef Systems Analyser, Ash *et al.* 2015).

The CLEM model is provided within the APSIM NG (Agricultural Production Systems sIMulator Next Generation) framework (Holzworth *et al.* 2018). The APSIM NG user interface consists of a tree structure that contains the model components needed for simulations, with CLEM providing a suite of additional components (Meier *et al.* 2019). In CLEM, resources are the assets available for use on the property and can include land, labour, crops, forage resources, livestock and cash. Ruminant nutrition and growth are based on the Nutrient Requirements of Domesticated Ruminants (Freer *et al.* 2007). CLEM includes an individual animal-based ruminant herd model which operates on a monthly time step. Data files containing crop and forage yields derived from other simulation activities can be used as input to CLEM. In this study, forage input was from GRASP.

CLEM has three main components; *Resources*, *Activities* and *Reports* (Figure 7-2). *Resources*, such as land, forage, labour and supplements, are used by *Activities*, such as an initial herd in which cows produce calves and animals grow, and then a wide range of outputs are reported in table formats (About CLEM in the online users guide: https://www.apsim.info/clem/Content/Details/About.htm). CLEM is fundamentally a simulation model that tracks farm *Resources* as they are affected by a range of farm *Activities*. *Resources*, or proportions of resources chosen using filters, are used by *Activities*

which can also be applied to specific cohorts of animals using filters and at specific times using timers. Tables containing the results relating to the use of resources and the outcomes of herd management can then be exported into Excel spreadsheets or other databases for collation and analysis.

The CLEM model is under continuous development and many versions of it have been developed over the period of time that bioeconomic modelling was undertaken for the Sweet Spot project. Simulations of the Barkly Tablelands herds were undertaken in November 2023, using the CLEM version 2023.7.7283.0. The same version of CLEM was used for the initial simulations of the Burdekin catchment herds, but then models were revised using the CLEM version 2024.5.7471.0.

In this project, the CLEM output database file from each simulation often exceeded the size limitations of Excel, and consequently, results were accessed through Open Database Connectivity (ODBC). Power Pivot Tables which were used to calculate a wide range of land, herd and financial performance metrics linked to ODBC.

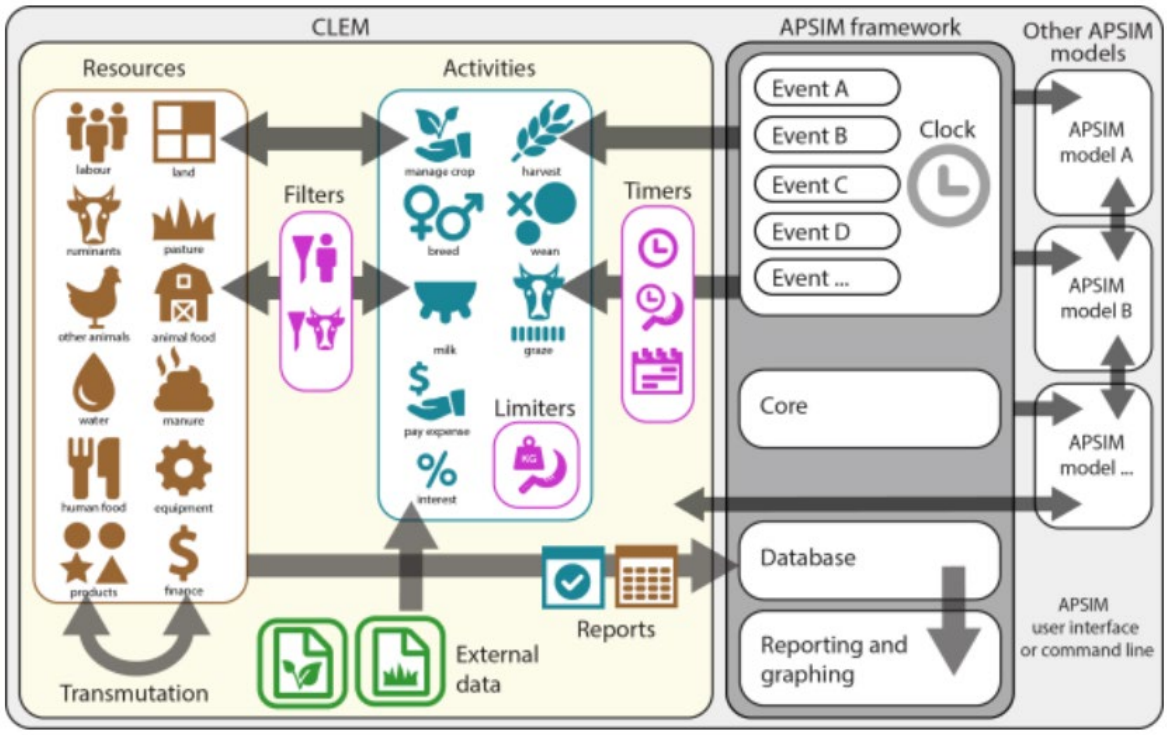


Figure 7-2: Diagram of the components within CLEM and interactions between them, and relationships between CLEM, the APSIM framework and databases

The CLEM interface resembles a computer directory which contains folders and sub-folders. The folders are organized in a manner that resembles a tree, with the terms parent and child used to describe the relationships within and between folders. As noted in *About CLEM* in the online users guide (https://www.apsim.info/clem/Content/Details/About.htm), the general tree structure (Figure 7-3) provides the minimum APSIM Next Generation and CLEM model components required to set up a CLEM simulation. The Clock near the top of this simulation tree is used to define the range of years for the simulation period.

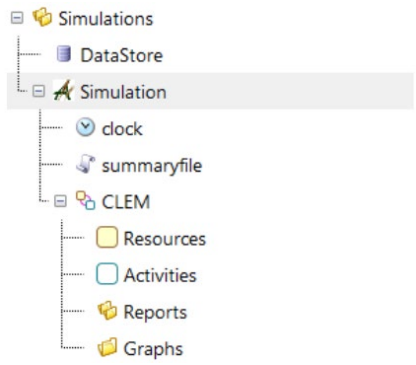


Figure 7-3: Diagram of the main components of CLEM

The tree above can then be expanded to accommodate the *Resources*, *Activities* and *Reports* needed for particular simulations. An example of one of the Burdekin property simulation trees used in this project is shown in Figure 7-4. The folder called FileSQLitePasture, near the top of this tree, identifies the database file that CLEM accesses for quantities of monthly pasture growth simulated by GRASP.

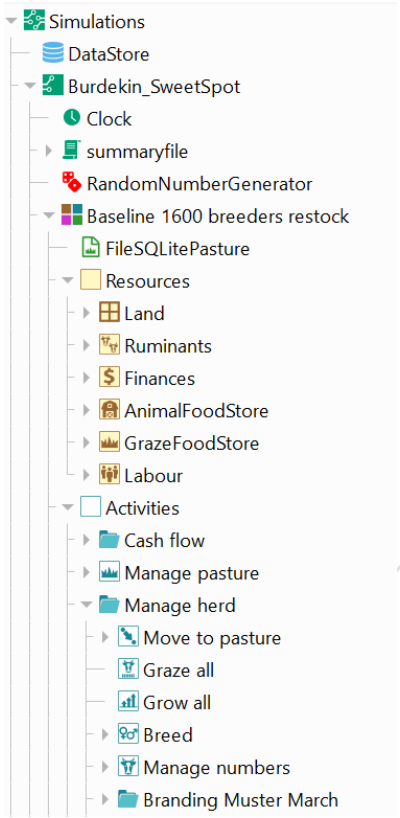


Figure 7-4: Part of the tree structure used for the Burdekin property simulations, showing resources available and some of the activities

Parts of this tree can then be expanded to accommodate specific resources, with the amounts needed and their prices. Below (Figure 7-5) is an expansion of the *Resources* component from above, which shows more information about individual resources.

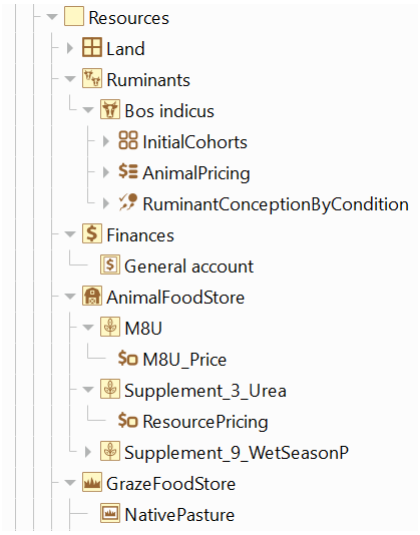


Figure 7-5: Folders within the Resources component expanded to show more detail about the types of resources available

Each of the sub-folders can be expanded further to show and enable parameterisation of specific resources. For the simulations undertaken for this project, for rangeland properties in the Burdekin and Barkly Tableland regions, the *GrazeFoodStore* folder is vitally important (Figure 7-6). It possesses parameters which reflect the quality of the pasture available to the herd. Parameters such as the percent nitrogen of new growth and the minimum percent digestibility of dry matter have a large impact on the performance of individual animals and the whole herd. In addition to native pastures, the Animal Food Store contains feeds that can also be fed to classes of animals at particular times. Dry season urea and wet season phosphorous were regularly fed to all classes of cattle at both Barkly and Burdekin properties, and M8U and browse was fed during droughts when forage yield dropped below 300 kg/ha at the Burdekin property only.

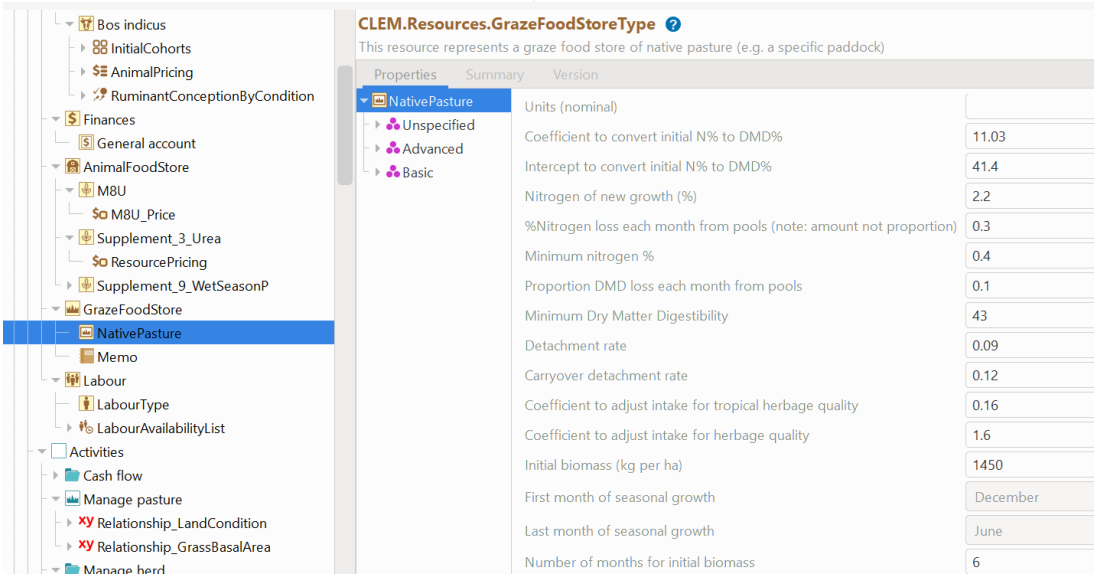


Figure 7-6: Parameters used to characterise the quality of native pasture available to cattle of the Burdekin herd

Ruminants is also an important folder for CELM simulations (Figure 7-7). It contains a large number of parameters associated with energy requirements, live weights, body conditions scores, growth,

mortality rates, food intake and reproduction. Another subfolder also contains the numbers, ages and live weights of the initial cohorts at the beginning of the simulation period. Similarly, purchase and sale prices were set for each cohort.

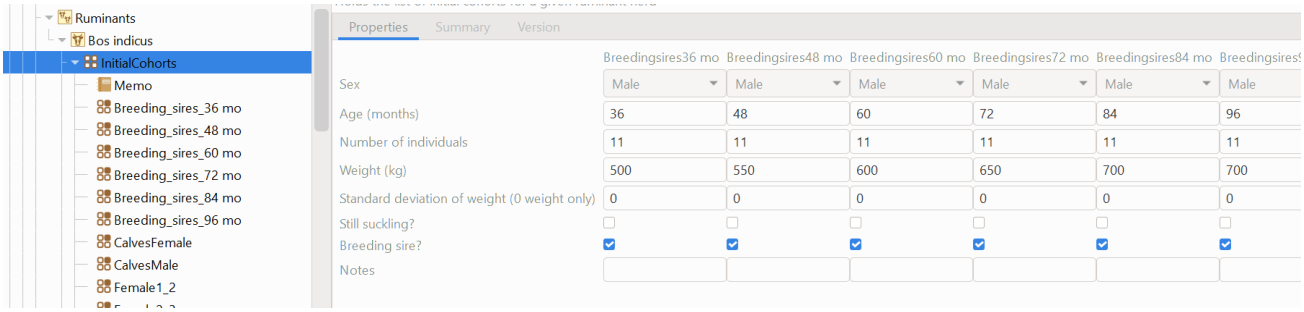


Figure 7-7: A part of the table used in CLEM to set the numbers and weights of the initial cohorts of cattle

The *Activities* parts of the simulation tree contain the management actions which will be applied to the herd. An example of components of the *Activities* used in simulations for this milestone report are shown in Figure 7-8.

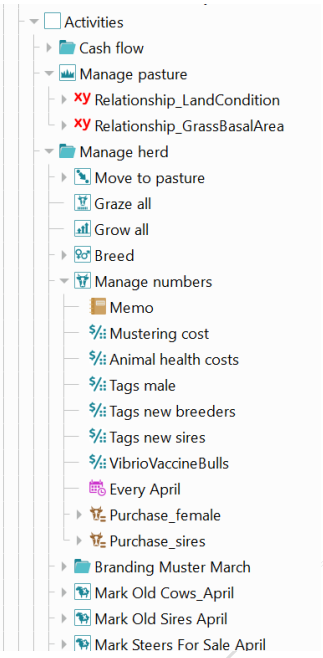


Figure 7-8: A copy of several components within the Activities section of the simulations for the Burdekin herd

Each of these activities and sub-activities hold all the parameters needed to set up and perform the activity. Of these, *Manage Herd* is a major component of herd simulations. It includes fundamental activities such as move to pasture, graze, grow and breed, and annual operations such as muster, brand, wean and identify and sell or buy particular classes of animals. For example, Figure 7-9 shows expanded components of a branding muster, mark old cows for sale and mark steers for sale. The folders include timers for when activities occur, and filters to apply them to particular groups of animals.

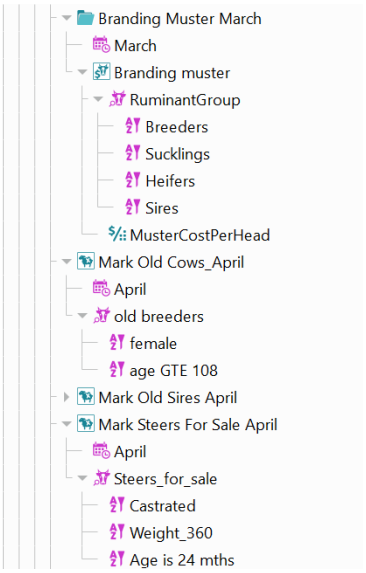


Figure 7-9: Copy of some of the ruminant groups, timers and filters used for management practices such as branding and marking cohorts for sale

Manage Numbers is one of the important components of *Manage Herd*, as it contains parameters needed to set up and manage the desired herd size, its composition and whether young males and females will be grown out to meet the requirements of a specific market for age and weight. As shown in Figure 7-10, there are many parameters within *Manage Numbers* which can be enabled for the purposes of automatically stocking (purchases) and destocking (sales), and for determining if weaner males and females will be kept and grown out to particular ages and weights. These management rules are applied every year.

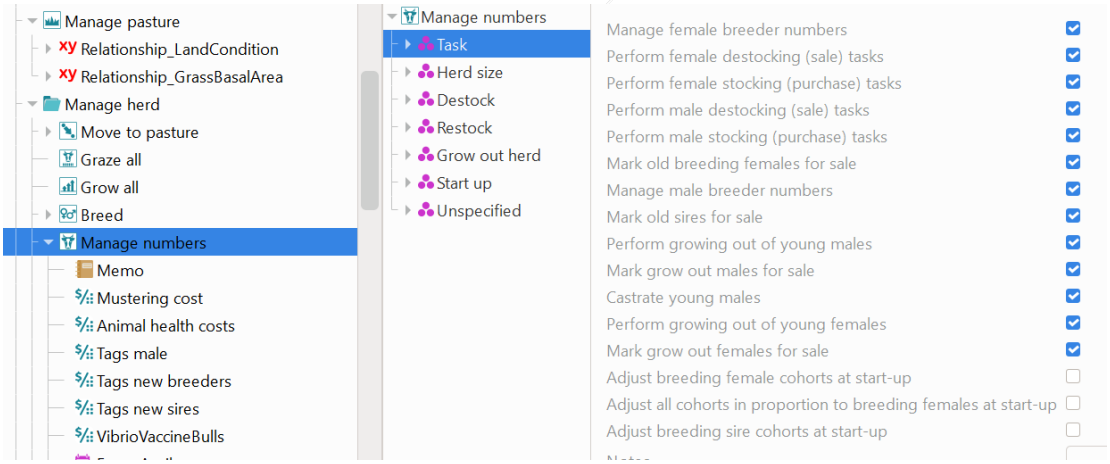


Figure 7-10: Parameters within Manage Numbers, which when enabled, will adjust the size of several cohorts of cattle

In this project, the automated management functions contained within Manage Numbers at the top right-hand side of Figure 7-10 above, such as manage female and male breeder numbers, and perform male and female destocking and stocking, were disabled. Instead, these functions were performed manually by adding folders under Manage Herd. This provided additional flexibility in how the herd was managed in response to climate variability. This enabled different proportions of female and male cohorts to be sold or purchased prior to, during and after droughts.

In this project, the only animals purchased were three-year old bulls and two-year old heifers. Bulls were purchased every year, but young cows were only purchased in simulations where the breeder herd had declined to very low numbers, as a means of quickly restoring breeder herd size when climatic conditions improved after droughts.

CLEM is a dynamic model, and as such, herds are not kept at a particular size. Instead, over time, in response to forage availability and quality, and a number of management actions, annual herd size and composition changes markedly.

CLEM pasture parameters

The GRASP data cube imported to CLEM contained the following inputs:

- Grass basal area
- Land condition
- Stocking rate
- Year
- Month
- Rainfall
- Pasture growth

Although TSDM and %N are simulated in GRASP, they are not used in CLEM, rather TSDM and diet quality are calculated in CLEM based on available forage pools, and specified CLEM pasture detachment and quality parameters.

Pasture degradation parameters are also specified in CLEM to allow for the selection of next year's pasture growth.

Detachment

Two detachment rates are required in CLEM: one for the pasture pool less than 12 months old and one for pools greater than 12 months (carry over detachment rate). Rates of detachment were calculated based on the relevant GRASP land type detachment rates.

Pasture quality and degradation

Feed intake and quality of diet are critical determinants of animal growth, with dry matter intake and live weight gain positively correlated with dry matter digestibility (DMD). Forage quality, detachment, and change in land condition and grass basal area parameter values were provided for use in CLEM.

In CLEM, pasture is divided into pools which decay in quality (% nitrogen and % dry matter digestibility) and biomass through detachment each month. It was difficult to find relevant sward level % DMD, but % N was available from SWIFTSYND sites. Diet quality, as measured through faecal NIRS, was available for the regions modelled, but this is higher than sward pasture diet quality due to animal selection.

7.2.2 Barkly CLEM pasture parameters

Detachment

The East Ranken (Cowley and Walsh 2023) and another fifteen Sweet Spot sites had trampling set at 0.75 and an average of 0.88, which means 0.25-0.12 was lost to trampling. Over 12 months, trampling would equal 0.02-0.01 lost per month.

The average dry season detachment of Rockhampton Downs and Newcastle Waters grazing trials was 0.0026 g/g/day (Cowley 2017), which is similar to the average detachment rates of the Barkly Sweet Spot sites 0.0024 g/g/day (Table 7-6).

CLEM detachment parameters were based on the detachment rate of the Barkly land type. The CLEM detachment rate for the Barkly scenario was set at 0.058 and the carryover detachment rate was set at 0.086.

Table 7-6: Detachment rates from different sources and equivalent detachment rates for CLEM in the Barkly

GRASP parameter	Parameter description	GRASP Default	East Ranken Calibrated	Average of 15 Sweet Spot sites	Barkly land type SWIFTSYND sites
128	Prop of Dead leaf detached per day from 1 Dec to 30 April	0.002	0.0025	0.0025	0.003 - 0.02
129	Prop of Dead stem detached per day from 1 Dec to 30 April	0.002	0.0025	0.0025	0.003 - 0.02
130	Prop of Dead leaf detached per day from 1 May to 30 November	0.002	0.002	0.0024	0.001 - 0.004
131	Prop of Dead stem detached per day from 1 May to 30 November	0.002	0.002	0.0024	0.001 - 0.004
	Average g/g/day	0.002	0.00225	0.0024	0.0025 – 0.011
	Monthly proportion	0.06	0.065	0.07	0.072-0.28
	Additional monthly lost to trampling	na	0.021	0.01	na
	Total monthly lost		0.086	0.08	

Pasture quality and degradation

Safe utilisation of annual pasture growth for the Barkly Mitchell grass land type is 20% (Walsh and Cowley 2011), similar to 20-22% for Queensland Mitchell grass (Hunt 2008, State of Queensland 2022). Degradation parameters were based on values used to simulate anecdotal long-term land condition change with infrastructure development at Station 1 (p628 & 629, Walsh and Cowley 2016), but adjusted so that the maximum extents of recovery and degradation at the lowest and highest URs respectively were the same (±0.6 land condition state, on a scale of 0-11 where 0 is A condition and 11 is D condition Table 7-7). The annual step change in land condition at the safe level of utilisation of 20% is 0. At 5% above and below the safe level of utilisation (15 and 25% utilisation) the step change was ±0.15 per annum.

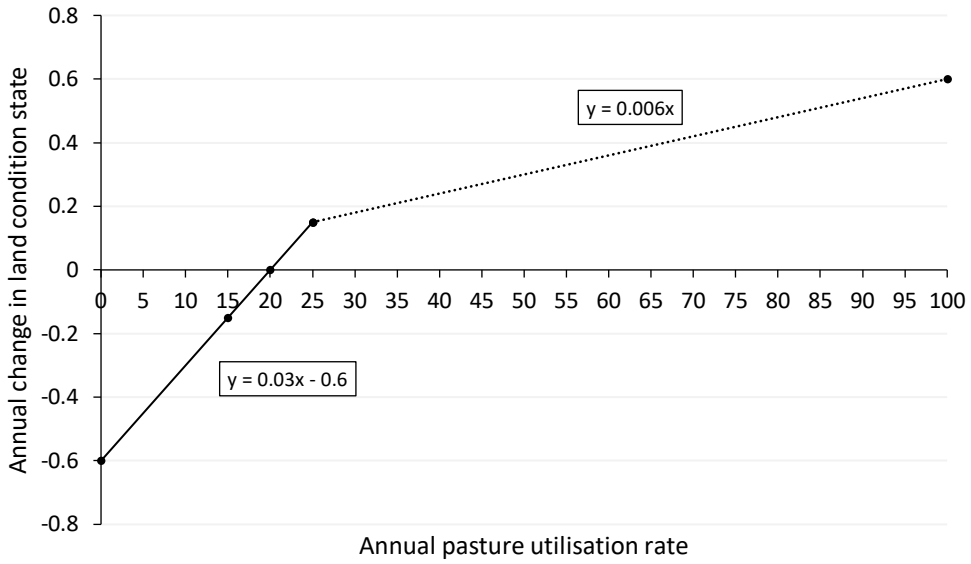


Figure 7-11: Annual change in land condition state in response to the relationship between land condition and pasture utilisation rate parameters shown in Table 7-7. Note that a positive value represents land condition decline and a negative value represents land condition recovery

This translates to the following annual change in % perennials with varying pasture utilisation (Figure 7-12). With no grazing the percent perennial grasses increase by 5.5% in 1 year, whereas with 100% utilisation, the percent perennials decrease by 5.5% in one year.

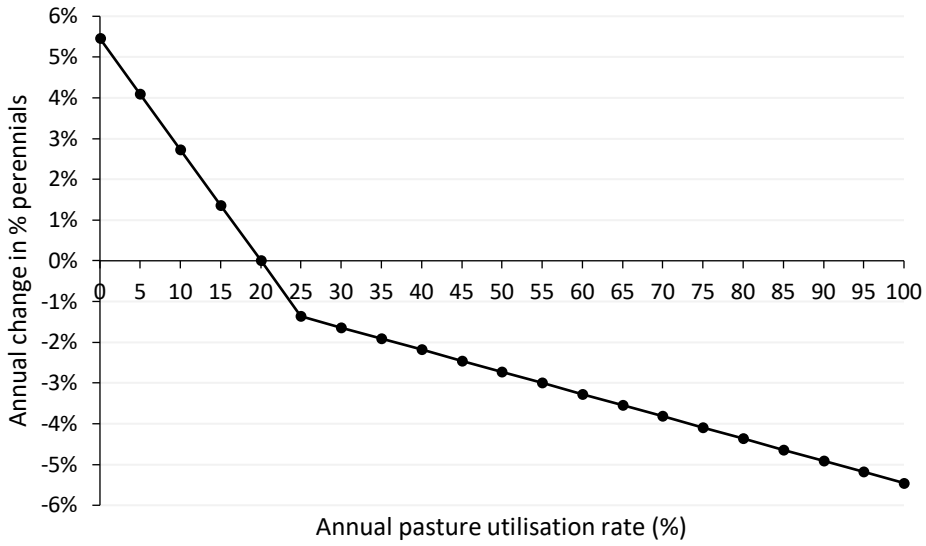


Figure 7-12: Annual change in percent perennials with varying pasture utilisation rates in the Barky simulations

All CLEM pasture quality and degradation parameters for the Barkly region are listed in Table 7-7.

Table 7-7: CLEM pasture, land condition and grass basal area parameter values determined for the Barkly beef grazing enterprise

CLEM Parameters	Native pastures
FORAGE QUALITY	

Units (nominal)	
Coefficient to convert initial N% to DMD%	11.03
Intercept to convert initial N% to DMD%	41.4
Crude protein denominator to convert initial N% to DMD%	0
Nitrogen of new growth (%)	2.1
%Nitrogen loss each month from pools (amount)	0.28
Minimum nitrogen %	0.58
Proportion DMD loss each month from pools	0.043
Minimum Dry Matter Digestibility	52
Detachment rate	0.08
Carry over detachment	0.1
Coefficient to adjust intake for tropical herbage quality	0.16
Coefficient to adjust intake for herbage quality	1.6
Initial biomass kg/ha	1400
LAND CONDITION	
X values of relationship	0, 15, 20, 25, 100
Y values of relationship	-0.6, -0.15, 0, 0.15, 0.6
Method for solving relationship	Interpolation
Name of the x variable	Percentage Utilisation
Name of the y variable	Change in Land Condition
Initial running value	3
Minimum running value possible	2
Maximum running value possible	9
GRASS BASAL AREA	
X values of relationship	0, 15, 20, 25, 100
Y values of relationship	1, 0.25, 0, -0.1, -1.5
Method for solving relationship	Interpolation
Name of the x variable	Percentage Utilisation
Name of the y variable	Change in Grass Basal Area
Initial running value	3
Minimum running value possible	1
Maximum running value possible	4

7.2.3 Burdekin CLEM pasture parameters

Detachment

The average dry season detachment rates of Sweet Spot Thalanga sites (0.0015-0.003 g/g/day) were similar to those of the narrow-leaved ironbark land type parameter (0.004 g/g/day) (Table 7-8).

Additionally, the proportion of pasture available to stock was set in GRASP at 0.75, hence pasture lost to trampling over 12 months was approximately 0.02 per month. However, there is little grazing trial data in the Burdekin to enable separation of detachment and trampling effect.

Total monthly proportion of pasture loss due to trampling and detachment was based on the detachment rate of the Thalanga Sweet Spot site and estimated to be 0.09. Carryover detachment rate was set at 0.12 (Table 7-8).

Table 7-8: Seasonal detachment rate GRASP parameter values for GRASP default parameter file, narrow-leaved ironbark land type, Spyglass SWIFTSYND sites, and three calibrated Thalanga paddocks (Dingo, JSW and Tom's), average daily rate and monthly detachment and trampling loss for CLEM in the Burdekin

GRASP parameter	Parameter description	GRASP Default	Land type	SWIFTSYND	Thalanga Dingo	Thalanga JSW	Thalanga Toms
128	Prop of Dead leaf detached per day from 1 Dec to 30 April	0.002	0.006	0.001 or 0.002	0.003	0.002	0.005
129	Prop of Dead stem detached per day from 1 Dec to 30 April	0.002	0.006	0.001 or 0.002	0.003	0.002	0.005
130	Prop of Dead leaf detached per day from 1 May to 30 November	0.002	0.002	0.001 or 0.002	0.001	0.001	0.001
131	Prop of Dead stem detached per day from 1 May to 30 November	0.002	0.002	0.001 or 0.002	0.001	0.001	0.001
	Average g/g/day	0.002	0.004	0.0015	0.002	0.0015	0.003
	Total monthly proportion lost	0.06	0.12	0.045	0.06	0.045	0.09

Pasture quality and degradation

A review of pasture, leaf, diet and faecal near infrared reflectance spectroscopy (NIRS) studies (Jones 1997, Benvenutti *et al.* 2011, Coates and Dixon 2008), and % nitrogen and faecal NIRS data from SWIFTSYND and Wambiana and Swans Lagoon grazing trails in north-east Queensland, provided the basis for setting the pasture quality parameters.

Five pasture plant groups (3Ps, other grasses, *Aristida*, Stylos, Dicots) were sampled four times a year between 2014-2018 at six SWIFTSYND sites at Spyglass Research Station. The weighted average % nitrogen of pasture decayed between 5-7 months ranged from a maximum 1.68% to a minimum 0.39%.

Pasture quality of leaves of native and introduced grasses plucked during January 1990 (Table 7-9, Jones 1997) was not unreasonably higher than SWIFTSYND pasture sward data. Dry matter digestibility of these grasses sampled during December 1989 ranged from 48.6 to 55.3 DMD% (Table 7-9, Jones 1997). The range of nitrogen content at SWIFTSYND sites was similar to plucked *Bothriochloa pertusa* (0.38 to 1.55 N%) sampled during 2001-2003 (Table 7-10, Coates and Dixon 2008). Dry matter digestibility of *B. pertusa* leaves ranged from <50 to 60% (Table 7-10, Coates and Dixon 2008). The quality of leaves declined from peak mean crude protein (CP) content (9.7%) in December to mean CP 2.5% from April//May through the dry season (Table 7-10, Coates and Dixon 2008).

Faecal samples from steers grazing the *B. pertusa* pastures were analysed by near infrared spectroscopy (Coates and Dixon 2008). The analyses indicated that nitrogen content ranged between 0.97 and 1.34% and dry matter digestibility between <46 to 54% (Table 7-10, Coates and Dixon 2008).

Table 7-9: Nitrogen (%) in January 1990 and dry matter digestibility (DMD %) in December 1989 of plucked leaves of Indian couch (*Bothriochloa p*ertusa) and the main native pasture species (Jones 1997)

	Jan-1990	Jan-1990	Dec-1989
Plant	Crude Protein %CP	Nitrogen %N	Dry Matter Digestibility %DMD
Bothriochloa pertusa	12.13	1.94	50.3
Heteropogon contortus	10.19	1.63	49.2
Bothriochloa decipiens	10.75	1.72	49.3
Chrysopogon fallax	12.69	2.03	55.3
Themeda triandra	8.75	1.4	48.6

Table 7-10: Crude protein (CP%), nitrogen (N%) and dry matter digestibility (DMD%) determined by conventional laboratory procedures for plucked samples of *Bothriochloa pertusa* for the dry seasons (DS1, DS2), wet season (WS), wet-dry transition season (TS) for the period August 2001 to January 2003. Faecal near infrared spectroscopy (F.NIRS) estimates of diet CP%, DMD% and N% of samples for the dry seasons (DS1, DS2), wet season (WS), wet-dry transition season (TS) for the period August 2001 to January 2003 are also shown (Coates and Dixon 2008). ND – not determined

Laboratory analysis		DS1	WS	TS	DS2
Conventional plucked samples of *Bothriochloa pertusa* indicating pasture quality	CP%	2.4	9.7	2.5	2.5
	N%	0.384	1.552	0.4	0.4
	DMD%	<50	60	<50	<50
Near infrared reflectance spectroscopy (NIRS) of dung samples indicating diet quality	CP%	2.5	11	ND	2.9
	Faecal N	0.99	1.34	1.04	0.97
	DMD%	<46	59	ND	48

Pasture quality at Swan's Lagoon (1996 – 2001) and Wambiana (1998 – 2004) was determined by near infrared spectroscopy analysis of faecal samples. Mean calibrated estimates of diet crude protein, diet nitrogen, faecal nitrogen and dry matter digestibility contents for Swans Lagoon and Wambiana indicated a wider range of pasture quality (max. 2.33-2.55 N%, 66.0-69.3 DMD%; min. 0.23 diet N%, 40.0-43.4 DMD%) compared to both SWIFTSYND pastures and plucked leaves data outlined previously (Table 7-11).

The grazing trial faecal NIRS data was further examined to identify relationships between nitrogen content and dry matter digestibility. The calculated coefficients and intercept to convert initial N% to DMD% selected for use in CLEM were the default values based on the Wambiana NIRS data and Ash *et al.* (2015). Coefficients to adjust intake for tropical forage quality and forage quality were default values (Ash *et al.* 2015).

Table 7-11: Near infrared spectroscopy determined average crude protein (CP%), diet and faecal nitrogen (N%) and dry matter digestibility (DMD%) for grazed pastures at Swans Lagoon (1996 – 2001) and Wambiana (1998 – 2004) grazing trials. ND=Not determined

Data		Diet Crude Protein %CP	Diet Nitrogen %N	Faecal Nitrogen %N	Dry Matter Digestibility %DMD
Swans Lagoon 1996 - 2001 Revised calibration Rob Dixon, 2020	Average	5.91		1.32	49.9
	Min	2.69	NDND	0.91	40.0
	Max	12.94	ND	2.36	66.0
Wambiana grazing trial 1998 - 2004	Average	5.78	0.92	1.23	52.3
	Min	1.44	0.23	0.79	43.4
	Max	15.92	2.55	2.33	69.3

The productivity of native pastures in north-eastern Queensland is strongly positively correlated with the percentage of perennial grasses in the pasture. The 'safe' utilisation rate of 25% for Narrow-leaved ironbark on deeper soils land type (State of Queensland 2022) was used in this study. The GRASP parameters associated with a degraded condition state (parameter numbers 181—200) were determined to enable the simulation of pasture growth for a range of pasture condition states. The rates of change in condition state for narrow-leaved ironbark pastures were based on the rates determined for moderately productive *Eucalypt* woodland pastures at Wambiana in the Burdekin GLM region (Scanlan *et al.* 2013).

The CLEM pasture, land condition and grass basal area parameter values determined for the Burdekin beef grazing enterprise are outlined in Table 7-12. Changes in grass basal area in relation to pasture utilisation were based on Spyglass SWIFTSYND sites albeit with dampened rates to reflect simulation of perennial pastures with less annual plants than present at Spyglass sites.

Unlike the Barkly property land condition parameters, the extent that land condition deteriorated at 100% pasture UR (0.75 of a state) was greater than it recovered at 0% pasture UR (0.65 of a state) (Figure 7-13, Table 7-12). The safe level of utilisation, when land condition did not change was set at 25%. The step change in degradation when utilisation was ±5% of safe levels was ±0.15.

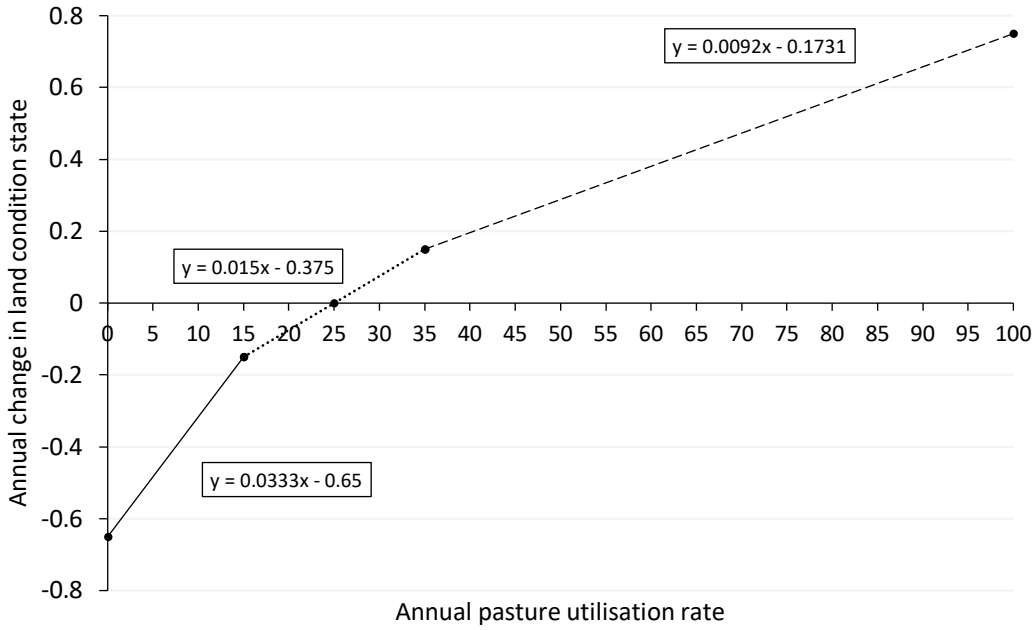


Figure 7-13: Annual change in land condition state in response to the relationship between land condition and pasture utilisation rate parameters shown in Table 38

This translates to the following annual change in % perennials with varying pasture utilisation (Figure 7-14). With no grazing the percent perennial grasses increase by 6% in 1 year, whereas with 100% utilisation, the percent perennials decrease by 7% in one year.

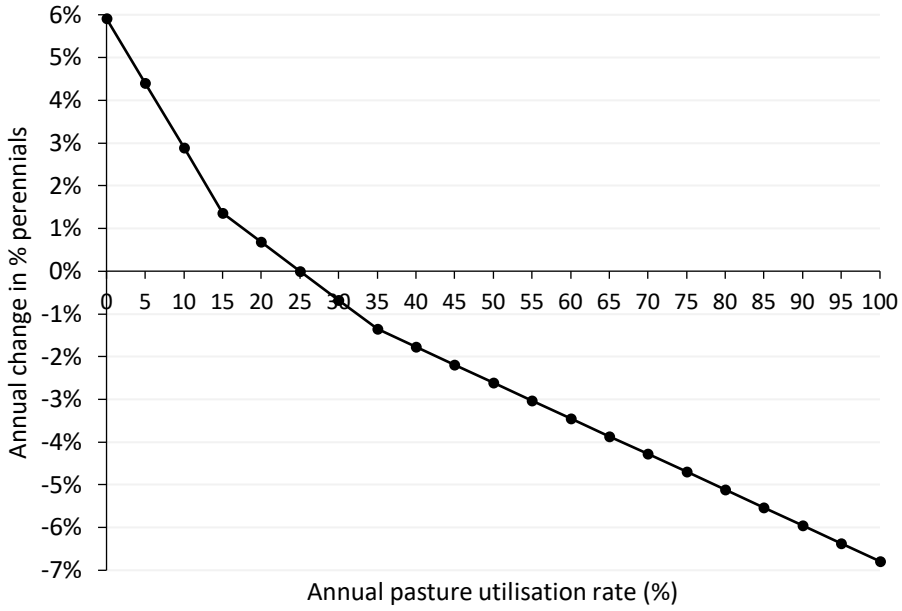


Figure 7-14: Annual change in percent perennials with varying pasture utilisation rates in the Burdekin simulations

Table 7-12: CLEM pasture, land condition and grass basal area parameter values determined for the Burdekin beef grazing enterprise

CLEM Parameters	Native pastures
FORAGE QUALITY	
Units (nominal)	
Coefficient to convert initial N% to DMD%	11.03
Intercept to convert initial N% to DMD%	41.4
Crude protein denominator to convert initial N% to DMD%	0
Nitrogen of new growth (%)	2.1
%Nitrogen loss each month from pools (amount)	0.2
Minimum nitrogen %	0.8
Proportion DMD loss each month from pools	0.09
Minimum Dry Matter Digestibility	48
Detachment rate	0.03
Carry over detachment	0.12
Coefficient to adjust intake for tropical herbage quality	0.16
Coefficient to adjust intake for herbage quality	1.7
Initial biomass kg/ha	1500
LAND CONDITION	
X values of relationship	0, 15, 25, 35, 100
Y values of relationship	-0.65, -0.15, 0, 0.15, 0.75
Method for solving relationship	Interpolation
Name of the x variable	Percentage Utilisation
Name of the y variable	Change in Land Condition
Initial running value	3.5
Minimum running value possible	1
Maximum running value possible	11
GRASS BASAL AREA	
X values of relationship	0, 15, 25, 35, 100
Y values of relationship	1.3, 0.2, 0, -0.2, -1.3
Method for solving relationship	Interpolation
Name of the x variable	Percentage Utilisation
Name of the y variable	Change in Grass Basal Area
Initial running value	5
Minimum running value possible	1
Maximum running value possible	9

7.3 Representative properties and their herds

The representative herds for the Barkly Tablelands and Burdekin catchment are described below.

Barkly representative property

The representative property for the Barkly Tablelands was based on a combination of the findings of a Barkly region pastoral industry survey (Collier 2014) and a modified version of a Breedcow and Dynama Barkly Tableland region (ABARE region 712) herd model provided by Trudi Oxley.

According to Collier (2014), in 2010, the average size of a property in the Barkly Tableland was 6653 km^2. Properties in this region consisted mainly of black soil and Mitchell grass pastures, but some also had considerable areas of much poorer red soil country. The bull to cow ratio was 4%, heifers were mated at 18 to 24 months of age, and cows were culled when between 11 and 12 years of age. Bulls purchased were 3 years old and they were sold when between 8 and 9 years of age. While continuous mating was dominant in the Barkly Tablelands in 2010, a controlled mating period of January to April was used for the simulated property. Pregnancy testing was also common practice, used to identity empty cows that would be sold, and/or to segregate breeders into groups based on their predicted time of calving. However, segregation of breeders into calving groups was not simulated for this property. The most common turn off animals were feeder steers to Queensland properties, with an average age and weight of 13 months and 250 kg. For excess heifers, the most common turnoff was for live export, at an average age and weight of 21 months and 290 kg.

The Breedcow and Dynama modified Barkly Tableland region model was used to provide numbers of male and female initial cohorts for a range of herd sizes. While this property had a total area of 6653 km^2, only 4657 km^2 (70%) was considered reliably available for grazing. The remaining land was remote from water and/or poor red soil land types. This is consistent with reported development at Alexandria Downs (Walsh and Cowley 2016) and land type composition of Barkly pastoral leases. The 4657 km^2 of land used for grazing a Mitchell grass land type. The Mitchell grass land type is representative of the productive Mitchell Grass Downs bioregion covering large swathes of inland Qld and the NT (Figure 7-15).

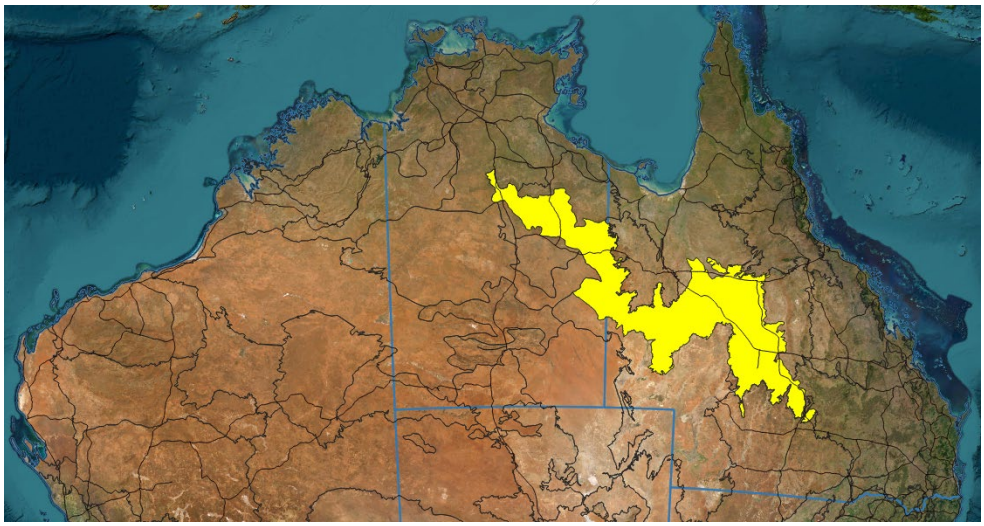


Figure 7-15: Mitchell Grass Downs bioregion highlighted in yellow

Based on GRASP monthly pasture growth accessed by the CLEM model, the safe carrying capacity of the simulated property in B land condition was 35,470 AE. Given that the purpose of this bioeconomic modelling was to investigate the implications of a range of pasture utilisation rates on breeder herd performance and land condition, a range of herd sizes were simulated in Breedcow and Dynama and then in CLEM. Simulations of the Barkly property included four herds with less cattle than the long-term carrying capacity, and five herds with more cattle.

The annual schedule of operations for the simulated Barkly property are shown in Table 7-13.

Table 7-13: The annual schedule of operations for the Barkly Tablelands property, commencing in July (Jl) and finishing in June (J)

Annual operations	Months (July to June)											
	Jl	A	S	O	N	D	Ja	F	M	A	M	J
Calving												
Controlled mating												
1st round weaning and branding												
Sell 13 month feeder steers to Qld												
Sell 21 month excess heifers to live export												
Sell Max Age Breeders												
Sell old bulls												
2nd round weaning and branding												
Pregnancy test and sell empty breeders												
Destock when necessary												

Burdekin catchment representative property

The representative property used for the Burdekin catchment was that described in detail by Bowen *et al.* (2023). This property was located centrally in the Burdekin Rangelands region (Figure 7-16 - Figure 7-17), near Charters Towers. The property modelled had a total area of 25000 ha, the land type was predominantly narrow leaf ironbark (*Eucalyptus crebra*) on deeper soils, and the native pastures were black speargrass (*Heteropogon contortus*) and associated native species. Additionally, the property was assumed to have some areas of more fertile land types such as alluvial frontage and/or areas of brigalow/gidyea or basalt land types (State of Queensland 2022). Naturalised legumes from the *Stylosanthes* genus were present across the property and 50% of the property was assumed to be in C condition.

As noted by Bowen *et al.* (2023), the base property, herd and business characteristics were informed by industry surveys and research relevant to the region (Round 1978; Hinton 1993, 1995; Bortolussi *et al.* 1999, 2005; McCullough and Musso 2004; McGowan *et al.* 2014; O'Reagain *et al.* 2018, 2022), as well as consultation with regional producer groups and experienced DAF staff in 2022. The production parameters assumed for the base property were intended to represent the long-term average expectations for this region.

In the study by Bowen *et al.* (2023), the long-term safe carrying capacity was assumed to be 2500 AE, with a stocking rate of 10 AE/100 ha. This aligned with the moderate stocking rate treatment applied in the local, long-term grazing research project at 'Wambiana' over 1997-98 to 2000-01 (O'Reagain and Bushell 2011; O'Reagain *et al.* 2018). Cattle numbers on the representative property were expected to be managed according to seasonal conditions so that stocking rate fluctuated above and below 2500 AE. According to best-practice recommendations, cattle numbers were expected to be reduced during extended and severe dry periods to prevent serious damage to pastures and so that expensive drought feeding to maintain livestock on the property would not be required.

While Bowen *et al.* (2023) regarded the carrying capacity of their representative property to be 2500 AE, the property simulated by GRASP for this project had much less Indian couch and was predominantly in B condition, rather than half being in C condition. Consequently, the median

annual pasture growth of this property was higher than that of Bowen *et al.* (2023), resulting in a long-term safe carrying capacity of 2700 AE.

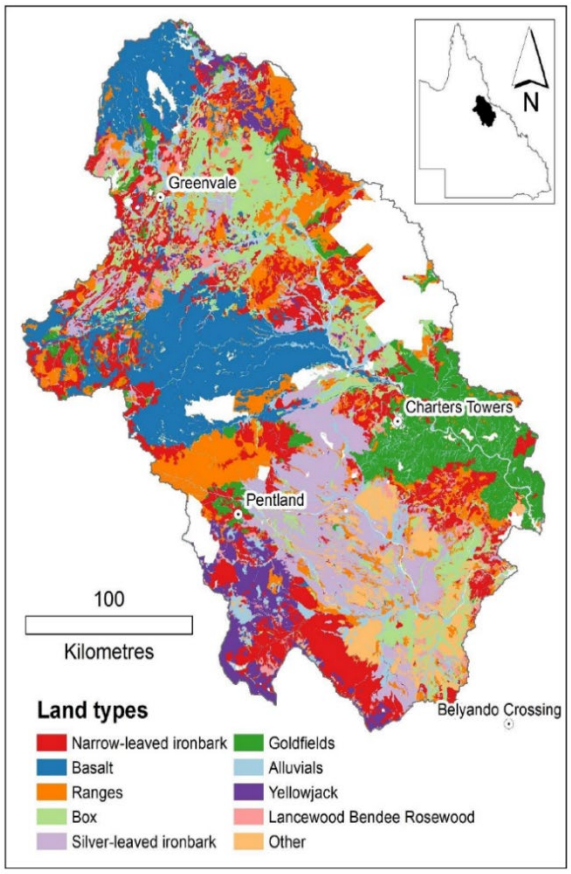


Figure 7-16: Land types of the Burdekin Rangelands region comprised of Upper Burdekin and Cape Campaspe sub-catchments (Bowen *et al.* 2023)

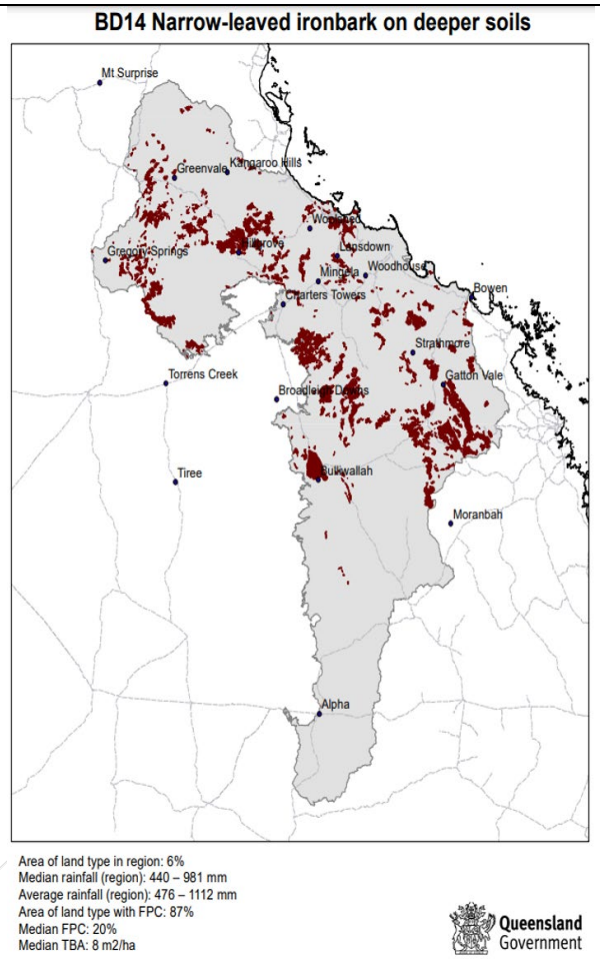


Figure 7-17: Narrow-leaved ironbark on deeper soils (BD14) of the Burdekin GLM region (State of Queensland 2022)

The Breedcow and Dynama software (Breedcow and Dynama 2020) model developed for this representative property by Bowen *et al.* (2023) was used to generate the initial composition of the Burdekin herds for use in CLEM simulations. The annual live weight gain for 1-2 year old steers was 110 kg. This herd turned off steers aged 3-4 years, excess heifers at the age of 2 years, and culled cows at the age of 9-10 years. Bulls purchased were 3 years old and sold when 8-9 years of age.

The annual schedule of operations for the simulated Burdekin property is shown in Table 7-14.

Table 7-14: The annual schedule of operations for the Burdekin rangelands property, commencing in July (Jl) and finishing in June (J)

Annual operations	Jy	A	S	O	N	D	J	F	M	A	M	Jn
Calving												
Bulls in												
Branding												
Weaning												
Sells 3.5 yr old steers												
Sell excess heifers												
Sell old cows												
Sell old bulls												
Preg test sell empty breeders												
Purchase breeders												
Destock												

7.4 Parameterisation of CLEM herd models

Simulations of herds which were similar in size to the long-term carrying capacity for the Barkly Tablelands and Burdekin catchment were developed first. These herds also achieved the live weights, birth rates, mortality rates, and variation in herd size expected of a herd at carrying capacity in each region. Also, these were herds which experienced little to no mortality through starvation of cattle during droughts. When these were finalised, simulations were developed for herds with initial sizes which were lower and higher than the long-term carrying capacity. The main parameters used to characterise the Burdekin and Barkly herds in CLEM are provided below.

7.4.1 Barkly Tableland herds

The simulation period commenced in January 1977 and ended in June 2023. The first two and a half years of the simulation results were discarded as it took around two years for the initial herd to adjust and stabilise in response to the resources available and the activities applied. This provided simulation results for 44 years, with each of these being financial years (July-June).

Simulated herds

Ten herds were simulated for the Barkly Tablelands property (Table 7-15). The initial size of these herds at the beginning of the simulation period ranged from 23,651 to 35,267 AEs, providing for a wide range of annual pasture utilisation rates. While simulations commenced in January 1978, the initial herd size used was that in 1979 after herds had adjusted to climatic conditions and management, coinciding with the first of the 44 years of modelling results. Consequently, their initial size in 1977 was often higher than that in 1979.

The long-term carrying capacity for the baseline Barkly Tableland property was 35470 AE. The modified Breedcow and Dynama model for Barkly Tableland region was then used to calculate the steady state numbers of each gender and annual age class of cattle present in a herd of this size. These numbers of individuals in each class of males and females were then entered as the initial gender and age cohorts in CLEM. The process of calculating the numbers of each gender and age class in Breedcow and Dynama was repeated for four herds which were smaller than and five herds larger than the long-term carrying capacity of this property. The number of AE used in the names of

the 10 Barkly herds (Table 7-15) was that present during the 3rd year of the 47-year CLEM simulation period, corresponding with the 1st year of 44 years of simulation results used to calculate herd performance metrics. For example, while the initial size of herd 5 - 30746 in 1977 at the beginning of the simulation period in CLEM was 35470 AE, the number present in 1979 was 30746 AE.

Table 7-15: Name and brief description of the 10 herds simulated for the Barkly property. Herd names include the initial size in adult equivalents (AEs). Names ending in PB are herd simulations which purchased breeders

Name / Initial AE	Description
1 - 23651 AE	Herd starts with 23651 AE, then varied a little with climatic conditions
2 - 25922 AE	Herd starts with 25922 AE, then varies a little with climatic conditions
3 - 27210 AE	Herd starts with 27210 AE, then varies with climatic conditions
4 - 28514 AE	Herd starts with 28514 AE, then varies with climatic conditions
5 - 30746 AE	Herd starts with 30746 AE, (long-term carrying capacity) then varies with climatic conditions
6 - 31908 AE PB	Herd starts with 31908 AE, breeders purchased to recover herd
7 - 33482 AE PB	Herd starts with 33482 AE, breeders purchased to recover herd
8 - 34400 AE PB	Herd starts with 34400 AE, breeders purchased to recover herd
9 - 35222 AE PB	Herd starts with 35222 AE, breeders purchased to recover herd
10 - 35267 AE PB	Herd starts with 35267 AE, breeders purchased to recover herd

For each simulated herd, attempts were made to maintain the initial herd size across the simulation period, but as initial herd size increased, it became increasingly necessary to reduce herd size during droughts. For example, for the larger herds, it was necessary to prevent mortality due to starvation during the 1990s drought by selling large numbers of empty breeders, and sometimes other classes of cattle. The number of female breeders in simulated herds with initial sizes ≥31908 AE were substantially reduced by sales of empty breeders. Natural recruitment took many years to recover the initial size of these herds, and in some cases, herds did not recover by the end of the simulation period. Restoration of initial herd size was achieved by purchasing young breeders after droughts when climatic conditions improved.

Sale and purchase prices, and overheads

The sale and purchase prices used in simulations of the Barkly Tableland herds were the same as those used for the Burdekin herds (see Table 7-17, Table 7-18). The average trucking distance of 200 km for sales and purchases used was also that used for the Burdekin property. This is considerably less than the trucking distances of approximately 1200 km associated with Barkly Tableland properties, and thus under-estimated these costs. However, while the costs of trucking weaners to other company properties is under-estimated in terms of travel distance, this cost should not have been attributed to this Barkly property, and instead would be a cost born by the property receiving and growing out these animals. Also, CLEM includes sale commission and the MLA levy for every animal sold from the simulated property, but these costs would not have been incurred for stock transferred between company properties. The trucking costs of purchased female breeders also assumed a travel distance of 200 km, whereas this was likely to be much higher. Consequently, the variable costs were under-estimated for simulated herds which purchased large numbers of female breeders. Overhead costs for each of the 10 simulated herds were calculated by multiplying their average annual herd size by $81.10, as per McLean *et al.* (2023).

Annual supplements

Supplementation costs, feeding periods and amounts of urea and phosphorous were as per the Burdekin herds. No drought or browse feeding occurred with the Barkly Tableland herds.

Native pasture

The GRASP model was used to provide the amounts of monthly native pasture that was available for the herds for a wide range of stocking rates, land condition states and grass basal areas, using historical daily climate records. The quality of the Barkly Tableland pasture was characterised by the parameters shown in Figure 7-18.

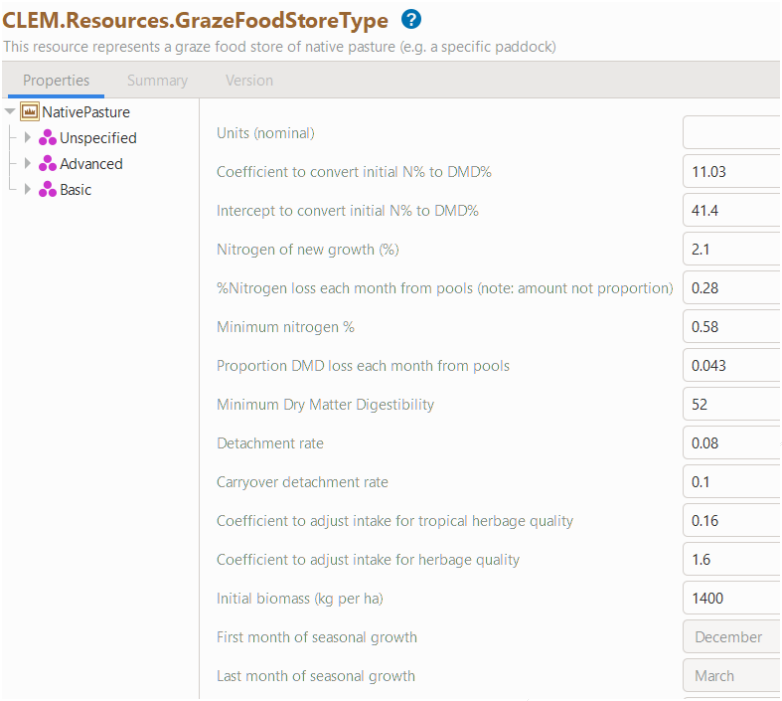


Figure 7-18: The parameters used to characterise the diet quality of native pasture available to the Barkly Tableland herd

The safe annual utilisation rate for the Barkly Tableland land type in B condition and long-term climate was 20%. The relationships between utilisation rate and land condition (Figure 7-19) and utilisation rate and grass basal (Figure 7-20) are shown below.

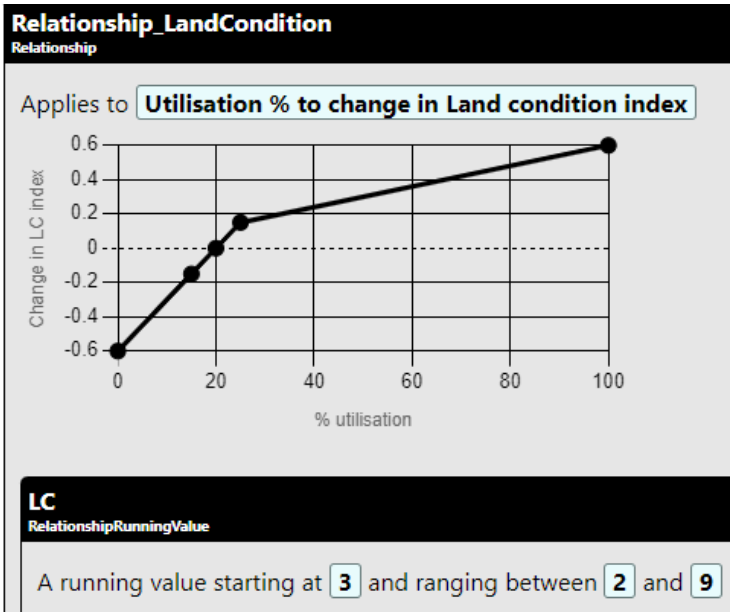


Figure 7-19: The relationship between Barkly simulation annual utilisation rate and changes in land condition state used in CLEM to determine the response of land condition to grazing pressure

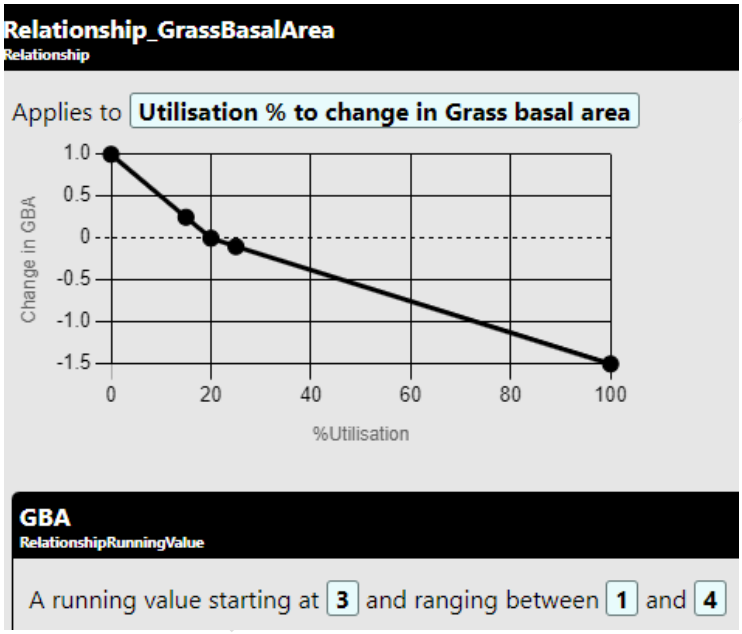


Figure 7-20: The relationship between Barkly simulation annual utilisation rate and changes in grass basal area used in CLEM to determine the response of grass basal area to grazing pressure

Manage herd

The schedule of annual operations for the Barkly Tableland herd included a 1st muster in April, at which time steers, surplus heifers, old cows and old bulls were sold. A second muster occurred in June for weaning, castration, pregnancy testing, and selling all or some proportion of empty breeders. Destocking of various proportions of steers, heifers and breeders could also be undertaken in June when pasture biomass was <1500 kg/ha, but only when needed to reduce rates of mortality. The proportion of empty breeders culled in June and the proportions of steers, heifers and breeders destocked in June varied in accordance with the initial size of herds, and with variation in climate over the simulation period. Attempts were made to keep as many breeders as possible. If substantial

rates of breeder mortality occurred, and as drought feeding was not available, heifers and breeders were proportionally destocked until mortality was greatly limited or eliminated. These adjustments were based on the knowledge of future climatic conditions and associated mortality rates which were provided by additional simulations. In reality, while cattle producers may also have destocked varying proportion of their herds in June when pasture biomass was unusually low, their decisions could not be informed by knowledge of future conditions.

For the herd 5 - 30746 AE which aligned with long-term carrying capacity, all empty breeders were culled in August each year, and there was no need to destock/sell any other classes of cattle. The same applied to smaller herds – 1 - 23651 AE, 2 - 25922 AE, 3 - 27210 AE and 4 - 28514 AE. With the larger herds (6 - 31908 AE PB, 7 - 33482 AE PB, 8 - 34400 AE PB, 9 - 35222 AE PB, 10 - 35267 AE PB), higher stocking and utilisation rates caused declines in the amount of pasture available in all years, and especially during successive years with well below average rainfall. Without destocking, this resulted in high rates of mortality during droughts. To prevent this, it was desirable to cull and destock different proportions of male and female classes during parts of the simulation period which had very different climatic conditions. This was not possible if the automated management rules contained within Manage Numbers were enabled, as this tended to sell or purchase similar proportions of male and female classes, regardless of climatic conditions and their impact on herd size. Instead, selling and purchasing classes of cattle were performed manually. This provided additional modelling flexibility in how the herd was managed in response to climate variability. This enabled different proportions of female and male cohorts to be sold or purchased prior to, during and after droughts. To facilitate this, the Barkly Tableland simulation period was broken up into seven segments, alternating between periods of low/moderate and high utilisation rates. These were:

1. 1977-1984
2. 1985-1987
3. 1988-1991
4. 1992-1996
5. 1997-2018
6. 2019-2021
7. 2022-2013

Management actions involving selling, destocking and purchasing of a range of female and male cohorts were added within each of the seven segments of the simulation period. An example of this, for the segment 1978 to 1984, is shown in Figure 7-21. The only animals purchased were three-year old bulls and two-year old cows. Bulls were purchased every year, but young cows were only purchased in simulations where the breeder herd had declined to very low numbers, as a means of quickly restoring breeder herd size when climatic conditions improved after droughts.

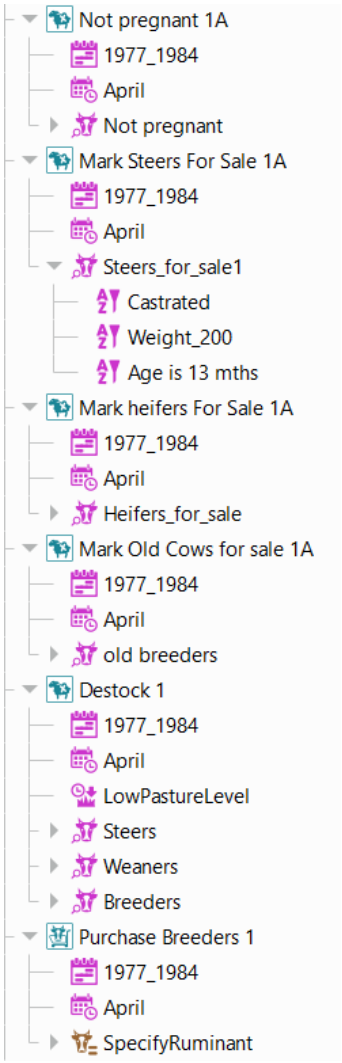


Figure 7-21: Management actions, involving selling, destocking and purchasing which could be differentially applied during each of the seven time segments of the Barkly simulation period

7.4.2 Burdekin catchment herds

The simulation period commenced in January 1978 and ended in June 2022. Climatic conditions in the late 1970s through much of the 1980s were relatively good, providing more than 10 years for the herd to stabilise prior to a major drought in the mid-1990s. As with the Barkly herds, the first two and a half years of the simulation results were discarded during which time the herds were adjusting to climatic conditions and management practices. This provided simulation results for 42 financial years (July-June). Consequently, the first year of simulation results used were those for 1980/81.

Simulated herds

Twenty-seven herds were simulated for the Burdekin property (Table 7-16). The Breedcow and Dynama herd model was used to simulate the numbers of each of the male and female cohorts present in the 27 simulated herds. These were then used as the initial cohorts in CLEM.

While CLEM simulations commenced in January 1978, the initial herd size used in simulation names was that in 1980, after herds had adjusted to climatic conditions and management, coinciding with the first of the 42 years of modelling results. The long-term carrying capacity of this property was 2700 AE, and the corresponding herd simulation was 4 - 2748 AE. Many initial herd sizes, ranging

from 2349 to 3269 AE, were simulated for the purpose of providing a wide range of median annual pasture utilisation rates. Also simulated were several different herd management responses to variable climate. While all steers >3 years old were sold each year in all simulated herds, proportions of heifers, pre-market-weight young steers, empty breeders and aged breeders sold annually varied. For each simulated herd, attempts were made to maintain the initial herd size across the simulation period, but as initial herd size increased, it was necessary to vary proportions of cattle classes sold in response to climate variability. For example, it was sometimes necessary to prevent mortality due to starvation during the 1990s drought by selling large numbers of empty breeders. In other simulations, 1- to 3-year-old steers were sold for the purpose of limiting sales of empty breeders. If this still did not adequately reduce mortality rate, then increasing proportions of empty breeders, heifers and 1- to 3-year-old steers were sold. For the simulated herds which did decline substantially during droughts, during a few years immediately following the drought when climatic conditions improved, no heifers, empty breeders or aged breeders were sold. The intention was to rebuild herd size through natural recruitment. In some simulations where the breeder herd had dropped to very low numbers, natural recruitment was insufficient, and young breeders were purchased to rapidly recover initial breeder herd size. The interaction between initial herds sizes and climate variability and associated herd management responses resulted in five broad groups of simulations:

1. Herds with relatively low initial sizes that enabled them to perform well during droughts, including high pregnancy rates and thus only small numbers of empty breeders sold, all excess heifer sold every year, and herd size relatively constant over the simulation period (simulations 1-3, 12, 13, 17, 18, 20, 21 as per Table 7-16);
2. Herds with higher initial sizes, lower pregnancy rates and higher sales of empty breeders during droughts, resulting in appreciable declines in herd size, followed by slow recovery of breeder herd size through natural recruitment and limited sales of females (simulations 4-6, 14, 15, 19 as per Table 7-16);
3. Herds with higher initial sizes, lower pregnancy rates and higher sales of empty breeders during droughts, resulting in appreciable declines in herd size, followed by purchasing breeders to rapidly recover initial breeder herd size when climatic conditions improved (simulations 7-11, 16 as per Table 7-16);
4. Herds with higher initial sizes, lower pregnancy rates during droughts but more empty breeders retained, made possible by destocking various proportions of 1- to 3-year-old steers (simulations 22-25 as per Table 7-16);
5. Herds with the highest initial sizes, lower pregnancy rates during droughts and considerable empty breeders needed to be sold even though high proportions of 1- to 3-year-old steers were destocked, followed by rapid recovery of breeder herd size through purchasing breeders (simulations 26-27 as per Table 7-16).

The names and brief descriptions of the 27 simulated herds are provided in Table 7-16. The herds which purchased breeders have PB in their names, herds which held breeders at relatively constant numbers over time have HB in their names, and herds which sold 1- to 3-year-old steers for the purpose of limiting sales of breeders have SS in their names. While sales of different classes of cattle may have achieved similar outcomes for pasture utilisation rate during droughts, these were examined to see if they had different consequences for long-term herd productivity and enterprise profitability. Superscripts against names of simulated herds in Table 7-16 identify herds which had the same initial herd sizes (in 1978), but which then varied in sales and purchases that impacted breeder herd size.

Table 7-16: Name and brief description of the 27 herds simulated for the Burdekin property. Herd names with the same superscripts had the same or almost the same initial AEs (adult equivalents) but then varied in regard to classes sold or purchased. Variations included purchasing young female breeders (PB), holding breeder numbers relatively constant (HB) and selling young steers (SS).

Name/Initial AE	Description
1 - 2349 AE[A]	Herd starts with 2349 AE, then varies a little with climatic conditions
2 - 2466 AE[B]	Herd starts with 2466 AE, then varies a little with climatic conditions
3 - 2670 AE[C]	Herd starts with 2670 AE, then varies with climatic conditions
4 - 2748 AE[D]	Herd starts with 2748 AE (long-term carrying capacity), then varies with climatic conditions
5 - 2917 AE[E]	Herd starts with 2917 AE, then varies with climatic conditions
6 - 3099 AE[F]	Herd starts with 3099 AE, then varies with climatic conditions
7 - 2670 AE PB[C]	Herd starts with 2670 AE, breeder numbers are kept constant
8 - 2801 AE PB[D]	Herd starts with 2801 AE, breeders purchased to recover herd
9 - 2915 AE PB[E]	Herd starts with 2915 AE, breeders purchased to recover herd
10 - 3099 AE PB[F]	Herd starts with 3099 AE, breeders purchased to recover herd
11 - 3269 AE PB	Herd starts with 3099 AE, breeders purchased to recover herd
12 - 2786 AE HB[C]	Herd starts with 2786 AE, breeder numbers are kept constant
13 - 2619 AE HB[B]	Herd starts with 2619 AE, breeder numbers are kept constant
14 - 2896 AE	Herd starts with 2896 AE, then varies with climatic conditions
15 - 2874 AE	Herd starts with 2874 AE, then varies with climatic conditions
16 - 2835 AE PB	Herd starts with 2835 AE, breeders purchased to recover herd
17 - 2610 AE HB	Herd starts with 2610 AE, breeder numbers are kept constant
18 - 2436 AE HB[A]	Herd starts with 2349 AE, breeder numbers are kept constant
19 - 2925 AE	Herd starts with 2925 AE, then varies with climatic conditions
20 - 2713 AE HB	Herd starts with 2713 AE, breeder numbers are kept constant
21 -2497 AE HB	Herd starts with 2497 AE, breeder numbers are kept constant
22 - 2670 AE SS[C]	Herd starts with 2670 AE, young steers sold in drought
23 - 2750 AE SS[D]	Herd starts with 2750 AE, young steers sold in drought
24 - 2917 AE SS[E]	Herd starts with 2917 AE, young steers sold in drought
25 - 3099 AE SS[F]	Herd starts with 3099 AE, young steers sold in drought
26 - 2917 AE SS PB[E]	Herd starts with 2917 AE, young steers sold in drought, breeders purchased
27 - 3099 AE SS PB[F]	Herd starts with 3099 AE, young steers sold in drought, breeders purchased

Sale and purchase prices, and overheads

The sale prices used in simulations were those of Bowen *et al.* (2023). These authors analysed sale price data over the past 7.5 years (October 2014–April 2022) for north Queensland saleyard markets, over-the-hooks markets, and live export markets (see Meat and Livestock Australia market statistics database at http://statistics.mla.com.au/Report/List). As price data was not available for live export steers from Townsville, prices for live export light steers exported from Darwin were included in the analyses. However, as indicated in Bowen *et al.* (2023), the on-farm prices (net of freight costs) for live export steers were similar whether sold through Darwin or Townsville. Therefore, price trends for Darwin, for the same class of steers, can be applied to indicate long-term values, on-farm, for the Burdekin property. The sale prices selected from their analyses were based on the historic 7.5-year averages adjusted downwards to account for the seasonally driven demand experienced since early 2021. In setting the price assumptions, consideration was given to the likelihood that the factors that

have driven increased demand and prices over the previous 18 months (to April 2022) will ease into the future. The sale prices and costs for females and males used in simulations of the Burdekin herds are shown in Table 7-17 - Table 7-18. All cattle were sold at the Charters Towers sale yards.

Table 7-17: Sale weights and prices and sale costs for heifers and cows from the Burdekin representative property (from Bowen *et al.* 2023)

	Heifers 1 year	Heifers 2 years	Cows 3+ years
Sale weight (kg)	266	372	418
Price ($/kg)	$2.85	$2.90	$2.40

Table 7-18: Sale weights and prices and sale costs for steers and bulls from the Burdekin representative property (from Bowen *et al.* 2023)

	Steers 1 year	Steers 2 years	Steers 3 years	Cull bulls
Sale weight (kg)	286	402	519	665
Price ($/kg)	$3.30	$3.15	$3.10	$2.50

For the simulated herds which purchased young female breeders, such as 7 - 2670 AE PB, 8 - 2801 AE PB and 9 - 2915 AE PB (Table 7-16), the purchase price was higher than the sale price. It was recognised that when seasonal conditions had improved after a drought, female cattle would be in high demand and prices would have been considerably higher than sale prices during the drought. An estimate of the percent increase in prices of cattle following the dry years between 2014 and 2018 was obtained from MLA's cattle physical reports for Restocker Cows at the Charters Towers saleyards (https://www.mla.com.au/prices-markets/cattlephysicalreport/). Prices for Restocker Cows, up to a live weight of 400 kg, with a muscle score of D and fat score of 2 (the most common class of Restocker Cows sold), for the years 2015 to 2019 (during drought), were compared with their prices for 2020 and 2021 (after drought). The average sale price for these Restocker Cows over 2015 to 2019 was $1.55/kg live weight, while that for 2020 and 2021 was $2.25/kg live weight. This 45% increase in sale price was then applied to the sale price of $2.90 for 2-year old heifers above in Table 7-17. Hence, the price of purchased 2-year old heifers used in simulations was $4.20/kg, with females purchased weighing 400 kg. Female cattle sold during dry years would have been further discounted due to their very low weights at these times. Consequently, there was a large difference between selling and purchasing prices during and following droughts respectively.

The total overhead cost used for this property, for items such as rates, fuel, electricity, insurance, vehicles and repairs and maintenance, was $308,000 (Bowen *et al.* 2023).

Drought feeding and annual supplements

Urea was fed to cows, bulls, weaners and steers between May and November each year. The respective daily amounts fed were 0.105, 0.105, 0.08 and 0.105 kg. The urea price used was $910/tonne landed.

Phosphorous was fed to cows, bulls, weaners and steers between December and April each year. The respective daily amounts fed were 0.08, 0.05, 0.02 and 0.04 kg. The phosphorous price used was $1340/tonne landed.

During droughts, M8U was fed to certain classes of cattle to help maintain body weight and limit deaths due to starvation. Simulations of herds commenced with an initial storage of 40,000 kg of M8U. For most herds, an additional 20,000 kg was purchased when storage levels dropped below 20,000 kg. For larger herds, such as 5 - 2917 AE and 6 - 3099 AE, 40,000 kg of M8U was purchased when storage levels dropped below 20,000 kg. M8U was fed to female breeders (2 kg/day), steers (2 kg/day), heifers (1.5 kg/day) and bulls (2 kg/day) when their body condition scores were ≤1 and pasture yield dropped below 300 kg/ha. While drought feeding should have commenced at higher body condition scores, doing so often resulted in M8U being fed to the herd for 12 to 24 consecutive months during droughts such as that during the early 1990s. This was not current or typical practice. The price of one tonne of M8U landed on property was $470.

To replicate consumption of leaves and small stems of shrubs and trees during droughts, the Animal Feed Store of CLEM also contained browse. The dry matter digestibility of browse was set at 35% and nitrogen content at 1.3%. These values were averages of common species of browse plants found in northern Australia (Wilson and Harrington 1980, Vercoe 1986, Dynes and Schlink 2002, Franklin-McEvoy and Jolly 2006, Revell *et al.* 2013). When pasture yield fell below 300 kg/ha, cows and steers consumed 2 kg/day of browse, heifers consumed 1.5 kg/day, and weaners consumed 0.8 kg/day.

Native pasture

The GRASP model simulated the monthly amounts of native pasture growth that was available for the herds for a wide range of stocking rates, land condition states and grass basal areas, using historical daily climate records. The quality of this pasture was characterised by the parameters shown in Table 7-12 above.

The safe utilisation rate for this Burdekin land type in B condition and long-term climate was 25%. As utilisation rate changed, so did land condition state and grass basal area. The graphs below in Figure 7-22 - Figure 7-23 show the relationships between utilisation rate and land condition, and utilisation rate and grass basal area. For example, the starting land condition state was 3.5. If the utilisation rate in the first year of the simulation was greater than 25%, then land condition would have declined in accordance with the relationship in Figure 7-22. Likewise for grass basal area, which commenced at 5, CLEM would then select the section of the GRASP pasture growth database which corresponded with this new land condition, new grass basal area, and the stocking rate of the herd at that time. In this way, the amount of pasture available to cattle varied over time in accordance with the impact that utilisation rate had on annual land condition and grass basal area.

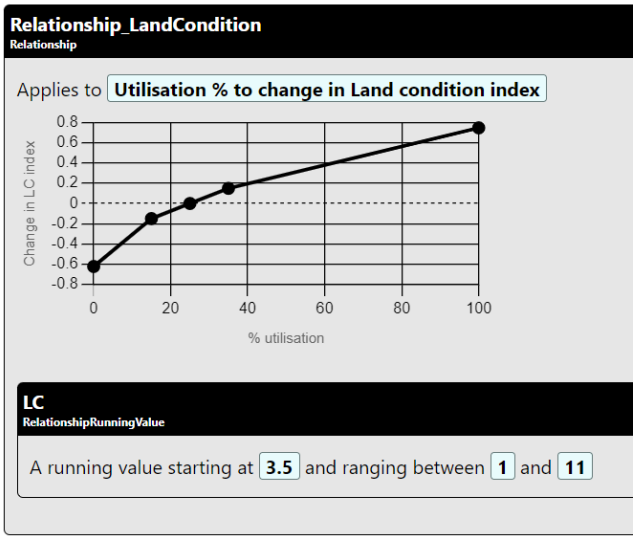


Figure 7-22: The relationship between Burdekin annual utilisation rate and changes in land condition state used in CLEM to determine the response of land condition to grazing pressure

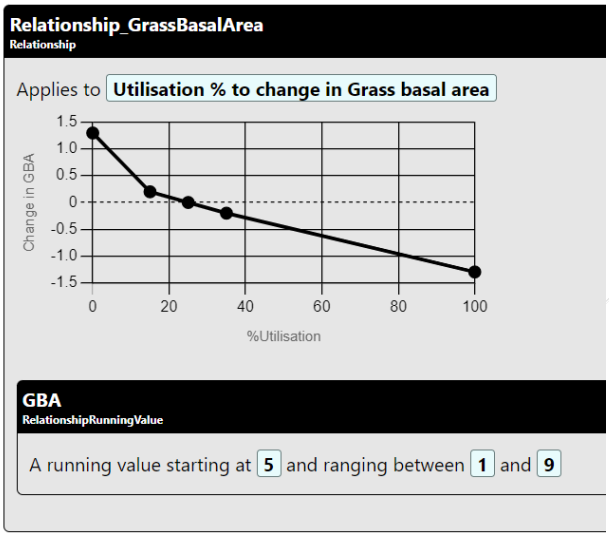


Figure 7-23: The relationship between Burdekin annual utilisation rate and changes in grass basal area used in CLEM to determine the response of grass basal area to grazing pressure

Manage herd

A number of annual herd management operations were conducted over the entire simulation period. This included a muster in April for branding and selling maximum age bulls, and then a muster in May for selling steers. A second muster was undertaken in August for weaning, castration, pregnancy testing, and selling all or some proportion of empty breeders. Destocking of various proportions of steers, heifers and breeders could also be undertaken in August when pasture biomass was <1500 kg/ha, but only if required to reduce mortality rates. The proportion of empty breeders culled in August and the proportions of steers, heifers and breeders destocked in August varied in accordance with the initial size of herds, and with variation in climate over the simulation period.

In simulations of all herds, attempts were made to maintain initial breeder herd size as much as possible throughout the simulation period. This was only possible for simulations of herds which had amongst the lowest initial herd sizes. They had high conception rates in most years of the simulation

period, and thus had adequate numbers of replacement heifers even when all empty breeders were sold. Even so, 20 to 30% of breeders did not conceive during major droughts. Some simulations sold all empty breeders, resulting in a decrease in breeder herd size. In other simulations, for the purpose of maintaining a constant breeder herd size, only a small proportion of empty breeders were sold.

Herds with amongst the highest initial AEs often resulted in high pasture utilisation rates and forage shortages, where breeders lost considerable weight and body condition. In these cases, high proportions of breeders did not become pregnant. If these were not sold, and if considerable mortality of breeders occurred during successive dry years or droughts, even with M8U drought feeding, then simulations were rerun with varying degrees of selling and destocking breeders and or steers in August.

For the simulated herds with amongst the highest initial AEs, a combination of high stocking rates and declining land condition often resulted in severe forage shortages during droughts of 1992 to 1997, 2003 to 2007, and between 2013 and 2017. To prevent this, it was desirable to cull and destock different proportions of male and female classes during parts of the simulation period which had very different climatic conditions. As with the Barkly herd simulations, the automated management rules contained within Manage Numbers were disabled, to provide more modelling flexibility in how the herd was managed in response to climate variability. To facilitate this, the 45-year simulation period was broken up into nine segments, alternating between successions of years with higher than or lower than average annual rainfall, and thus low and high utilisation rates. The nine time segments were:

1. 1978-1986
2. 1987-1988
3. 1989-1991
4. 1992-1997
5. 1998-2002
6. 2003-2007
7. 2008-2012
8. 2013-2017
9. 2018-2022

7.5 Performance metrics used to compare herds

A wide range of performance metrics for pastures, herd productivity and finances were used to compare simulated herds. These are listed and described in Table 7-19 to Table 7-21 below. The most important of these were land condition state, pasture utilisation rate, kg beef produced annually, reproductive rates, gross profit and profit.

Table 7-19: The metrics used for comparing the performance of herds in relation to pastures. UR – pasture utilisation rate

Pasture metric	Metric description
Grass Basal Area	Average annual grass basal area
Land Condition State	Average annual land condition state (0-11)
Utilisation rate% (Average)	Average annual utilisation rate (%)
Utilisation rate% (Median)	Median annual utilisation rate (%)
Bands of utilisation rates for the Burdekin	
Years with UR 0 to ≤15%	Number of years when UR was between 0 and 15%

Years with UR >15 to ≤25%	Number of years when UR was between 15.01 and 25%
Years with UR >25 to ≤35%	Number of years when UR was between 25.01 and 35%
Years with UR >35 to ≤60%	Number of years when UR was between 35.01 and 60%
Years with UR >56 to ≤100%	Number of years when UR was between 50.01 and 100%
Bands of utilisation rate for the Barkly	
Years with UR 0 to ≤12%	Number of years when UR was between 0 and 12%
Years with UR .12 to ≤20%	Number of years when UR was between 12.01 and 20%
Years with UR >20 to ≤30%	Number of years when UR was between 20.01 and 30%
Years with UR .30 to ≤48%	Number of years when UR was between 30.01 and 48%
Years with UR .448 to ≤100%	Number of years when UR was between 48.01 and 100%

Table 7-20: The metrics used for comparing the performance of herds in relation to herd productivity

Production metric	Metric description
Head (Avg pFinYr)	Average annual head of cattle
AE (Avg pFinYr)	Average annual AE of cattle
Breeders AE (with Bulls in FinYr)	Average annual AE of breeders exposed to bulls
Breeders Head (with Bulls in FinYr)	Average annual head of breeders exposed to bulls
Kg_Beef Sold perYear	Average annual kg of beef sold = combined live weights of all animals sold each year, and includes weaners, prebreeder females, culled and destocked cows and aged bulls
Kg_Beef Sold perHa	Average annual kg of beef sold/ha
Kg_Beef Sold perAE	Average annual kg of beef sold/AE
Kg_Beef Sold per Breeder Head	Average annual kg of beef sold/ breeder head
Kg_Beef Produced perYear	Average annual kg beef produced = change in liveweight of all animals from July 1 to June 30, or from July 1 to when they left the herd during each year
Kg_Beef Produced perHa	Average annual kg beef produced/ha
Kg_Beef Produced perAE	Average annual kg beef produced/AE
Kg_Beef Produced per Breeder Head	Average annual kg beef produced/breeder head
Conceptions/yr	Average annual conceptions
Conceptions per Ha	Average annual conceptions/AE
Conceptions per Breeder Head	Average annual number of conceptions/breeder head
Calves/yr	Average annual number of calves
Calves per Ha	Average annual calves/ha
Calves per Breeder Head	Average annual calves/breeder head
Weaners/yr	Average annual number of weaners
Weaners per Ha	Average annual weaners/ha
Weaners per Breeder Head	Average annual weaners/breeder head
Kg Weaners/yr	Average annual kg of weaners
Kg Weaners per Ha	Average annual kg of weaners/ha
Kg Weaners per Breeder Head	Average annual kg of weaners/breeder head
% Breeders P4M	Average annual % of breeders pregnant within 4 months of calving
% Foetal Mortality	Average annual % mortality of foetuses
% Calf Mortality Birth to Weaning	Average annual % mortality of calves

Table 7-21: The metrics used for comparing the performance of herds in relation to finances

Financial metric	Metric description
Direct Costs Total	Average annual direct or variable costs
Direct Costs per Ha	Average annual direct or variable costs/ha
Direct Costs per AE	Average annual direct or variable costs/AE
Income Sales	Average annual income from sales of all cattle
Overhead Costs	Average annual costs of all overheads

Cost of Purchases	Average annual costs of purchasing all cattle
Change in Value Animals	Average annual change in value of cattle between July and June
Gross Profit	Average annual gross profit (=income from sales-costs of purchased + change in value of animals)
Gross Profit per Ha	Average annual gross profit/ha
Gross Profit per AE	Average annual gross profit/AE
Gross Profit/Breeder AE	Average annual gross profit/AE
Gross Profit Margin	Average annual gross profit margin (=annual gross profit-direct costs)
Gross Profit Margin per Ha	Average annual gross profit margin/ha
Gross Profit Margin per AE	Average annual gross profit margin/AE
Gross Profit Margin/Breeder AE	Average annual gross profit margin/breeder AE
Net Profit	Average annual net profit (=gross profit margin-overhead costs)
Net Profit per Ha	Average annual net profit/ha
Net Profit per AE	Average annual net profit/AE
Net Profit per Breeder AE	Average annual net profit/breeder AE

Percent perennial grass composition, which is later used in this report as an index of the four land condition ratings of A, B, C and D (Quirk and McIvor 2003, FutureBeef 2024), was not an output of CLEM. Instead, percent perennial grass composition was calculated from the CLEM output of the 12-point scale of 'land condition state'. This was based on the values shown in Table 7-22, from Scanlan *et al.* (2014). While grass basal area, another output of CLEM, is also an index of land condition ratings, this relationship has not been calibrated.

Table 7-22: Land condition state and associated percent perennial grass composition for the A, B, C and D land condition ratings

Land condition state	Percent perennial grasses	Land condition rating
0	90	A
1	88	A
2	84	A
3	70	B
4	50	B
5	32	C
6	20	C
7	15	C
8	10	C
9	5	D
10	2	D
11	1	D

The relationship between land condition state and percent perennial grass composition, based on the values in Table 7-22 were graphed in Microsoft Excel (Figure 7-24). A 4th order polynomial provided a close fit (R^2=0.99) between land condition state and perennial grass composition. This equation was used to convert land condition state outputs of CLEM to percent perennial grass composition for reporting purposes. From this point on in the results and discussion, percent perennial grass composition is used as the measure of land condition rather than land condition state. According to Walsh and Cowley (2016), A condition land is characterised by percent perennial grass composition of ≥78%, B condition land has between 41 and 77% perennial grasses, C condition land between 8 and 40%, and D condition land is <8%. However, percent perennial grass composition of pastures is an index of land condition, and therefore not all grazing lands in northern

Australia in A condition would have native pastures consisting of around 80% or more of perennial grasses (e.g. the annual pasture in the channel country of Queensland).

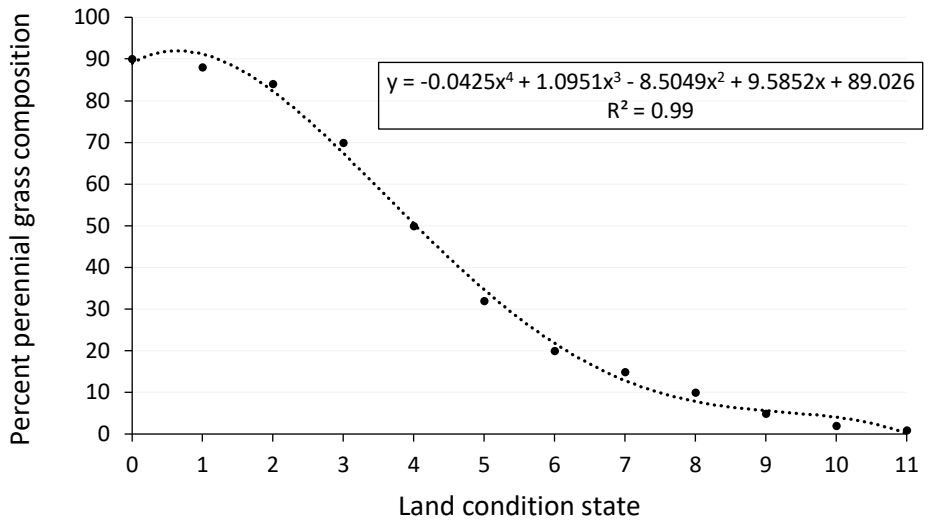


Figure 7-24: Relationship between land condition state and percent perennial grass composition

Calculation of performance metrics

The results generated by simulations which were needed to calculate the above performance metrics were captured in the *Reports* component of CLEM. These were available in tabular form for a range of financial, herd and pasture outcomes. Some reports, such as the *Herd Ledger* (Figure 7-25), were very large, containing records for every individual for every month of the simulation period. While it was often possible to export results from the *Data Store* folder in CLEM for Burdekin herds to a Microsoft Excel spreadsheet, those for Barkly herds exceeded the size capacity of Excel. Consequently, for both Burdekin and Barkly herd simulations, CLEM database results files were accessed by Microsoft Open Database Connectivity (ODBC) interface. Power Pivot tables linked to ODBC were then used to calculate the performance metrics for each herd simulation.

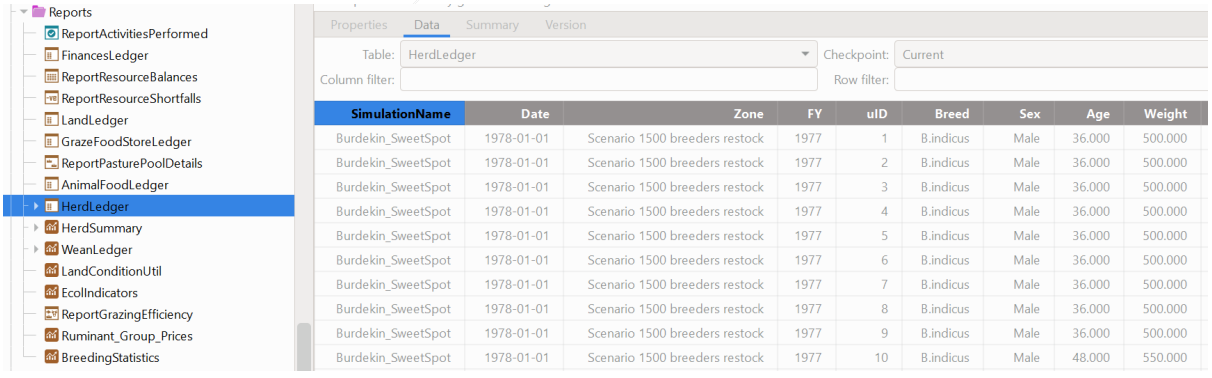


Figure 7-25: Part of the data table within the Herd Ledger, containing output generated by CLEM

7.6 Results: GRASP pasture growth

7.6.1 Barkly

Pasture growth declined with declining land condition and grass basal area (Figure 7-26) from a maximum of 1711 kg/ha with A land condition (condition state = 0) and grass basal area (GBA) = 5%,

to a minimum of 517 kg/ha, a reduction of 70%, with D land condition (condition state = 11) and GBA = 1% (Figure 7-26).

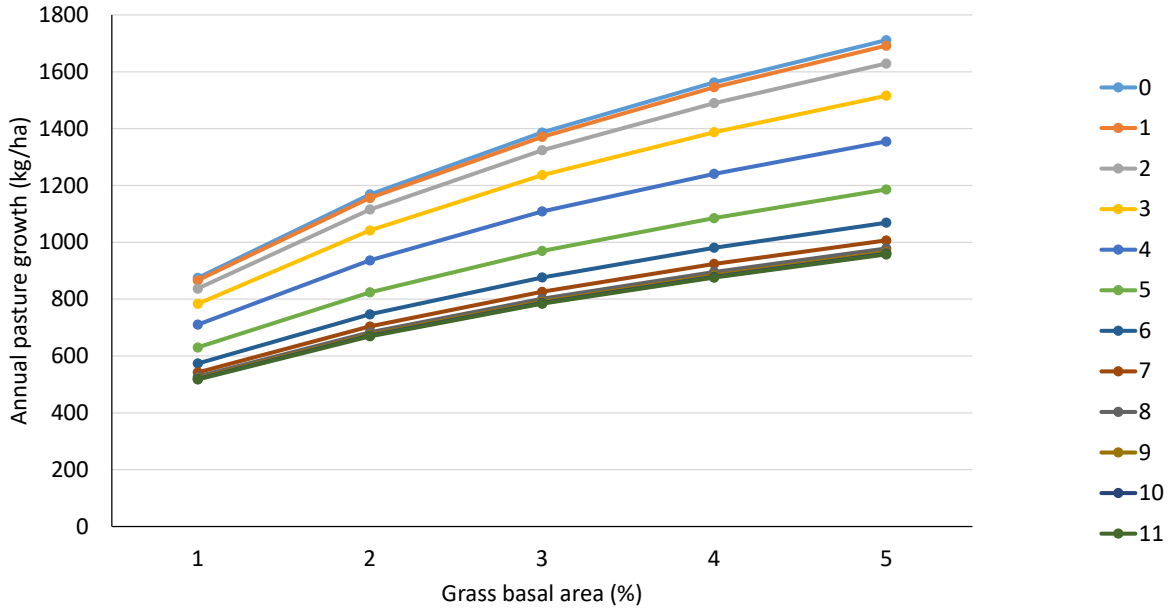


Figure 7-26: Average Barkly GRASP simulated annual pasture growth for land condition state (0-11) and grass basal area (1-5%) at stocking rate = 6 AE/km²

7.6.2 Burdekin

Average annual pasture growth declined with declining land condition and grass basal area. When in A condition (condition state = 0) and with maximum GBA of 9, annual pasture growth was ~1900 kg/ha. This reduced to~200 kg/ha when land condition state was 11 and GBA was 1 (Figure 7-27).

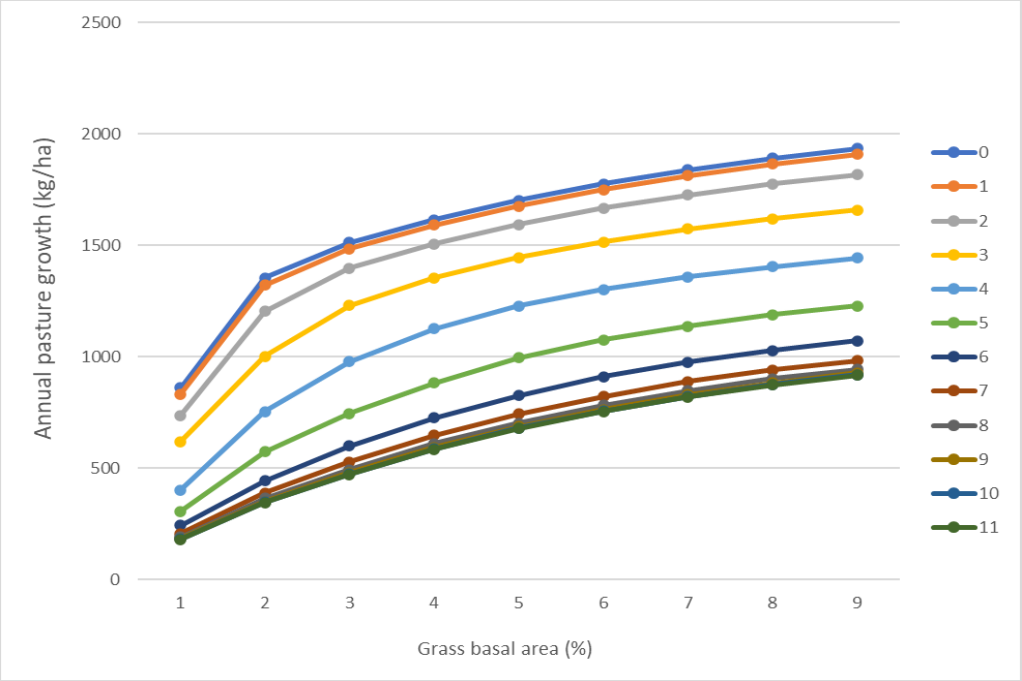


Figure 7-27: Average Burdekin GRASP simulated annual pasture growth for land condition state (0-11) and grass basal area (1-9%) at stocking rate = 10 AE/km^2

7.7 Results: CLEM

Results are presented first for simulations of herds on the Barkly Tablelands property. This begins with a herd aligned to the long-term carrying capacity of the property, then comparisons were made with smaller and larger herds which had lower and higher average annual pasture utilisation rates, respectively.

7.7.1 Barkly Tablelands property simulations

The following graphs, from the graphical reporting component of CLEM, are used to demonstrate the variation in annual breeder herd size, total herd size, pasture yield, pasture utilisation rate and land condition state which occurred across the 10 simulated herds. These time series graphs demonstrate the extent that herd size and utilisation rates varied over time for herds that were simulated with different initial sizes and different herd management approaches during and after droughts, such as recovering herd size through natural recruitment or purchasing young breeders. Presented first are time series graphs of the dynamics of the simulated Barkly herd with an average annual size close to the long-term carrying capacity. This is followed by time series graphs of the dynamics of smaller and larger herds.

Barkly rainfall during simulations

Annual rainfall (using Brunette Downs climate data) in the Barkly Tablelands during the simulation period 1977 to 2023 ranged from a minimum of 134 mm to a maximum of 954 mm. Average and median annual rainfall were 464 mm and 428 mm respectively, and the coefficient of variation was 44%. Compared with the Burdekin catchment, annual rainfall in the Barkly Tablelands was lower and slightly more variable.

Figure 7-28 shows annual differences between actual rainfall and average annual rainfall and the 3-year moving average of the differences, indicating there were three main periods of rainfall

variability. Annual rainfall during the first 21 years was generally below the average annual rainfall of 462 mm for the simulation period. During this period of 21 years, there was a deficit of rainfall relative to the average, as the accumulated differences between annual and average annual rainfall was -1546 mm. Consequently, annual pasture utilisation rates over this time were often higher than the safe rate of 20%. This was followed by a period of 20 years when annual rainfall was often considerably higher than the annual average, where the accumulated differences between annual and average annual rainfall was +1951 mm. Hence, annual pasture utilisation rates over this period of time were often lower than the safe rate of 20%. Furthermore, during this time, there was only one instance where there were two consecutive years with below average rainfall. In all other cases, individual years with below average rainfall were followed by years with above average rainfall, and the 3-year moving average of differences was predominantly positive. Then, rainfall abruptly dropped to well-below average during the years 2018 to 2022, with a deficit of -801 mm, leading to a spike in annual utilisation rates.

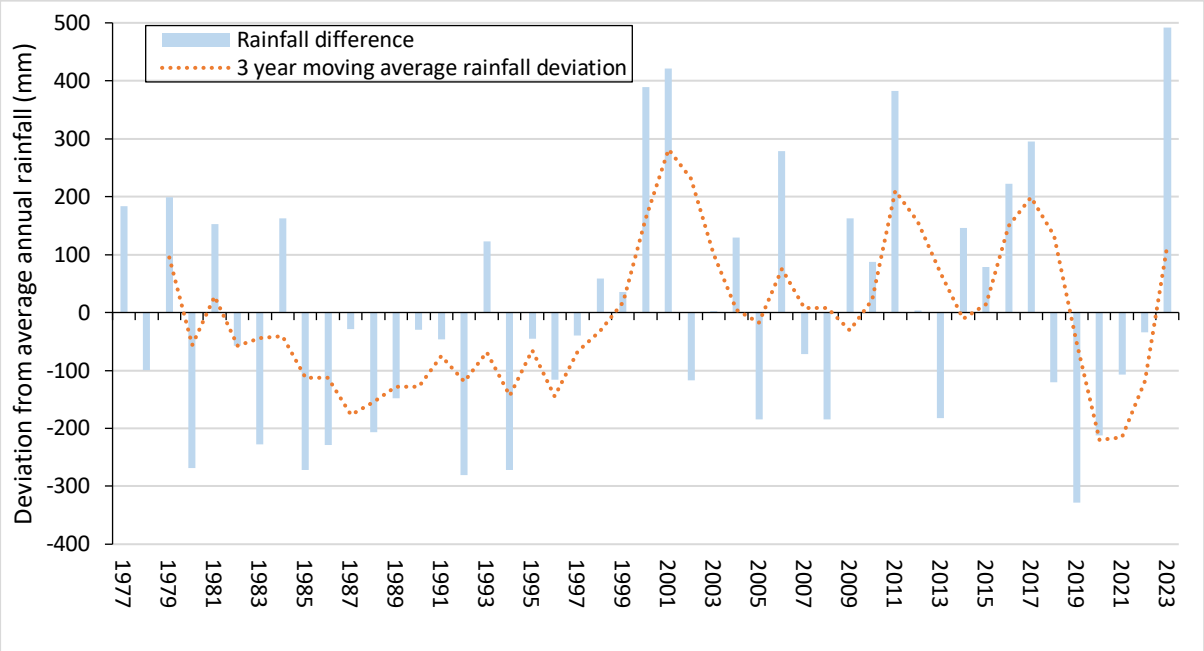


Figure 7-28: Differences between annual rainfall and average annual rainfall (rainfall deviation) and 3-year moving average deviation over the simulation period of the Barkly Tablelands property

Time series of the Barkly herd at long-term carrying capacity

The simulation of herd 5 – 30746 AE, with an average annual size of 37274 AE and stocking rate of 8AE/km^2 over 44 years which was slightly higher than the long-term carrying capacity of 35470 AE, included culling of all empty breeders each year, with no destocking necessary throughout the simulation. Total AE herd size and total head of breeders varied considerably over the simulation period, mostly due to variation in annual pasture biomass (Figure 7-29).

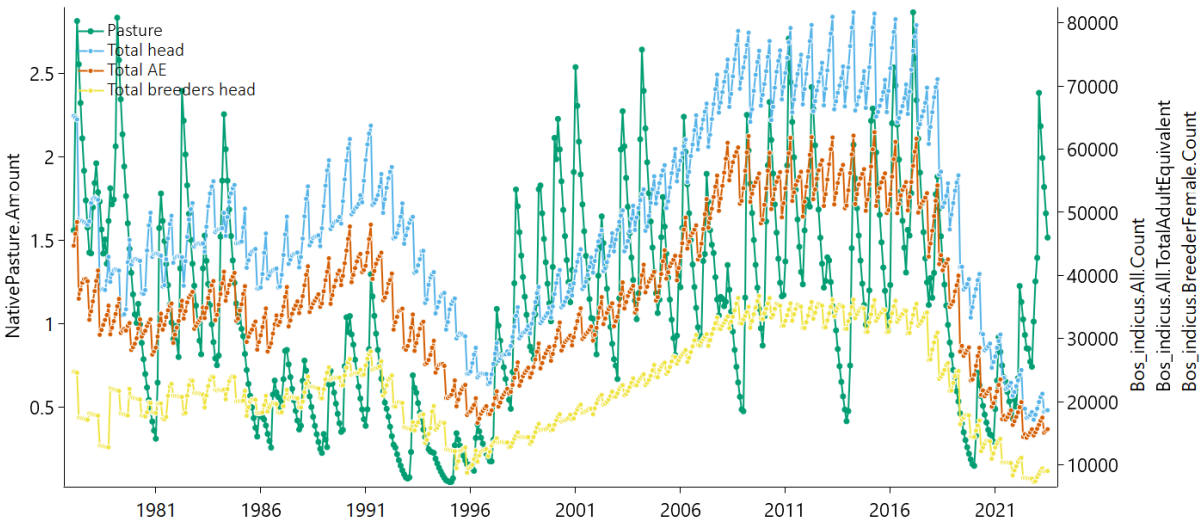


Figure 7-29: Annual changes in native pasture biomass (NativePasture.Amount; tonnes/ha), total head (Bos_indicus.AllCount), total AE (Bos.indicusAll.TotalAdultEquivalent) and total breeder head (Bos.indicusBreederFemale.Count) for the Barkly herd 5 – 30746 AE

While herd size varied in response to changes in forage availability, there was still considerable annual variation in pasture utilisation rates (Figure 7-30). Given that the safe pasture utilisation rate for this predominantly black soil land type is 20%, annual utilisation rates were well above safe for several years during the first 21 years of the simulation period, when rainfall and thus pasture biomass were often low. This culminated in very high pasture utilisation rates during the 1990s drought. Both land condition and grass basal area declined considerably during this time. Following this was 20 years when annual rainfall and pasture biomass were mostly above average, during which time both land condition and grass basal area improved and remained close to their maximum values. Then, 2019 and 2020 were dry years, resulting in high utilisation rates, and rapid declines in land condition and grass basal area. These only began to recover with increases in rainfall and pasture biomass at the end of the simulation period. For the entire simulation period, the average annual utilisation rate was 25.7% and the median annual utilisation rate was 15.5%.

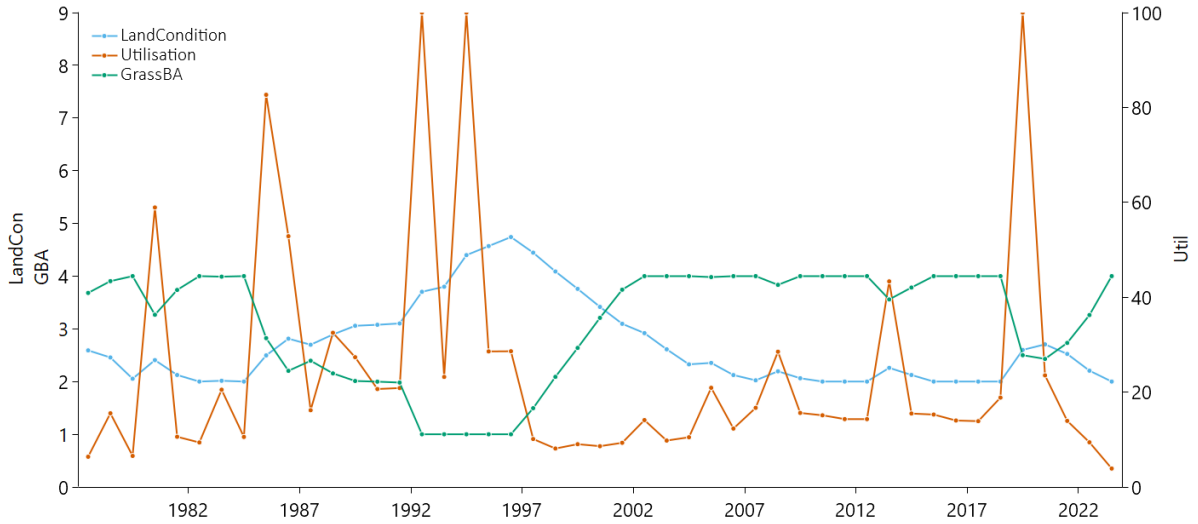


Figure 7-30: Annual utilisation rate (Util), land condition state (LandCon) and grass basal area (GBA) for the Barkly herd 5 – 30746 AE

Herd 7 had higher herd numbers than herd 5 but still generally matched herd size to carrying capacity, keeping utilisation lower than 20% for enough years to maintained land condition (Figure 7-31).

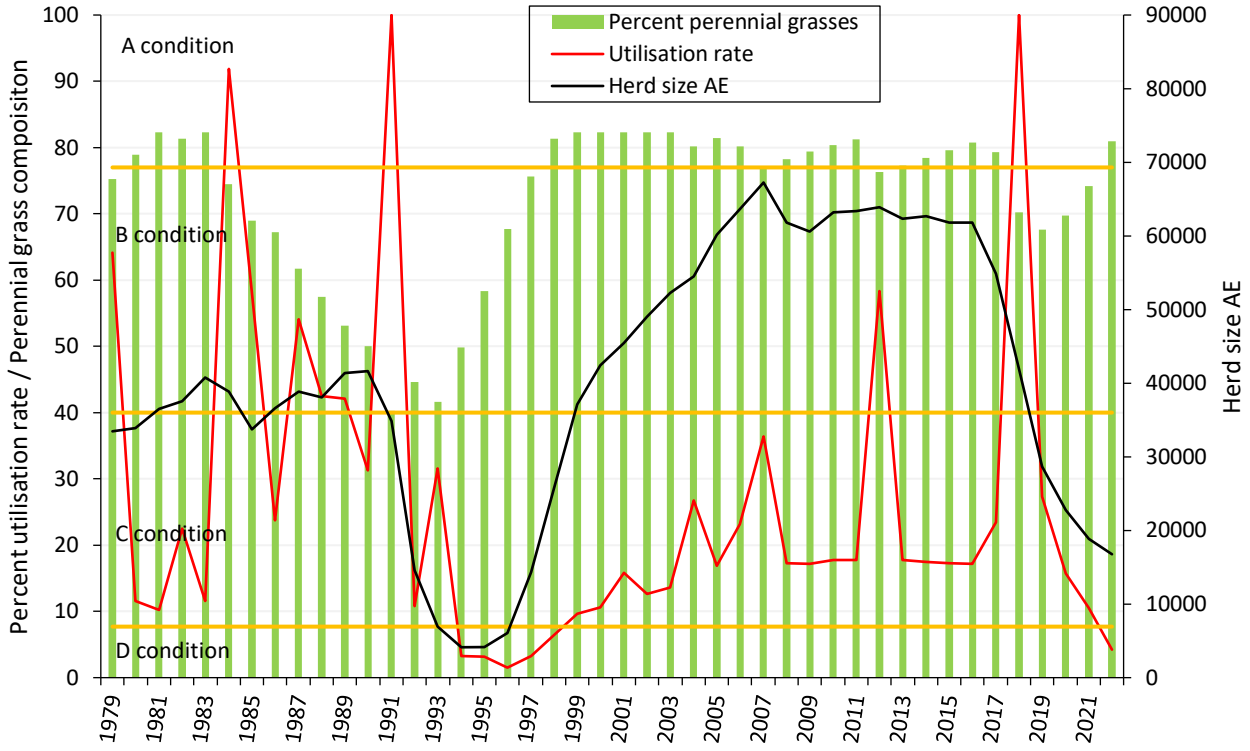


Figure 7-31: Time series of annual herd size, related annual pasture utilisation rate, annual percent perennial grass composition and related land condition ratings for the herd 7 - 33482 AE PB

Time series of the Barkly herd sizes below long-term carrying capacity

Four herds were simulated with initial herd sizes which were less than the long-term carrying capacity. They were 1 - 23651 AE, 2 - 25922 AE, 3 - 27210 AE and 4 - 28514 AE. For each of these four herds there was less but still considerable variation in total annual AEs and total breeder numbers. An example of this is shown in for the herd 2 – 25922 AE (Figure 7-32).

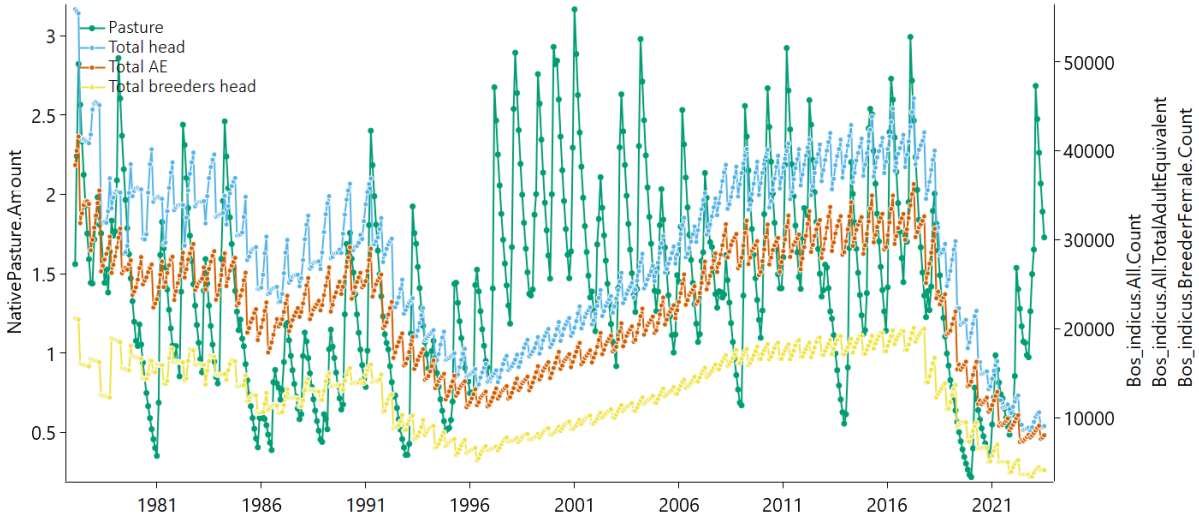


Figure 7-32: Annual changes in native pasture biomass (NativePasture.Amount; tonnes/ha), total head (Bos_indicus.AllCount), total AE (Bos.indicusAll.TotalAdultEquivalent) and total breeder head (Bos.indicusBreederFemale.Count) for the Barkly herd 2 – 25922 AE

Given that the size of this herd was less than the properties long-term carrying capacity, with average stocking rates of 4.7 AE/km^2, annual utilisation rates over the simulation period were mostly below the safe rate of 20% (Figure 7-33). There were only four periods of dry years when utilisation rates exceeded the safe rate, which caused land condition and grass basal area to decline by relatively small amounts, and for short periods of time. Average annual utilisation rate was 13.6% and median utilisation rate was 7.6%.

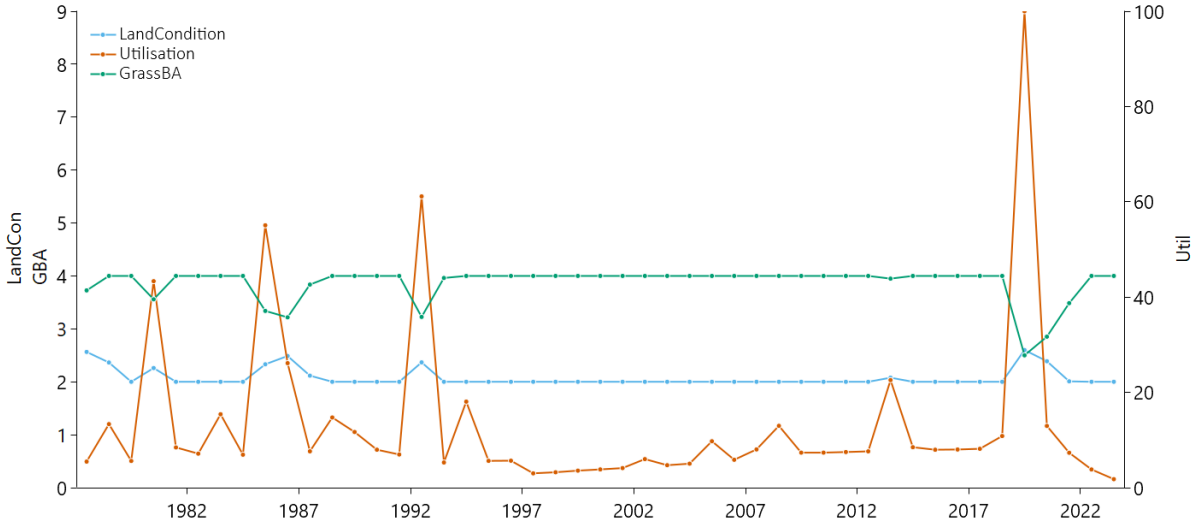


Figure 7-33: Annual utilisation rate (Util), land condition state (LandCon) and grass basal area (GBA) for the Barkly herd 2 – 25922 AE

Time series of the Barkly herd sizes above long-term carrying capacity

Herds with initial sizes well above long-term carrying capacity could not be maintained during droughts, and particularly the severe drought of the 1990s. For example, a herd with an initial size of 35222 AE in 1979 declined in size by around 80% during the drought years of 1992 to 1994. Pasture utilisation rates were 100% in two of these three years, which were associated with simulated deaths of around 14000 females (approximately 50% of the female breeder herd) from starvation and the culling of a further 7000 empty breeders. With only natural recruitment, this herd with an initial size of 35222 AE took close to 20 years before it recovered its original size.

The very high mortality rate of the herd with initial size of 35222 AE is generally not typical of what now occurs in the Barkly Tablelands with best practice management during severe droughts. Cattle producers avoid this by agistment and/or destocking, or by adding waters to previously unwatered parts of stations. Also, cattle producers would not wait 20 years during favourable climatic conditions and abundant forage supplies to rebuild herd size through natural recruitment. Instead, they would have brought cattle back from agistment or purchased breeders and/or other cattle to rebuild herds quickly. Consequently, unrealistic simulations such as this with an initial herd size of 35222 AE were rejected as potential scenarios for the Barkly property. Instead, all simulations of herds with initial sizes considerably higher than the long-term carrying capacity involved destocking of various proportions of empty breeders, heifers and pregnant breeders during droughts to minimise mortality due to starvation. In addition to this, young breeder females were purchased after droughts to recover herd size when climatic conditions improved.

The five herds with initial sizes above long-term carrying capacity were 6 - 31908 AE PB, 7 - 33482 AE PB, 8 - 34400 AE PB, 9 - 35222 AE PB and 10 - 35267 AE PB. The PB at the end of these herd names signifies purchasing of female breeders after droughts. An example of the decline of total and breeder herd size through destocking during drought and its recovery through purchasing is shown for herd 9 - 35222 AE PB in Figure 7-34.

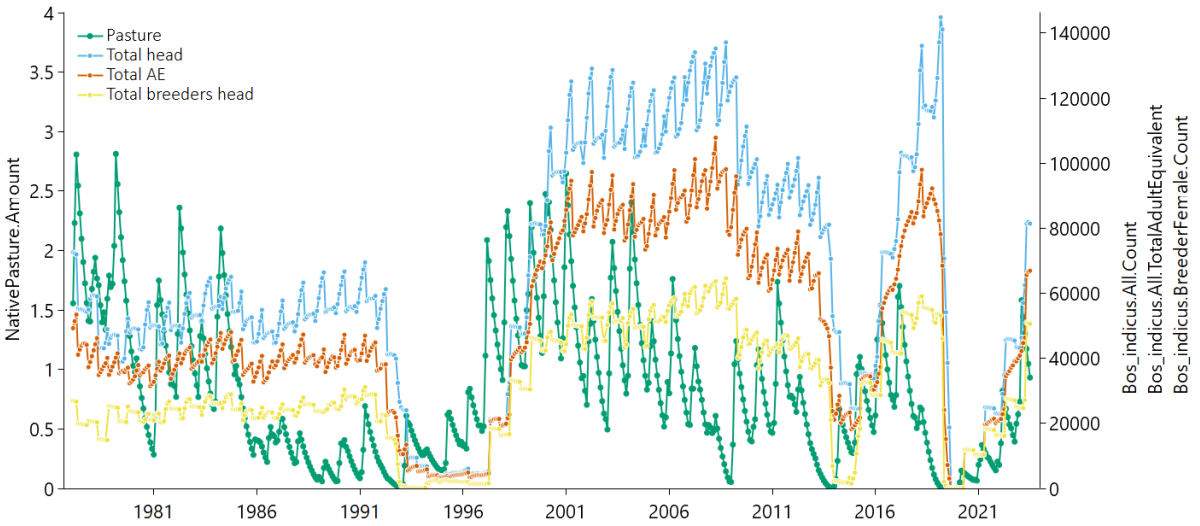


Figure 7-34: Annual changes in native pasture biomass (NativePasture.Amount; tonnes/ha), total head (Bos_indicus.AllCount), total AE (Bos.indicusAll.TotalAdultEquivalent) and total breeder head (Bos.indicusBreederFemale.Count) for the Barkly herd 9 - 35222 AE PB

Maintaining a herd with an initial and average annual size much greater than the long-term safe size resulted in many years where pasture utilisation rates were well above safe (Figure 7-35). Average stocking rate was 9.8 AE/km^2 and annual utilisation rate was 34.6% and median utilisation rate was 25.2%.

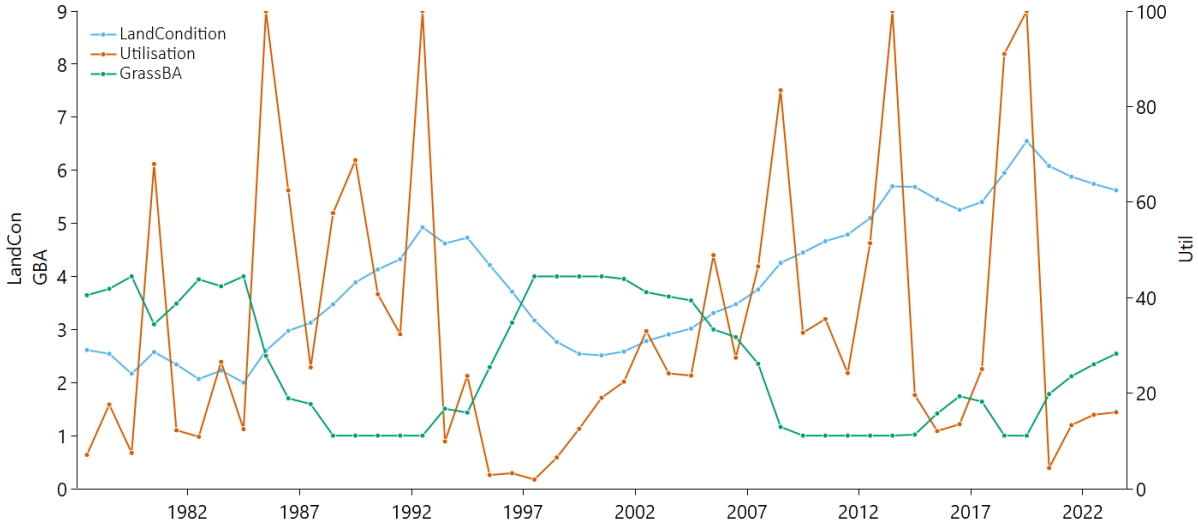


Figure 7-35: Annual utilisation rate (Util), land condition state (LandCon) and grass basal area (GBA) for the Barkly herd 9 – 35222 AE PB

Herd 8 was also above long-term carrying capacity (9.6 AE/km^2), but was the most profitable because the climate of the simulation was wetter than usual (Figure 7-36).

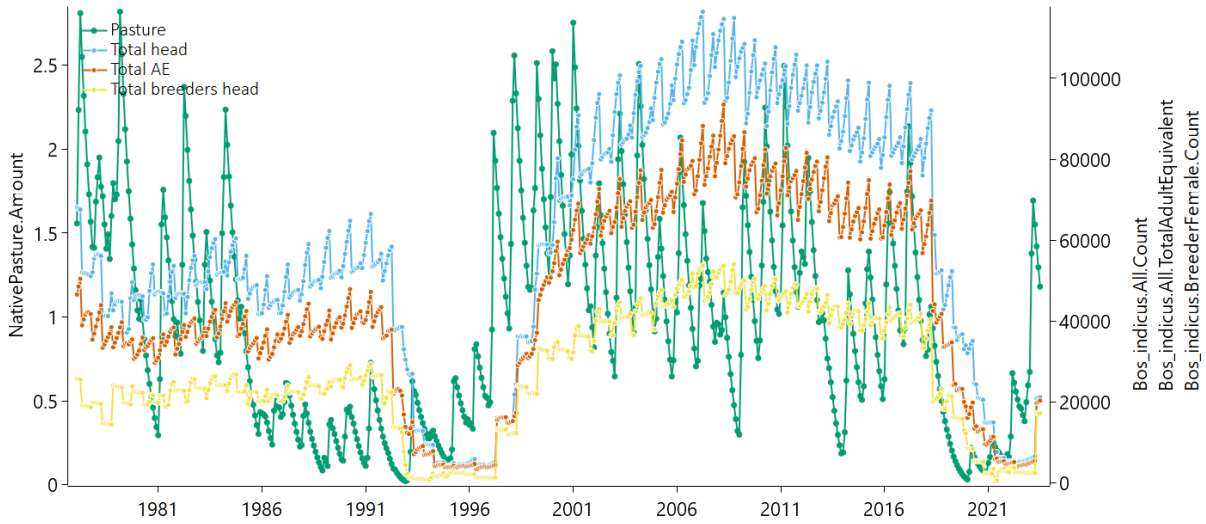


Figure 7-36: Annual changes in native pasture biomass (NativePasture.Amount; tonnes/ha), total head (Bos_indicus.AllCount), total AE (Bos.indicusAll.TotalAdultEquivalent) and total breeder head (Bos.indicusBreederFemale.Count) for the Barkly herd 8 – 34400 AE PB

During the period 2005 to 2020, with the very high herd numbers, average or below average rainfall years led to high annual pasture utilisation rates well above 20%, which caused land condition to deteriorate substantially (Figure 7-37). While the herd was largely destocked through forced sales at the end of the simulation period, the previous 17 years of very high productivity and profitability, achieved at the expense of land condition, made this the most profitable herd. If the simulation period had been continued for a further 10 years, then the average annual productivity and profitability of this herd would have been lower.

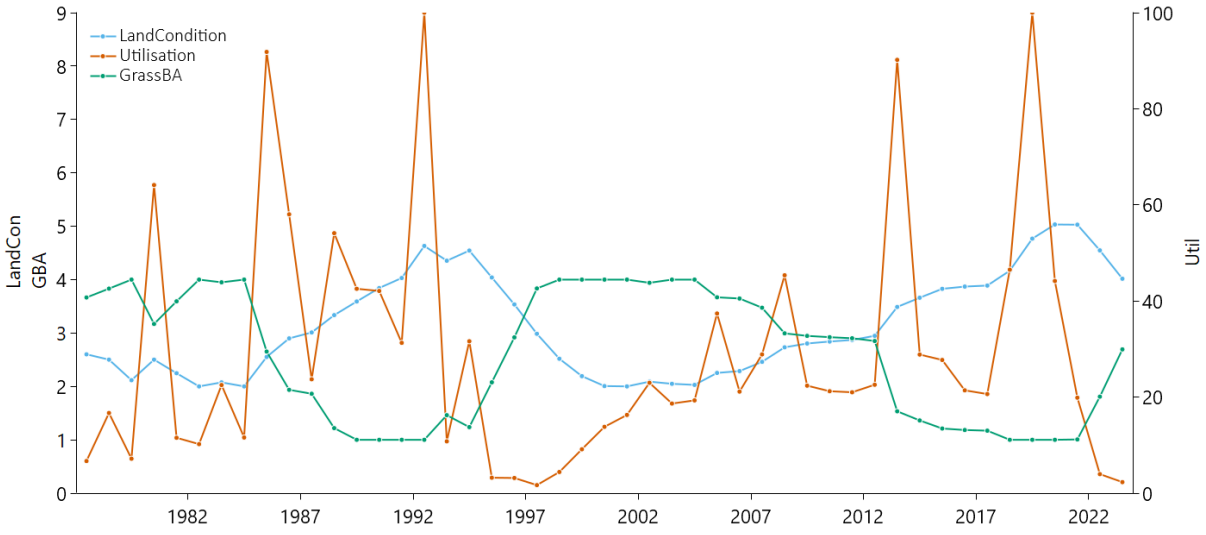


Figure 7-37: Annual utilisation rate (Util), land condition state (LandCon) and grass basal area (GBA) for the herd 8 – 34400 AE PB

Changes in annual percent perennial grass composition (index of land condition) over the 44-year simulation period for herd 8 – 34400 AE PB are shown in Figure 7-38. As annual pasture utilisation rates were lower than the safe rate of 20% during the first few years of the simulation period, percent perennial grass composition improved from 67 to 82%. This represents land condition improvement from B to A at this time (Walsh and Cowley 2016). Then from 1983 to 1991, a period of

eight years, percent perennial grass composition declined to 40% (high C condition). From 1994 to 2003, due to a combination of high annual pasture growth rates and relatively low herd sizes, annual utilisation rates were low and percent perennial grass composition increased to 82% (A condition) in six years. This was followed by 16 years of utilisation rates mostly >20%, over which time percent perennial grass composition fell from 82 to 34% (C condition). Land condition was only just recovering from C to B at the end of the simulation period. Consequently, herd productivity and profitability would have been low during the next decade, as it would have been difficult to recover herd size when land condition and pasture productivity were low.

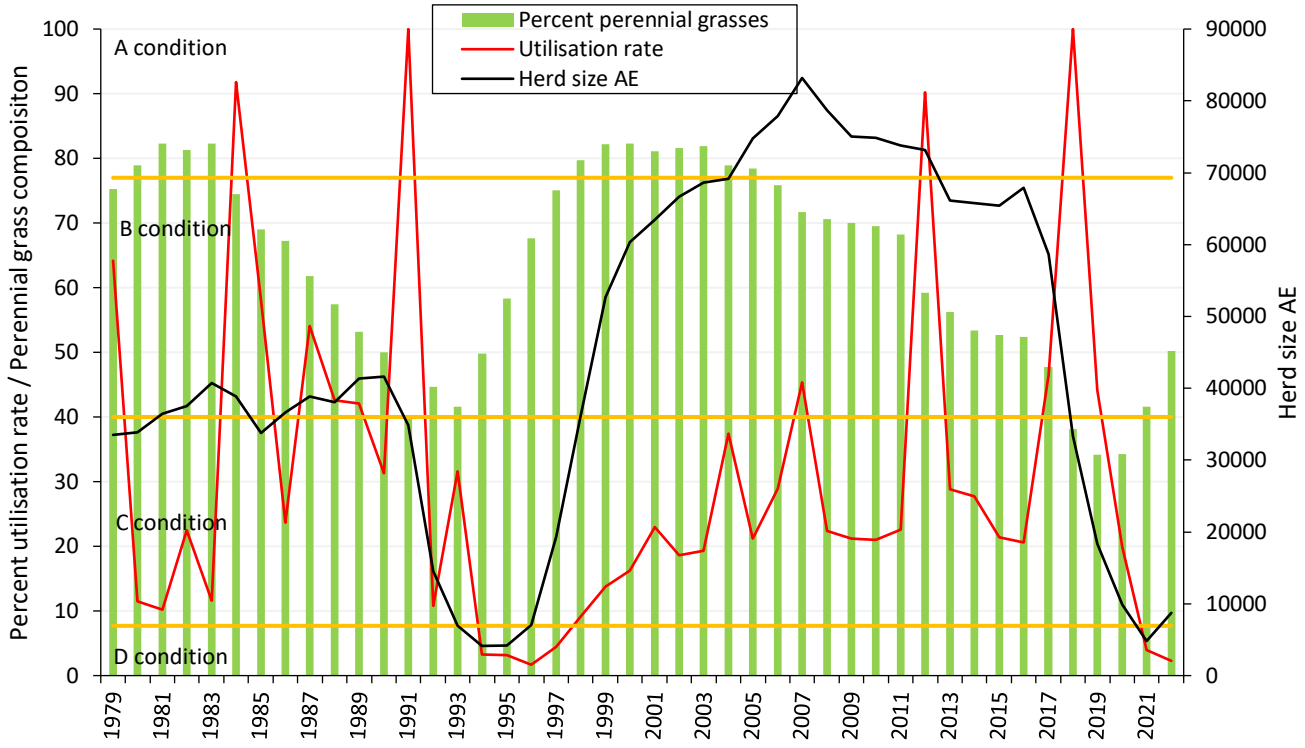


Figure 7-38: Time series of annual herd size, related annual pasture utilisation rate, annual percent perennial grass composition and related land condition ratings for the herd 8 – 34400 AE PB

Impact of pasture utilisation on Barkly Tableland herds

The 44 years of simulated annual values such as herd size, land condition state and utilisation rate were averaged for each of the 10 Barkly herds. This enabled the 10 different sized herds and their associated different pasture utilisation rates to be compared for a wide range of pasture-, reproduction-, herd productivity- and financial-related performance metrics. These performance metrics are presented in Table 14-7 - Table 14-10 of Appendix 14.5, page 409. A smaller number of key metrics which were representative of the outcomes of herds in relation to pastures, herd productivity and finances are shown in Table 7-23.

Table 7-23: Key average annual performance metrics for pastures, herd productivity and enterprise finances for the 10 simulated Barkly herds over 44 years, listed in descending order of average annual profitability/ha/year (AE = adult equivalent; SR* = stocking rate per accessible area; UR = utilisation rate)

Simulation Name / Initial AE	Average annual AE	Average annual SR* (AE/km2)	Average pasture UR (%)	Median pasture UR (%)	Pasture yield June 30 (kg/ha)	Percent perennial grasses	Kg beef/ ha/yr	Kg Beef/ AE/yr	Gross Profit/ ha/yr	Gross profit/ AE/yr	Variable costs/ ha/yr	Variable costs/ AE/yr	Gross profit margin/ ha/yr	Gross profit margin/ AE/yr	Profit/ ha/yr	Profit/ AE/yr
8 - 34400 AE PB	44768	9.6	30.5	22.4	967	64	14.0	146	$36.49	$380	-$7.75	-$81	$28.74	$299	$20.94	$217.87
6 - 31908 AE PB	40186	8.6	25.6	16.8	1115	74	12.9	149	$34.64	$401	-$7.08	-$82	$27.56	$319	$20.56	$238.31
7 - 33482 AE PB	40433	8.7	26.6	17.4	1093	73	12.8	147	$34.23	$394	-$7.09	-$82	$27.15	$313	$20.11	$231.59
5 - 30746 AE	37274	8.0	25.7	15.5	1098	72	12.0	149	$32.47	$406	-$6.56	-$82	$25.92	$324	$19.43	$242.71
4 - 28514 AE	32831	7.0	19.6	12.7	1319	80	10.7	151	$28.94	$411	-$5.84	-$83	$23.10	$328	$17.38	$246.57
9 - 35222 AE PB	45791	9.8	34.6	25.2	806	50	13.4	137	$31.15	$317	-$7.72	-$78	$23.43	$238	$15.46	$157.23
3 - 27210 AE	28193	6.1	17.0	10.2	1376	81	9.1	151	$24.91	$411	-$5.14	-$85	$19.77	$327	$14.86	$245.46
2 - 25922 AE	21932	4.7	13.6	7.6	1431	81	7.0	149	$19.26	$409	-$4.16	-$88	$15.10	$321	$11.28	$239.52
10 - 35267 AE PB	50282	10.8	36.0	27.8	772	49	13.1	121	$24.96	$231	-$8.14	-$75	$16.83	$156	$10.03	$92.93
1 - 23651 AE	19811	4.3	12.4	6.8	1448	82	6.3	148	$17.26	$406	-$3.82	-$90	$13.43	$316	$9.98	$234.72

In contrast to the Burdekin herds where there tended to be a negative relationship between the size of herds at the start of simulations and the average annual herd size achieved over the simulation period (Figure 7-76), this relationship for the Barkly herds was strongly positive and linear (Figure 7-39). While Barkly herds with high starting sizes did crash during drought, quickly restoring herd size by purchasing female breeders after drought did not always substantially degrade land condition and hence pasture production, due in large part to an unusually long period of higher-than-average annual rainfall.

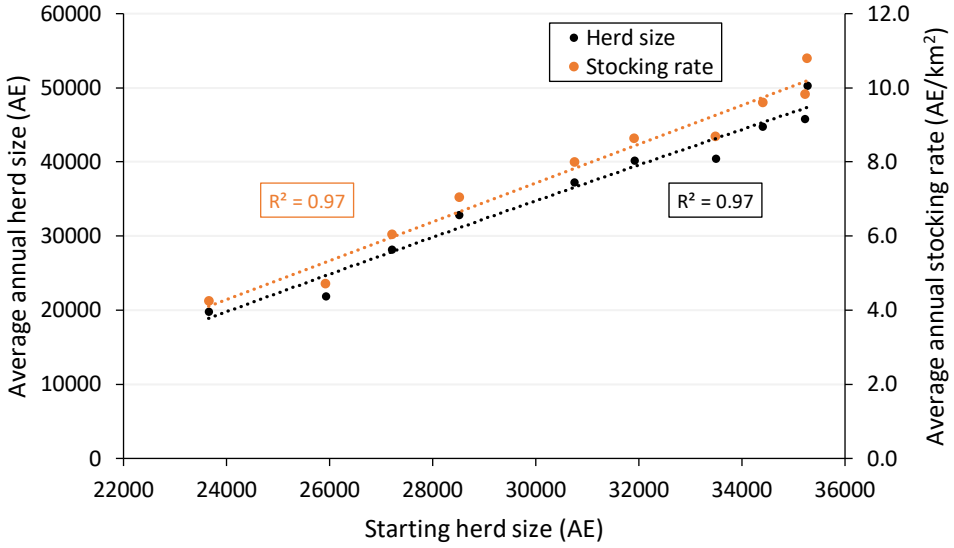


Figure 7-39: Relationship between herd size at the start of simulations, average annual herd size and average annual stocking rate, for the 10 simulated Barkly herds (fitted lines are linear). Average of 44 years

While the focus of this work was the extent that pasture UR was correlated with each performance metric, it was unclear if this should be based on average or median values. Microsoft Excel was used to calculate R^2 values, based on a 2nd order polynomial trend line, to show the extents that average and median annual URs were correlated with 42 average and median annual performance metrics. As such, for each performance metric, R^2 values were calculated for median UR vs median performance metric, median UR vs average performance metric, average UR vs median performance metric, average UR vs average performance metric. For 28 of 42 performance metrics (67%), the relationship which most frequently had the highest R^2 values was median UR vs average performance metric. For only six performance metrics, including pasture yield, grass basal area and land condition state, average UR vs average performance metric had the highest R^2 values. This was followed by median UR vs median performance metric and average UR vs median performance metric, both of which had the highest R^2 values for only four performance metrics. Consequently, the combination of values used to compare herds with different stocking rates was median annual utilisation rate vs. average annual performance metrics.

The median is also likely to be a more representative measure of annual utilisation rates because of the skewed distribution of annual utilisation rates during the 44-year Barkly simulation period (Table 7-24). The simulated herds generally had many more years with low utilisation rates and only a few years with very high rates. In seven of the 10 herds, the two smallest of five bands of utilisation rate (UR >0 and ≤12%, UR >12 and ≤20%) accounted for more than 50% of years. Consequently, median annual utilisation rates were only 55 to 77% of average annual rates. When the median pasture utilisation was 20%, the average pasture utilisation was 28.5% (Figure 7-40).

Table 7-24: Average and median annual percent utilisation rate (UR) and the number of years with utilisation rates in five bands of utilisation for each of the 10 simulated Barkly herds (average of 44 years) (AE = adult equivalent; PB = purchase female breeders)

	1 - 23651 AE	2 - 25922 AE	3 - 27210 AE	4 - 28514 AE	5 - 30746 AE	6 - 31908 AE PB	7 - 33482 AE PB	8 - 34400 AE PB	9 - 35222 AE PB	10 - 35267 AE PB
Average	12.4	13.6	17.0	19.6	25.7	25.6	26.6	30.5	34.6	36.0
Median	6.8	7.6	10.2	12.7	15.5	16.8	17.4	22.4	25.2	27.8
UR >0 and ≤12	35	33	30	18	12	10	13	11	9	12
UR >12 and ≤20	4	5	7	16	14	18	13	5	7	5
UR >20 and ≤30	1	2	1	3	10	7	6	13	10	7
UR >30 and ≤48	1	1	3	3	2	2	5	8	6	7
UR >48 and ≤100	3	3	3	4	6	7	7	7	12	13
% years > 20%	11%	14%	16%	23%	41%	36%	41%	64%	64%	61%
% years >30%	9%	9%	14%	16%	18%	20%	27%	34%	41%	45%

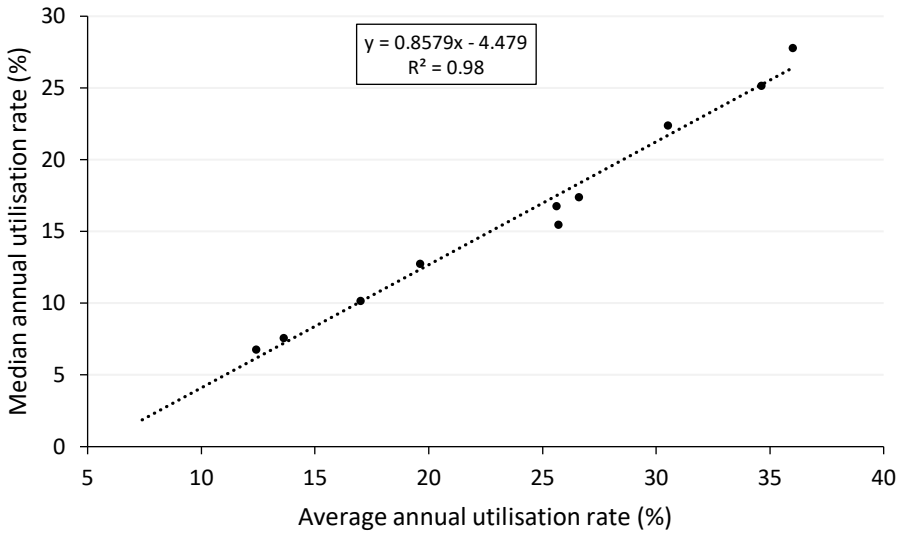


Figure 7-40: Median vs. average pasture utilisation in Barkly herd simulations (fitted line is linear). Average of 44 years

At a median pasture utilisation rate of 20%, annual pasture utilisation rates exceeded 30% in 29% of years (Figure 7-41).

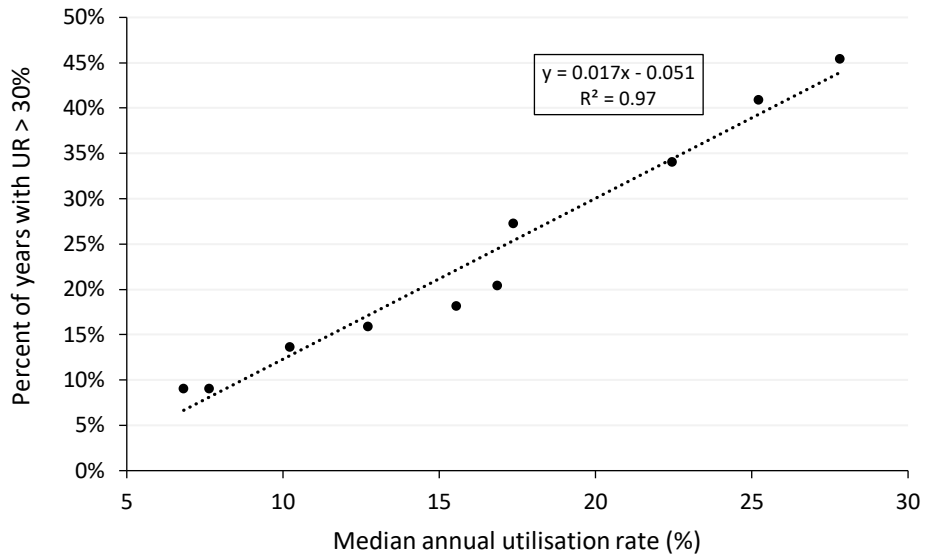


Figure 7-41: Relationship between percent of years with annual pasture utilisation rates greater than 30% and median pasture utilisation rate for the 10 simulated Barkly herds (fitted line is linear). Average of 44 years

Total herd size, stocking rate and breeder herd size

Pasture utilisation increased with average annual herd size in the Barkly herds (Figure 7-42). Herd size in AE did not increase at the same rate as herd size in head, due to lower individual animal performance at higher pasture utilisation (page 174).

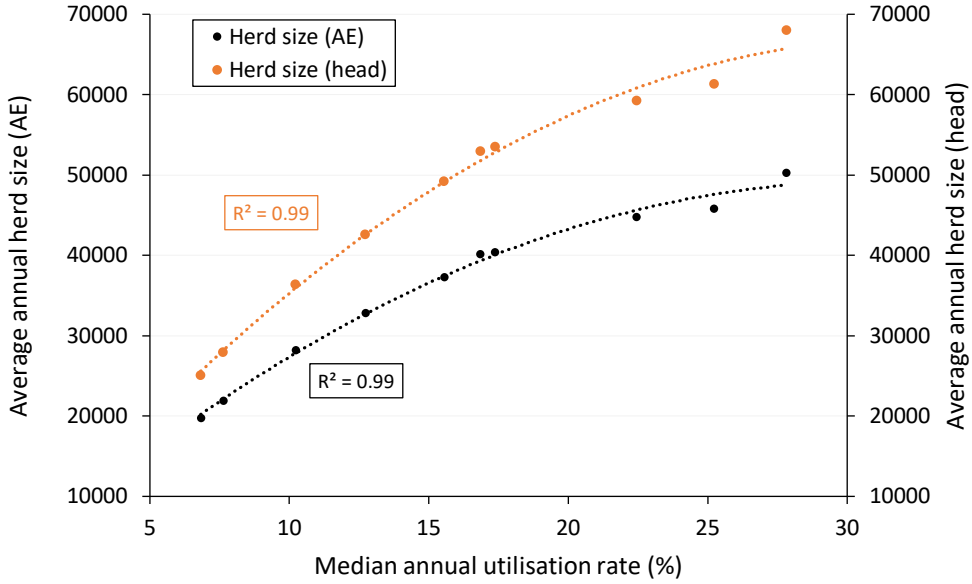


Figure 7-42: Relationships between average annual herd size (AE and head) with median annual pasture utilisation rate for the 10 simulated Barkly herds (fitted lines are a 2nd order polynomial). Average of 44 years

Increasing average annual total herd size from 20,000 to 40,000 AEs, and stocking rate (AE/km^2) from 4.3 to 9 AE/km^2, increased median annual pasture utilisation rates from 7 to 17%, but increases in pasture utilisation began to plateau with higher stocking rates (Figure 7-43).

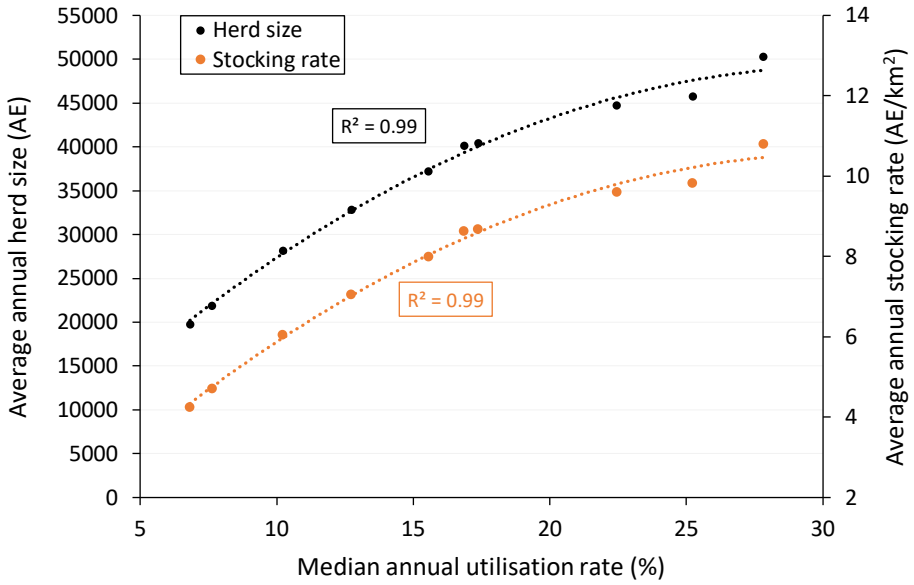


Figure 7-43: Relationships between the average annual total herd size, average annual stocking rate and median annual pasture utilisation rate, for the 10 simulated Barkly herds (fitted lines are 2nd order polynomials). Average of 44 years

As with herd size which increased with increases in pasture utilisation rate, so did year-to-year variability in herd size, represented here as the coefficient of variation in herd size expressed in AEs (Figure 7-44). Higher variability in year-to-year herd size was indicative of needing to sell and restock more often at higher utilisation.

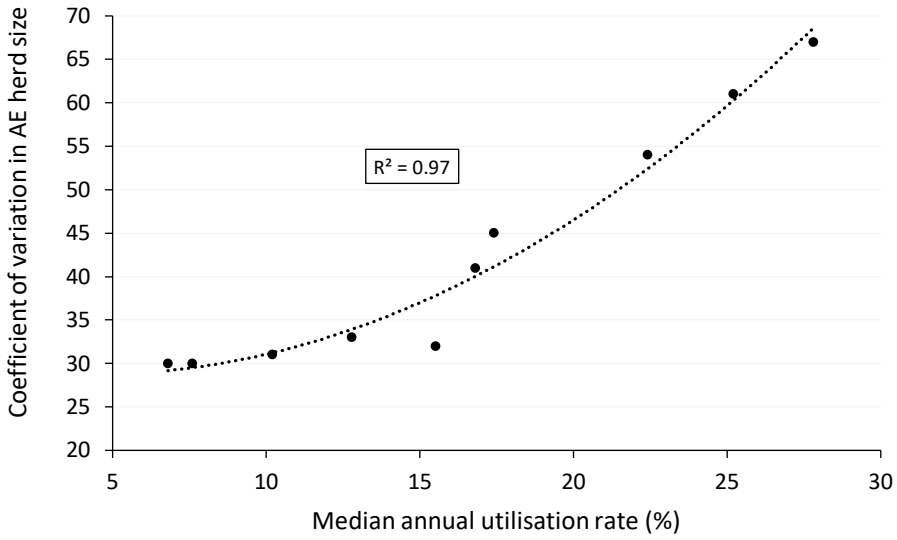


Figure 7-44: Relationships between the coefficient of variation in average annual herd size (AE) and median annual pasture utilisation rate for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

As with total herd size, and as expected, increasing breeder herd size from 12,444 AEs (63% total AEs) to 36,899 AEs (73% of total AEs) also increased pasture utilisation rate from 7% to 28% (Figure 7-45).

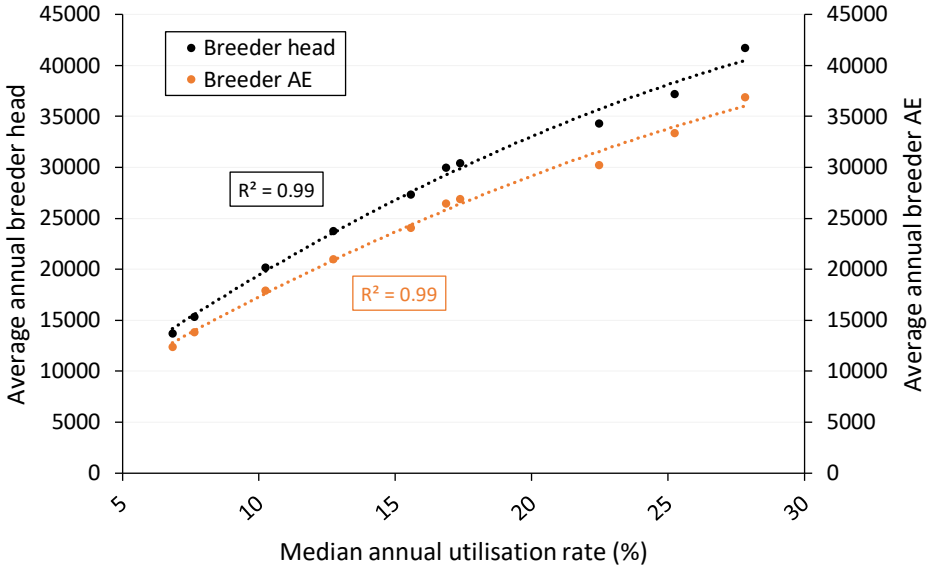


Figure 7-45: Relationships between the average annual breeder herd size and median annual pasture utilisation rate for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

The resource base

As average annual herd size (and pasture utilisation) increased (Figure 7-45), average percent perennial grass composition declined from around 80 to 50% (Figure 7-46). The start condition for the Barkly simulations was 70% perennial grasses which represents high B condition. For simulations where the median pasture utilisation rates were lower than 15%, average % perennial grasses increased to around 80% which represents low A condition. When median pasture utilisation rates were higher than 20%, average % perennial grasses declined to levels below the start condition to mid B condition.

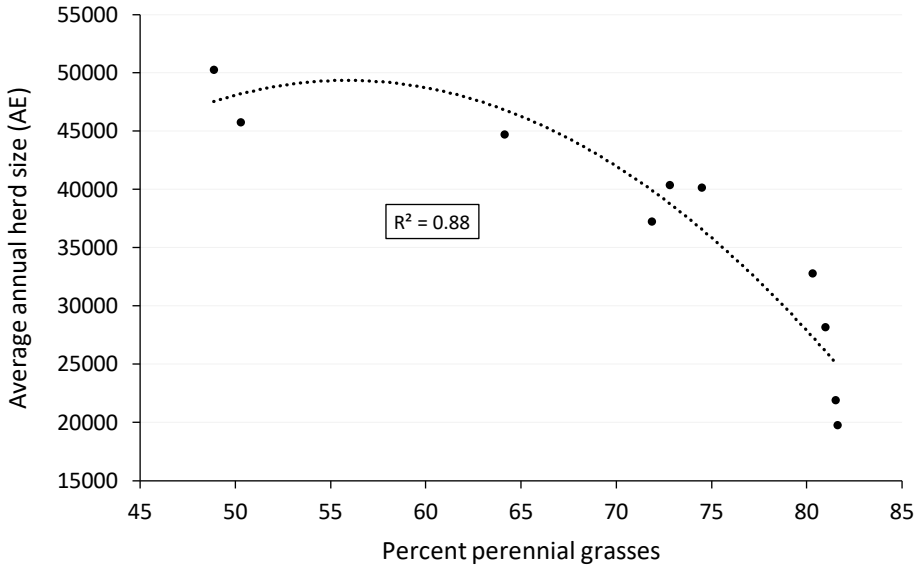


Figure 7-46: Relationships between the average annual breeder herd size and average annual percent perennial grass composition for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

Average June 30 pasture yield was closely and negatively associated with median annual pasture utilisation rate (Figure 7-47), due to both the negative impact of pasture condition on pasture growth (Figure 7-48), and the higher total intake.

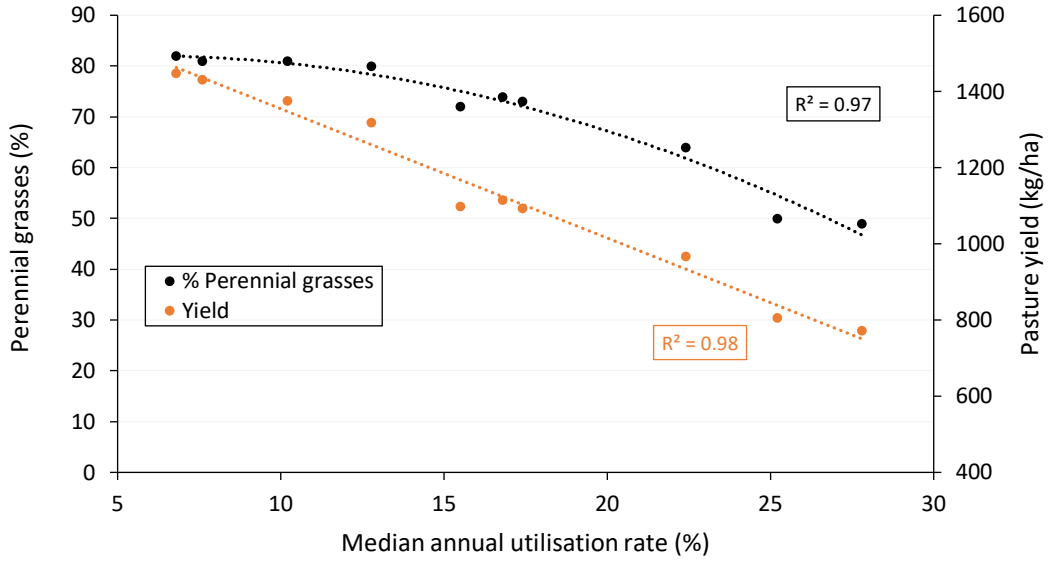


Figure 7-47: Relationship between the average June 30 pasture yield (kg/ha) and median annual pasture utilisation rate for the 10 simulated Barkly herds (pasture yield fitted line is linear, % perennial grasses fitted line is 2nd order polynomial). Average of 44 years

Pasture yield at June 30 increased from 800 to 1400 kg/ha as average annual percent perennial grass composition increased from 50 to 80% (Figure 7-48).

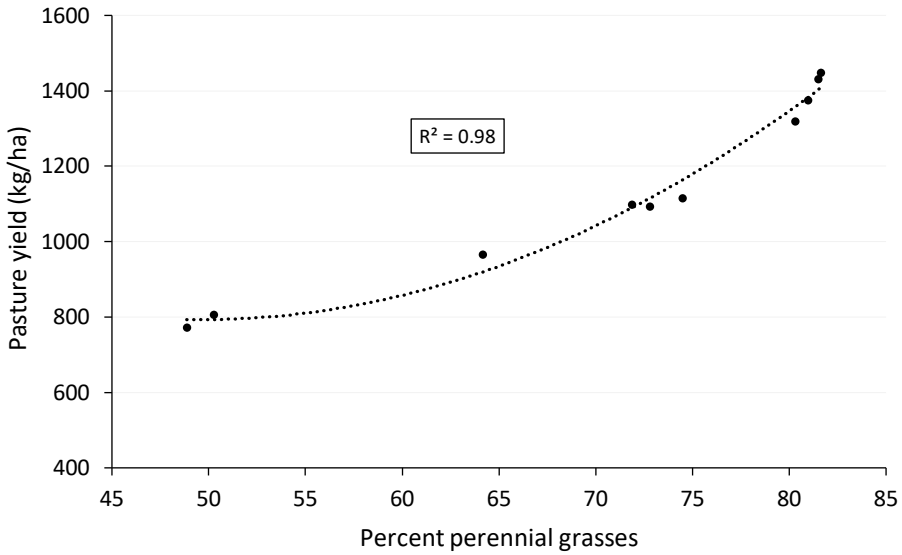


Figure 7-48: Relationship between the average June 30 pasture yield (kg/ha) and average annual perennial grass composition for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

Individual animal performance

Herds with utilisation rates between 7 and 16% had the highest weaning rates of around 73%, then weaning rates declined quickly to 57% as pasture utilisation rate rose above 18% (Figure 7-45). Also, the annual variability in weaning rates increased with increases in utilisation rate. The range in annual weaning rates for the four herds with the lowest utilisation rates was 59-82%, whereas that for the two herds with the highest utilisation rates was 0-98% (see Table 14-8 in Appendix 14.5)

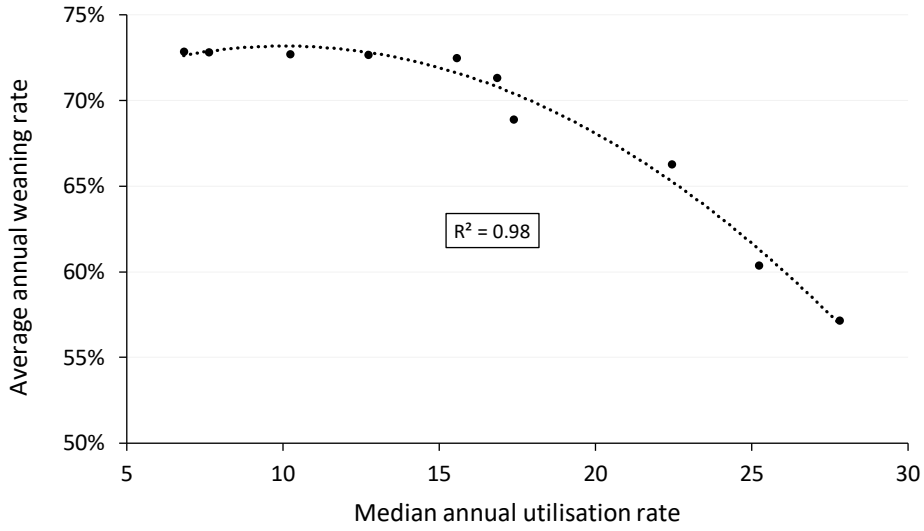


Figure 7-49: Relationship between the average annual weaning rate and median pasture utilisation rate for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

The lower weaning rates at higher utilisation led to fewer kg of weaner produced per breeder head and AE (Figure 7-50).

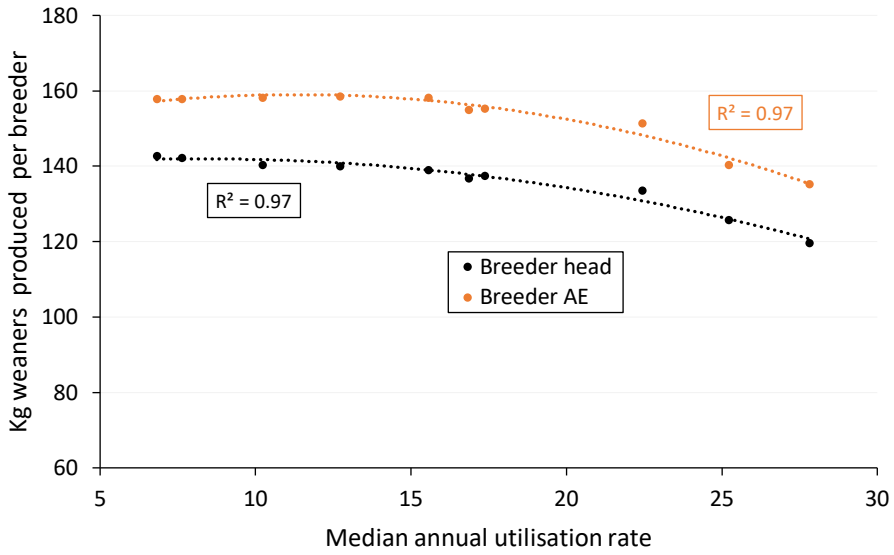


Figure 7-50: Relationship between the average kg of weaners produced/AE and median annual pasture utilisation rate for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

The kgs of beef produced/AE (Figure 7-51) was more sensitive to median utilisation than kg weaners produced per breeder AE. Beef produced/AE was very similar for herds with median utilisation rates of 7 to 17%, ranging from around 148 to 151 kg, then declined sharply with further increases in utilisation rate. At the two highest median utilisation rates of 25 and 28%, kgs beef produced/AE were only 137 and 121 kgs respectively.

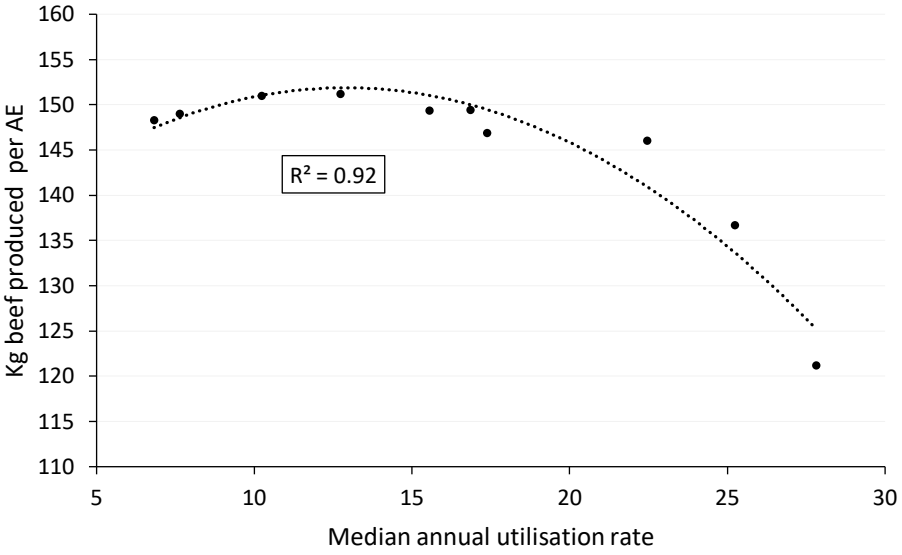


Figure 7-51: Relationship between the average annual kg beef produced per AE and median annual pasture utilisation rate for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

Herd productivity

While individual animal performance such as weaning rate, kg weaners produced/breeder AE and kg of beef produced/AE tended to be lowest at the highest utilisation rates, productivity per hectare

tended to increase with increases in utilisation rate. Annual average kg of weaners produced/ha increased rapidly as utilisation rate increased from 7 to 17%, then plateaued with further increases in utilisation rate (Figure 7-52). While herd size increased by 15% from 59,290 head at a utilisation rate of 22 to 68,004 head with a utilisation rate of 28%, the kg weaners produced/ha only increased by 9%, due to a drop in weaning rates at these highest utilisation rates.

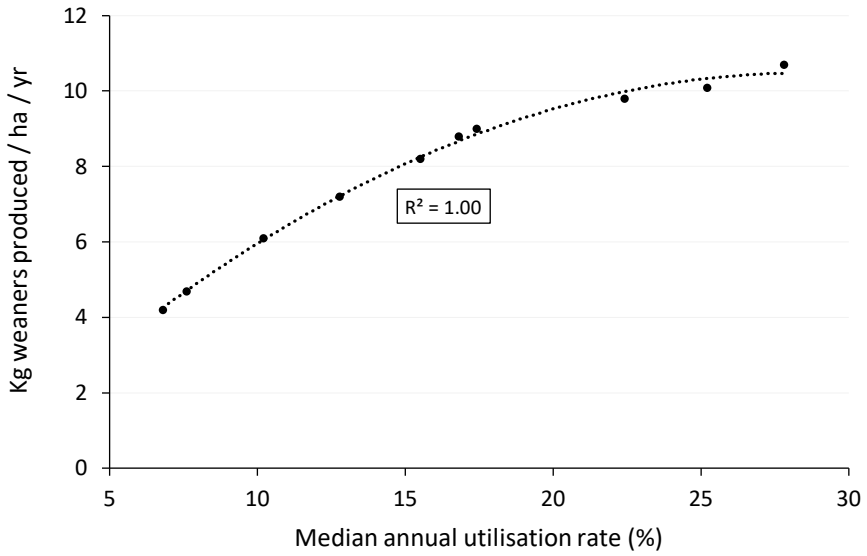


Figure 7-52: Relationship between the average kg of weaners produced/ha/year and median annual pasture utilisation rate for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

Average annual kg beef produced (change in liveweight of all animals) also increased steadily as the utilisation rates of simulated herds increased from 7 to 22%, then declined marginally with further increases in utilisation rate (Figure 7-53). The latter was due to lower growth rates and lower adult liveweights at the higher utilisation rates.

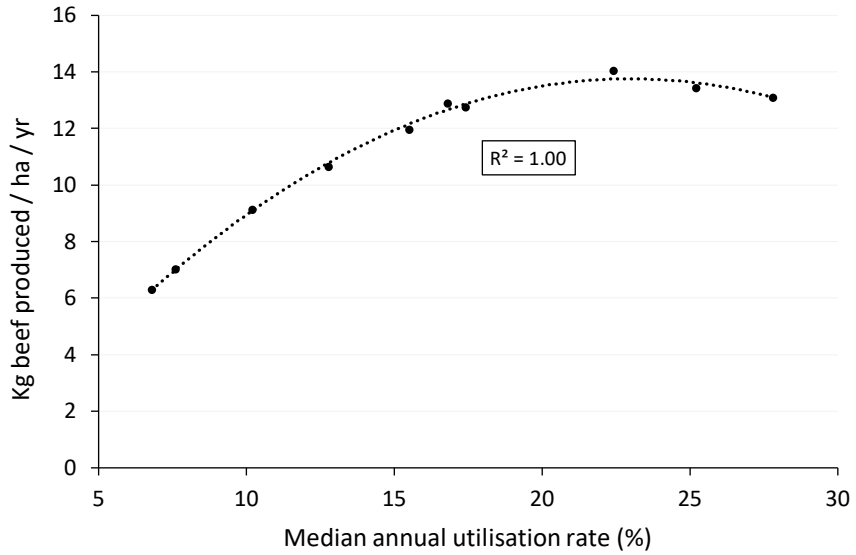


Figure 7-53: Relationship between the average annual kg beef produced/ha/year and median annual pasture utilisation rate for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

Gross profit

Annual profit = gross profit – variable and overhead costs. Gross profit is the annual income from cattle sales minus costs of purchasing cattle plus the difference in the value of cattle present at the end and beginning of the financial year. The relationship between average annual gross profit/ha and utilisation rate (Figure 7-54) was similar to that for the kgs of beef produced/ha/year (Figure 7-53). Gross profit increased as utilisation rates increased from 7 to 22%, and then instead of plateauing, it fell sharply with further increases in utilisation rate. Gross profit/ha declined more steeply than kg of beef produced/ha above 22%, so that gross profit at 28% utilisation was equal to that at just 10% pasture utilisation. The steep fall in gross profit at the two highest utilisation rates was largely due to the large numbers of female breeders purchased by these herds (Figure 7-44).

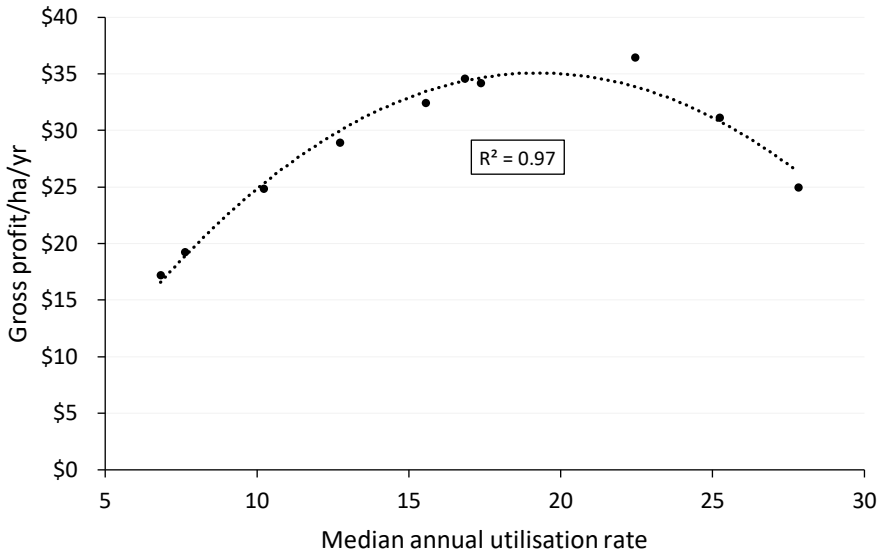


Figure 7-54: Relationship between the average annual gross profit/ha/year and median annual pasture utilisation rate for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

Variable costs

Variable costs are the per-individual animal expenses incurred for activities such as mustering, weaning, castration, tags and husbandry treatments. Annual variable costs increased with increases in median annual utilisation rates (Figure 7-55) reflecting total herd size increases with increases in utilisation rate (Figure 7-42).

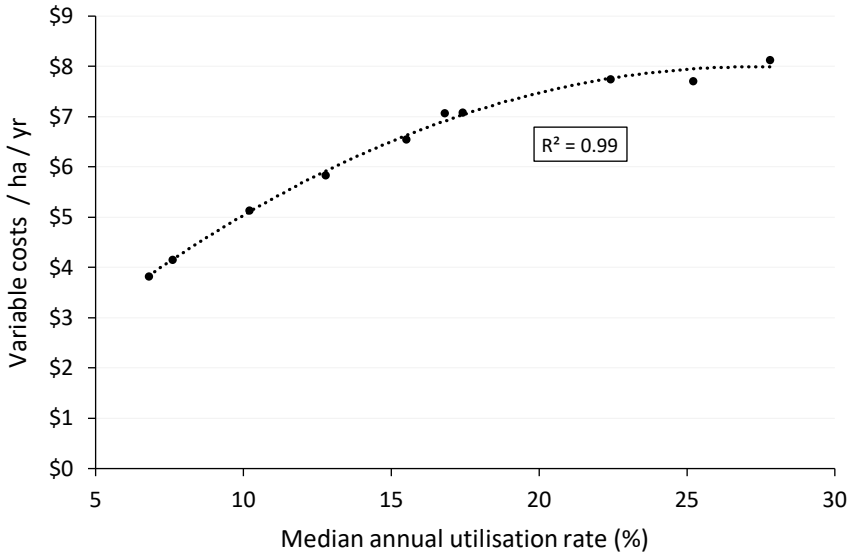


Figure 7-55: Relationship between the average annual variable costs/ha/year and median annual pasture utilisation rate for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

Average annual variable costs/AE decreased consistently with increases in median pasture utilisation rate (Figure 7-56). This was largely due to the avoided costs of mustering, branding, weaning, husbandry and supplementation associated with purchasing large numbers of mature female

breeders, and partly due to cost-efficiencies associated with increasing stocking rates. There was a reduction of $15/AE in variable costs between the lowest and highest utilisation.

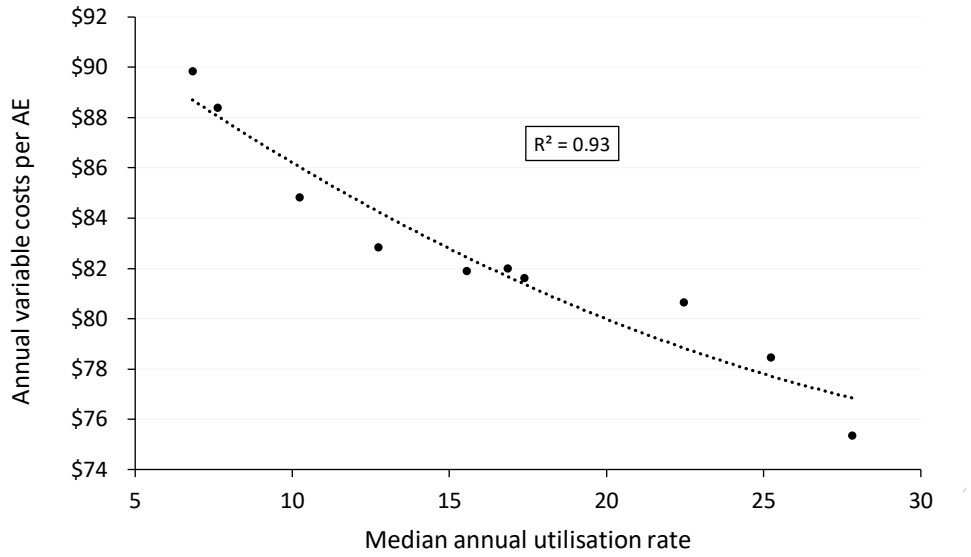


Figure 7-56: Relationship between the average annual variable costs/AE and median annual pasture utilisation rate for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

Total variable costs per kg beef produced were highest for the smaller herds with low median pasture utilisation rates and for the largest herds with the highest utilisation rates, while they were lowest for herds with utilisations rates of between 13 and 22% (Figure 7-57). There was a rapid increase in the average annual kg of beef produced/ha as utilisation rate increased from 7 to 17%, leading to a reduction in the variable costs per kg of beef produced. Because the total annual kg of beef produced/ha plateaued at approximately 22% utilisation (Figure 7-53), then declined with increasing utilisation rate, variable costs per kg of beef produced increased as utilisation rate increased above 22%.

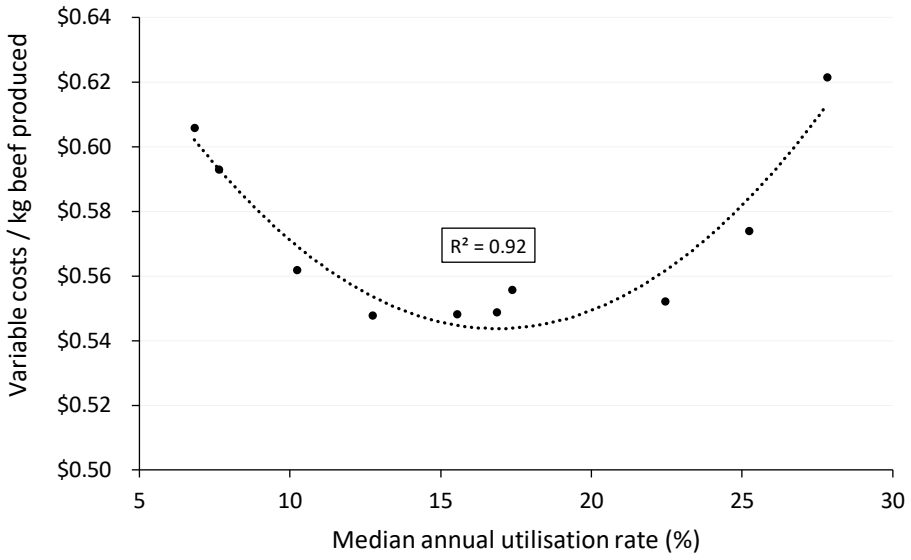


Figure 7-57: Relationship between the average annual variable costs/kg beef produced and median annual pasture utilisation rate for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

Profit

Average annual profit (gross profit – overhead and variable costs)/ha increased with increases in median utilisation rates from 7 to 17%. There was little additional profit at a utilisation rate of 22%, and profit declined above 22% (Figure 7-58).

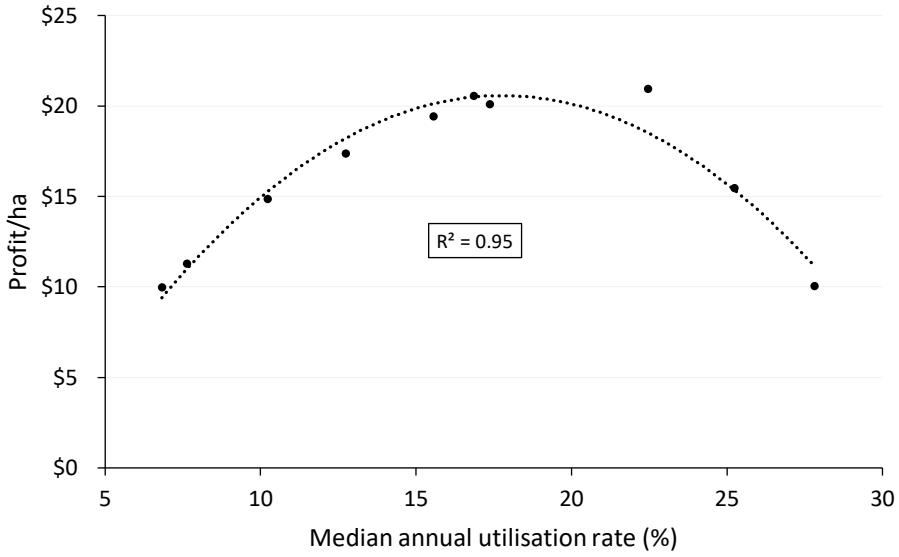


Figure 7-58: Relationships between the average annual profit/ha and median annual pasture utilisation rate for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

The trendline for the relationship between profit/ha and percent perennial grass composition (Figure 7-59) indicated that profits increased when perennial grass composition increased from 50 to 65% (low to mid B condition), were similar between 65 to 75% (mid to high B condition), then fell as perennial grass composition rose from 75 to 82%. This suggests peak profits were achieved at a mid

to high B condition, and achieving A condition on average across the 44 years was only possible with lower profits due to the lower stocking rates required to achieve this.

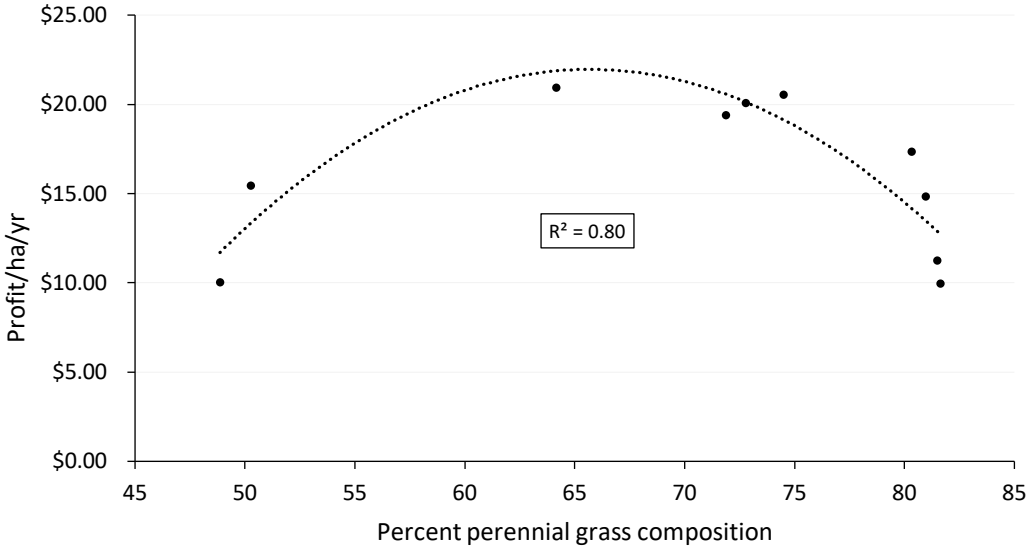


Figure 7-59: Relationships between the average profit/ha and average annual percent perennial grass composition for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

There were only minor differences in profit per AE between herds with utilisation rates <18%, then profit/AE declined with utilisation rates >22%. Profit per kg of beef produced followed a very similar trend (Figure 7-60).

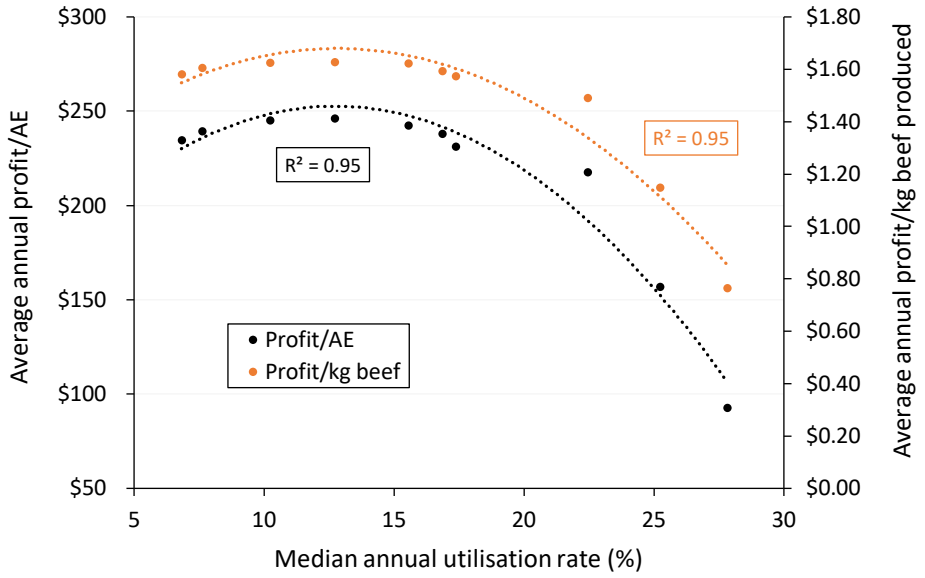


Figure 7-60: Relationship between the average annual profit/AE and profit / kg beef produced and median annual pasture utilisation rate for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

When graphed against average stocking rates instead of utilisation, profit/ha increased rapidly as average stocking rate increased from 4 to around 9 AE/km^2, then was much lower when stocking

rate was 10-11 AE/km^2 (Figure 7-61). Profit/AE was similar for all stocking rates up to 8.5 AE/km^2, then fell sharply at stocking rates >9 AE/km^2.

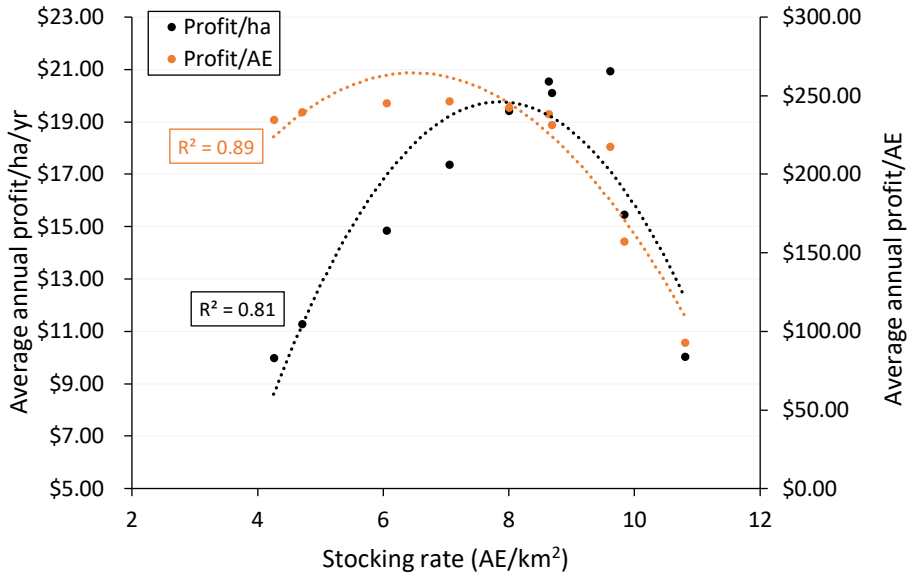


Figure 7-61: Relationship between the average profit, profit per AE and average stocking rate for the 10 simulated Barkly herds (fitted lines are 2nd order polynomials). Average of 44 years

7.7.2 Burdekin catchment property simulations

Graphs from the graphical reporting component of CLEM are used below to demonstrate the variation in annual breeder herd size, total herd size, pasture yield, pasture utilisation rate and land condition state which occurred across the 27 simulated herds. These time series graphs demonstrate the extent that herd size and utilisation rates varied over time for herds that had different initial sizes. The graphs also show differences in the dynamics of herd sizes due to different herd management approaches during and after droughts, such as selling empty breeders or selling pre-market steers during droughts, followed by natural buildup of herds after droughts or by purchasing young breeders to quickly recover herd size. Presented first are time series graphs for herd 4 - 2748 AE which had an initial size that was close to the simulated long-term carrying capacity for this property of 2700 AE. This is followed by herds with initial sizes which were lower or higher than the long-term carrying capacity.

Burdekin rainfall during simulations

Annual rainfall (using Hillgrove climate data) in the Burdekin catchment during the simulation period 1978 to 2022 ranged from a minimum of 214 mm to a maximum of 1411 mm. Average and median annual rainfall were 588 mm and 549 mm respectively, and the coefficient of variation was 41%.

In contrast to the Barkly property which had three main periods of below- and above-average annual rainfall, the 3-year moving average differences for Burdekin rainfall showed there were seven main alternating periods of below- and above-average annual rainfall (Figure 7-62). This occurred even though the coefficient of variation in annual rainfall of 41% for the Burdekin was lower than that of 44% for the Barkly. In comparison to the Barkly simulation period which had mostly 20 years of above average rainfall from 1998 to 2017, the Burdekin property experienced four consecutive years of above average rainfall, followed by five consecutive years with below average rainfall, then five out of six consecutive years of above average rainfall, and finally, five consecutive years of below

average rainfall. Consequently, the Burdekin herds experienced more periods of time where successive years with low pasture availability limited their productivity through reduced reproductive and liveweight growth rates combined with partial destocking. Furthermore, any deterioration in land condition during periods of below-average annual rainfall would have reduced pasture productivity even when climatic conditions improved.

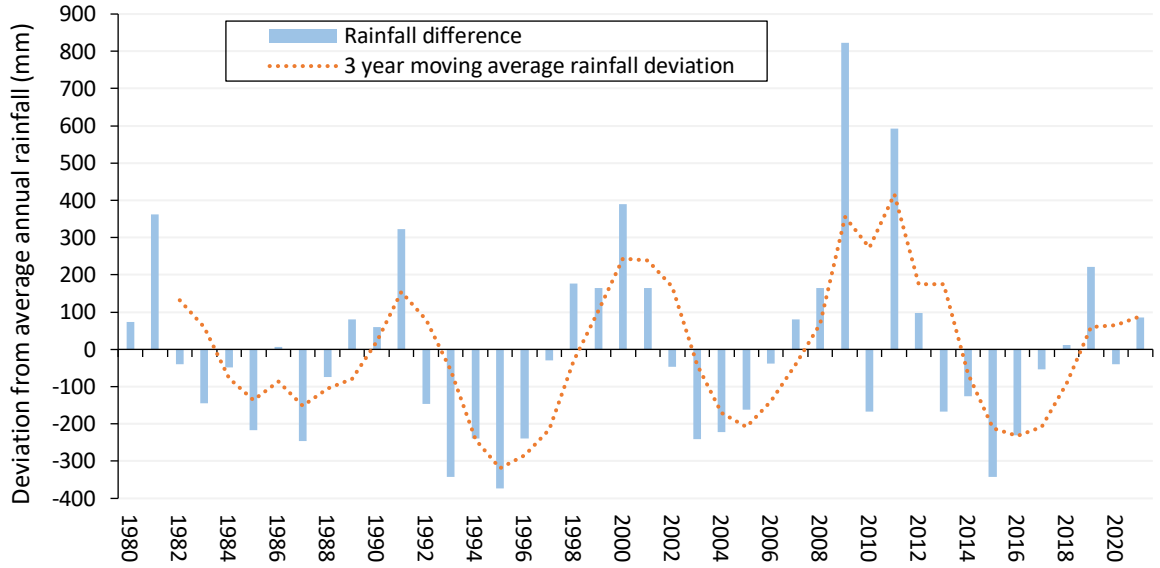


Figure 7-62: Differences between annual rainfall and average annual rainfall (rainfall deviation) and 3-year moving average deviation over the simulation period of the Burdekin property

Time series of the Burdekin herd at long-term carrying capacity

Annual herd size and annual number of female breeders for the simulated herd 4 - 2748 AE are shown in Figure 7-63. While it was possible to maintain between 1300 and 1400 head of breeders during the first 15 years of the simulation period, a high proportion of the female breeder herd was sold during the drought of the 1990s to prevent substantial mortality from starvation. Consequently, compared with smaller herds, it was not possible to hold the initial number of breeders constant throughout the entire simulation. With natural recruitment, the female breeder herd took 10 years to recover its initial size.

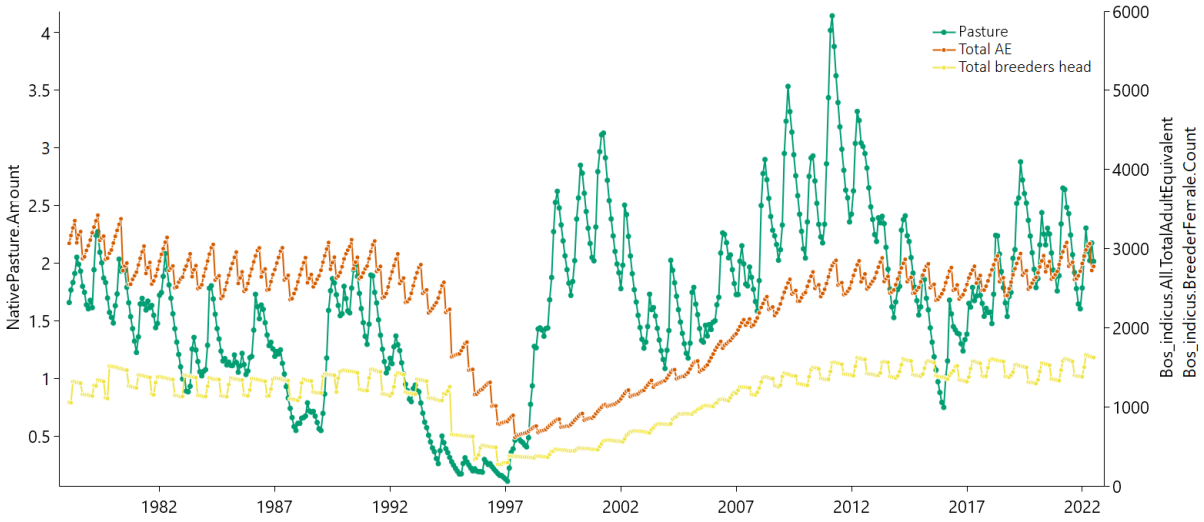


Figure 7-63: Monthly pasture yield (NativePastures.Amount; tonnes/ha), total herd size (Bos_indicusAll.TotalAdultEquivalent; AE) and number of female breeders (Bos_indicusBreederFemale.Count; head) for the simulated Burdekin herd 4 - 2748 AE

Maintaining the initial herd size during the first 15 years of the simulation period caused a small decline in land condition and grass basal area (Figure 7-64), and hence pasture yield also declined (Figure 7-65). A combination of higher pasture demand and less available pasture resulted in high pasture utilisation rates during the 1990s drought, even though a high proportion of the herd was destocked over that time. However, given that climatic conditions improved substantially after the drought, which coincided with a much-reduced herd size, both land condition and grass basal area improved quickly. Average annual pasture utilisation rate for herd 4 - 2748 AE was 21.1%, and the median was 16.5%.

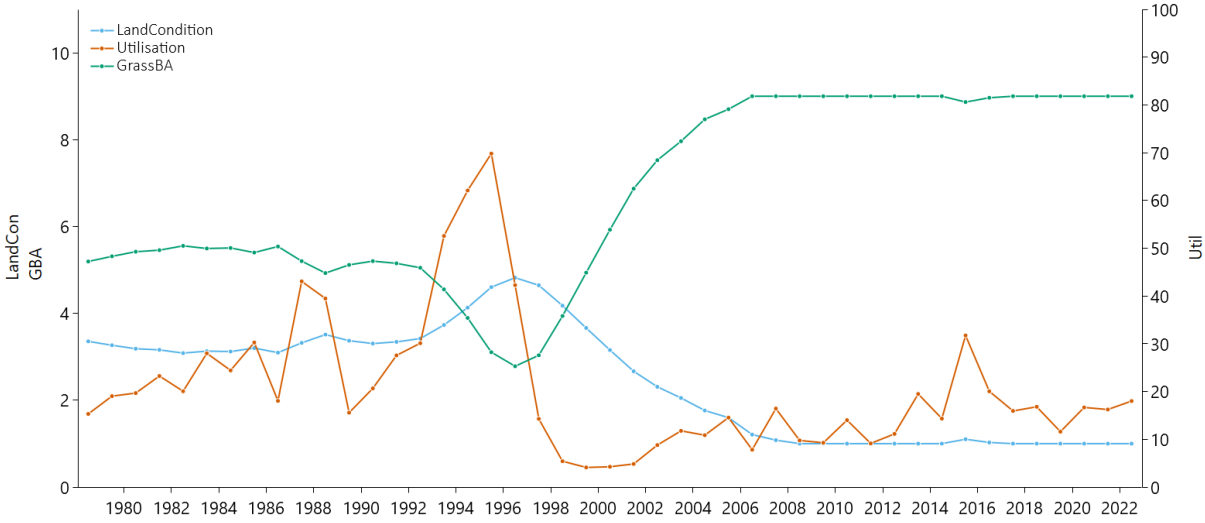


Figure 7-64: Annual percent pasture utilisation rate (util), land condition state (LandCon) (where 0 equals best A condition and 11 equals worst D condition) and grass basal area (GBA) for the simulated Burdekin herd 4 - 2748 AE

Purchasing young female breeders after the 1990s drought was then added to the simulated herd 4 - 2748 AE, to produce a new herd simulation 8 - 2801 AE PB. Purchasing 150 female breeders each year from 1997 to 2001 restored the breeder herd to its initial size by around 2002 (Figure 7-65).

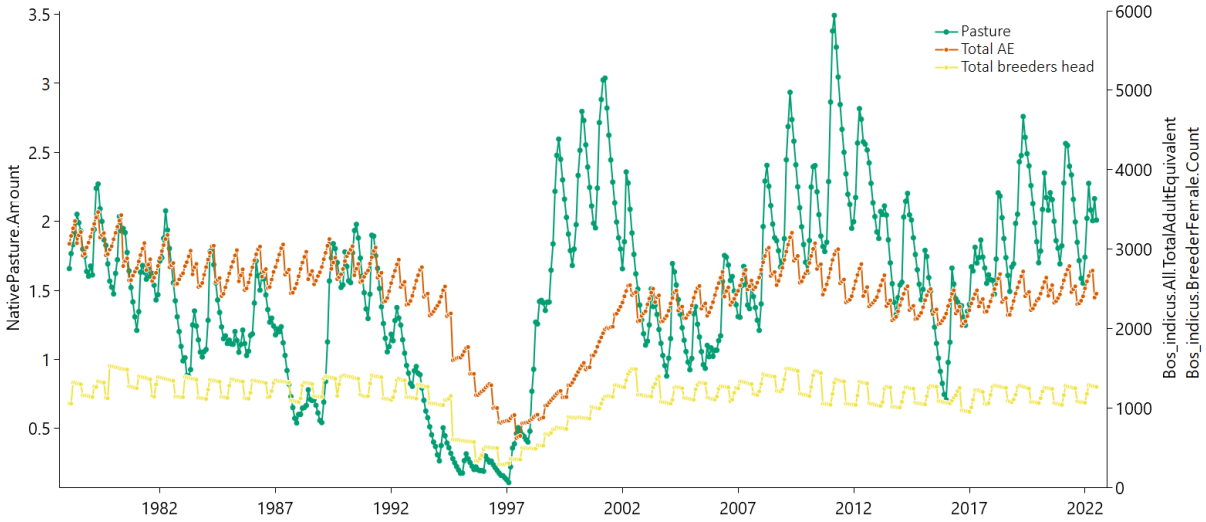


Figure 7-65: Monthly pasture yield (NativePastures.Amount; tonnes/ha), total herd size (Bos_indicusAll.TotalAdultEquivalent; AE) and number of female breeders (Bos_indicusBreederFemale.Count; head) for the simulated Burdekin herd 8 - 2801 AE PB

Restoring herd size more rapidly through purchasing breeders increased the average annual pasture utilisation rate from 21.1 to 23.2%, but this still enabled both land condition and grass basal area to improve to maximum levels by the end of the simulation period (Figure 7-66).

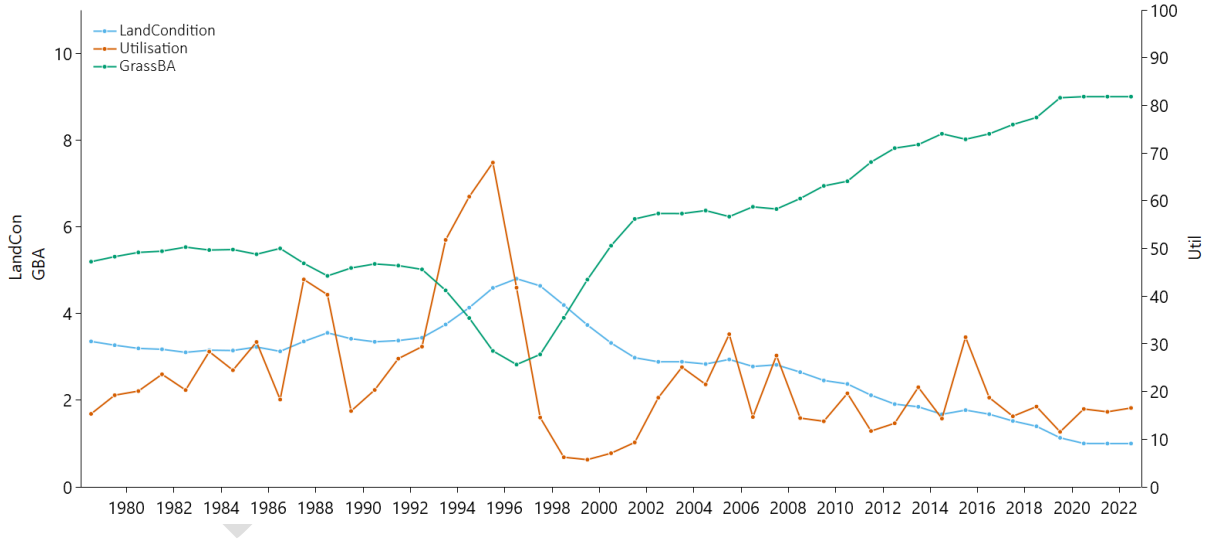


Figure 7-66: Annual percent pasture utilisation rate (util), land condition state (LandCon) (where 0 equals best A condition and 11 equals worst D condition) and grass basal area (GBA) for the simulated Burdekin herd 8 - 2801 AE PB

An alternative to destocking female breeders during the 1990s drought (4 - 2748 AE) was to destock pre-market age steers instead. This new herd simulation of 23 - 2750 AE SS destocked between 150 and 600 young steers each year during the drought of 1991-1996, between 190 and 340 each year between 2002-2006, and between 330 and 450 each year between 2013-2017. While this enabled the initial number of female breeders to be retained over the entire simulation period, total herd size decreased because of sales of large numbers of steers (Figure 7-67) and because of reduced reproductive performance of breeders.

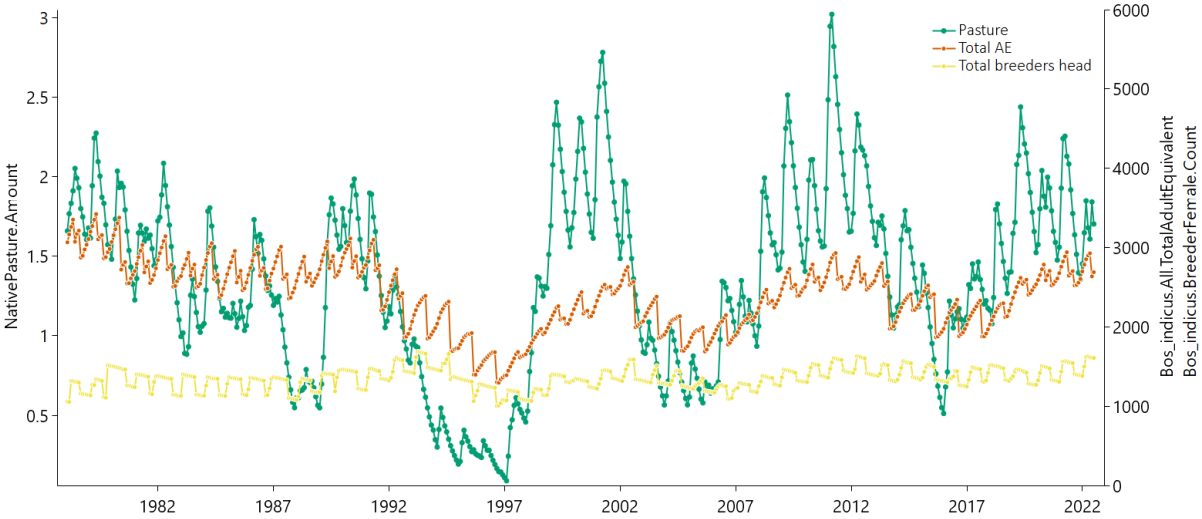


Figure 7-67: Monthly pasture yield (NativePastures.Amount; tonnes/ha), total herd size (Bos_indicusAll.TotalAdultEquivalent; AE) and number of female breeders (Bos_indicusBreederFemale.Count; head) for the simulated Burdekin herd 23 - 2750 AE SS

Pasture utilisation rates during the second half of the simulation period, which were mostly less than 25%, regarded as the long-term safe utilisation rate for this narrow-leaved ironbark woodlands land type, allowed both land condition and grass basal area to improve (Figure 7-68). Average annual pasture utilisation rate for this herd was 24.7%.

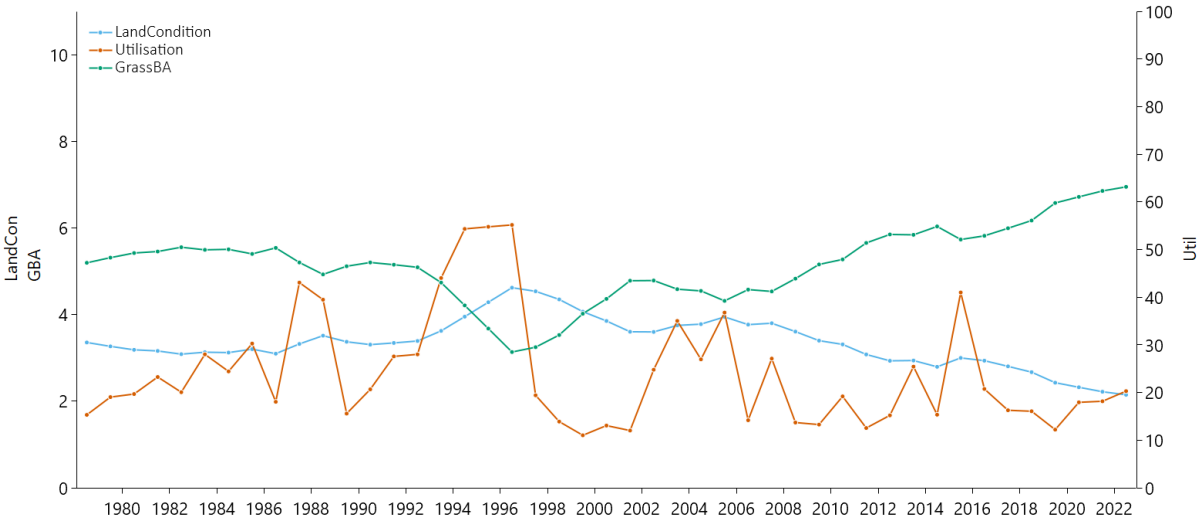


Figure 7-68: Annual percent pasture utilisation rate (util), land condition state (LandCon) (where 0 equals best A condition and 11 equals worst D condition) and grass basal area (GBA) for the simulated Burdekin herd 23 - 2750 AE SS

Time series of the Burdekin herds below long-term carrying capacity

The simulated herd with the smallest initial size was 1 – 2349 AE (Table 7-16). Monthly total herd size in adult equivalents (AE) and head of female breeders both varied little over the simulation period, despite substantial variation in annual pasture yields (Figure 7-69).

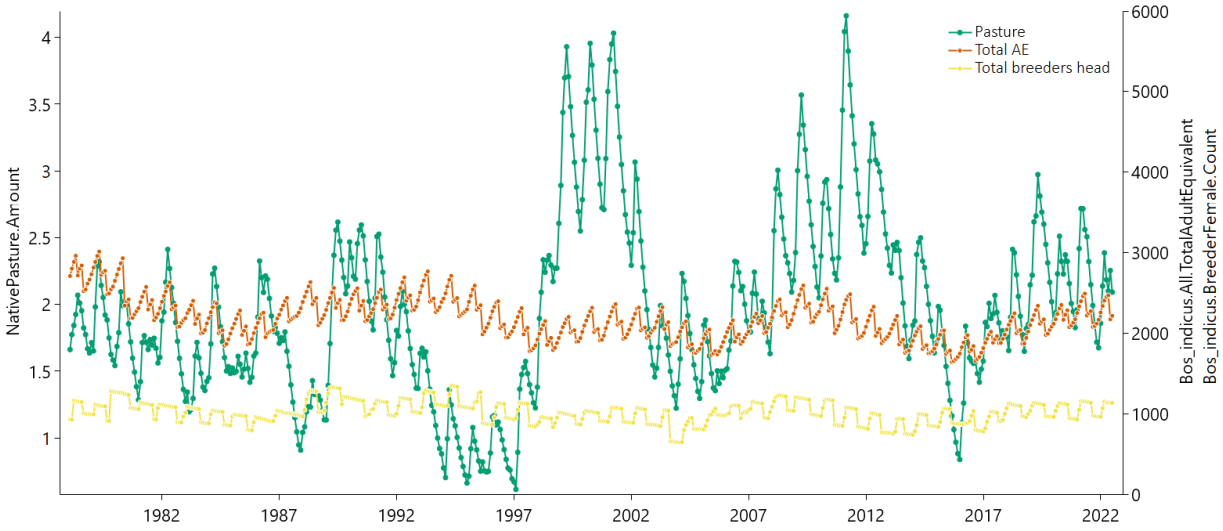


Figure 7-69: Monthly pasture yield (NativePastures.Amount; tonnes/ha), total herd size (Bos_indicusAll.TotalAdultEquivalent; AE) and number of female breeders (Bos_indicusBreederFemale.Count; head) for the simulated Burdekin herd 1 – 2349 AE

Annual pasture utilisation rates for herd 1 – 2349 AE were mostly below the safe rate of 25% (Figure 7-70). Given that the average annual pasture utilisation rate was 15.6%, both land condition and grass basal areas improved quickly to the maximum values possible over the simulation period.

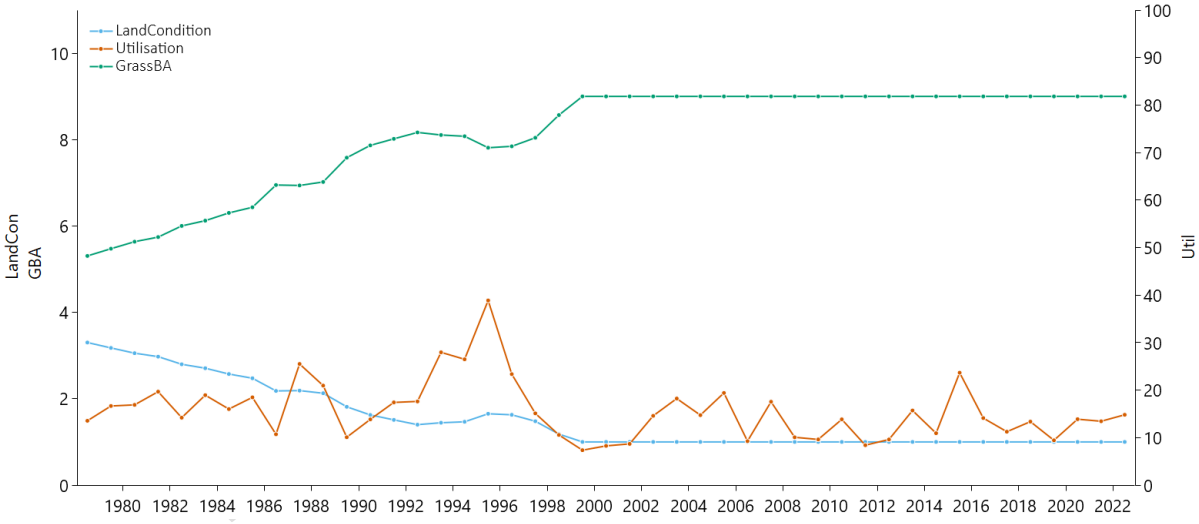


Figure 7-70: Annual percent pasture utilisation rate (util), land condition state (LandCon) (where 0 equals best A condition and 11 equals worst D condition) and grass basal area (GBA) for the simulated Burdekin herd 1 – 2349 AE

Time series of the Burdekin herds above long-term carrying capacity

Not surprisingly, it was impossible to maintain the initial herd size of simulation 6 - 3099 AE (15% above long-term carrying capacity) across the entire simulation period (Figure 7-71). Total herd size fell to under 300 AE and female breeder number to zero during the 1990s drought. Apart from approximately 400 steers and 200 heifers which were simulated to have died of starvation during this drought, this large drop in herd size was mostly due to the sale of empty female breeders. While no females were sold after the 1990s drought, natural recruitment was still unable to recover the initial size of this herd by the end of the simulation period.

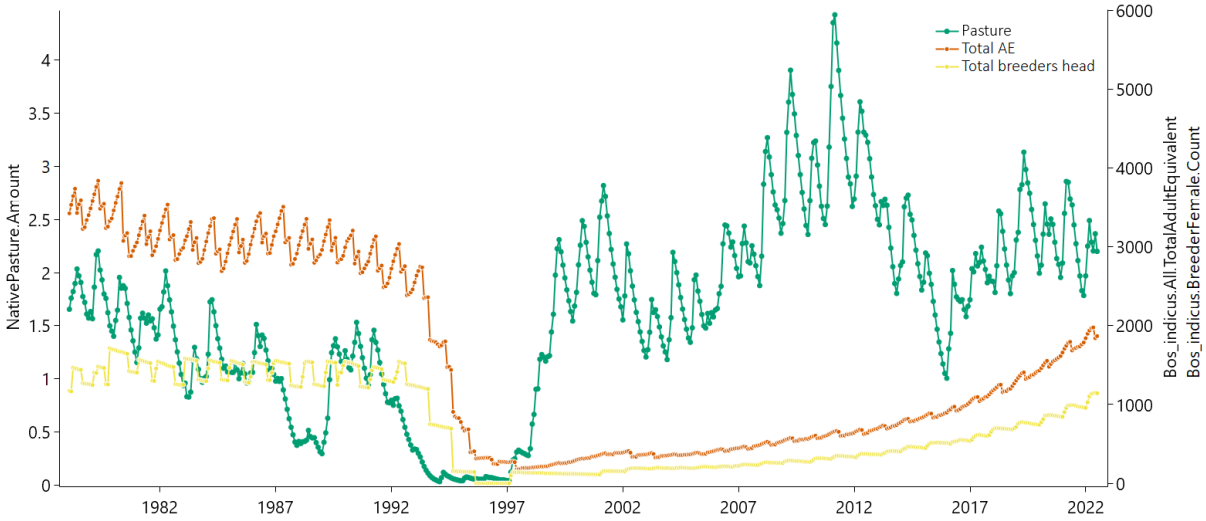


Figure 7-71: Monthly pasture yield (NativePastures.Amount; tonnes/ha), total herd size (Bos_indicusAll.TotalAdultEquivalent; AE) and number of female breeders (Bos_indicusBreederFemale.Count; head) for the simulated Burdekin herd 6 - 3099 AE

The high pasture utilisation rates during the first 15 years of the simulation period caused land condition and grass basal area to decline (Figure 7-72), and along with this so did pasture yield (Figure 7-73). Pasture utilisation rate reached 100% at the commencement of the 1990s drought and remained high even though the total herd size declined sharply. As climatic conditions improved after the 1990s drought, and as the rate of increase in herd size was very slow with natural herd build up, land condition and grass basal area quickly increased to their maximum possible values. Herd 6 - 3099 AE and its management were unrealistic, as attempting to maintain large numbers of cattle during dry years resulted in very high pasture utilisation rates and subsequent substantial declines in land condition and the availability of forage, to the point where almost all stock would have died if they were not sold early in the 1990s drought. Also, it was unrealistic for a beef cattle enterprise to have a period of around 27 years with very few cattle and large excesses of pasture. When climatic conditions improved post the 1990s drought, the enterprise would have purchased female breeders and/or young growing cattle to for the purpose of restoring herd productivity and income, or it would have earned income from agistment of cattle.

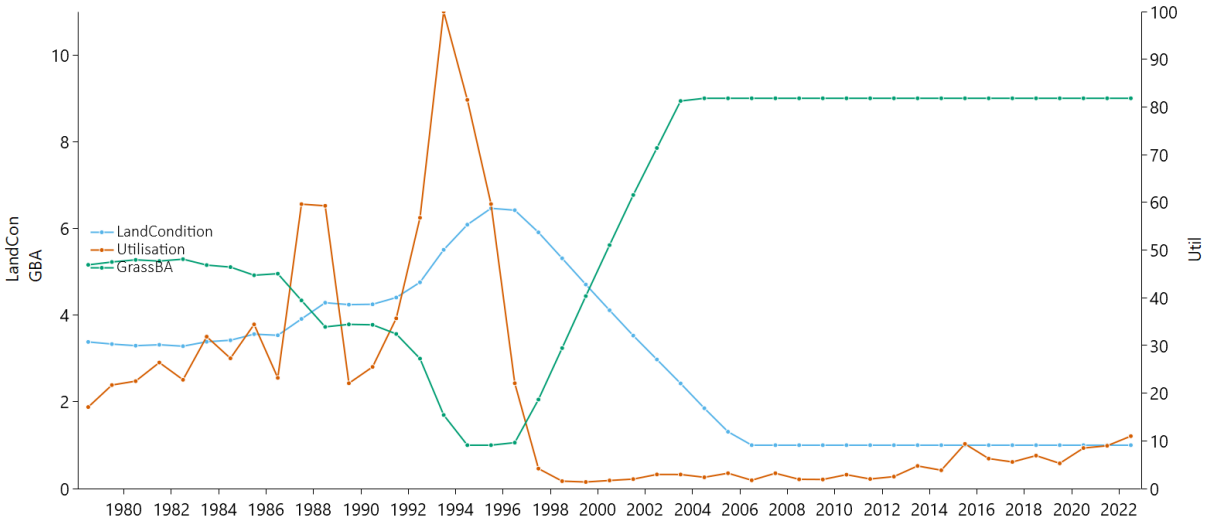


Figure 7-72: Annual percent pasture utilisation rate (util), land condition state (LandCon) (where 0 equals best A condition and 11 equals worst D condition) and grass basal area (GBA) for the simulated Burdekin herd 6 - 3099 AE

Destocking all steers during the 1990s drought (herd 25 - 3099 AE SS) enabled close to 400 breeders to be retained during the drought, but this new simulation included deaths by starvation of around 800 heifers and breeders and 250 steers. While 400 breeders were retained during this drought, the herd still did not recover its initial size by the end of the simulation period. To recover this herd, it was necessary to destock the steers and purchase breeders after each of the three droughts (Figure 7-74). The simulated herd 27 - 3099 AE SS PB purchased 175 breeders each year between 1997 and 2001, 30 breeders each year between 2007 and 2011, and 200 breeders each year between 2018 and 2021. While these purchases recovered the size of the female breeder herd, the initial total herd size could not be recovered due to poor land condition and associated low pasture productivity.

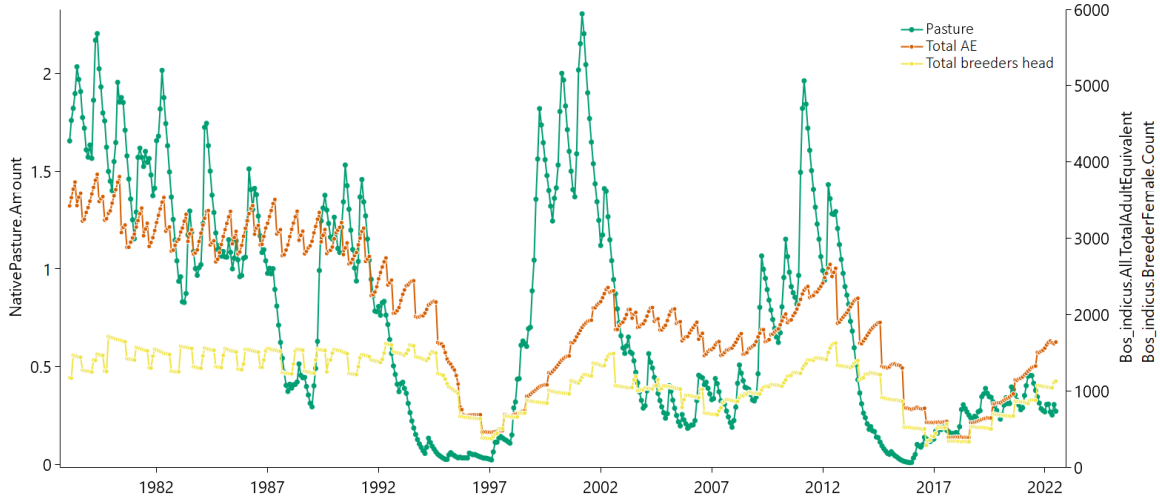


Figure 7-73: Monthly pasture yield (NativePastures.Amount; tonnes/ha), total herd size (Bos_indicusAll.TotalAdultEquivalent; AE) and number of female breeders (Bos_indicusBreederFemale.Count; head) for the simulated Burdekin herd 27 - 3099 AE SS PB

Purchasing replacement breeders resulted in very high pasture utilisation rates during the second half of the simulation period. This caused substantial declines in land condition and grass basal area

(Figure 7-74), and resultant low reproductive rates of breeders did not enable total herd size to recover.

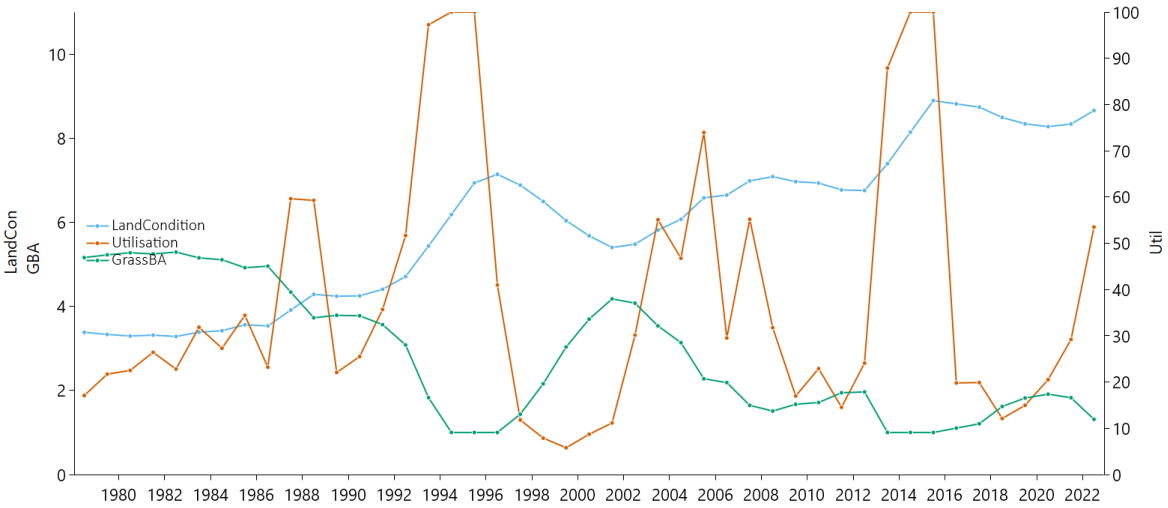


Figure 7-74: Annual percent pasture utilisation rate (util), land condition state (LandCon) (where 0 equals best A condition and 11 equals worst D condition) and grass basal area (GBA) for the simulated Burdekin herd 27 - 3099 AE SS PB

As evident in Figure 7-75, the initial mid-B land condition with 60% perennial grass composition was only maintained for the first seven years. After that, maintaining the initial large herd size during some dry years in the late 1980s resulted in high utilisation rates which a caused land condition to decline to low B. Land condition continued to decline rapidly to low C during the 1990s drought, and while it recovered partially after this drought, attempts to recover initial herd size resulted in high utilisation rates and D land condition by the end of the simulation period.

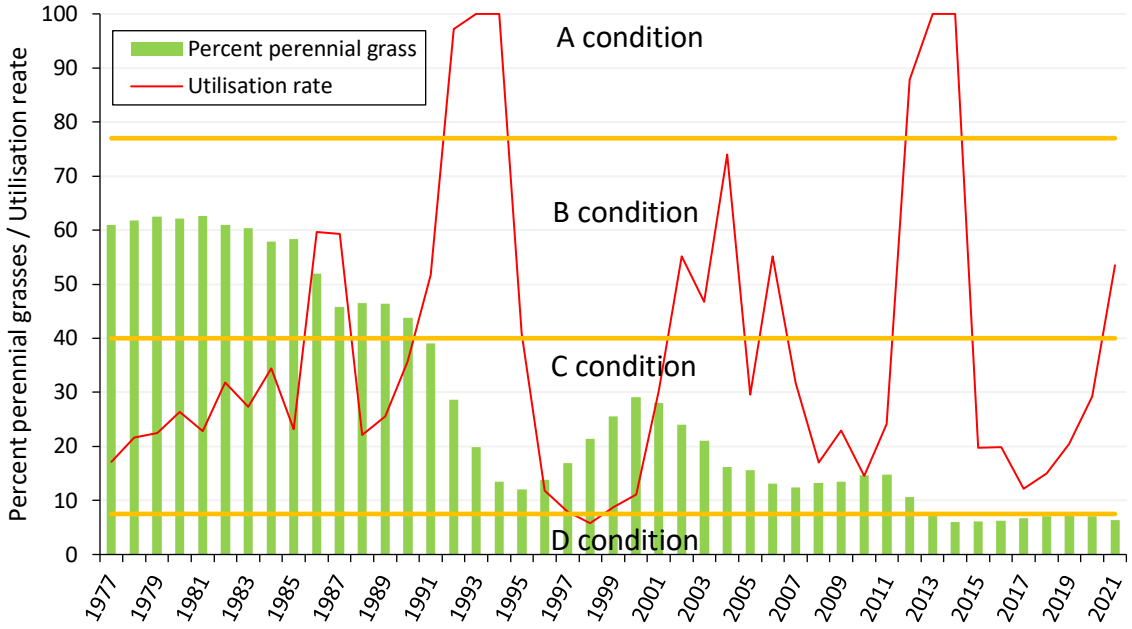


Figure 7-75: Time series of annual pasture utilisation rate, annual percent perennial grass composition and related land condition ratings for one of the least profitable Burdekin herds 27 - 3099 AE SS PB

Impact of pasture utilisation on Burdekin herds

The results for all average annual pasture-, reproduction-, herd productivity- and financial-related performance metrics for the 27 simulated Burdekin herds are presented in Table 14-7 - Table 14-10 respectively of Appendix 14.5, page 394. A smaller number of key metrics, representative of the outcomes of herds in relation to pastures, herd productivity and finances, are shown in Table 7-25. While the results of two of the 27 simulated herds, 6 - 3099 AE and 25 - 3099 AE SS, are shown in these tables, they are not included in the results presented below. Both herds, as can be seen for 6 - 3099 AE in Figure 7-27 above, collapsed to very low numbers during the 1990s drought and remained at very low levels throughout the remainder of the simulation period. These were not realistic scenarios for beef breeding herds in northern Qld. Also, the average annual performance metrics for these two herds were not representative of their responses to climate and management over 42 years. For example, herd 6 - 3099 AE had an average annual herd size of 1425 AE, but herd size was around 3000 AE for the first 15 years, fell abruptly to <200 AE during the 1990s drought, and then remained at below 1000 AE for most of the remaining simulation period (Figure 7-71). Similarly, the median annual utilisation rate was 6.6%, but annual utilisation rates were mostly between 20 and 100% for the first 15 years, dropped rapidly as herd size crashed, then remained at between 1 and 11% for the last 26 years of the simulation period (Figure 7-72). Consequently, while this herd had the second highest starting herd size, it had the lowest average annual herd size and the lowest median utilisation rate. The responses of herd 25 – 3099 AE SS were similar. The high level of stocking rate flexibility required when attempting to main herds with these high starting sizes could not be achieved without purchasing breeders when climatic conditions improved after droughts.

Table 7-25: Key performance metrics for pastures, herd productivity and enterprise finances for the 27 simulated Burdekin herds, listed in descending order of average annual profit/ha (AE = adult equivalent; SR = stocking rate; UR = utilisation rate). Average of 42 years

Simulation Name	Average annual AE	Average annual SR (AE/km^2)	Average pasture UR (%)	Median pasture UR (%)	Pasture yield June 30 (kg/ha)	Percent perennial grasses	Kg beef/ ha/yr	Kg Beef/ AE/yr	Gross Profit/ ha/yr	Gross profit/ AE/yr	Variable costs/ ha/yr	Variable costs/ AE/yr	Gross profit margin/ ha/yr	Gross profit margin/ AE/yr	Profit/ ha/yr	Profit/ AE/yr
13 - 2619 AE HB	2649	10.7	22.8	20.1	1731	77	12.3	115	$34.84	$326	-$11.55	-$108	$23.30	$218	$10.86	$101
17 - 2610 AE HB	2457	9.9	19.0	17.8	1933	85	11.5	116	$32.22	$324	-$10.86	-$109	$21.36	$215	$8.92	$90
7 - 2670 AE PB	2465	9.9	20.7	18.6	1824	82	11.5	115	$32.11	$322	-$10.80	-$108	$21.31	$214	$8.87	$89
2 - 2466 AE	2290	9.2	17.0	16.1	2015	87	10.9	117	$30.24	$327	-$10.21	-$110	$20.03	$217	$7.60	$82
18 - 2436 AE HB	2273	9.2	16.5	15.6	2040	88	10.7	117	$29.88	$325	-$10.11	-$110	$19.76	$215	$7.32	$80
3 - 2670 AE	2309	9.3	19.5	16.8	1859	83	10.6	114	$29.28	$314	-$10.15	-$109	$19.13	$205	$6.69	$72
22 - 2670 AE SS	2375	9.6	19.8	17.7	1826	81	10.7	111	$29.39	$306	-$10.39	-$108	$19.01	$198	$6.57	$68
8 - 2801 AE PB	2336	9.4	23.2	19.2	1611	70	10.8	114	$29.36	$311	-$10.49	-$111	$18.87	$200	$6.44	$68
1 - 2349 AE	2148	8.7	15.6	14.4	2076	89	10.2	117	$28.18	$325	-$9.58	-$110	$18.59	$214	$6.16	$71
23 - 2750 AE SS	2357	9.5	24.7	20.5	1447	61	10.1	106	$28.45	$299	-$10.45	-$110	$18.00	$189	$5.56	$58
4 - 2748 AE	2195	8.8	21.1	16.5	1732	77	9.6	108	$27.14	$306	-$9.59	-$108	$17.56	$198	$5.12	$58
21 -2497 AE HB	2379	9.6	20.4	17.5	1825	80	10.0	104	$27.31	$284	-$10.01	-$104	$17.30	$180	$4.86	$51
16 - 2835 AE PB	2454	9.9	35.2	28.6	1180	50	10.9	110	$27.81	$281	-$10.91	-$110	$16.91	$171	$4.47	$45
24 - 2917 AE SS	2274	9.2	24.9	19.5	1424	59	9.6	105	$25.99	$283	-$9.92	-$108	$16.07	$175	$3.63	$40
20 - 2713 AE HB	2266	9.1	23.9	19.3	1529	67	9.5	104	$25.76	$281	-$9.77	-$107	$15.99	$175	$3.56	$39
5 - 2917 AE	2005	8.1	21.7	16.2	1690	73	8.7	108	$23.72	$293	-$8.93	-$110	$14.79	$183	$2.35	$29
12 - 2786 AE HB	2226	9.0	26.5	21.8	1325	56	9.1	101	$24.29	$270	-$9.54	-$106	$14.75	$164	$2.31	$26
15 - 2874 AE	2180	8.8	24.4	19.2	1533	67	8.7	99	$23.82	$270	-$9.28	-$105	$14.54	$165	$2.10	$24
9 - 2915 AE PB	2098	8.5	32.0	26.8	1078	43	9.2	109	$23.59	$278	-$9.58	-$113	$14.01	$165	$1.58	$19
19 - 2925 AE	2052	8.3	32.9	25.4	1060	43	8.7	105	$21.06	$254	-$9.50	-$115	$11.56	$139	-$0.88	-$11
10 - 3099 AE PB	2005	8.1	35.7	27.0	940	33	8.5	105	$20.42	$252	-$9.53	-$118	$10.90	$135	-$1.54	-$19
11 - 3269 AE PB	2102	8.5	37.7	29.3	858	24	8.6	101	$19.92	$235	-$9.90	-$117	$10.02	$118	-$2.41	-$28
26 - 2917 AE SS PB	2141	8.6	39.2	32.2	924	32	8.0	92	$19.76	$228	-$9.84	-$114	$9.92	$115	-$2.52	-$29
25 - 3099 AE SS	1829	7.4	23.5	12.7	1557	62	7.0	94	$17.44	$236	-$8.07	-$109	$9.38	$127	-$3.06	-$41
14 - 2896 AE	1930	7.8	35.2	28.1	945	35	7.7	99	$18.17	$233	-$9.12	-$117	$9.05	$116	-$3.39	-$43
6 - 3099 AE	1425	5.7	19.0	6.6	1723	70	5.8	101	$13.88	$241	-$6.58	-$114	$7.30	$127	-$5.13	-$89
27 - 3099 AE SS PB	1908	7.7	39.6	29.4	817	20	7.2	93	$16.42	$213	-$9.17	-$119	$7.25	$94	-$5.19	-$67

In contrast to the Barkly herds where there was a strong positive linear relationship between herd size at the start of simulations and average annual herd size, the relationship tended to be negative for the Burdekin herds (Figure 7-76). While it was possible to maintain starting herd sizes of between 2148 and 2649 AE (stocking rates of 8.7 to 10.7 AE) over the simulation period, this could not be achieved with herds with higher starting sizes, even when female breeders were purchased after droughts. This occurred because larger starting herd sizes caused declines in land condition and thus pasture production, making it impossible to support large herds over the entire simulation period.

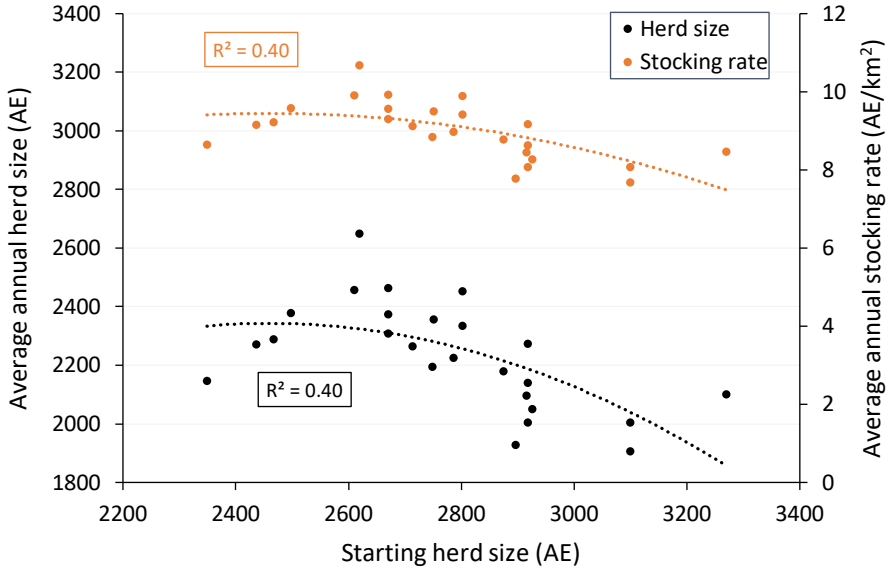


Figure 7-76: Relationship between herd size at the start of simulations, average annual herd size and average annual stocking rate for the 25 simulated Burdekin herds (fitted lines are 2nd order polynomials). Average of 42 years

As with the simulations of Barkly herds, the choices of measures (median or average) of both URs and performance metrics used to compare herds were based on the R^2 values of relationships between them. In contrast to the Barkly herds where median UR vs average performance metrics had the highest R^2 values for the majority of performance metrics, median UR vs median performance metric had the highest R^2 values for 21 of 38 performance metrics when all 27 Burdekin herds were assessed. When this was repeated without herds 6 - 3099 AE and 25 - 3099 AE SS (only 25 herds), then average UR vs average performance metrics had the highest R^2 values for all 38 performance metrics. Overall, across all Barkly and Burdekin herds, there was much variation in the extent that median or average URs were correlated with median or average performance metrics.

While the distributions of annual URs for the Burdekin herds were also skewed, consisting predominantly of low rates with a few very high rates (Table 7-26), they were not as skewed as those for the Barkly herds. The Barkly herds had a higher proportion of years with URs in the lowest bands of utilisation (< safe). Thus, the median URs for the Barkly herds were only 55 to 77% of average annual rates, whereas median values for the Burdekin herds were 74 to 95% of average values. Given that the median is regarded as a more representative measure of skewed distributions, and that median was used for the Barkly herds, median annual pasture UR was also used for Burdekin herds, in conjunction with average annual performance metrics.

Table 7-26: Average and median annual percent pasture utilisation rate (UR) and the number of years with utilisation rates in five bands of pasture utilisation for 25 simulated Burdekin herds. Average of 42 years

	1-2349 AE	2-2466 AE	3-2670 AE	4-2748 AE	5-2917 AE	7-2670 AE PB	8-2801 AE PB	9-2915 AE PB	10-3099 AE PB	11-3269 AE PB	12-2786 AE HB	13-2619 AE HB	14-2896 AE	15-2874 AE	16-2835 AE PB	17-2610 AE HB	18-2436 AE HB	19-2925 AE	20-2713 AE HB	21-2497 AE HB	22-2670 AE SS	23-2750 AE SS	24-2917 AE SS	26-2917 AE SSPB	27-3099 AE SSPB
Average UR	15.6	17.0	19.5	21.1	21.7	20.7	23.2	32.0	35.7	37.7	26.5	22.8	35.2	24.4	35.2	19.0	16.5	32.9	23.9	20.4	19.8	24.7	24.9	39.2	39.6
Median UR	14.4	16.1	16.8	16.5	16.2	18.6	19.2	26.8	27.0	29.3	21.8	20.1	28.1	19.2	28.6	17.8	15.6	25.4	19.3	17.5	17.7	20.5	19.5	32.2	29.4
UR >0 and ≤15	24	17	15	17	19	12	13	6	5	9	8	11	6	15	5	14	17	8	14	18	15	9	11	4	8
UR >15 and ≤25	14	20	18	14	11	20	15	14	11	8	19	20	12	14	12	22	21	13	15	15	17	17	16	10	9
UR >25 and ≤35	3	4	5	5	6	6	8	9	10	6	7	6	7	7	8	5	3	5	7	4	7	7	7	9	9
UR >35 and ≤60	1	1	4	4	2	4	4	7	11	9	5	4	13	2	11	1	1	12	3	4	3	9	8	13	9
UR >60 and ≤100	0	0	0	2	4	0	2	6	5	10	3	1	4	4	6	0	0	4	3	1	0	0	0	6	7
% years UR >25 %	10%	12%	21%	26%	29%	24%	33%	52%	62%	60%	36%	26%	57%	31%	60%	14%	10%	50%	31%	21%	24%	38%	36%	67%	60%
% years UR >30%	2%	5%	14%	21%	19%	14%	21%	40%	43%	50%	24%	17%	48%	21%	48%	12%	2%	43%	21%	19%	12%	24%	26%	60%	48%
% years UR >35%	2%	2%	10%	14%	14%	10%	14%	31%	38%	45%	19%	12%	40%	14%	40%	2%	2%	38%	14%	12%	7%	21%	19%	45%	38%

Average annual pasture utilisation rate was higher than median annual utilisation rate for all 25 simulated Burdekin herds (Figure 7-77). This occurred because infrequent high utilisation years skewed the average upwards. When median pasture utilisation was 25% (the safe long-term rate), average pasture utilisation was 32%.

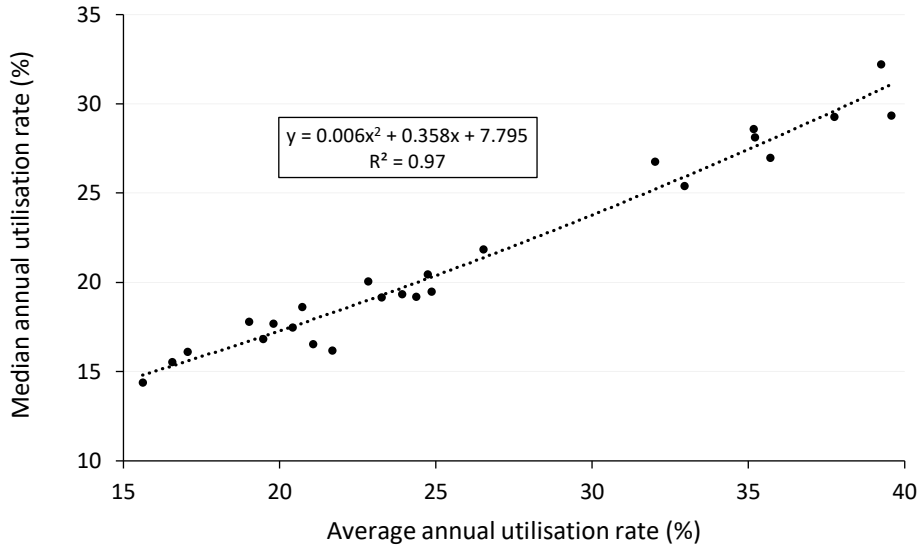


Figure 7-77: Relationship between average annual pasture utilisation rate and median pasture utilisation rate for the 25 simulated Burdekin herds (fitted line is 2nd order polynomial). Average of 42 years

The percent of years during simulation periods when annual pasture utilisation rate was ≤25% (long-term safe rate) was closely and negatively correlated with median annual utilisation rate (Figure 7-78). For example, for herd 19 - 2925 AE which had a median utilisation rate of 25%, 50% of years had simulated annual utilisation rates <25%. In comparison, herds with median utilisation rates of ≤22% had >60% of years with annual utilisation rates ≤25%, while herds with median utilisation rates ≥27% had around 40% of years with utilisation rates ≤25%.

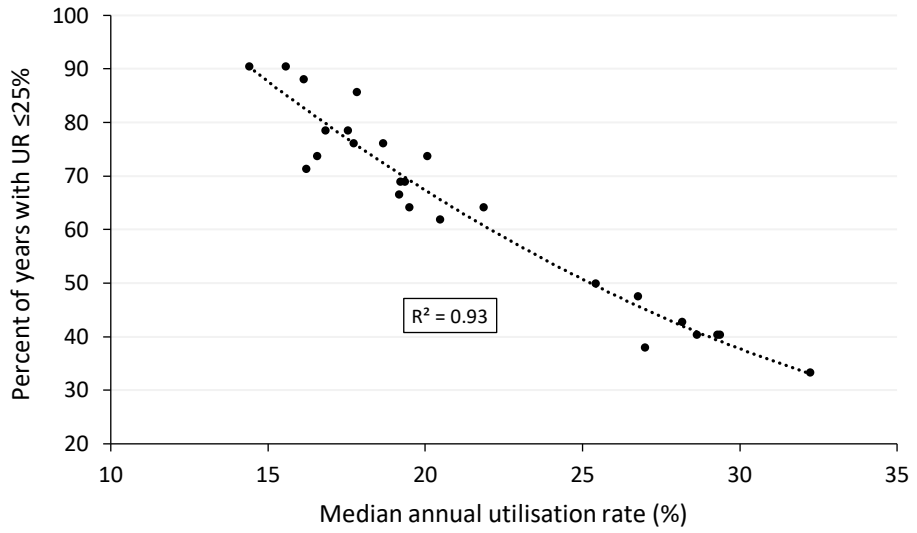


Figure 7-78: Relationship between percent of years with annual pasture utilisation rates (UR) ≤25% and median pasture utilisation rate for the 25 simulated Burdekin herds (fitted line is 2nd order polynomial). Average of 42 years

Given that McKeon *et al.* (2004) recommended that grazing was likely to be sustainable when at least 70% of years had annual utilisation rates <30%, the percent of years with <30% utilisation rates were identified for the 25 simulated Burdekin herds (Figure 7-79). Only the herds with median utilisation rates of ≤22% had more than 70% of years with annual utilisation rates ≤30%.

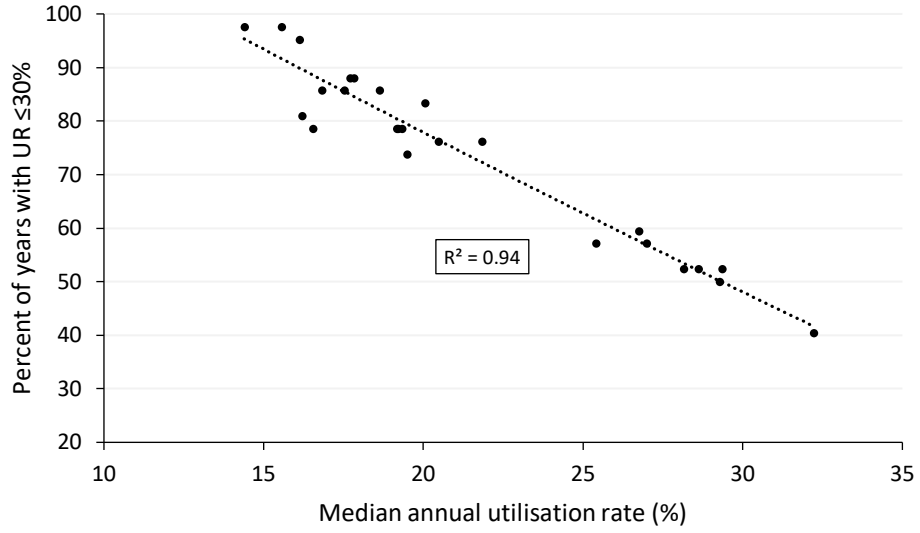


Figure 7-79: Relationship between percent of years with annual pasture utilisation rates (UR) ≤30% and median pasture utilisation rate for the 25 simulated Burdekin herds (fitted line is 2nd order polynomial). Average of 42 years

Total herd size, stocking rate and breeder herd size

Burdekin herd size was not correlated with median utilisation rate (R^2 of 0.18 to 0.25) (Figure 7-80), whereas this was strongly correlated for the Barkly herds (R^2 of 0.99). Also, in contrast to the size of Barkly herds which kept increasing with increases in median utilisation rate, there was a tendency for Burdekin average annual herd size to increase as median pasture utilisation rates increased from

14 to 20%, then decline with further increases in utilisation rate. Median utilisation rates >25% caused appreciable declines in land condition, resulting in decreased pasture productivity and smaller herds (Figure 7-85). The wider range of herd management practices modelled for the Burdekin herds during and after droughts also reduced the correlation between average annual herd size and median annual pasture utilisation rate. Some simulations sold large proportions of empty breeders during droughts, some sold young steers in preference to breeders during droughts, some recovered breeder herd size slowly through natural recruitment, and some recovered this quickly by purchasing large numbers of breeders.

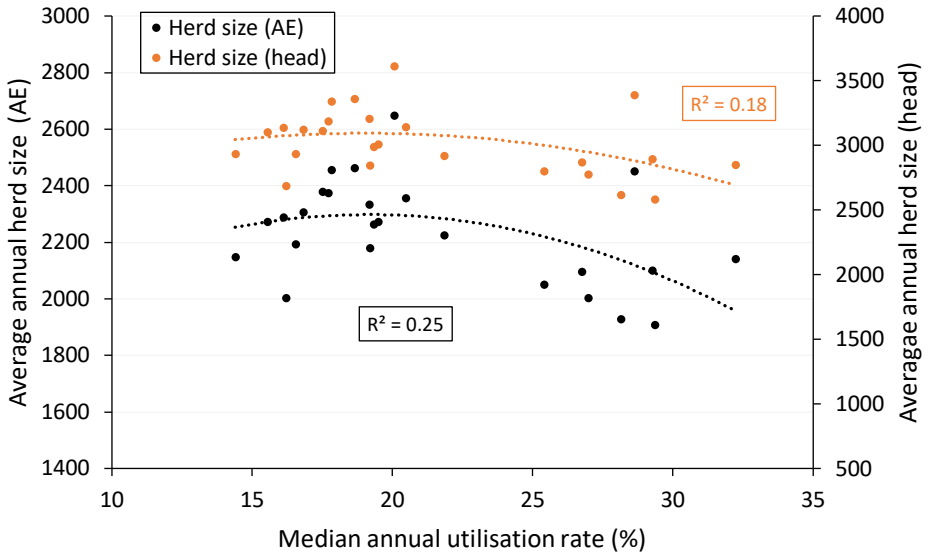


Figure 7-80: Relationships between average annual herd size (AE), average annual herd size (head), and median annual pasture utilisation rate, for the 25 simulated Burdekin herds (fitted lines are 2nd order polynomials). Average of 42 years

Likewise, average annual stocking rate tended to increase from around 9 to 11 AE/km^2 as median utilisation rate increased from 14 to 20%, then decline to around 8 AE/km^2 at median utilisation rates >25% (Figure 7-81).

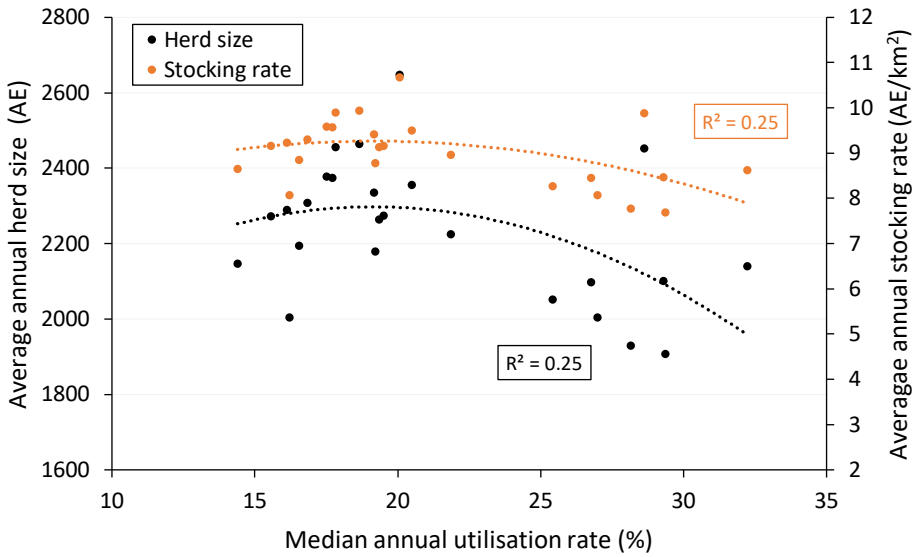


Figure 7-81: Relationships between average annual total herd size (AE), average annual stocking rate and median annual pasture utilisation rate, for the 25 simulated Burdekin herds (fitted lines are 2nd order polynomials). Average of 42 years

The coefficient of variation in average annual AE herd size, while also poorly correlated with median utilisation rate, tended to be lowest for herds with utilisation rates between 14 and 20% (Figure 7-82). As seen in Figure 162, these herds also tended to have the highest average annual herd size. As such, some simulated herds with median utilisation rates of around 20% were maintained at high sizes or stocking rates with little year-to-year variability.

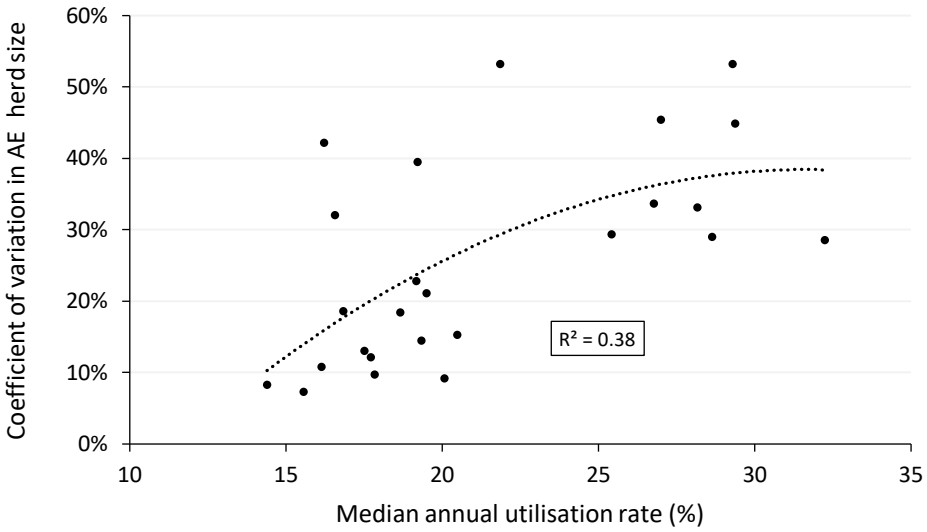


Figure 7-82: Relationships between the coefficient of variation in average annual herd size and median annual pasture utilisation rate for the 25 simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

Average annual female breeder herd size was also poorly correlated with median annual pasture utilisation rate (Figure 7-83), partly due to different management responses during and after droughts, and partly because of deterioration in land condition at the higher utilisation rates. However, there was a tendency for the average annual number of breeders to increase as median

utilisation rates increased from 14 to 20%, then decline with further increases in utilisation rate. This relationship occurred because it was often necessary to sell large numbers of empty breeders (forced sales) during droughts for herds with high utilisation rates. Even so, some herds with high utilisation rates were able to maintain relatively large numbers of breeders due to purchasing breeders after droughts.

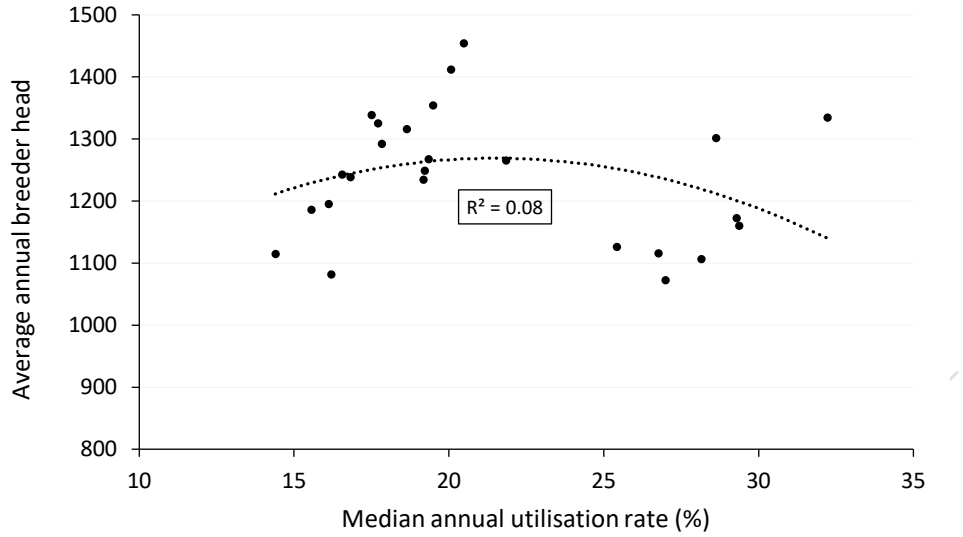


Figure 7-83: Relationships between average annual breeder herd size (head) and median annual pasture utilisation rate for the 25 simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

Simulations with higher initial sizes often required substantial sales or destocking of cattle during droughts to prevent high mortality from starvation. Differences in the classes of cattle sold and in proportions of classes sold were in large part responsible for differences in breeder herd size. Some simulated herds sold all empty breeders during droughts, others sold very few for the purpose of maintaining a relatively constant breeder herd size over time, some recovered breeder herd size slowly through natural recruitment, some recovered breeder herd size quickly by purchasing large numbers of breeders after droughts, while others destocked young pre-market steers in preference to empty breeders during droughts.

Generally, the higher the initial size of simulated herds, the greater was the variation in annual breeder herd size over the 42-year simulation period. Herd 1 - 2349 AE was the smallest simulated and had the lowest median annual utilisation rate of 14.4%. Even so, its breeder herd declined in size by around 20% during the 1990s drought, due mainly to sales of empty breeders at that time. In comparison, the herd with the same initial size, 18 - 2436 AE HB and a utilisation rate of 15.6%, maintained similar breeder herd size over the entire simulation period by limiting sales of empty breeders.

Herd 2 - 2466 AE with a utilisation rate of 16.1% sold even more empty breeders during droughts. Even so, the simulation of herd 13 - 2619 AE HB (same initial herd size) with a higher utilisation rate of 20.1% showed it was possible to keep its breeder herd size relatively constant over time, again by reducing the proportions of empty breeders sold.

Herd 3 - 2670 AE with a utilisation rate of 16.8% experienced even more variability in the annual size of its breeder herd. Its breeder herd declined by 60% during the 1990s drought due to sales of empty breeders. To rebuild this herd at a faster rate after this drought, herd 7 - 2670 AE PB (utilisation rate

of 18.6%), which had the same initial herd size as 3 - 2670 AE, recovered the initial breeder herd size by purchasing breeders following the 1990s drought. Again, variation in the annual size of this same breeder herd was reduced in the simulation 12 - 2786 AE HB (utilisation rate 21.8%), by limiting sales of empty breeders. Another version of the same base herd was 22 - 2670 AE SS (utilisation rate 17.7%), sold 50% of 1- to 3-year-old steers in each of the five years of the 1990s drought. This greatly reduced the need to sell empty breeders, thus the breeder herd declined in size by only 30% during the 1990s drought.

With the larger herd 4 - 2748 AE with a utilisation rate of 16.5%, the breeder herd declined by 75% due to sales of empty breeders during the 1990s drought. Holding breeder numbers relatively constant over the simulation period was not possible, as doing this resulted in high mortality rates despite drought feeding M8U. Consequently, selling 1- to 3-year-old steers for the purpose of retaining more breeders occurred with herd 23 - 2750 AE SS (utilisation rate 20.5%). This simulation sold all 1- to 3-year-old steers each year during the 1990s drought, 50% of these steers each year during the 2003 to 2006 drought, and 70% of them during each year of the 2013 to 2018 drought. Additionally, as natural recruitment was slow to recover this herd after the 1990s drought, herd 8 - 2801 AE PB (utilisation rate 19.2%) purchased breeders.

The decline in breeder herd size during the 1990s drought was even greater for simulation 5 - 2917 AE (utilisation rate 16.2%). Purchasing breeders occurred with herd 9 - 2915 AE PB (utilisation rate 26.8%) which quickly recovered the size of this herd. Herd 24 - 2917 AE SS (utilisation rate 19.5%) also sold 1- to 3-year-old steers for the purpose of retaining more breeders during droughts, and herd 26 - 2917 AE SS PB (utilisation rate 32.2%) sold young steers and purchased breeders.

The herds with the largest initial sizes, 6 - 3099 AE (utilisation rate 6.6%), 10 - 3099 AE PB (utilisation rate 27.0%), 11 - 3269 AE PB (utilisation rate 29.3%), 25 - 3099 AE SS (utilisation rate 12.7%) and 27 - 3099 AE SS PB (utilisation rate 29.4%), experienced the highest variability in herd size over simulation periods. Forced sales of most of the breeders and/or steers were necessary during droughts to limit mortality and then large numbers of breeders were purchased post-drought to quickly recover herd size.

The resource base

Average annual herd size (AE) was also poorly correlated with percent perennial grass composition (Figure 7-84). This was expected given differences in herd management practices during and after droughts. Even so, generally, breeder herd size increased with increases in perennial grass composition.

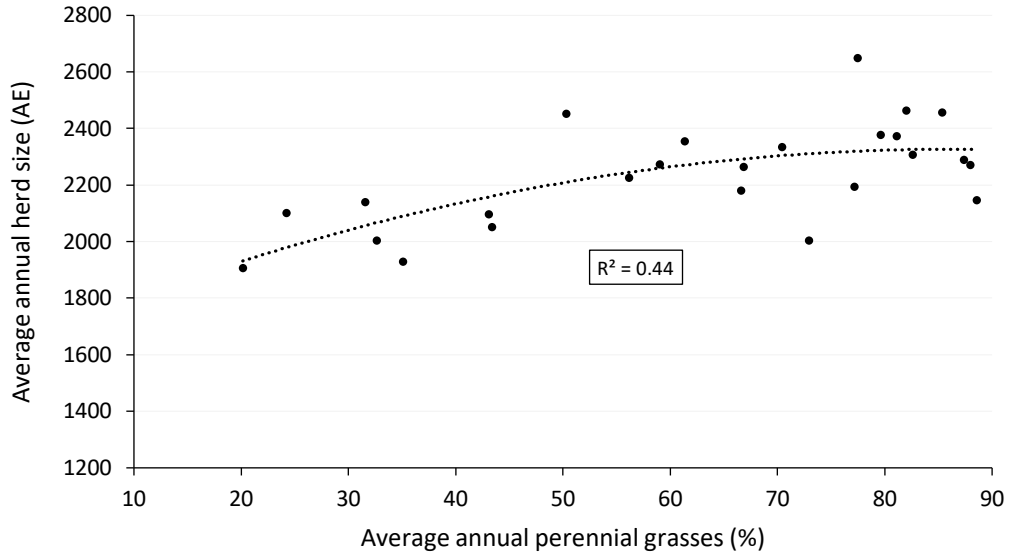


Figure 7-84: Relationships between average annual herd size (AE) and average annual percent perennial grass composition for the 25 simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

In accordance with assumptions within the GRASP and CLEM models, both average annual perennial grass composition and pasture yield were closely correlated with median utilisation rate (Figure 7-85). The starting land condition state for the Burdekin simulations was 3.5, equivalent to 60% perennial grass composition and mid-B land condition. This was maintained when median pasture utilisation rate was 20%. Lower median utilisation rates improved land condition to high B and A, while higher median utilisation rates reduced land condition to low B and C. When median annual pasture utilisation rate was 20%, average annual pasture yield was close to 1435 kg/ha. As median utilisation rate declined to 14%, average annual pasture yield increased by 45% to 2076 kg/ha. In contrast to this, when median utilisation rate was around 30%, average annual pasture yield was reduced by 37% to 900 kg/ha.

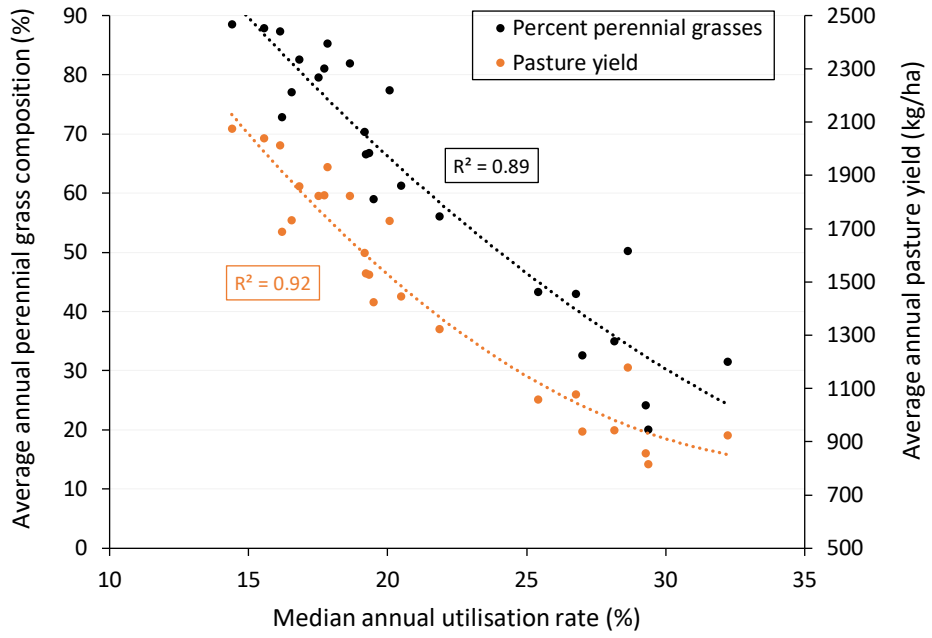


Figure 7-85: Relationships between both average June 30 pasture yield (kg/ha) and average annual perennial grass composition with median annual pasture utilisation rate for 25 simulated Burdekin herds (fitted lines are 2nd order polynomials). Average of 42 years

The steep decline in average annual pasture yield which occurred as average annual perennial grass composition declined is further demonstrated in Figure 7-86. Differences between the 25 simulated Burdekin herds in utilisation rates resulted in substantial differences in perennial grass composition (land condition) and thus pasture yield (productivity).

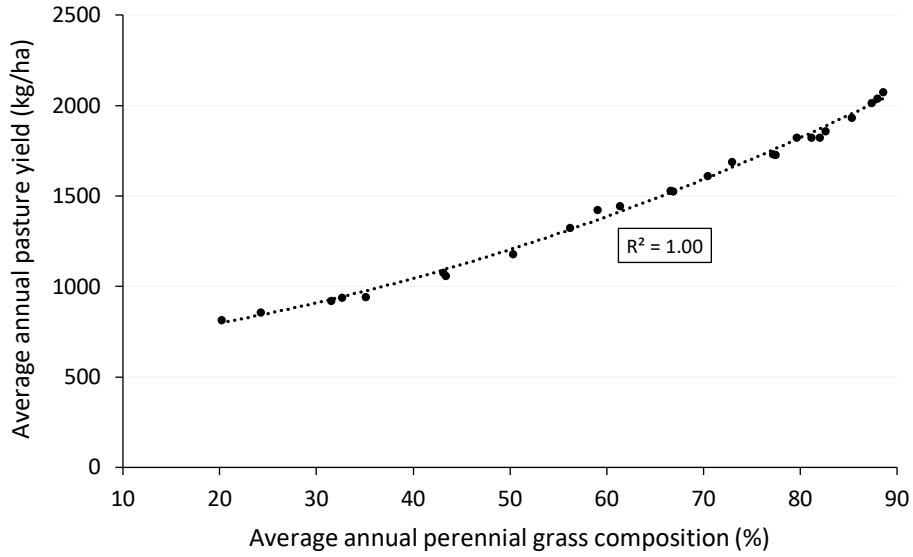


Figure 7-86: Relationship between both average June 30 pasture yield (kg/ha) and average annual perennial grass composition for 25 simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

Individual animal performance

Average annual weaning rate was not correlated with median utilisation rate, even though weaning rate was highest (67%) at the lowest utilisation rate and lowest (47%) at the highest utilisation rate (Figure 7-87). The lack of correlation was largely due to differences in the simulated management practices of herds during and following droughts, including holding breeder numbers constant over the simulation period, varying breeder numbers through sales and purchasing, and selling pre-market steers in preference to empty breeders. Of note though, the herds which achieved the highest weaning rates had median utilisation rates of between 14 and 20%.

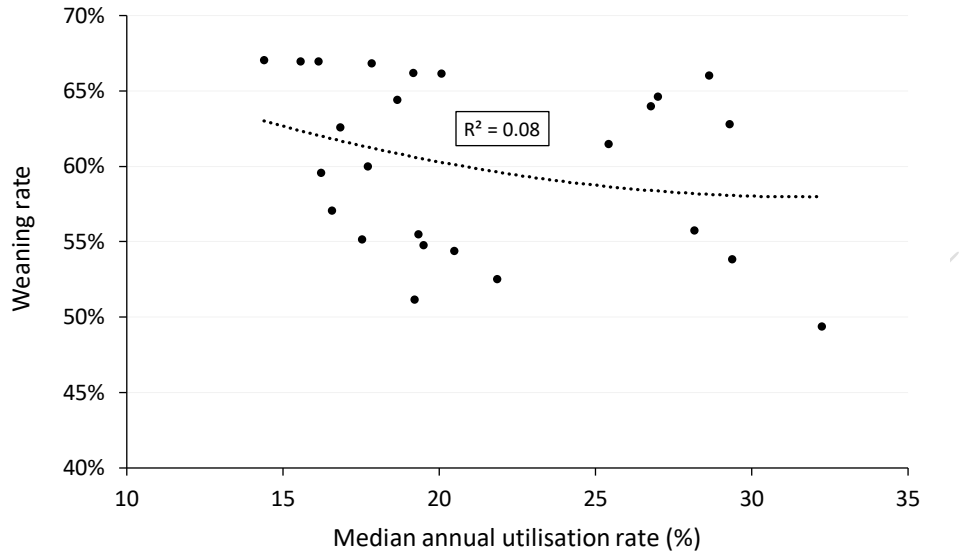


Figure 7-87: Relationship between the average annual weaning rate and median pasture utilisation rate for 25 simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

The kg of weaners produced/AE was even less correlated with median annual utilisation rate (Figure 7-88), with the relationship similar to that for weaning rate. Herds which produced the highest kg of weaners/AE had median utilisation rates between 14 and 20%. However, the expected decline in kgs of weaners produced/AE with increases in utilisation rate was masked by differences in herd management practices during and after droughts.

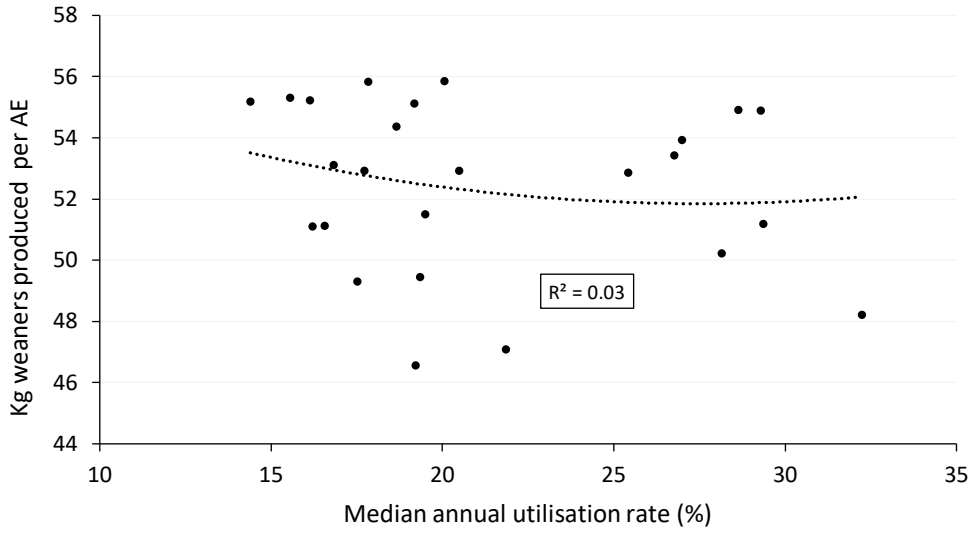


Figure 7-88: Relationship between the average annual kg of weaners produced/AE and median annual pasture utilisation rate for 25simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

The average annual kg of beef produced/AE was more closely correlated with median utilisation rate than were weaning rate and kg of weaners produced/AE (Figure 7-89). Generally, kg beef produced/AE declined from 117 at a utilisation rate of 14% to 92 at a utilisation rate of 32%. This was largely due to declines in liveweights and liveweight gains that occurred with increases in median utilisation rate.

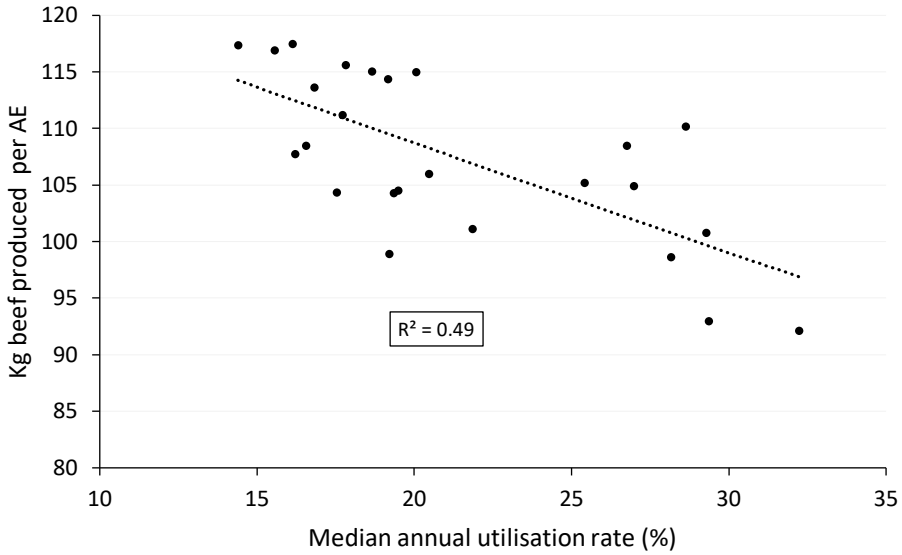


Figure 7-89: Relationship between the average annual kg beef produced per AE and median annual pasture utilisation rate for 25 simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

Herd productivity

The kgs of weaners produced/ha/year by simulated herds were poorly correlated with median utilisation rate (Figure 7-90). The highest weaner production of 5.4 to 6 kg/ha/year was achieved by herds with median utilisation rates of between 18 and 20%. However, due to differences in herd management practices, simulated herds with similar utilisation rates also had amongst the lowest weaner productivity. Generally, simulated herds with median utilisation rates lower and higher than 18-20% had lower weaner productivity of 4 to 5 kg/ha/year.

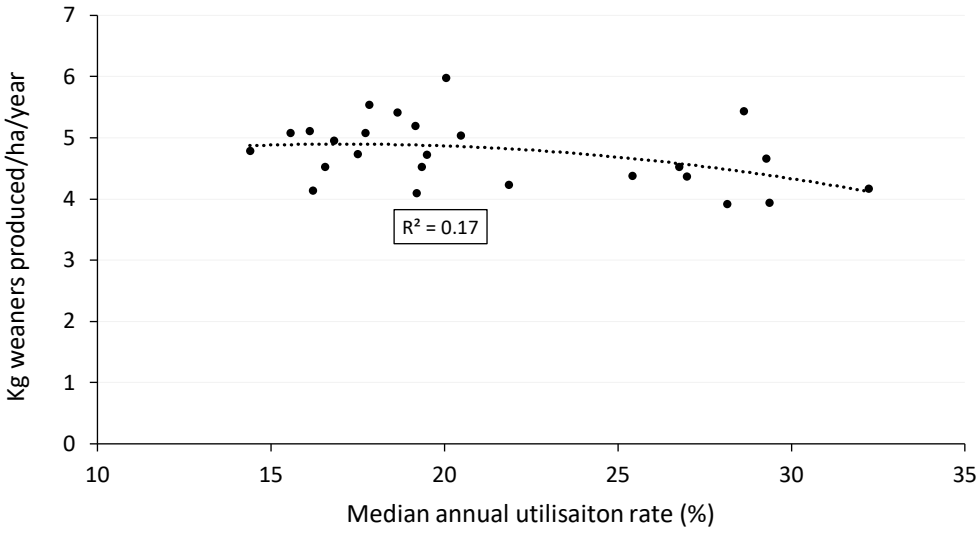


Figure 7-90: Relationship between the average kg of weaners produced/ha/year and median annual pasture utilisation rate for 25 simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

The relationship between average annual kg beef produced/ha/year (change in liveweight of all animals from July 1 to June 30, or from July 1 to when they left the herd each year) and median utilisation rates of simulated herds (Figure 7-91) was similar to that for kg of weaners produced/ha/year (Figure 7-90). However, the kg beef produced/ha/year declined at a slightly faster rate than kg weaners produced/ha/year at utilisation rates >25%. Animals within herds with median utilisation rates >25% were generally smaller than those in herds with lower utilisation rates.

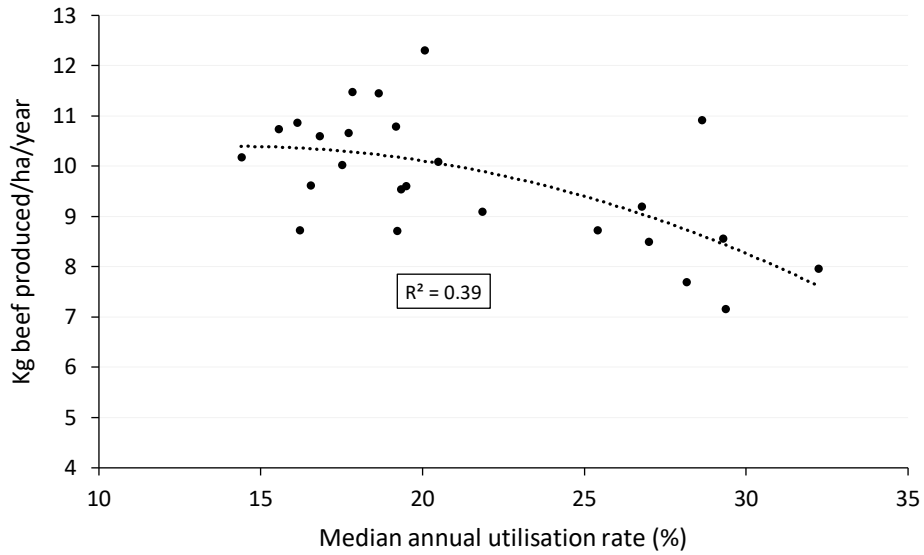


Figure 7-91: Relationship between the average kg of beef produced/ha/year and median annual pasture utilisation rate for 25 simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

Gross profit

The relationship between gross profit/ha/year and median utilisation rate (Figure 7-92) was also similar to those for kg of weaners and kg of beef produced/ha/year. However, gross profit was more strongly correlated with utilisation rate, and the overall trend was for a more rapid decline in gross profits at utilisation rates >25%. Again, the highest average annual gross profit was achieved by herds with median utilisation rates of 18 to 20%.

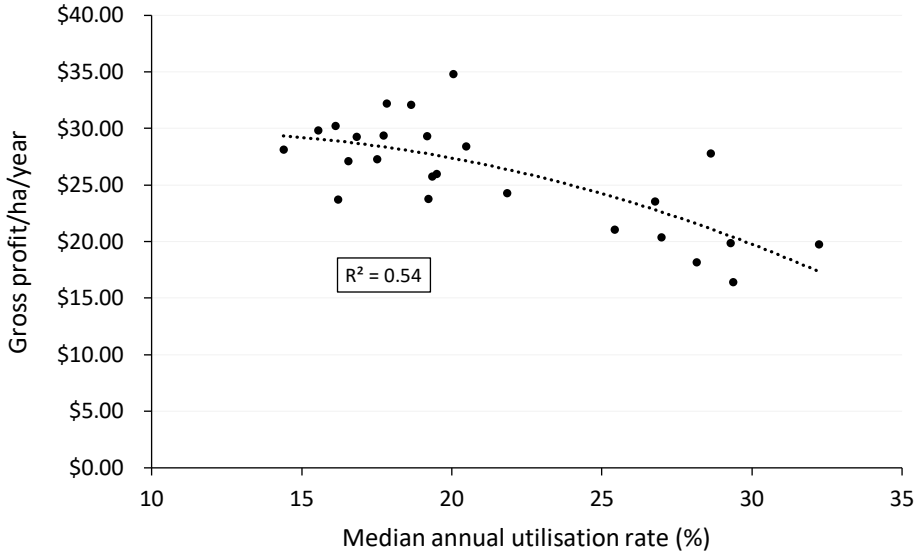


Figure 7-92: Relationship between the average annual gross profit/ha/year and median annual pasture utilisation rate for 25 simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

Variable costs

While the relationship between annual variable costs/ha and median utilisation rate (Figure 7-93) was similar to those for kg weaners produced/ha/year, kg beef produced/ha/year and gross profit/ha/year, it was far less correlated with utilisation rate and generally did not decline at utilisation rates >25%. As expected, the herds with the highest variable costs/ha had the largest total and breeder herd sizes (Figure 7-80 and Figure 7-83).

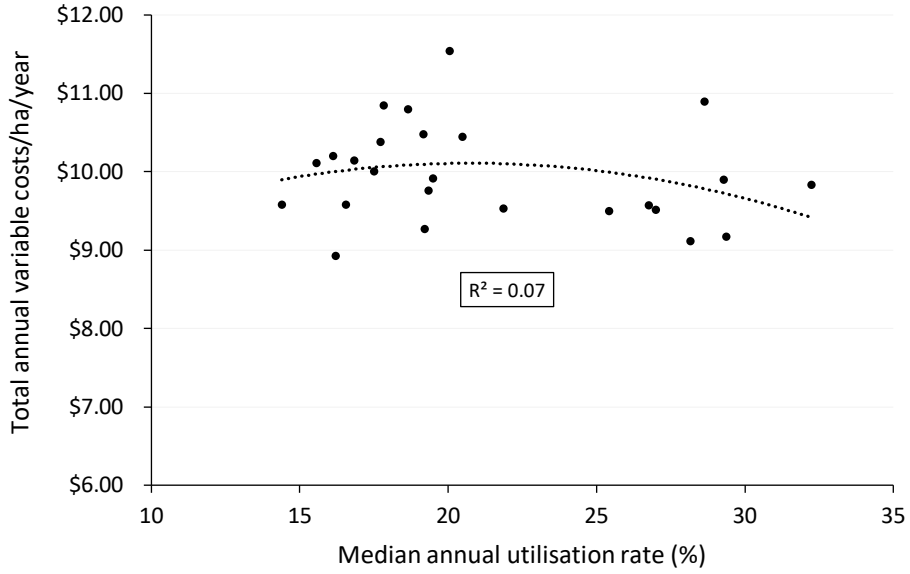


Figure 7-93: Relationship between the average annual variable costs/ha/year and median annual pasture utilisation rate for 25 simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

Variable costs/AE were more highly correlated with median utilisation rate, tending to increase with increases in utilisation rate (Figure 7-94). However, there was little difference in the variable

costs/AE for herds with median utilisation rates between 14 and 20%. The simulated herds with utilisation rates >25% had the highest variable costs/AE of $110-$119, whereas herds with lower utilisation rates had approximately 5% lower variable costs/AE of $104-$111. This was partly due to the smaller size of individual animals and the increased need for M8U supplementation in herds with utilisation rates >25%.

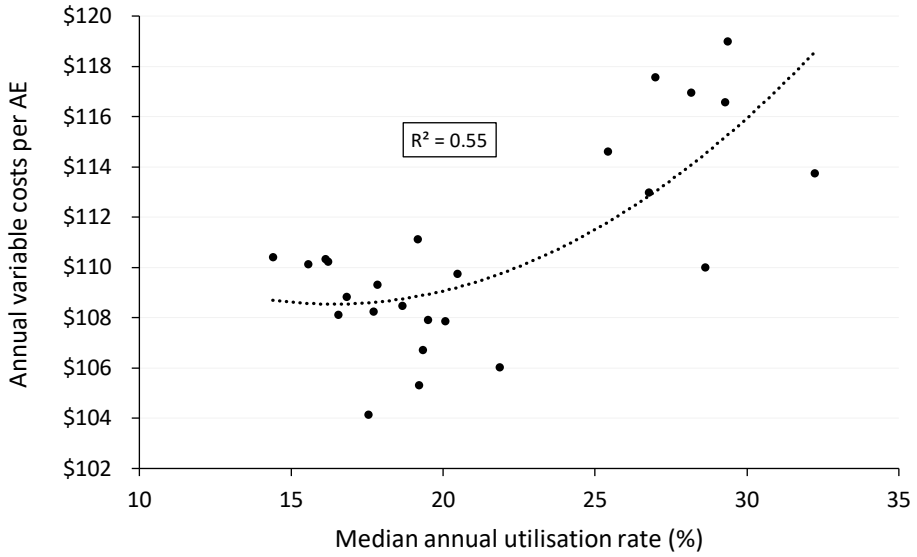


Figure 7-94: Relationship between the average annual variable costs/AE and median annual pasture utilisation rate for 25 simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

Total variable costs/kg beef produced were more highly correlated with median utilisation rate than was variable costs/AE, tending to increase more rapidly with increases in utilisation rate (Figure 7-95). Again, this was due to the smaller liveweights and greater need for M8U supplementation in herds with higher utilisation rates.

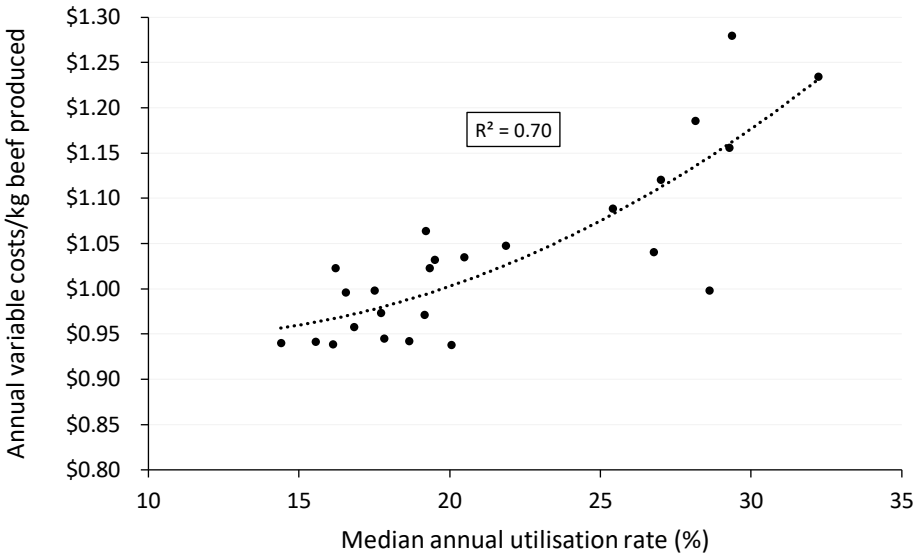


Figure 7-95: Relationship between the average annual variable costs/kg beef produced and median annual pasture utilisation rate for 25 simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

Profit

Average annual profit/ha (gross profit – overhead and variable costs) generally decreased rapidly with increases in median utilisation rate (Figure 7-96). While the highest profits of $9-$11/ha/year were achieved by herds with utilisation rates of 18-20%, herds with similar utilisation rates, but different management practices, had considerably lower profits. Herds with utilisation rates >25% generally had negative profits of -$2 to -$5/ha/year.

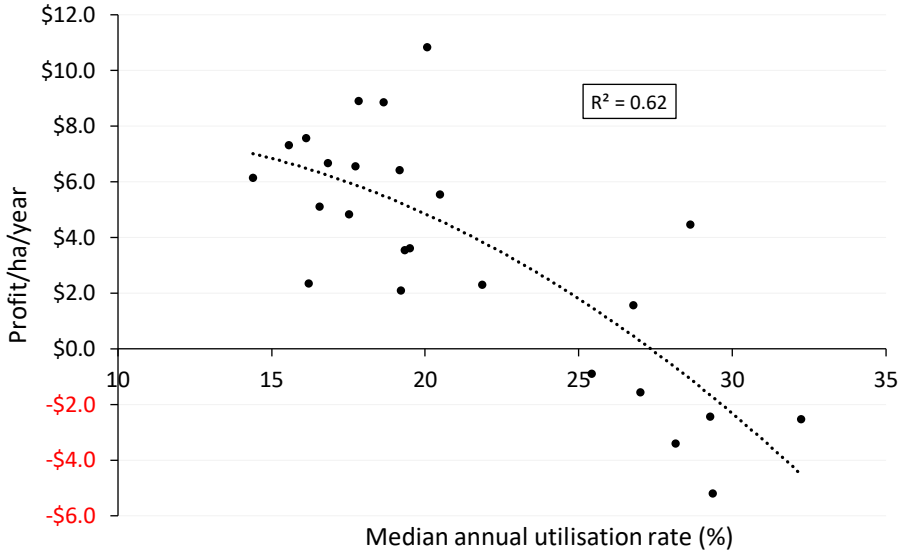


Figure 7-96: Relationships between the average profit/ha/year and median annual pasture utilisation rate for 25 simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

Profit/ha/year was highly correlated with and increased rapidly with increases in percent perennial grass composition (Figure 7-97). The most profitable herds were able to improve perennial grass

composition from a starting point of 60% (mid B land condition) to >84% (A condition) by the end of the simulation period, resulting in average annual perennial grass compositions of >75%. Herds which maintained mid-B land condition were less profitable, and those which reduced land condition to low-B or high-C were the least profitable.

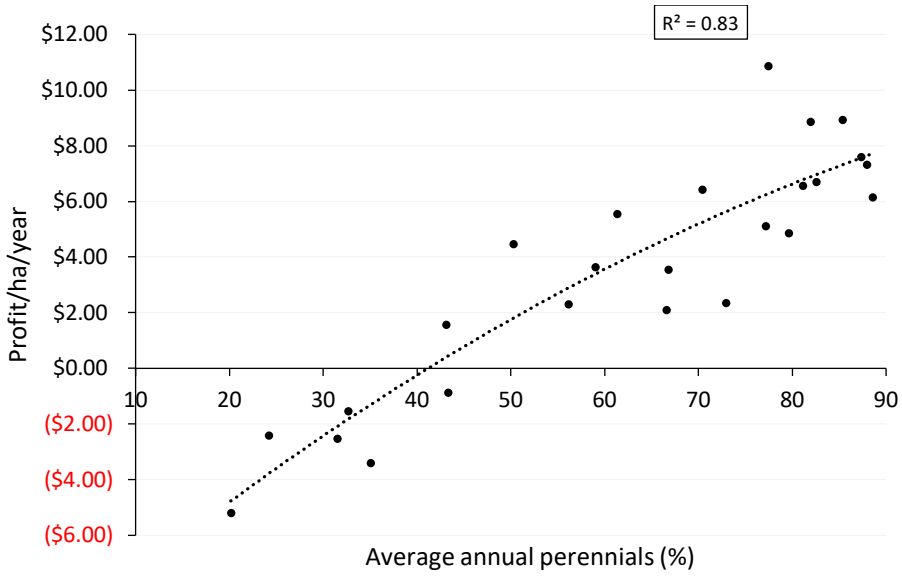


Figure 7-97: Relationships between the average profit/ha/year and average annual perennial grass composition for 25 simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

Given the negative relationship between percent perennial grass composition and utilisation rate, it is not surprising that profit/AE and profit/kg beef produced both decreased sharply with increases in median annual utilisation rate (Figure 7-98). Again, the highest profits were achieved by herds with median utilisation rates of 18 to 20%. While there was some variation due to variation in herd management practices, nearly all herds with utilisation rates >25% had the lowest profits.

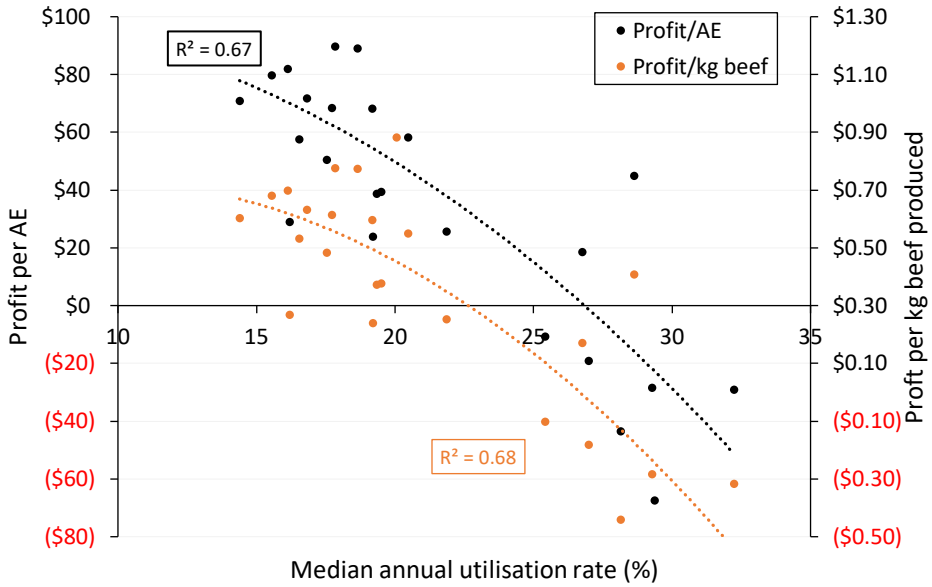


Figure 7-98: Relationship between the average annual profit/AE and profit/kg beef produced with median annual pasture utilisation rate for 25 simulated Burdekin herds (fitted lines are 2nd order polynomials). Average of 42 years

Both profit/ha/year and profit/AE were highly and positively correlated with average annual stocking rate (Figure 7-99). Profits increased almost linearly as average annual stocking rates increased from 7.7 to 9.5 AE/km^2, then began to asymptote with further increases in stocking rate to 10.7 AE/km^2.

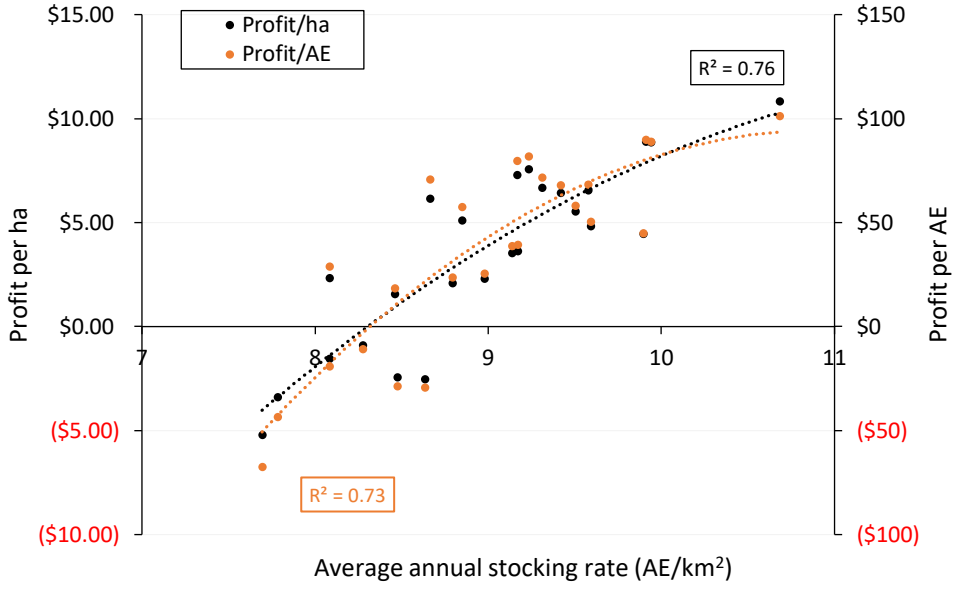


Figure 7-99: Relationship between the average profit/ha/year and profit per AE with average annual stocking rate for 25 simulated Burdekin herds (fitted lines are 2nd order polynomials). Average of 42 years

7.8 Discussion

A bioeconomic modelling framework was used to quantify the outcomes of a range of pasture utilisation rates on land condition, herd productivity and finances of two breeding enterprises, one typical of those in the Burdekin region of north-east Queensland, and the other typical of those in the Barkly Tablelands of the Northern Territory. This framework consisted of the GRASP pasture growth production model and the Crop Livestock Enterprise Model (CLEM). This is the first time CLEM has been used to model the impacts of pasture utilisation on breeder herds in northern Australia. CLEM has distinct advantages over other less dynamic bioeconomic modelling approaches (e.g. Bowen *et al.* 2021), because it tracks the impact of changing pasture availability and diet quality on animal growth, body condition, weight, pregnancy etc for every individual animal on a monthly time step basis. Furthermore, it allows feedback of the pasture utilisation on land condition, and how this impacts growth and forage availability over the following years. It also incorporates climate variability and how that can influence pasture growth and animal performance. It is not necessary to guesstimate and tell the model how animal performance varies with climate and pasture utilisation, because it calculates this from first principles based on individual animal intake and growth. This modelling exercise has provided insights into how pasture utilisation affects all aspects of a cattle grazing system, from the resource base to individual animal and breeder herd performance, through to enterprise level animal production and profitability. In particular, it has allowed the longer-term impacts of pasture utilisation, combined with the influence of long-term climate variability on land condition, animal production and profitability, to be investigated. Grazing trials are rarely long enough to impact the resource base, and can give misleading results when there are no apparent long-term impacts on pasture productivity and carrying capacity (e.g. the Pigeon Hole Project and Mount Sanford grazing trials in the VRD) (Cowley *et al.* 2007, Hunt *et al.* 2013). The Wambiana grazing trial (O'Reagain *et al.* 2022) is an exception to this, although it was with steers, not breeders.

The downside of this modelling approach is that it is very complex to parameterise and requires a high level of understanding and skill across a range of disciplines that is unlikely to be found in any one individual person. Rather it requires a team of experts to parameterise, simulate and summarise the outputs of potentially tens of thousands of animals on a monthly basis. The CLEM parameter sets characterising the different regions have taken a long time to develop and should be made available to the broader research community to extend the value of the investment in this modelling exercise to the cattle industry.

The parameters driving land condition response to pasture utilisation are amongst the most important, but also the least understood, due to a paucity of relevant empirical data. This is needed to inform the rates of change of land condition and threshold pasture utilisation levels for different land types across northern Australia. Further research is warranted.

7.8.1 Barkly simulations

The amounts and sequence of annual rainfall during the 44-year Barkly simulation period had a large influence on the performance of herds with different stocking rate and pasture utilisation approaches. Relative to the average annual rainfall of the 44-year Barkly simulation period, the first half was largely a period of rainfall deficit, most of the second half was a period of rainfall surplus, then rainfall abruptly dropped to deficit during the last four years (Figure 7-28). The long and largely uninterrupted period of rainfall surplus was atypical of historical climate for this Barkly property, and hence median annual pasture growth for the simulation period 1979 to 2023 was 40% higher than that for 1892 and 2023. Thus, the long-term carrying capacity of the Barkly property during the

simulation period was 40% higher than the 35470 AE calculated using much longer-term climate data. Accordingly, the carrying capacity for the simulation period was 49658 AE. The long-term safe utilisation rate for this property is 20%.

At the Barkly property median annual pasture utilisation rate increased with increases in average annual female breeder and total herd sizes. However, the increase was not linear and tended to increase less at higher utilisation (Figure 7-42) due to feedbacks of higher pasture utilisation on animal performance, where at higher utilisation animal intake/head was lower due to lower forage quality / quantity (Figure 7-47). This was further compounded when considering AE, due to lower performance per head at higher utilisation (Figure 7-45 - Figure 7-47), as well as negative feedbacks on pasture growth due to land condition decline at the highest utilisation rates (Figure 7-48). In contrast to this, the negative feedbacks of higher pasture utilisation rates were even greater on the average annual size of Burdekin herds so that herd sizes were lower at the highest median pasture utilisation rates, due to declines in land condition that limited pasture growth (Figure 7-80, Figure 14-222, Figure 14-223).

While average annual size of Barkly herds kept increasing with increasing utilisation rate, the average annual kg of beef produced plateaued at a utilisation rate of 18% (Figure 7-51), then declined with further increases in utilisation rate. This occurred because the kg of beef produced/AE declined as utilisation rates rose above 18% (Figure 7-51). Furthermore, the two Barkly herds with the highest average annual sizes were the least profitable (Figure 7-58) because the increase in herd size produced no extra beef (Figure 7-53) but had higher total variable costs (Figure 7-55, Figure 7-57) and high costs of purchasing breeders to restore herd size after droughts. This trend was even more extreme when comparing production to stocking rate (Figure 7-61).

The most profitable of the 12 Barkly herds simulated was 8 - 34400 AE PB. It had an average annual profit of $9,753,580 and a median annual pasture utilisation rate of 22.5%. However, this was similar to the annual profits of herds 5 - 30746 AE, 6 - 31908 AE PB and 7 - 33482 AE PB, which had median annual utilisation rates of 15.9 to 17.6%. The average annual profits of these three herds ranged from $9,046,771 to $9,576,704, which were only 2 to 7% lower than the most profitable herd. The simulated median annual pasture utilisation rates of these four most profitable herds of 16 to 23% were similar to the simulated long-term safe utilisation rate of 20% for this Mitchell grass land type on the Barkly Tablelands. Accordingly, average annual percent perennial grass composition, an index of land condition, ranged from 64 to 74% for these four herds, which was similar to the percent perennial grass composition of 67% at the commencement of the simulation period. Hence, these four herds had simulated land condition ratings of mid to high B. The lower pasture utilisation rates resulting in a greater improvement in land condition of these smaller herds increased the buffer for dry periods and droughts with very little loss in profitability.

The three most profitable herds (8 - 34400 AE PB, 6 - 31908 AE PB, 7 - 33482 AE PB) all purchased young breeders for the purpose of rapidly restoring breeder herd size following the 1990s drought. This also enabled them to take advantage of an approximately 20-year period of mainly above - average annual rainfall, and consequently, a long period of high pasture productivity. Of these four herds, 8 - 34400 AE PB purchased the most breeders. During each year between 1996 and 1998, 12300 breeders were purchased at an annual cost of $20.8 million. Also, in 2022, 15300 breeders were purchased at a cost of $25.6 million. Herds 6 - 31908 AE PB and 7 - 33482 AE PB purchased 7300 and 8300 respectively each year from 1996 to 1998, at the annual cost of $12.3 and $14.1 million respectively. Due to partial destocking during droughts and purchases of breeders following droughts, annual herd size for these three herds had high coefficients of variation, ranging from 41 to 54% (Figure 7-44), which were similar to the coefficient of variation for annual rainfall of 44%.

Purchasing large numbers of breeders also enabled these herds to take advantage of the abnormally large amount of pasture available during the second half of the simulation period, reaching very high total sizes and producing large amounts of beef. While this worked well under this very long period of consistently high rainfall, in reality, would have these large numbers of female breeders been available, and if so, would have managers spent these large sums of money purchasing them immediately after a drought? There are considerable risks involved with this approach. As observed with the Burdekin simulations, purchasing large numbers of breeders after a similar drought was not successful. Annual rainfall declined soon after, leading to high utilisation rates, deterioration of land condition and periods of low herd production and high costs.

In comparison, the 4th most profitable herd, 5 - 30746 AE, did not purchase breeders following sales of a substantial number of breeders during the 1990s drought, and thus, recovery of initial breeder herd size through natural recruitment was slow. Consequently, there were fewer years when this herd was able to take advantage of high pasture productivity during the second half of the simulation period. This would have enhanced post drought land condition recovery, but at the cost of additional profits that could have accrued if higher stocking rates were achieved sooner post drought through purchasing breeders. However, this may reflect the reality for stations due to breeder restocking costs and supply issues. The coefficient of variation for annual herd size of 32% was lower than those of the three most profitable herds.

The lower profitability of the remaining six herds was due to two reasons. First, herds 1 - 23651 AE, 2- 25922 AE, 3 - 27210 AE and 4 - 28514 AE had the lowest initial and average annual herd sizes and did not purchase cows as a mechanism for utilising the large amount of pasture available post the 1990s drought. Consequently, coefficients of variation in herd size of between 31 and 33% for these four herds were relatively low. These herds had median annual utilisation rates of 7 to 13%, and accordingly, average annual perennial grass composition was high at 80 to 82%. As such, land condition improved from mid B to A during the simulation period. While these four herds produced beef at relatively low costs, the average annual amount of beef produced was considerably lower than that produced by the four larger and most profitable herds.

Two other herds, 9 - 35222 AE PB and 10 - 35267 AE PB, with the largest initial and average annual herd sizes, and thus the highest median annual pasture utilisation rates of 25.9 and 29.3% respectively, produced close to the largest amounts of beef annually (but less than herd 8 at 22% utilisation). They were less profitable because they produced the least kg of beef/AE consistent with findings for northern beef herds (McLean *et al.* 2023), they had the highest variable costs and the highest cattle purchase costs, and therefore they had the lowest profit/kg of beef produced (Figure 7-56). Also, these two herds had the highest inter-annual variation in herd size, with coefficients of variation of 61 and 67% respectively. Average annual perennial grass composition was the lowest of all 10 herds, at 50 and 49% respectively, which reduced average annual pasture biomass availability. Consequently, these herds were substantially destocked during sequences of dry or drought years. However, herd productivity was maintained by purchasing large numbers of young breeders when climatic conditions improved after droughts. Around 18000 breeders were purchased each year between 1996 and 1998, around 19000 breeders each year between 2014 and 2017, and 25000 breeders in 2022. The annual costs of purchasing these breeders ranged from 30 to 42 million, which occurred in seven to eight years of the 44-year simulation period. Given that the breeders sold during drought were poor with low liveweights, while those purchased after droughts were heavier and cost 45% more per kg, overall profitability declined with increasing occurrences of sales and purchases of breeders. Also, as noted earlier, the 200 km trucking distance for purchased female

breeders under-estimated their purchasing costs, and thus, these two herds which purchased the most breeders would have been even less profitable.

As can be seen in Figure 7-36 - Figure 7-38 for herd 8 - 34400 AE PB, with a median pasture utilisation rate of 22.5%, which was the most profitable of all 10 simulated herds, its high productivity and profitability were largely accrued during the years 2000 to 2017, when total herd size was between 60,000 and 80,000 AE. In comparison, at the same time, land condition of smaller herds 5 - 30746 AE, 6 - 31908 AE PB and 7 - 33482 AE PB were high B to A, and therefore, their productivity and profitability were more closely aligned with the carrying capacity of the simulation period than was herd 8 – 34400 AE PB. Their median annual utilisation rates were 16 to 18%, and their final annual percent perennial grass compositions were 82, 73 and 81% respectively. For example, at the end of the simulation period for herd 7 - 33482 AE PB (Figure 7-31), land condition had improved from high B to A and herd size was 17000 AE. At the same time, land condition of the most profitable herd, 8 - 34400 AE PB, improved from high C to B, and herd size was 9000 AE (Figure 7-38). In consideration of these results, the profitability and sustainability of herds 5 - 30746 AE, 6 - 31908 AE PB and 7 - 33482 AE PB were regarded as more typical of the simulation period. They achieved only marginally lower annual average profits, without compromising land condition and future pasture productivity, and with much less volatility in herd size and less requirement to sell during dry periods, and lower costs to restock following drier periods.

The average annual size of the three most profitable and sustainable Barkly herds ranged from 37274 to 40186 AE, (stocking rates around 8 to 8.5 AE/km^2) which were 5 to 13% higher than the simulated long-term (100+ years) carrying capacity of 35470 AE (7.5 AE/km^2) for the Barkly property. However, as median pasture growth during the simulation period was 40% higher than longer-term growth, the equivalent carrying capacity was higher than the long-term average.

Overall, the annual amounts and distribution of rainfall over the 44-year simulation period, which were atypical of historical climate, were responsible for the outcomes of the simulated herds. Low rainfall and correspondingly low pasture growth during the first half of the simulation period limited herd productivity and size, and thus herds were unable to take full advantage of the large amounts of forage available during the remaining years of the simulation. Also, natural recruitment as the means of building herd size after the 1990s drought was inadequate, given the sudden and sustained increase in forage supply. Consequently, even though purchasing large numbers of young female breeders was costly, this was more than remunerated by many years of sustained high herd productivity. As such, high inter-annual variability in herd size was needed to take advantage of the large amounts of forage available during the second half of the simulation period. This resulted in median annual pasture utilisation rates that were similar to or lower than safe, and thus, initial land condition was either maintained or improved over the duration of the simulation period. This demonstrates the potential difficulty in stocking to safe levels when rainfall and pasture growth can vary so much, even on a decadal to multidecadal scale.

In addition to the productivity benefits associated with increasing herd size in proportion to increases in rainfall, the most profitable herds also had the highest reproductive performance. The average pregnancy and weaning rates of the most profitable herds were ≥82% and ≥66% respectively. This was in contrast to the least profitable herd where pregnancy and weaning rates were 74% and 57% respectively. This suggests, assuming other recommended herd management practices are in place, that lower breeder performance in Barkly station herds may be indicative of less-than-optimal pasture utilisation and signal room for not only better breeder herd performance, but also better production and profit if stocking rates are reduced.

7.8.2 Burdekin simulations

The Burdekin simulation period commenced in January 1978 and ended in June 2022. The simulation period consisted of eight alternating periods of below- and above-average rainfall (Figure 7-62). The second period of below-average rainfall during 1992-1996 was a substantial drought. Herds with high initial sizes were largely destocked during this drought, to avoid high rates of mortality from starvation. Other challenging periods of time for herds were a less major drought during 2003 to 2005, and then another substantial drought during 2015 to 2018. The drought in 2003 to 2005, which considerably interrupted the productivity of the Burdekin herds, did not occur on the Barkly property.

In contrast to the Barkly, the Burdekin herd with the largest average annual size was the most profitable. It produced the highest average annual kg of weaners and kg of beef with amongst the lowest variable costs/AE, and achieved this without needing to purchase female breeders. The median annual utilisation rate for this herd was 20.1%, average annual percent perennial grass composition was 77%, and perennial grass composition during the last 14 years of the simulation period exceeded 80% (indicative of A land condition). Hence the highest breeder herd size with an average stocking rate of 10.7 AE/km^2 was that which maintained or improved land condition, because trying to run larger herds led to declines in carrying capacity due to high utilisation leading to poorer land condition.

Of the five most profitable herds (18 - 2436 AE HB, 2 - 2466 AE, 7 - 2670 AE PB, 17 - 2610 AE HB, 13 - 2619 AE HB), four deliberately held breeder numbers relatively constant throughout the simulation period. These herds had amongst the lowest initial sizes of 2436 to 2670 AE, and amongst the lowest median annual pasture utilisation rates. Their initial stocking rates of 9.8 to 10.7 AE/km^2 were such that these could be maintained over the entire simulation period, as they were very similar to their average annual stocking rates of 9.2 to 10.7 AE/km^2. The only herd smaller than these was 1 – 2349 AE, which consequently had the lowest utilisation rate and highest perennial grass composition. Due in part to it being the smallest herd, with a relatively low average annual stocking rate of 8.7 AE/km^2, it had the 9th highest profitability.

While purchasing young breeders to recover herd size after drought mostly reduced the long-term profitability of herds, the third most profitable herd, 7 – 2670 AE PB, purchased a relatively small number of breeders after the 1990s drought, thereby quickly rebuilding herd size. Overall, purchasing breeders after the 1990s and other droughts was only profitable if relatively small numbers were purchased.

The herds with higher initial sizes of 2700 to 2800 AE (10.9 to 11.3 AE/km^2) were less profitable than those with initial sizes of 2436 to 2670 AE. For herds with initial sizes of 2700 to 2800 AE, it was not possible to hold breeder numbers relatively constant over the simulation period. In these cases, it was necessary to substantially reduce herd size through sales during the 1990s drought to prevent high rates of mortality. Purchasing breeders after droughts was then required to quickly rebuild herd size, and while this achieved average annual stocking rates of 8.8 to 9.9 AE/km^2, comparable with the more profitable herds, this was costly, and it also caused declines in land condition and thus reductions in pasture and herd productivity. With herds of this range of initial sizes, selling empty breeders during the 1990s drought and then purchasing breeders to rapidly restore breeder herd size immediately after the drought when climatic conditions improved was the most profitable strategy. This was more profitable than selling 1- to 3-year-old steers instead of empty breeders during the drought, and it was more profitable than retaining female cattle post-drought as the only mechanism for rebuilding the herd.

Herds with an initial size close to 2900 AE (11.7 AE/km^2) had low annual profit. During the 1990s drought it was necessary to substantially reduce herd size to prevent very high rates of mortality. Selling all but 100 breeders during the 1990s drought and then slowly building the herd by natural recruitment was less profitable than selling most of the 1- to 3-year-old steers in preference to empty breeders. Less profitable than both these scenarios was destocking the breeder herd to 100 head during droughts and then purchasing large numbers of breeders to rapidly restore breeder herd size. The average annual stocking rates of 7.8 to 9.2 AE/km^2 achieved by herds with these high initial sizes and several destocking and restocking practices were lower than those of the most profitable herds.

Herds with the highest initial sizes of 3099 to 3269 AE (12.5 to 13.2 AE/km^2) were the least profitable. During the 1990s drought, their entire breeder herds had to be sold, and even then, several-100 male and female cattle died of starvation. Purchasing breeders substantially improved profitability compared to destocking steers for the purpose of maintaining more breeders, and least profitable of all was rebuilding the herd through slow natural recruitment. Due largely to high pasture utilisation rates and declining land condition, these herds achieved the lowest average annual stocking rates of 5.7 to 8.6 AE/km^2.

The least profitable herds, with initial AEs of 2900 and higher, displayed high annual variability in herd size, with coefficients of variation of between 29 and 79%. These herds, with high median utilisation rates and occasional years of very high utilisation, reduced land condition and pasture productivity, leading to forced sales of breeders or steers which reduced herd productivity, and then purchased large numbers of young breeders to restore herd size.

These simulations provide insights into the impacts of utilisation on breeder herd performance and profits. The average pregnancy and weaning rates of the most profitable herds were ≥75% and ≥65% respectively. This was in contrast to the least profitable herds where pregnancy rates of 57% - 72% and weaning rates of 52% - 66%. These lower breeder performance averages may be indicative of less-than-optimal utilisation and signal opportunity for not only better breeder herd performance, but also better production and profit in Burdekin herds if stocking rates are reduced.

Given that the most profitable and productive herds were able to improve land condition from mid B to mostly A condition, while maintaining herds with the highest average annual size, of particular interest was the impact of pasture utilisation rate on land condition. Examples of the rates of change in percent perennial grass composition (index of land condition) over the 42-simulation period are shown in Figure 7-100 and Figure 7-101. For the most profitable herd 13 - 2619 AE HB, as annual pasture utilisation rates were mostly below the safe rate of 25% for the first 15 years of the simulation period, percent perennial grass composition slowly improved from 60 to 75%. This equates with an improvement in land condition from mid to high B (Walsh and Cowley 2016). Then, during the 1990s drought when utilisation rates increased to 60%, percent perennial grass composition dropped to 58% in four years. As utilisation rates declined to around 10% following the drought, perennial grass composition increased to 76% in five years (close to A condition). It remained at close to A condition during the dry years of 2002 to 2006, then as utilisation rates were mostly below 25% for the remainder of the simulation period, perennial grass composition increased to around 90% (A condition). This herd size was just below the estimated long-term safe carrying capacity of 2700 AE. It was the most profitable because the slightly lower than safe pasture utilisation rates led to an increase in land condition and hence carrying capacity, making the property more resilient to dry periods and able to minimise herd fluctuations.

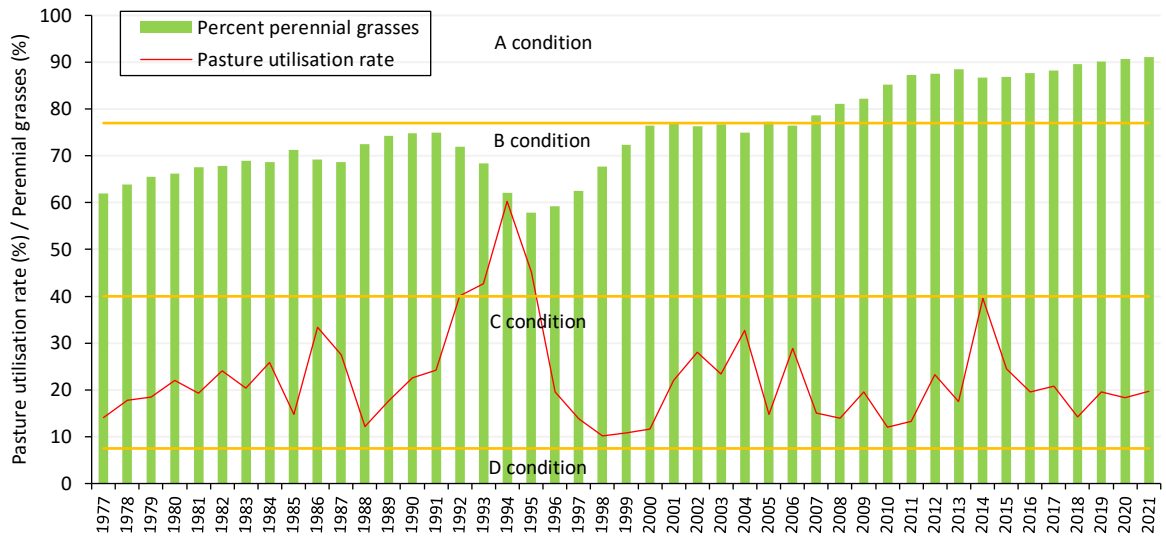


Figure 7-100: Time series of annual pasture utilisation rate, annual percent perennial grass composition and related land condition ratings for the most profitable Burdekin herd 13 - 2619 AE HB

In contrast to herd 13 – 2619 AE HB, for herd 19 – 2925 AE, which was deliberately simulated to achieve high pasture utilisation rates, land condition declined from B to low C over the simulation period (Figure 7-101). Land condition leading into the 1990s drought for Herd 19 was mid B vs. high B for Herd 13, which put Herd 19 in a less productive state leading into the drought. With herd 19, it took four years to reduce land condition from mid B to high C during the 1990s drought, then towards the end of the simulation period, took six years to reduce land condition from low B to low C when average pasture utilisation rates between 2014 and 2018 were more than double the safe level of 25%.

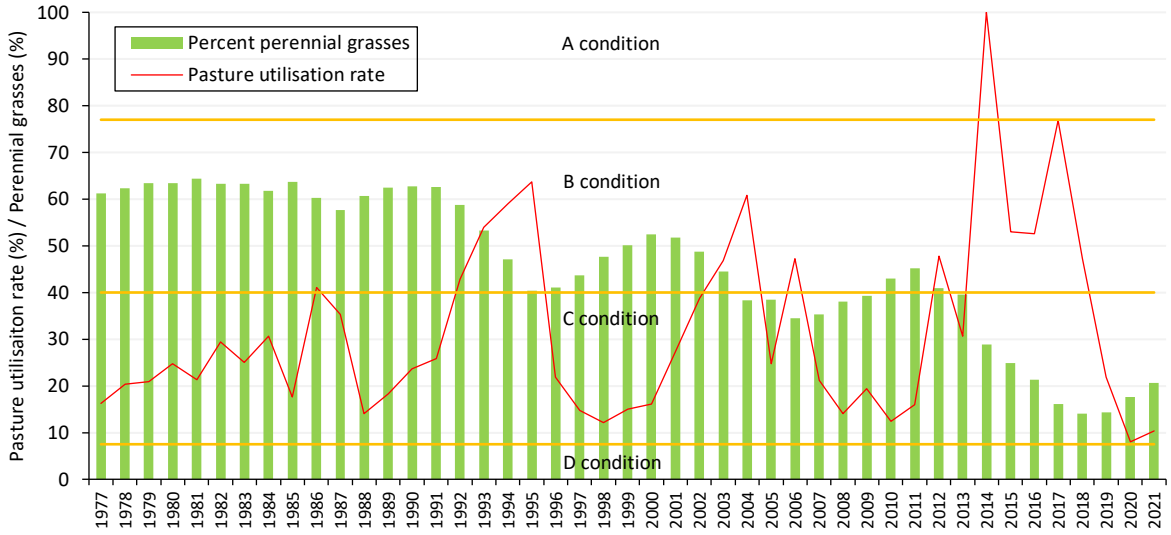


Figure 7-101: Time series of annual pasture utilisation rate, annual percent perennial grass composition and related land condition ratings for one of the least profitable Burdekin herds 19 - 2925 AE HB. Average of 42 years

When all 27 simulated herds were examined, listed from left to right in order of increasing average annual profitability (Figure 7-102), it is apparent that the most profitable herds enabled land

condition to improve from mid B to high B or A. This occurred even though annual average herd size was amongst the highest of all herds, made possible by the maintenance of amongst the highest annual pasture growth rates. In summary, the most profitable herds were those that resulted in the highest land condition which enabled the highest average stocking rates to be carried. Note that Figure 7-102 includes Herds 6 and 25 that were excluded from other discussions. These herds, with the highest initial herd sizes, had the highest utilisation rates prior to the 1990s drought, but were then almost completely destocked during this drought. They did not recover original herd size by the end of the simulation period because purchasing breeders was not included. Consequently, the first half of the simulation period consisted of high utilisation rates and poor land condition, whereas the second half had very low utilisation rates and rapidly improving land condition. While average annual land condition for these herds was relatively high, their low average annual herd size meant that they had amongst the lowest profitability of all 27 herds.

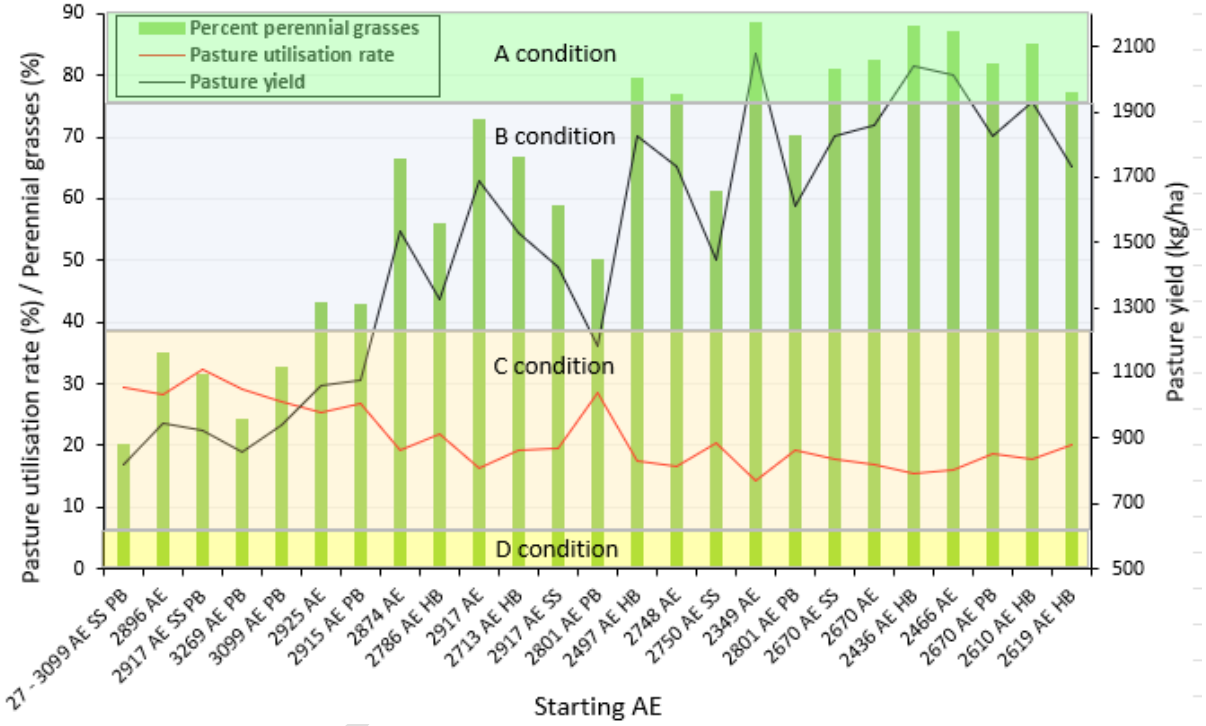


Figure 7-102: Average annual pasture yield, median annual utilisation rate, and average annual percent perennial grass composition relating to land condition ratings A to D, for the 27 simulated Burdekin herds, ordered from left to right in increasing average annual profitability. Average of 42 years

The increasing average annual profitability of the Burdekin herds was closely aligned with increasing herd productivity. Profit increased steadily as the kg of weaners and kg of beef produced per year and per AE increased. At the same time, gross profit and total gross profit margin also increased steadily with increasing profit. These trends were particularly apparent for the three most profitable herds. Their profitability was 17 to 43% higher than the 4th most profitable herd.

The long-term carrying capacity for the 42-year simulation period of 2700 AE (10.9 AE/km^2) was similar to the average annual herd size of 2649 AE (10.7 AE/km^2) for the most profitable herd, while those of the 2nd and 3rd most profitable herds were slightly smaller at 2457 (9.9 AE/km^2) and 2465 AE (9.94 AE/km^2). Similarly, the long-term safe pasture utilisation rate of 25% was also higher than the median annual utilisation rates of 17.8 to 20.1% for these three most profitable herds.

A common characteristic of the five most profitable Burdekin herds was that annual breeder and total herd sizes were near the maximum that could be kept relatively constant over the entire simulation period, without causing lasting declines in land condition. This was possible because their median annual utilisation rates of 15.6 to 20.1% were considerably lower than the safe rate of 25%. Land condition improved from mid B to high B or A by the middle of the simulation period, then was held in this condition over the remaining years. Herds with higher initial sizes could not be maintained during droughts. At these times, pasture utilisation rates were far above safe, animals lost weight, conception rates dropped markedly, and if large proportions of female and/or male classes of cattle were not sold during droughts, then many cattle would have died of starvation. Income/head from forced sales were low due to the low weight of animals sold. Given the lower sale prices and weights of breeders sold during droughts compared with those purchased after drought, breeders were purchased after droughts at twice the cost they were sold during drought. These large swings in herd size made enterprises vulnerable to risks associated with high climate variability. These risks included selling cattle when they were in poor condition and prices were low and buying cattle when prices were high, and the high costs and limited availability of both drought feed and agistment for cattle when they were needed. Many of these risks were not fully accounted for in these simulations, and thus performances of the most stable herds were likely under-estimated compared to the more variable herds.

The most profitable simulated herds were those which achieved the most productive balance between herd productivity, pasture productivity and enterprise profitability – essentially the sweet spot of breeder herd performance.

7.8.3 Stocking rate-productivity-profit relationships

Identification of the sweet spot or optimal pasture utilisation rate for breeder herds in northern Australia has been informed by the Jones and Sandland (1974) and Hart (1978) stocking rate-productivity relationships assessed by Ash and Stafford Smith (1996). Ash and Stafford Smith (1996) noted these were based on widely accepted assumptions that stocking rate (head/area) was linearly (or slightly curvilinearly) related with individual animal performance (gain per head) and quadratically related with herd productivity (gain per area) (Figure 7-103). This model predicted that gains per head, such as liveweight/head, did not vary below some relatively low threshold stocking rate, but then declined with further increases in stocking rate. At the same time, gains per area, such as liveweight/ha, increased with increases in stocking rate, and then declined when a higher threshold stocking rate was surpassed. At that point in Figure 7-103, increases in the number of animals could no longer counteract the rapid decline in individual animal performance. While Ash and Stafford Smith (1996) regarded these relationships as simple and appealing, they judged them inappropriate for rangelands. They contended this was because of the high spatial and temporal variability of the rangelands, including inter-annual and seasonal fluctuations in forage production and quality, and long-term changes in vegetation. While Ash *et al.* (1995) proposed that the utility of these stocking rate models would be improved if they were based on utilisation rather than stocking rate, they still believed them to be inappropriate because animal productivity in the rangelands is influenced by perpetual changes in the composition, quality and quantity of forage that occur over long periods of time.

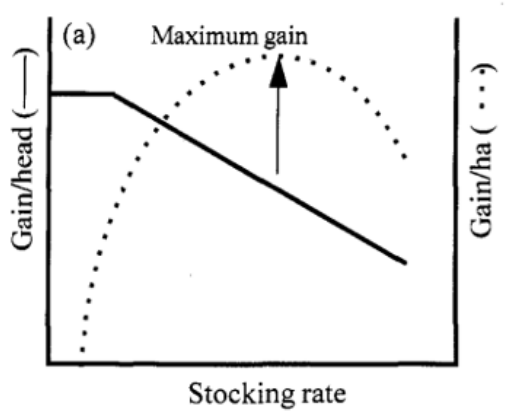


Figure 7-103: Relationships between stocking rate, individual animal productivity (gain per head) and herd productivity (gain per ha) (from Ash and Stafford Smith 1996)

Ash and Stafford Smith (1996) also reported that the linear stocking rate relationships with per head and per area productivity were assumed to result in a similar trend for economic performance (Figure 7-104). That is, variable and other production costs continued to increase with increases in stocking rate, while income fell sharply as a threshold stocking rate was exceeded. Consequently, profit would have been negative at the lowest stocking rate, increased as stocking rate increased towards the threshold stocking rate, then declined after that.

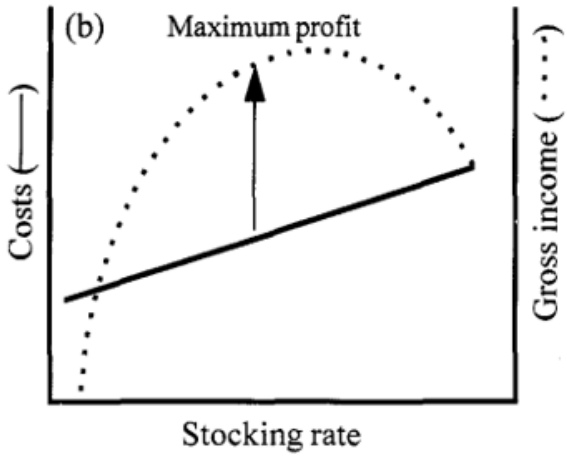


Figure 7-104: Relationships between stocking rate, costs of production and income (from Ash and Stafford Smith 1996)

As inferred by Ash and Stafford Smith (1996) and Ash *et al.* (1995), these two-dimensional and simplistic stocking rate-productivity models better predict the outcomes of intensive grazing in small paddocks with uniform pasture composition, over short periods of time (<5 years). As stocking rate increases, the quality and quantity of forage available will decline and cause a reduction in production per head. In contrast to this, the production per area will initially increase because the total animal production gain exceeds the sum of the individual animal production losses. This continues until total gains equal total losses, and at that point, production per area falls as per head stocking rate is increased. At the higher stocking rates, livestock may even cease breeding or die from excessive weight loss.

Rangeland paddocks are very large and have a diverse range of forage for livestock, sometimes including palatable browse, which often act as buffers against shortages in forage supply. Animals will often patch-graze more preferred vegetation, and if these patches are exhausted or become unattractive, they can move to other patches. Also, in large poorly watered paddocks, if forage in the vicinity of waters (<4km) runs out or quality deteriorates, livestock can, to some degree, access additional feed by extending their grazing distribution. Consequently, gains per head will decline much less slowly with increases in stocking rate, and the relationship between gains per area and stocking rate will tend to be linear or curvilinear instead of quadratic. However, at some point in time, the quantity and quality of all accessible forage will decline, and therefore the production gains or losses will conform with the original relationships of Jones and Sandland (1974) and Hart (1978).

Similarly, if rainfall over several years increases or is consistently high, then gains per head will decline much less with increases in stocking rate, and gains per area will tend to be linear. Thus, the high inter-annual variability in rainfall and hence forage production experienced in rangelands will tend to confound short-term relationships between stocking rate and livestock production. Even so, given the continuously alternating periods of low and high rainfall characteristic of the rangelands, it is likely that when averaged over many years, the relationships between stocking rate, gains per head and gains per area will conform with those provided in Ash and Stafford Smith (1996) and shown in Figure 7-103. Gains per head and gains per area averaged over long periods of time in rangelands with their high level of spatial and temporal variability in climate and vegetation are likely to be very different to those averaged over a few years in much smaller and more uniform paddocks. Also, the slope and intercept of the stocking rate-gain per head relationship will likely vary depending on the climate of the period of grazing examined, which in turn changes the nature of the quadratic relationship between stocking rate and gains per area.

If the grazing period is again extended from a few years to a decade or more, and if stocking rates have caused land condition to deteriorate and carrying capacity to decline (O'Reagain *et al.* 2022), it is likely that the Jones and Sandland (1974) and Hart (1978) relationships will still hold. However, gains per head will decline at a faster rate with the same increases in stocking rate (Ash *et al.* 1995, gains per area will begin to fall at a lower stocking rate, and overall, gains per area will be lower than those when land condition was higher.

Under the short and longer-term conditions described above, the associated relationships between stocking rate, variable costs and income should also generally conform with those shown in Ash and Stafford Smith (1996). Total handling, husbandry, feeding and other variable costs will generally increase with increases in stocking rate, but income will start to decline when gains per area begin to decrease. If land condition declines, then variable costs are likely to increase more quickly with stocking rate due to higher supplementation and drought feeding costs, income will decline because of the lower gains per area, and overall profit will be lower.

Barkly herd simulations

The bio-economic modelling in this study included the longer-term impacts of pasture utilisation on land condition and subsequent pasture growth, together with the impacts of climate and climate variability. In agreement with the stocking rate-gain/head relationship in Figure 7-103, simulated Barkly herd weaning rates (% of breeders that produced a weaner) were similar at median pasture

utilisation rates <16%, then declined curvilinearly as median pasture utilisation rates increased (Figure 7-105).

The gain per area component of the stocking rate relationship (Figure 7-103) was less aligned with the equivalent simulated measure of annual average number of weaners /km^2 in the Barkly herds (Figure 7-105). Simulated number of weaners/km^2 only just began to asymptote at the highest utilisation rate and thus the highest stocking rates, whereas that in Figure 7-103 declined sharply after a threshold stocking rate was reached. One main reason for this difference was that the size of herds which had the highest median utilisation rates and highest stocking rates were maintained by purchasing large numbers of female breeders after two major droughts, after herd size had crashed due to destocking.

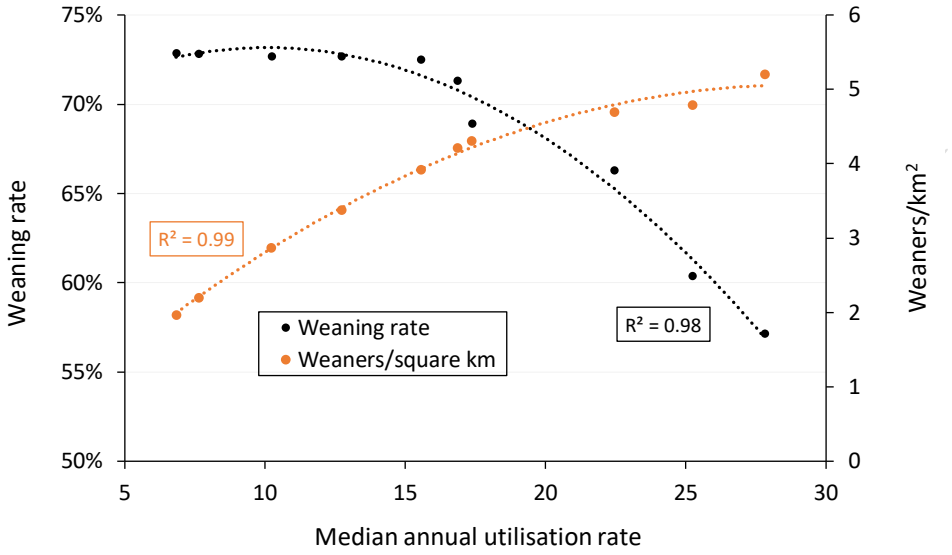


Figure 7-105: Relationships between median annual utilisation rate, average annual weaning rate and average annual weaners/km^2, for the 10 simulated Barkly herds (fitted lines are a 2nd order polynomial). Average of 44 years

Also consistent with the stocking rate relationships of Figure 7-103 was the relationships between average annual stocking rate (compared to utilisation rate above) and weaning rate (Figure 7-106). Weaning rate did not vary for stocking rates between 5 and 11 head/km^2, but then declined sharply at stocking rates > 12 head/km^2. The relationship between stocking rate and weaners/km^2 was not consistent with that in Figure 7-103, as it increased linearly with increases in stocking rate.

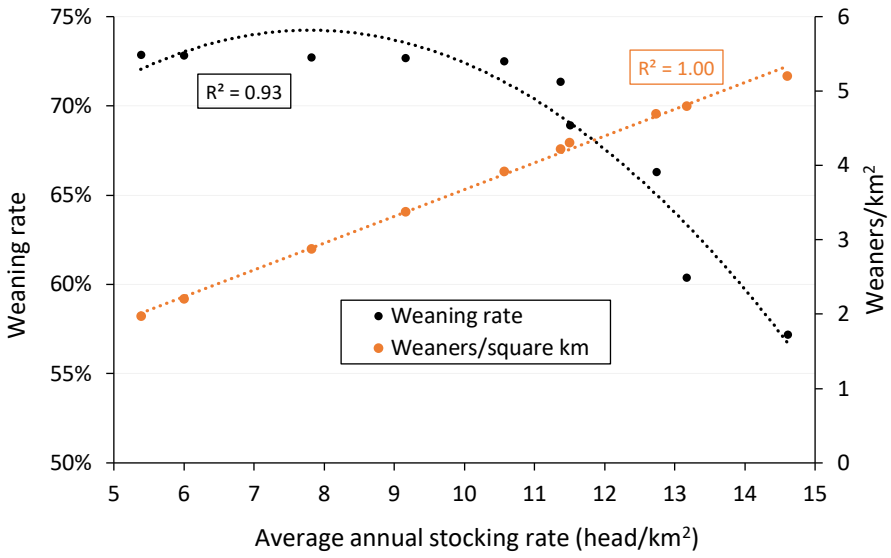


Figure 7-106: Relationships between average annual stocking rate (head/km^2), average annual weaning rate and average annual weaners/km^2, for the 10 simulated Barkly herds (fitted lines are a 2nd order polynomial and linear). Average of 44 years

Average annual kgs of beef produced/head, an additional metric of gain/head, were very similar for herds with median utilisation rates <13%, then declined with further increases in utilisation rate (Figure 7-107), due to lower individual performance at higher utilisation rates. This was consistent with the gain/head model of Figure 7-103 shown in Ash and Stafford Smith (1996).

The relationship between kg of beef produced/km^2 and utilisation rate for the Barkly herds (Figure 7-107) was similar to that of the weaners/km^2, except it began to decline at the highest utilisation rates, and thus was more closely aligned with the gain/area stocking rate relationship shown previously in Figure 7-103. This was due to the rapid decline in kg beef produced/head at the higher utilisation rates. This occurred even though the size of the largest herds with the highest utilisation rates were maintained by purchasing large numbers of female breeders. The kg beef produced/km^2 combines the impact of utilisation on both the number of calves weaned but also their growth rate and the growth rate of all other classes of cattle, which is lower at higher utilisation. Breeder, calf, weaner, steer and cull-cattle growth rates are all part of the total gain per area, and when these are taken into account, the gain/km^2 relationship with utilisation found in the Barkly simulations (Figure 7-107) conforms with that of Ash and Stafford Smith (1996).

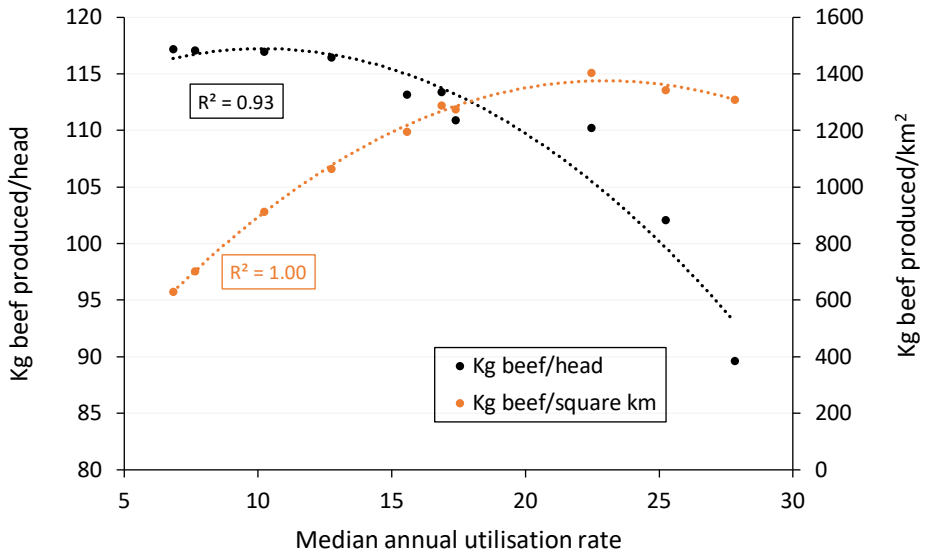


Figure 7-107: Relationships between median annual utilisation rate, average annual kg of beef produced/head and average annual kg beef produced/km^2, for the 10 simulated Barkly herds (fitted lines are a 2nd order polynomial). Average of 44 years

The relationships between average annual stocking rate (compared to utilisation rate above), kg beef produced/head and /km^2 (Figure 7-108) were very similar to those with median annual utilisation rate (Figure 7-107). Again, this demonstrates the close alignment between average annual stocking rate and median annual utilisation rate for the Barkly herd simulations (Figure 7-43).

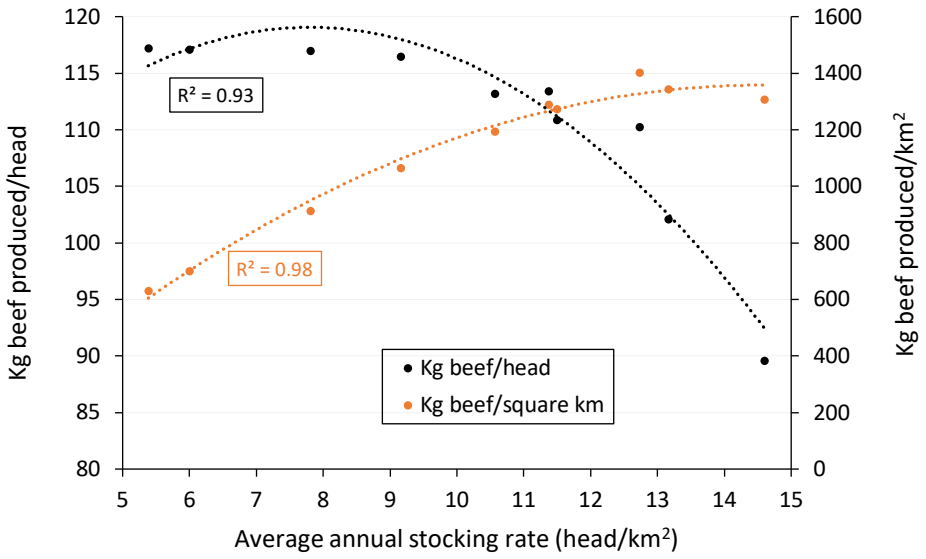


Figure 7-108: Relationships between average annual stocking rate (head/km^2), average annual kg of beef produced/head and average annual kg beef produced/km^2, for the 10 simulated Barkly herds (fitted lines are a 2nd order polynomial). Average of 44 years

The results of simulations of the profitability of the Barkly herds aligned with those predicted in Figure 7-104. Gross profit (income from sales – costs of purchases – change in herd inventory) increased quickly as utilisation rate increased from 7 to 22%, then declined rapidly with further

increases in utilisation rate (Figure 7-109). Annual variable costs also increased quickly as utilisation rate increased from 7 to 22%, then plateaued or only increased slightly at higher utilisation rates.

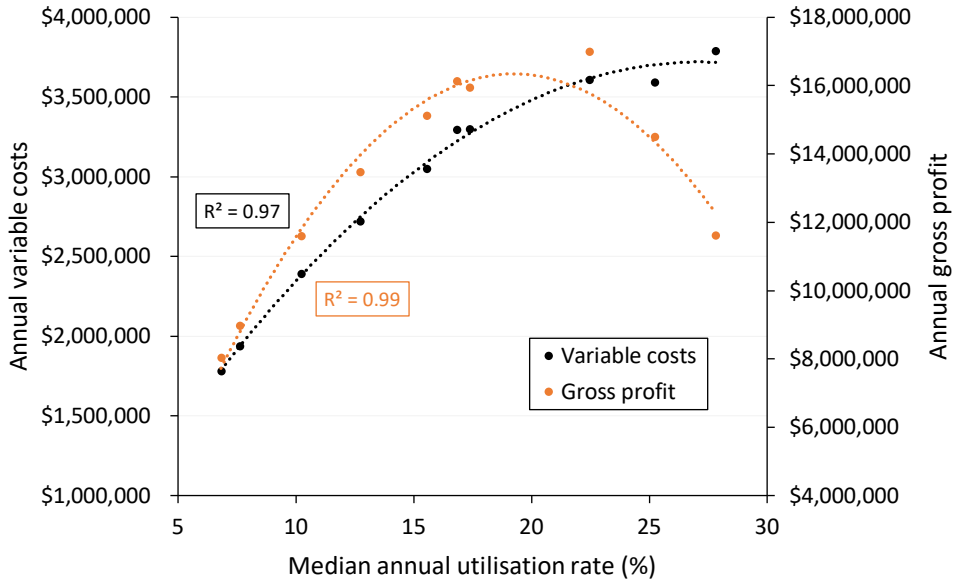


Figure 7-109: Relationships between median annual utilisation rate, gross profit / year and variable costs / year, for the 10 simulated Barkly herds (fitted lines are 2nd order polynomials). Average of 44 years

The relationships between variable costs, gross profit and average annual stocking rate were almost identical to those with median annual utilisation rate (Figure 7-110). However, on this occasion, variable costs increased more linearly with increases in stocking rate, aligning closely with Figure 7-104. Overall, the results of simulations of the Barkly herds conformed closely with the Jones and Sandland (1974) and Hart (1978) stocking rate-productivity relationships as interpreted by Ash and Stafford Smith (1996) even though concluded they were overly simplistic and unlikely appropriate. The CLEM modelling does not include the impacts of spatial buffering that can happen in large variable paddocks, hence simulations are likely to conform to Ash and Stafford Smith (1996).

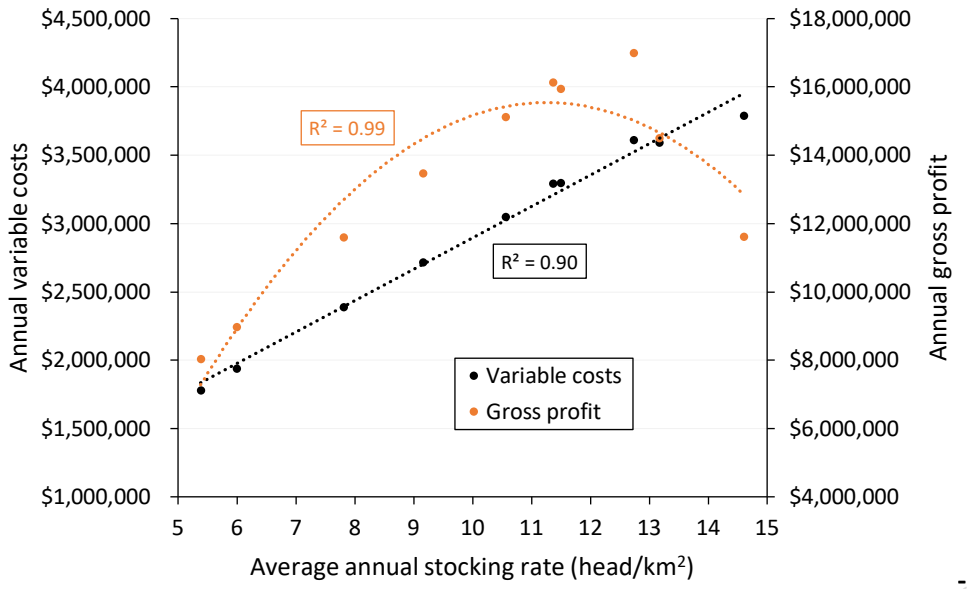


Figure 7-110: Relationships between median annual stocking rate (head/km^2), gross profit / year and variable costs / year, for the 10 simulated Barkly herds (fitted lines are a 2nd order polynomial and linear). Average of 44 years

Burdekin herd simulations

In the Barkly, stocking rate was highly correlated with utilisation rate. Counterintuitively, this was not the case for the Burdekin simulations, because in the Burdekin, higher pasture utilisation led to declines in land condition, lower pasture growth and carrying capacity, requiring more and longer destocking, resulting in lower average stocking rates over the simulation period. This major difference between the two regional responses of stocking rate to utilisation rate flows through to all the stocking rate relationships in the Burdekin. In the Burdekin, lower stocking rates actually represent degraded poor potential production scenarios, whereas in the Barkly, lower stocking rates had the highest land condition, pasture growth and individual animal performance. Conversely, in the Burdekin, the highest stocking rates were close to the safe carrying capacity so could be sustained while maintaining pasture condition and growth, leading to better performance and production.

The median utilisation rates of the Burdekin herd simulations were poorly correlated with the gains/head measure of weaning rate and the gains/area measure of weaners born/km^2 (Figure 7-111). While there may have been a general trend for weaning rate and weaners/km^2 to decline with increasing utilisation rate, a number of herds with utilisation rates between 25 and 30% had similar weaning rates and weaners/km^2 as herds with utilisation rates of between 15 and 22%. The herds with utilisation rates of 25-30% all purchased large numbers of 400 kg young breeders after herds declined to low numbers during droughts, and due to their good condition, purchased breeders had high weaning rates. Without these purchased breeders, weaning rates would have been much lower due to poor land condition and relatively high median pasture utilisation rates. The purchasing of these breeders also coincided with improved climatic conditions and lower pasture utilisation rates. In this way, herd management - buying and selling stock was used to circumvent the otherwise poor outcomes of high utilisation.

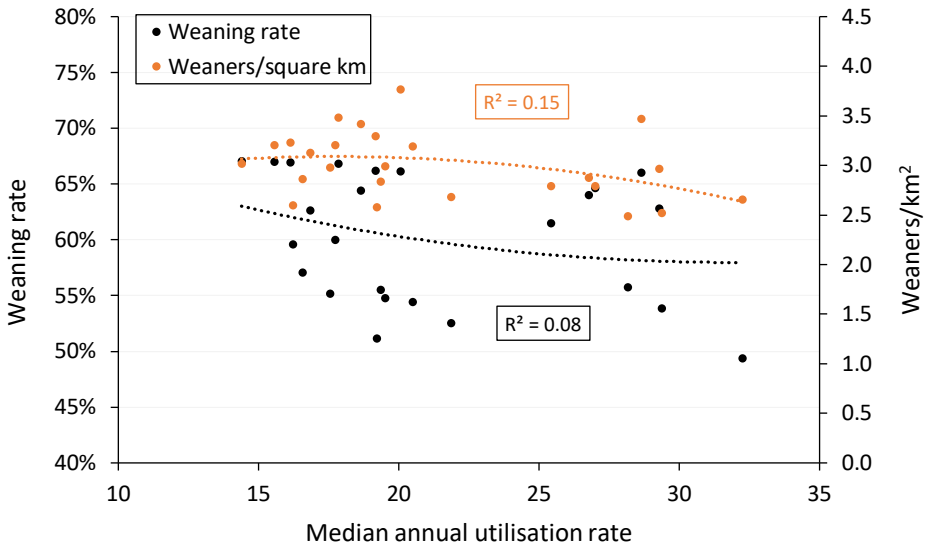


Figure 7-111: Relationships between median annual utilisation rate, average annual weaning rate and average annual weaners/km^2, for the 25 simulated Burdekin herds (fitted lines are 2nd order polynomials). Average of 42 years

Weaning rate was also not well correlated with average annual stocking rate, but tended to increase with increasing stocking rate (Figure 7-112). This was therefore inconsistent with the per head relationship in Figure 7-103 reported in Ash and Stafford Smith (1996). Weaners/km^2 was highly and almost linearly correlated with stocking rate. This is also different to the gain/area relationship shown in Figure 7-103, as the latter declined markedly after a threshold stocking rate was exceeded. In the Burdekin, attempting to maintain high initial stocking rates over the simulation period resulted in high utilisation rates which caused substantial declines in land condition and carrying capacity. Large herds could not be maintained, leading to declines in average annual herd size, along with poor individual animal and herd performance. Hence, the low average annual stocking rates in Figure 7-112 represent the land degradation scenarios where land condition and potential pasture growth had declined so much that the ability to carry livestock declined. Consequently, per head and per area gains tended to decline with increasing utilisation rate but increased with increasing stocking rate.

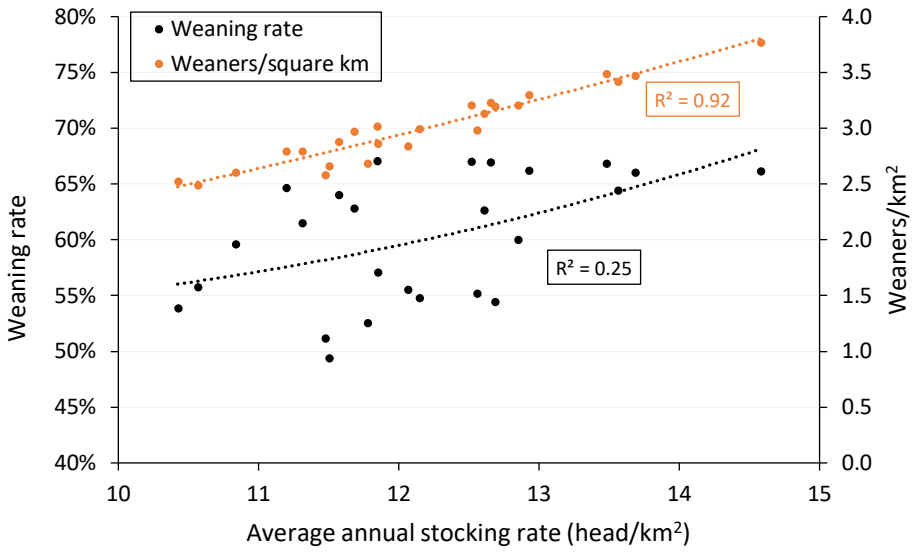


Figure 7-112: Relationships between average annual stocking rate (head/km^2), average annual weaning rate and average annual weaners/km^2, for the 25 simulated Burdekin herds (fitted lines are 2nd order polynomials). Average of 42 years

Average annual kgs beef produced/head (Figure 7-113) was more closely correlated with utilisation rate than was weaning rate, and was more consistent with the stocking rate gains/area relationship shown in Ash and Stafford Smith (1996) and in Figure 7-103. As expected, annual kgs beef produced/head tended to decline with increases in utilisation rate and decreases in land condition. Gains/area, in the form of kg of beef produced/km^2, also tended to decline with increases in utilisation rate, but this was in part due to the different management practices simulated during and after droughts. There were several herds with median utilisation rates of between 15 and 20% which produced the most beef/km^2, due to a combination of high kg beef produced/head and the highest herd sizes or stocking rates. These herds achieved the optimal balance between utilisation rate, land condition and stocking rate. Also, simulated herds with the highest utilisation rates would have produced less kg beef/km^2 if they had not purchased large numbers of breeders. If simulations did not include destocking of breeders and steers, followed by purchasing breeders, then the relationship between utilisation rate and kg beef produced/km^2 would have been much more similar to that of Figure 7-103.

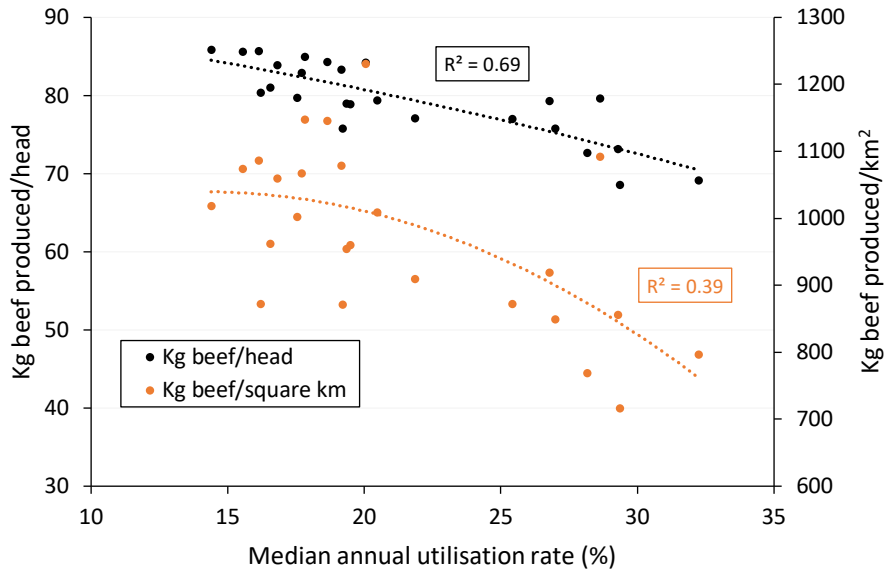


Figure 7-113: Relationships between median annual utilisation rate, average annual kg beef produced/head and average annual kg beef produced/km^2, for the 25 simulated Burdekin herds (fitted lines are a 2nd order polynomial and linear). Average of 42 years

While the kg beef produced/head declined as utilisation rate increased, there was a tendency for it to increase with increases in stocking rate (Figure 7-114). More pronounced was the linear increase in kg beef/km^2 as stocking rate increased. These relationships were almost opposite of those shown in Ash and Stafford Smith (1996) and in Figure 7-103, because lower stocking rates represent degraded land with lower productive capacity in the Burdekin.

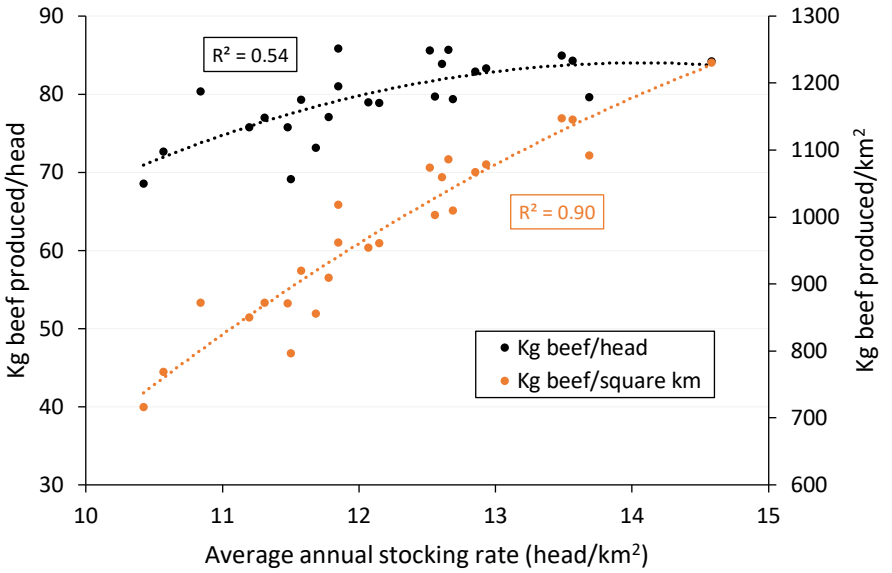


Figure 7-114: Relationships between average annual stocking rate (head/km^2), average annual kg beef produced/head and average annual kg beef produced/km^2, for the 25 simulated Burdekin herds (fitted lines are a 2nd order polynomial and linear). Average of 42 years

The relationship between average annual variable costs, average annual gross profit and median annual utilisation rate for the simulated Burdekin herds (Figure 7-115) were also markedly different to those provided in Ash and Stafford Smith (1996), as shown in Figure 7-104. Variable costs did not

increase with increasing utilisation rate due to declines in average annual herd size at higher utilisation rates, even though variable costs such as drought feeding did increase with increasing utilisation rate. Gross profit declined with utilisation rate because of high purchasing costs and sales of poor cattle. This is consistent with the 2nd half of the curve in Ash and Stafford Smith (1996) as shown in Figure 7-103.

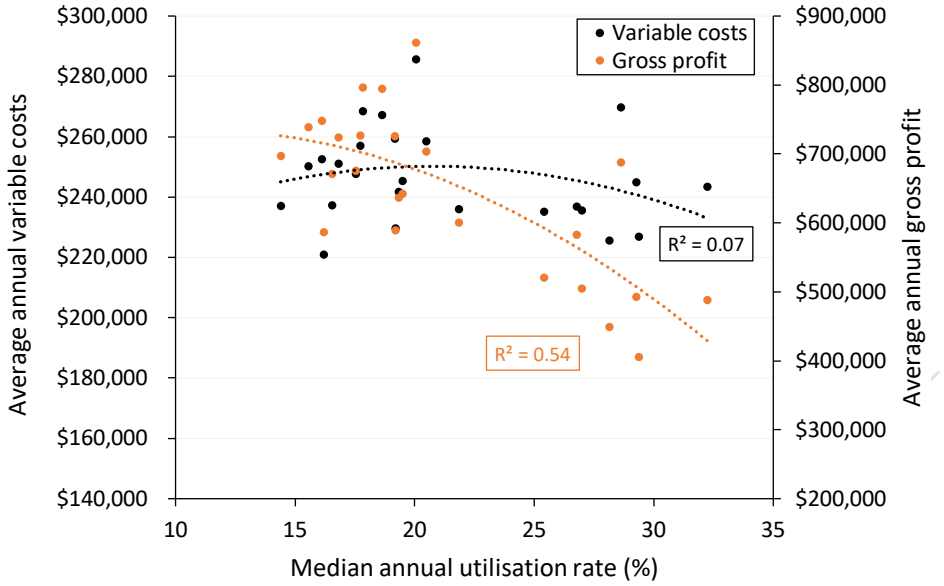


Figure 7-115: Relationships between median annual utilisation rate, average annual variable costs and average annual gross profit, for the 25 simulated Burdekin herds (fitted lines are a 2nd order polynomial). Average of 42 years

Annual variable costs and gross profit were strongly and positively correlated with average annual stocking rate (Figure 7-116). This was expected, as costs and income generally both rise with increases in stocking rate or herd size. The close to linear increase in variable costs with increases in stocking rate aligns well with that shown in Ash and Stafford Smith shown and in Figure 7-104, but gross profit did not. Instead of increasing with stocking rate until a threshold was reached, then declining with further increases in stocking rate, gross profits of the Burdekin herds continued to increase with stocking rate. This reflects the higher land condition, animal performance and production at the highest stocking rates in the Burdekin simulations.

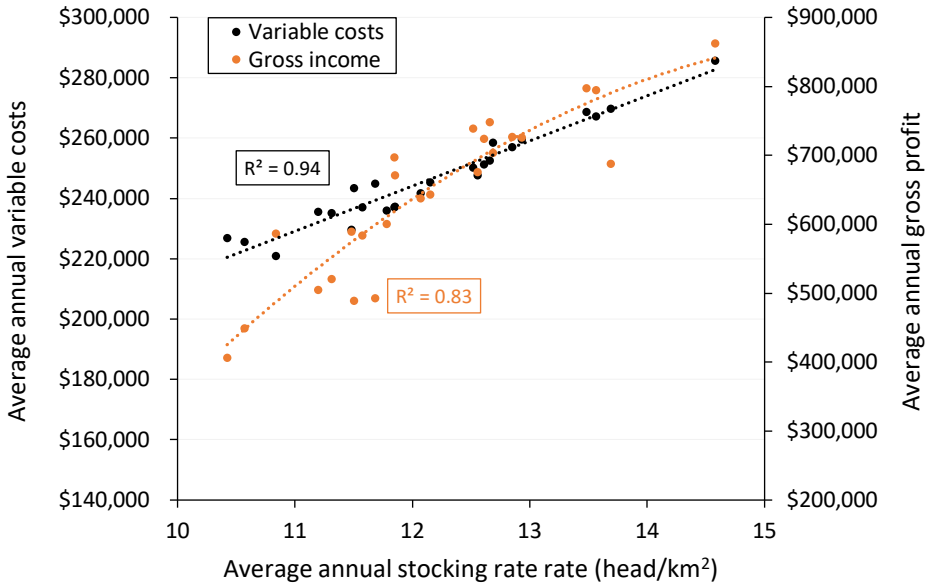


Figure 7-116: Relationships between average annual stocking rate (head/km^2), average annual variable costs and average annual gross profit, for the 25 simulated Burdekin herds (fitted lines are a 2nd order polynomial and linear). Average of 42 years

Overall, median utilisation rates were mostly poorly correlated with per head and per area metrics of productivity and with costs and income for the simulated Burdekin herds. This was partly because a wide range of herd management practices were simulated, such as deliberately holding female breeder numbers constant over simulation periods, destocking young steers instead of empty breeders and purchasing breeders. Even so, average annual stocking rates were mostly highly correlated with the production and financial metrics of simulated Burdekin herds, and especially the per area metrics. However, the stocking rate relationships still did not conform with those shown in Ash and Stafford Smith (1996). This occurred because high stocking rates during the early part of the Burdekin simulation period damaged land condition and thereby reduced forage growth, and thus average annual stocking rate was relatively low. If per head and per area livestock production was compared with initial rather than average annual stocking rate, then it was much more likely that these relationships would have conformed with those of Figure 7-103.

Insights from stocking rate-productivity relationships

While the stocking rate-productivity relationships (Figure 7-103) proposed by Jones and Sandland (1974) and Hart (1978) are dated and were considered overly simplistic for rangelands by Ash and Stafford Smith (1996) and Ash *et al.* (1995), insights may be gained by comparing them with the results of simulations of the Barkly and Burdekin herds.

The stocking rate-productivity and stocking rate-financial relationships simulated for the 44-year period of historical climate for Barkly herds largely conformed with those of Figure 7-103 and Figure 7-108. Gains per head, such as weaning rate and kg beef produced, were very similar to those of Figure 7-103, and the variable costs and gross profit mirrored those in Figure 7-104. The same relationships were also observed with median annual pasture utilisation rate, because stocking rate (head) was strongly, positively and almost linearly correlated with median utilisation rate (Figure 7-42).

Gains per area for Barkly herds, in the form of weaners/km^2 and beef produced/km^2, were linearly or curvilinearly related to average annual stocking rate, instead of the strong quadratic relationships shown in Ash and Stafford Smith (1996). That is, gains per area tended to increase linearly with increases in stocking rate over most of the stocking rate range examined, only just becoming curvilinear or slightly quadratic at the highest stocking rates. This is consistent with Hunt *et al.* (2014) who noted that many studies have also reported continuously increasing production/area with increasing stocking rate. Among other factors, they suggested this can be due to favourable climatic conditions, which was the case for the Barkly simulation period. Simulated variable costs and income also conformed closely with those shown in Ash and Stafford Smith (1996) and Figure 7-104, even though gains per area were almost linearly related with stocking rate. The simulated quadratic relationship between stocking rate/utilisation rate and gross income occurred because the income from sales relative to variable costs was lower for herds with the highest stocking rates, and they purchased more breeders to restore herd size after forced sales during droughts.

In the Burdekin, relationships between stocking rate/utilisation rate and gains per head, gains per area and financial metrics did not appear to conform with those of Figure 7-103 and Figure 7-104. This was partly because management practices differed between herds, but also because of the relationship between average annual stocking rate and median annual pasture utilisation rate differed to that of Barkly herds. In contrast to the Barkly simulations, and while stocking rate or herd size was poorly correlated with utilisation rate for Burdekin herds, it generally decreased as utilisation rate increased (Figure 7-80). For Burdekin herds, gains per head increased linearly or curvilinearly with increases in stocking rate. This was also opposite to what occurred in Barkly herds, and opposite to the gains per head relationships in Figure 7-103. Gains per area relationships with stocking rate also did not conform with those in Figure 7-103. Instead of being quadratic, they were linear or slightly curvilinear. When utilisation rate was used for the x-axis rather than average annual stocking rate, correlations with gains per head and area were even lower and they were more obscured by different management practices. When different management practices were accounted for, it was evident that gains per head were similar for median utilisation rates lower than around 20%, and then declined with further increases in utilisation. Gains per area were lowest at the lowest median utilisation rates, increased as utilisation rate increased to around 20%, then declined markedly with further increases in utilisation. Consequently, the relationships between median utilisation rate and gains per head and gains per area conformed much more closely with those of Figure 7-103 than was evident in Figure 7-111 and Figure 7-112 above. Likewise, when the range of management practices were considered, both variable costs and gross profit also increased with increases in utilisation rate up to around 20%, then declined at higher rates.

Differences between Barkly and Burdekin herds in relationships between stocking rate/utilisation rate, gains per head, gains per area, variable costs and income were primarily due to regional differences in how land condition responded to pasture utilisation rate. Land condition (percent perennial grass composition) in the Burdekin declined more and at a faster rate in response to increases in utilisation rate than in the Barkly. Consequently, gains per area and gross profit in the Barkly tended to increase linearly with increases in utilisation rate, only just starting to decline at the highest rates simulated. In contrast in the Burdekin, declining gains per area and gross profit occurred at much lower utilisation rates, due to a greater decline in land condition.

Results of the Barkly simulations were somewhat consistent with the findings of Bowen and Chudleigh (2018), who concluded that profit of a steer-turnover enterprise grazing buffel grass pasture on a brigalow land type in central Queensland could be increased by increasing utilisation rates to levels that reduced land condition. These authors used a property-level herd model in

conjunction with output from GRASP to compare the productivity and profitability of grazing pastures at the safe rate of 30% with a much higher rate of 50%. While these authors used marginal economic analysis and net present values to compare the profitability of scenarios and our simulations used average annual profit without discounted cash flow, their conclusions appear influenced more by their assumptions of rates of decline in land condition and associated changes in the liveweights of steers. For example, they assumed that pasture would remain in A condition when grazed at 50% utilisation for periods of 10 or 20 years, and that a further 10 years would be required for land condition to decline from A to B and then another 10 years for it to decline from B to C. These rates of change are much slower than those which occurred in our simulations of Barkly and Burdekin land types. For example, in our simulations of Burdekin herds, 10 years of grazing at 50% utilisation reduced land condition from high A to low B, and likewise, it took a further 10 years to reduce land condition from low B to low C. While the rate of decline in land condition of simulated Burdekin herds would have been slightly greater than was the case for the brigalow land type due to the lower safe utilisation rate of 25% for the Burdekin, it is expected that grazing pastures at utilisation rates much higher than safe for periods of 10 to 20 years will cause substantial declines in land condition (Thornton and Elledge 2021).

Additionally, at utilisation rates of 50%, Bowen and Chudleigh (2018) assumed an annual liveweight gain (LWG) of 173 kg for steers on A condition land, declining to 165 kg on B condition land (5% lower than A), then to 148 kg/ha on land in C condition (14% lower than A). These are minor changes in individual animal productivity relative to the differences in pasture productivity of these three states of land condition. Large differences in pasture productivity were acknowledged by Bowen and Chudleigh (2018), as they used a median annual pasture biomass productivity of C condition land of 2300 kg/ha and 3800 kg/ha for B condition land, which are 45% and 75% respectively that of 5100 kg/ha for land in A condition. These proportional differences in the pasture productivity of land condition states were the same as those found in FutureBeef (2024). Furthermore, it appears these authors used the same median annual pasture biomass productivities for both 30% and 50% utilisation rates. For our simulations of Burdekin herds, pasture biomass at the end of June was 2076 kg/ha when median annual utilisation rate was 15%, then declined to 817 kg/ha when utilisation rate was 30%. Overall, Bowen and Chudleigh (2018) appear to have underestimated the rates of decline in land condition that occur at higher than safe utilisation rates over long periods of time, overestimated the amount of pasture biomass available for combinations of poor land condition and high utilisation rates, and overestimated the LWGs of steers under the combined conditions of high utilisation and poor land condition.

7.8.4 Differences between Barkly and Burdekin simulated herds

The most important common outcome of simulations of the Barkly and Burdekin herds was that the most profitable herds, at both locations, achieved the highest average annual herd productivity that was possible without causing appreciable and lasting declines in land condition. These herds were the most profitable because they produced large amounts of beef with relatively low variable costs, over long periods of time, and relative to other simulated herds in their regions, they needed to be destocked less during drought and purchase female breeders to restore herd size after droughts. They could keep production high because numbers were the highest they could be while still having safe utilisation to maintain land condition and pasture growth.

At both locations, herds with the smallest initial sizes that were maintained over simulation periods had the highest reproductive rates, produced the largest amounts of beef/AE and had the lowest pasture utilisation rates. These herds achieved maximum land condition but not maximum herd

productivity and enterprise profitability. Also, at both locations, the least profitable herds were those where attempts were made to maintain high herd sizes over simulation periods. They had the highest annual utilisation rates, poorest land condition and the highest production costs.

In contrast to these commonalities, the means by which the Barkly and Burdekin herds achieved their highest average annual profits were different. Median annual pasture utilisation rate and average annual herd size were closely and positively correlated for the simulated Barkly herds, even though the largest herds purchased large numbers of female breeders after droughts. This was not the case for the Burdekin herds, where average annual herd size initially increased with increasing utilisation rate, but then declined markedly with further increases in utilisation rate. This difference appears to be due to the more rapid decline in land condition in response to increasing utilisation rate in the Burdekin compared with the Barkly. Land condition for the Burdekin property, in the form of percent perennial grass composition of pastures, declined 2.4-times more rapidly with increasing pasture utilisation rate than did the Barkly property (Figure 7-117).

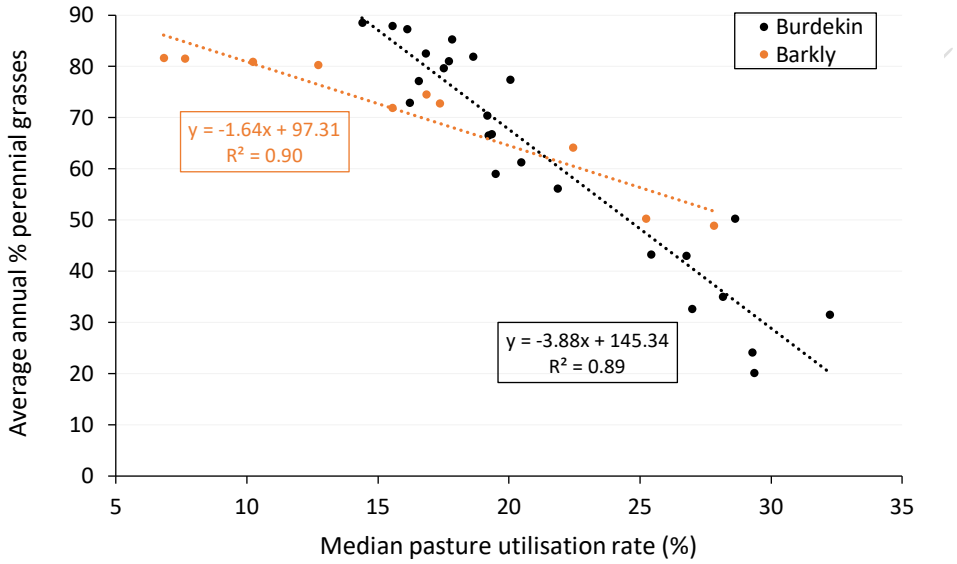


Figure 7-117: Relationships between the percent perennial grass composition of pastures and median utilisation rate for the 10 simulated Barkly herds and the 25 simulated Burdekin herds (fitted lines are linear)

The following sections explore further how the different climate and land type resilience and recovery assumptions used in modelling of the two regions may have contributed to the different responses to pasture utilisation.

Climatic differences

The Barkly and Burdekin simulation periods both experienced high rainfall variability, but the nature of this variability was quite different. While the coefficient of variation for annual rainfall during the Barkly simulation period of 44% was slightly higher than that of 41% for the Burdekin simulation, the Barkly climate window contained a longer period of high and mostly uninterrupted herd productivity compared with the Burdekin climate window.

The first 19 years of the Barkly simulation was a period of mostly rainfall deficit relative to the average annual rainfall of the 44-year simulation period (Figure 7-118). During this time, even the smallest herd, 1-23651 AE (not shown in Figure 7-118), had several years of pasture utilisation rates that were considerably higher than the safe rate of 20%. The much larger herds shown in Figure

7-118, including the most and least profitable Barkly herds, had more years at this time with even higher but similar annual utilisation rates. During the first 19 years, utilisation rates were highest and land condition (percent perennial grass composition) lowest during the early 1990s (Figure 7-119). Consequently, after 19 years, land condition of two of the least profitable herds (9-35222 AE PB and 10-35267 AE PB) was similar to that of the two most profitable herds (6-31908 AE PB and 8-34400 AE PB), and the same was the case for annual AE herd size (Figure 7-120). While there was a general deterioration in both land condition and herd size during the first 19 years of the simulation, land condition had recovered to initial values by around 1998, and herd size was recovering quickly, for all four herds. The recovery of herd size was due to low pasture utilisation rates, rapidly improving land condition and purchasing of female breeders.

With the Burdekin simulation period, the rainfall deficit during the first 10 years was not as large as that for the same period during the Barkly simulation, then there was a short period of rainfall surplus, followed by a period of longer and deeper rainfall deficit which coincided with the early 1990s drought (Figure 7-121). During the first 19 years of the Burdekin simulation period, the annual utilisation rates of two of the least profitable herds (14-2896 AE and 27-3099 AE SS PB) were often much higher than those of the two most profitable herds (13-2619 AE HB and 17-2610 AE HB) (Figure 7-119), and consequently, land condition of the less profitable herds was much lower (Figure 7-122). While annual AE herd size of the two least profitable herds was higher during the first 10 years, this reversed during the next nine years due to declining land condition and associated forced sales (Figure 7-123).

The long initial dry period of the Barkly simulation ended in 1998, and while there were occasional single years of rainfall deficit, the majority of years between 1999 and 2017 were years of rainfall surplus (Figure 7-118). However, attempts to maintain large herd sizes still resulted in high utilisation rates of two of the least profitable herds (9-35222 AE PB and 10-35267 AE PB) which caused a deterioration of land condition (Figure 7-119), and by around 2012, it was not possible to support these large herds (Figure 7-120), necessitating extensive destocking. In comparison, the two most profitable herds (6-31908 AE PB and 8-34400 AE PB) had much lower utilisation rates between 1999 and 2011, much higher land condition, and destocking was not required until 2017 (Figure 7-118 - Figure 7-120). Herd 8-34400 AE PB, the most profitable herd, had higher utilisation rates and poorer land condition during this period, largely due to its higher size and stocking rate compared with the slightly less profitable herd 6-31908 AE PB. The size of these two most profitable herds declined to very low numbers by 2021, similar to those of the much less profitable herds. However, the two most profitable herds maintained annual herd sizes over a period of 15 years which were around twice the size of these herds at the beginning of the simulation period.

With the Burdekin simulation period, utilisation rates were very low during between 1996 and 2000 (Figure 7-121), which allowed for corresponding improvements in both land condition (Figure 7-122) and herd size (Figure 7-123). The pasture utilisation rates of the two most profitable herds, 13-2619 AE HB and 17-2610 AE HB, then remained at close to or less than the safe rate of 25% for the remainder of the simulation period. Land condition improved and remained at high B or A, and herd size remained fairly constant also. Two of the least profitable herds, 14-2896 AE and 27-3099 AE SS PB, had high pasture utilisation rates between 2001 and 2007, coinciding with a period of rainfall deficit, and both land condition and herd size declined. The years 2008 to 2014 were a period of rainfall surplus, but this enabled only minor improvement in land condition and increases in herd size for these low profitability herds. Then utilisation rates again peaked towards the end of this period of rainfall surplus and continued through the next period of rainfall deficit, land condition dropped to C and herd size fell to very low levels. For these two low profitability herds, declines in

land condition which occurred during the major period of rainfall deficit of the 1990s were only partly recovered during the following rainfall surplus of 1999 to 2002. Then land condition declined again during the period of rainfall deficit of 2003 to 2007, only recovered marginally during the rainfall surplus of 2008 to 2013, and then declined further to C condition during the rainfall deficit period 2014 to 2018. All this occurred while the sizes of these herds were considerably lower than those of the two most profitable herds. This was due to the negative feed-backs of high pasture utilisation on poorer land condition and lower pasture growth, which led to increased pasture utilisation rates even with lower total AE. When land condition declined, attempting to carry previously safe numbers of cattle lead to higher than safe pasture utilisation, further exacerbating land condition decline.

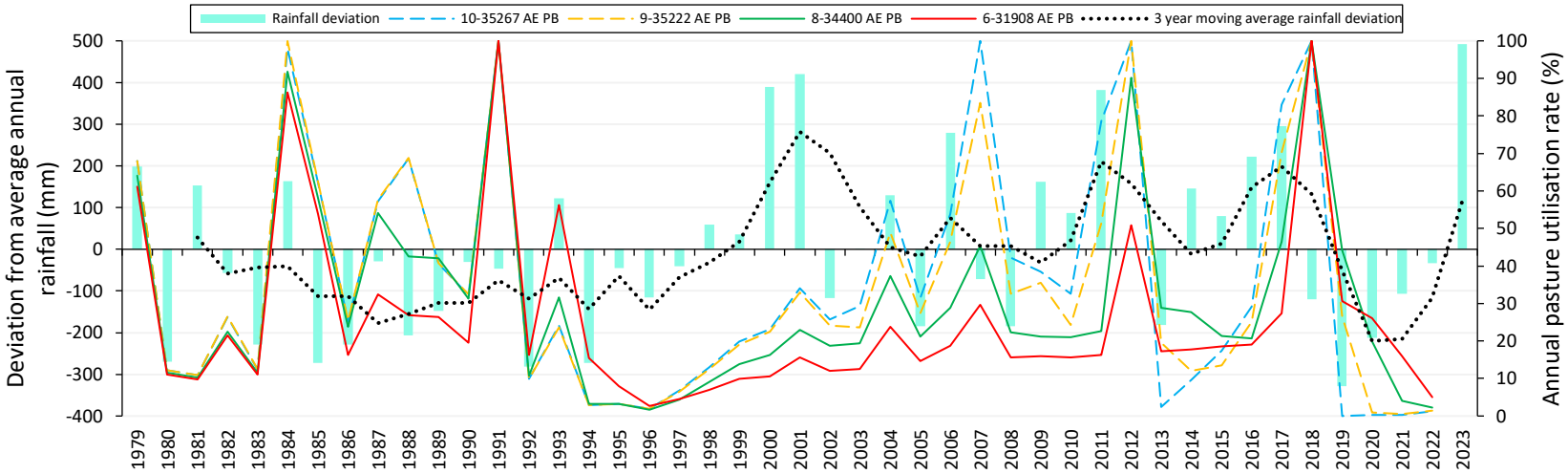


Figure 7-118: Annual rainfall deviation from average annual rainfall and 3-year moving average rainfall deviation for the Barkly simulation period, and annual pasture utilisation rates for two of the most profitable herds (solid lines, median UR = 18-23%, average SR = 8.6-9.6 AE/km^2) and two of the least profitable herds (dashed lines, median UR = 25-28%, average SR = 9.8-10.8 AE/km^2)

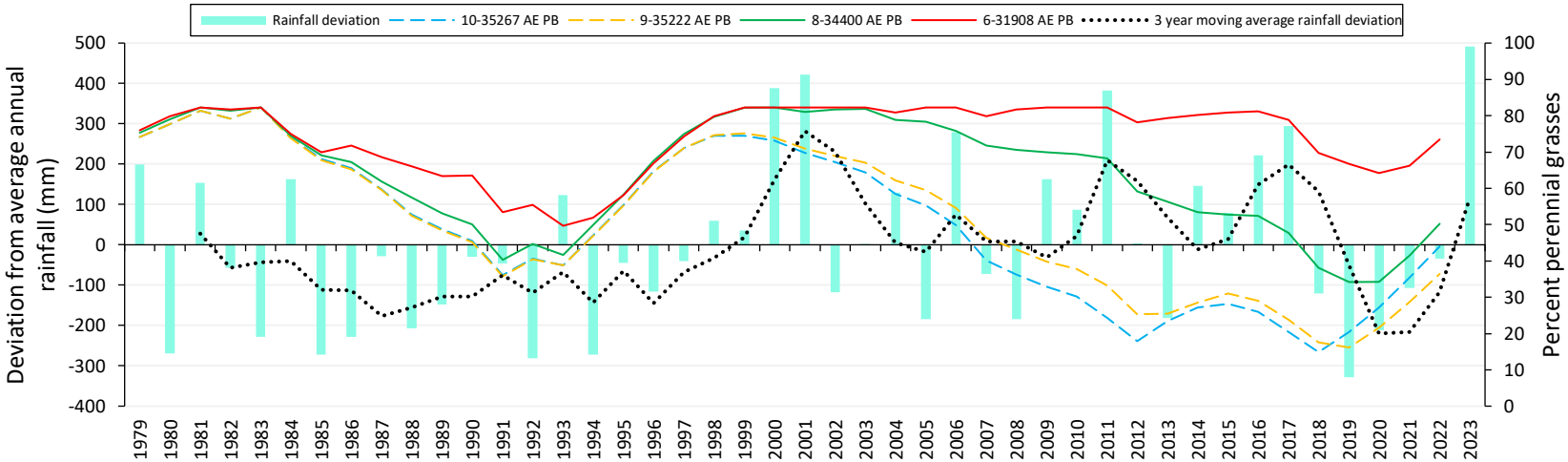


Figure 7-119: Annual rainfall deviation from average annual rainfall and 3-year moving average rainfall deviation for the Barkly simulation period, and average annual perennial grass composition for two of the most profitable herds (solid lines) and two of the least profitable herds (dashed lines)

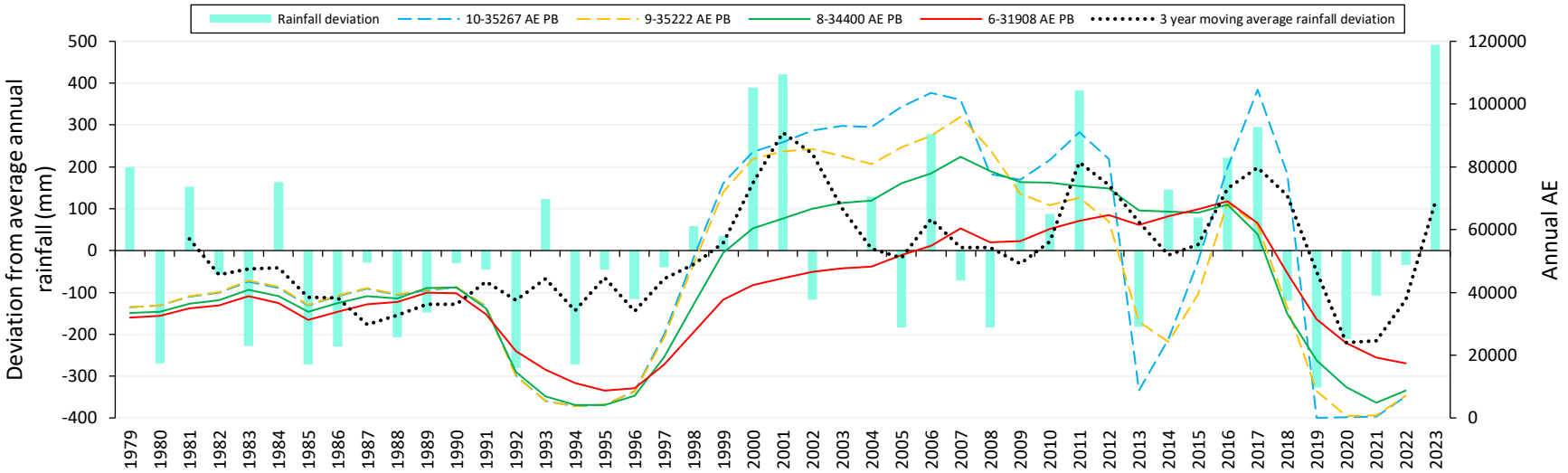


Figure 7-120: Annual rainfall deviation from average annual rainfall and 3-year moving average rainfall deviation for the Barkly simulation period, and annual herd size for two of the most profitable herds (solid lines) and two of the least profitable herds (dashed lines)

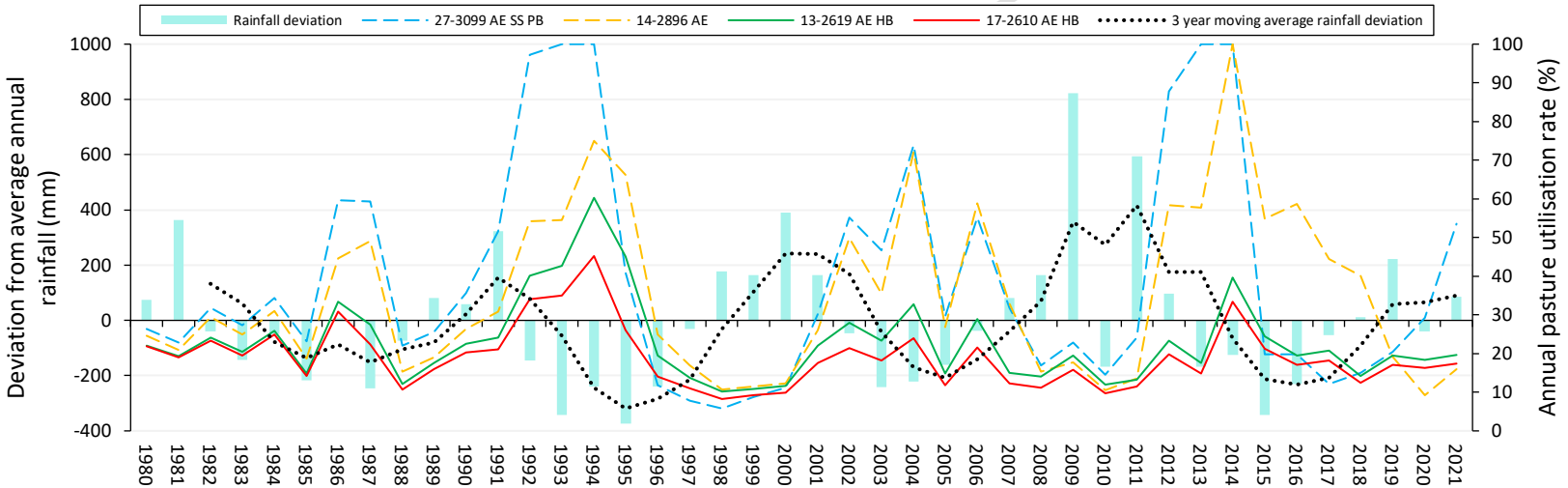


Figure 7-121: Annual rainfall deviation from average annual rainfall and 3-year moving average rainfall deviation for the Burdekin simulation period, and annual pasture utilisation rates for two of the most profitable herds (solid lines, UR = 18-20%, SR = 9.9-10.7AE/km^2) and two of the least profitable herds (dashed lines, UR = 28-29%, SR = 7.7-7.8AE/km^2)

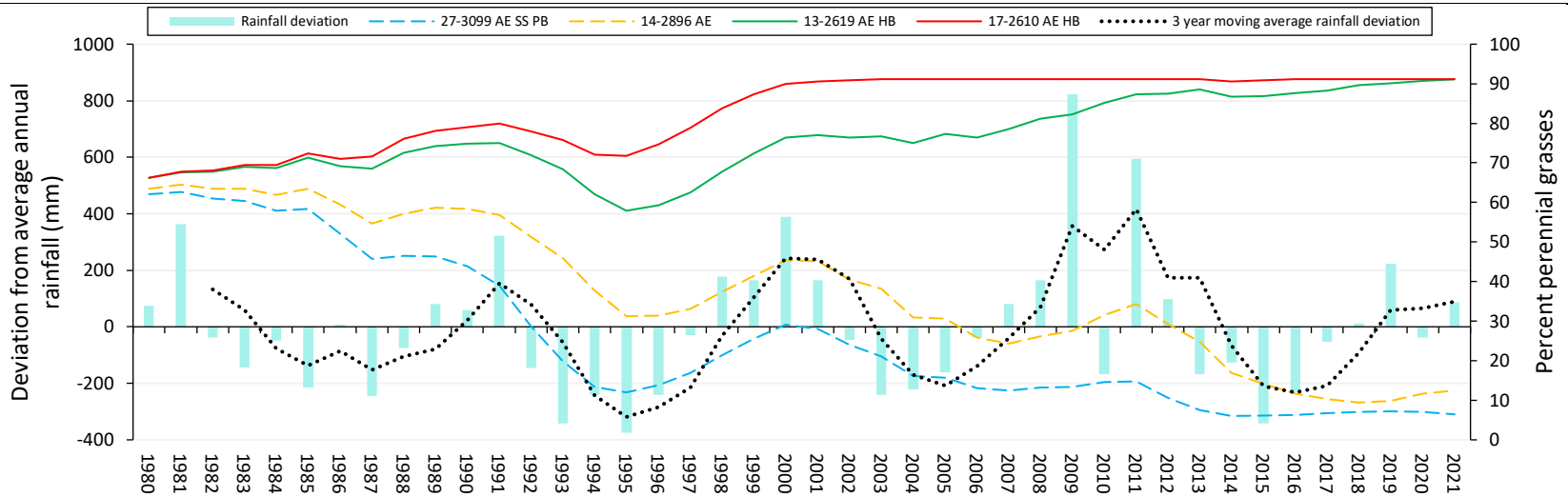


Figure 7-122: Annual rainfall deviation from average annual rainfall and 3-year moving average rainfall deviation for the Burdekin simulation period, and average annual perennial grass composition for two of the most profitable herds (solid lines) and two of the least profitable herds (dashed lines)

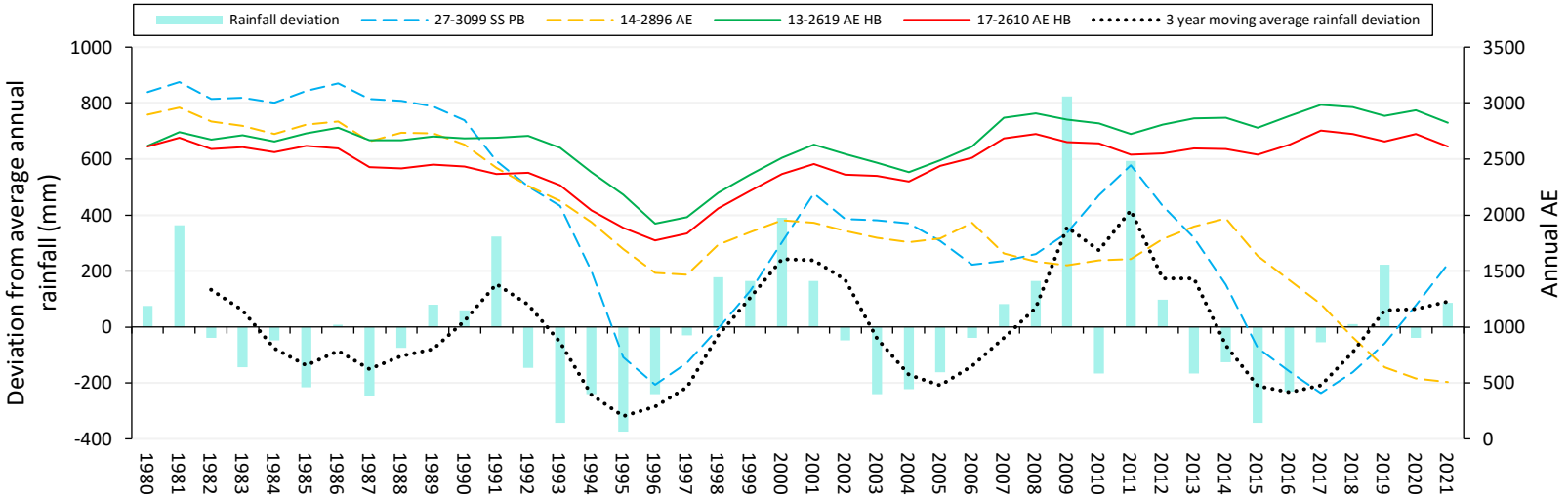


Figure 7-123: Annual rainfall deviation from average annual rainfall and 3-year moving average deviation for the Burdekin simulation period, and annual herd size for two of the most profitable herds (solid lines) and two of the least profitable herds (dashed lines)

Overall, while the Barkly simulation period contained eight periods with high utilisation rates of 30-100% compared with four periods in the Burdekin with similarly high rates (compare Figure 7-118 with Figure 7-121), those of the Barkly were mostly for just one to two years duration. In the Burdekin simulation period (Figure 7-121) the four high periods of utilisation rates were two to seven years in length. Attempts in the Burdekin to maintain high herd size through purchasing breeders maintained high utilisation rates and caused land condition to decline, and the regular occurrences of long periods of rainfall deficits accentuated the adverse impact of high utilisation rate on land condition. This caused land condition to decline from high B to low C over the simulation period, greatly reducing the capacity of pastures to grow and support large herds. In contrast to this, land condition remained much higher during most of the Barkly simulation period, even for the largest herds. This was made possible in the Barkly by a long period of 20 consecutive years between 1998 and 2017 of largely rainfall surplus.

During the Barkly simulation period, availability of large amounts of pasture after 1999 was only occasionally interrupted by single years with below-average rainfall, and thus herds grew steadily due to high reproductive rates. However, herd growth through natural recruitment following the 19-year period of poor climatic conditions and associated destocking was slow relative to pasture growth after 1999. Thus, herds were unable to take full advantage of the large amounts of pasture available over the following 20 years. Consequently, purchasing large numbers of female breeders, while expensive, became a cost-effective mechanism for rapidly building herd size to take full advantage of a long period of consistently high pasture biomass availability. Very high variability in annual herd size was required to cope with and take full advantage of these atypical climatic conditions. While the most profitable Barkly herds grew quickly and to large sizes, pasture utilisation rates were often around the safe rate of 20%, and hence high herd productivity was often achieved without compromising land condition. However, with more extreme versions of this approach, such as that with the two largest herds (9-35222 AE PB and 10-35267 AE PB, average stocking rate 9.8-10.8, median pasture utilisation 25-28%), more frequent higher than safe utilisation rates caused declines in land condition and made it necessary to reduce herd size when short periods of lower-than-average rainfall occurred. This was the case during the dry years of 2012 and 2013, when herds 9-35222 AE PB and 10-35267 AE PB required some destocking whereas herds 6-31908 AE PB and 8-34400 AE PB did not (Figure 7-120).

The early part of the Burdekin simulation period was also a time of rainfall deficit, but it was less of a deficit and not as long as the corresponding period for the Barkly. Then, the 1990s drought in the Burdekin was a period of higher rainfall deficit compared with that in the Barkly at that time. While rainfall increased and land condition improved after the 1990s drought in the Burdekin, more and longer occurrences of rainfall deficits prevented herds from increasing to and being maintained for long periods of time at sizes above those at the commencement of simulation period. Purchasing female breeders after the major 1990s drought was profitable providing herds only had to be partially destocked and only small numbers were purchased. If substantial destocking was required, which likely meant that land condition had deteriorated also, purchasing large numbers of female breeders made Burdekin herds more vulnerable to the next period of rainfall deficit, and thus the high costs of purchasing breeders resulted in higher herd productivity for only a short time relative to what occurred in the Barkly. Coping with regular bottlenecks in pasture productivity on the Burdekin property required a much more conservative approach to managing herd size. This is potentially why the most profitable Burdekin herds had low inter-annual variability in herd size, lower average and median utilisation rates relative to the safe rate, and high land condition.

The simulation results for the Barkly herds may have been atypical for that region, as the climatic conditions during the 44-year simulation period were atypical of those since 1886 (Figure 7-124). While long periods of below average rainfall were common since 1886, a 20-year period of predominantly above-average rainfall had not occurred previously. However, historically, it was common for long periods of below-average rainfall to be followed by short periods with high rainfall. For this reason, the long-term average annual Barkly rainfall of 415 mm was much higher than the long-term median rainfall of 362 mm, and the coefficient of variation was high at 52%. During the simulation period of 1977 to 2023, average and median annual rainfall were considerably higher at 462 and 428 mm respectively, and the coefficient of variation was lower at 44%. Given these differences, it seems unlikely that the stocking rate approach that was successful during the simulation period would have been appropriate during historical climate. It would have been possible to quickly increase herd size by purchasing large numbers of breeders during years of high rainfall, but as these were soon followed by years of rainfall deficits, destocking would have been required, high utilisation rates would have caused declines in land condition and carrying capacity, and the high costs of purchasing breeders would not have been repaid. Instead, the more conservative stocking rate approach that was successful during the Burdekin simulation period is likely to have been more appropriate for the long-term climate of the Barkly.

The climatic conditions of the Burdekin simulation period, with more alternating periods of below- and above-average rainfall, was also atypical of longer climate history that was characterised by long periods of below-average rainfall (Figure 7-125). Since 1897, the average annual rainfall of 568 mm was not much higher than median rainfall of 554 mm, and the coefficient of variation was smaller than that of the Barkly at 41%. Compared with the Barkly, the rainfall during the Burdekin simulation period of 1979 to 2022 was similar to long-term historical rainfall, where average and median annual rainfall were 588 and 549 mm respectively, and the coefficient of variation was 41%. Hence, the stocking rate approach that was most successful during the simulation period is also likely to have been appropriate for the long-term historical Burdekin climate.

The annual changes in herd size over the 40+ years of historical climate for the two most profitable Burdekin herds shown in Figure 7-123 are consistent with recommendations by Pahl *et al.* (2016). These authors compared herd productivity (liveweight gain/ha) and sustainability (percent perennial grasses) of strategies which varied greatly in the extent that stocking rates were changed in response to climate variability. This was done using GRASP for multiple 30-year simulations of historical climate at 28 locations across northern Australia which varied enormously in rainfall amounts and rainfall variability. Of 56 flexible stocking strategies modelled, constrained flexible stocking, with a 10% limit for annual increases when pasture production improved and a 20% limit for annual decreases in stocking rates when pasture production declined, was able to both improve land condition and achieve amongst the highest liveweight gains of steers in semiarid rangelands. While other more flexible strategies which also decreased stocking rates by twice as much as increasing them in response to climate variability resulted in equal or higher herd productivity and land condition, the strategy with limits of 10% increases and 20% decreases in stocking rates annually was considered the most practical, given the limited availability and high costs of livestock available for sale when climatic conditions improved.

The GRASP-CLEM modelling framework used for the Burdekin herd simulations, which included a breeding herd model and financial analysis not used in the work of Pahl *et al.* (2016), demonstrated

that increasing interannual variability in stocking rates generally reduced land condition, herd productivity and profit. For the Burdekin herd simulation period where alternating periods of high and low rainfall were similar in frequency to those of historical climate, the most profitable and sustainable herds had median annual utilisation rates which were lower than the safe rate. This enabled these herds to limit declines in land condition during successive dry years, and conversely, improve land condition during periods of high rainfall.

The most successful Barkly herds had much higher interannual variability in stocking rates, which was needed to take advantage of the atypically long period of constantly high rainfall that followed a long period of rainfall deficit. Also atypical of these herds were the purchases of very large numbers of breeders. It is unlikely that these would have been available, and even if they were, it is unlikely that managers would have spent vast amounts of money purchasing them when they did not know how long the improved climatic conditions would last. Instead, they more likely allowed their herds to grow naturally and steadily through improved rates of reproduction, liveweight gain and survival. This alone had the potential to markedly increase the size of their herds over 20 years of abnormally high rainfall, and make them vulnerable to the next period of rainfall deficit. This occurred at the end of the simulation period, necessitating substantial destocking to avoid high rates of mortality and declines in land condition. In consideration of this and the atypically long period of high rainfall, a combination of moderate stocking rates and constrained flexibility in response to climate variability is also likely to be more successful in the Barkly tablelands.

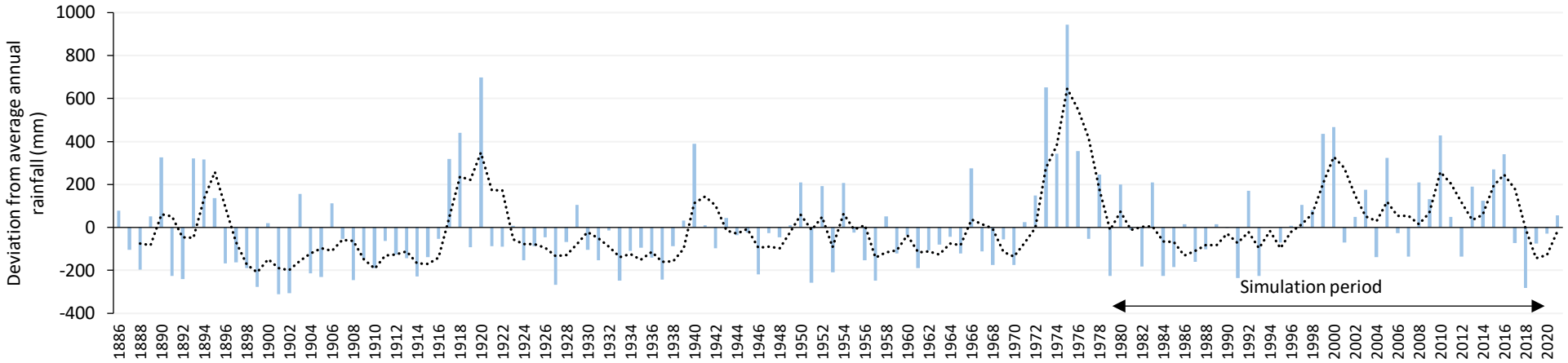


Figure 7-124: Differences between annual rainfall and average annual rainfall (rainfall deviation) and 3-year moving average deviation over the period 1886 to 2021 of the Barkly Tablelands property (Brunette Downs rainfall station)

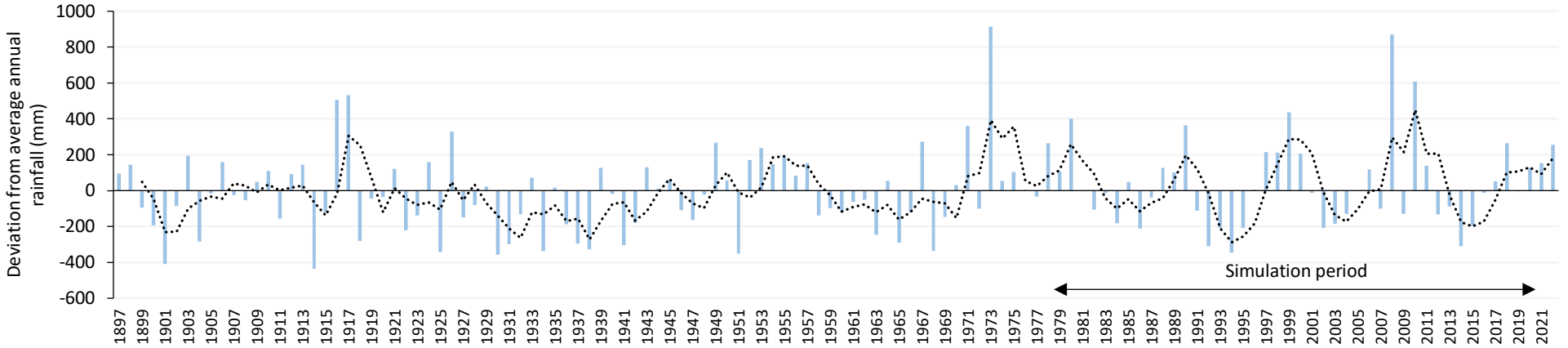


Figure 7-125: Differences between annual rainfall and average annual rainfall (rainfall deviation) and 3-year moving average deviation over the period 1897 to 2021 of the Burdekin property (Hill Grove rainfall station)

Land type differences

Figure 7-117 above showed that the rate of decline in average annual percent perennial grasses in response to increasing median utilisation rate in the Burdekin was 2.4 times that in the Barkly. Burdekin herds had higher average annual percent perennials than Barkly herds for median utilisation rates of 15-20%, whereas this reversed for median utilisation rates >20%. However, this is not an entirely valid comparison of the Barkly and Burdekin responses of percent perennials to increasing utilisation rate, as the safe utilisation rate for Barkly was 20% and that for Burdekin was 25%. A more appropriate comparison is the change that occurs in percent perennials as the proportion of years with higher than safe utilisation rates increase (Figure 7-126). The responses of Barkly and Burdekin herds are now closer, as the rate of decline in percent perennials with increasing median utilisation rate in the Burdekin was then only 1.9 times that of the Barkly. Also, there is more overlap in the proportions of years with utilisation rates higher than safe.

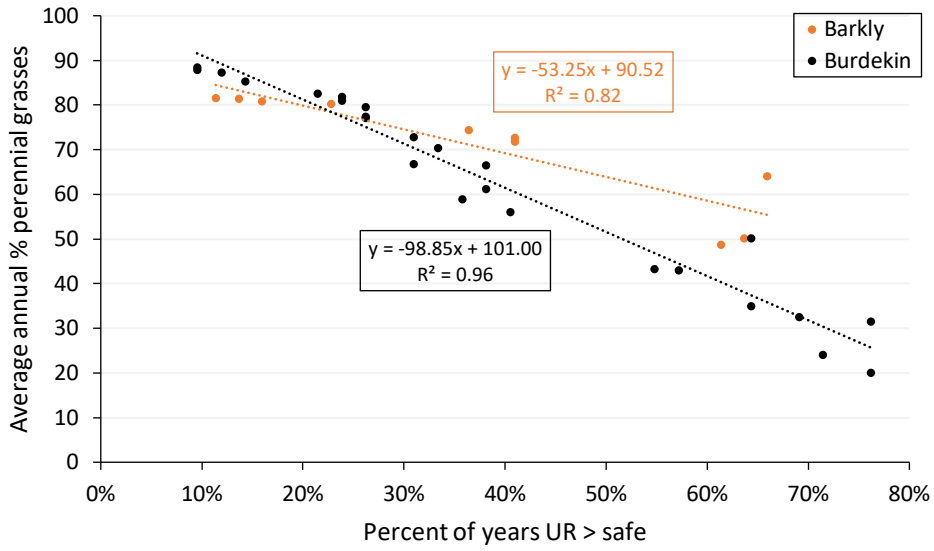


Figure 7-126: Relationships between the percent perennial grass composition of pastures and percent of years pasture utilisation is higher than safe for the 10 simulated Barkly herds and the 25 simulated Burdekin herds (fitted lines are linear)

Differences in the CLEM parameters driving responses of the Barkly Mitchell grass and the Burdekin narrow-leaved ironbark land types to grazing have contributed to differences in the outcomes of simulations for the two regions (Table 7-27). The Barkly land type was assumed more resilient, and hence had slightly slower rates of both decline and recovery (Figure 7-127). Also, the Burdekin land type was allowed to decline to lower levels and improve to higher levels of pasture condition than the Barkly land type (Table 7-27). The safe level of utilisation was assumed to be higher for the Burdekin land type (25 vs. 20% for the Mitchell grass land type). The differences in land condition recovery and degradation parameters of the two regions were deliberate, to reflect the different assumed land type tolerance or resistance to grazing (safe utilisation rate) and resilience to grazing (rate and direction of change at different tipping points of pasture utilisation) *sensu* Van Marbeek *et al.* (2021).

Table 7-27: Land condition rates of change and thresholds for the Barkly and Burdekin simulations

Parameter	Barkly Mitchell grass	Burdekin Narrow-leaved ironbark
Simulation start land condition (% perennials)	3 (70%)	3.5 (60%)
Minimum land condition (% perennials)	9 (5%)	11 (1%)
Maximum land condition (% perennials)	2 (84%)	1 (88%)
Safe utilisation rate at which there is no change in land condition	20%	25%
Lower utilisation threshold below which increasing rate of recovery	15%	15%
Upper utilisation threshold above which increasing rate of decline	25%	35%
Annual land condition recovery at 0% utilisation (change in % perennials)	0.6 (5.5%)	0.65 (5.9%)
Annual land condition decline at 100% utilisation (change in % perennials)	0.6 (-5.5%)	0.75 (-6.8%)

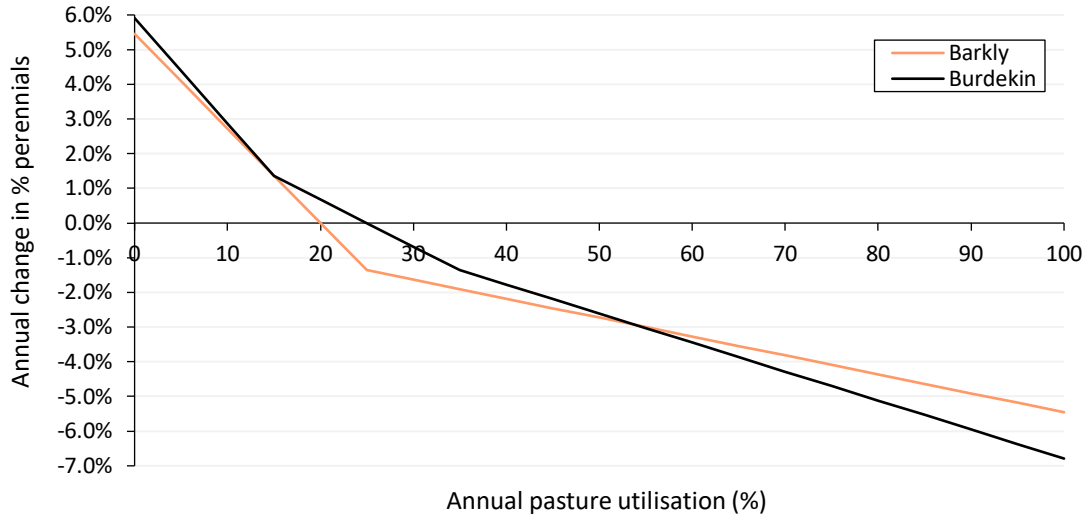


Figure 7-127: Annual step change in land condition (shown as equivalent change in % perennials) with varying annual pasture utilisation in simulations of the Barkly and Burdekin properties

The maximum percent perennials possible for Barkly simulations was 84% compared with 88% for Burdekin, and the minimum perennials was 5% for Barkly and 1% for Burdekin (Table 7-27). While this explains the slightly higher percent perennial grass composition achieved for the Burdekin herds when only 10-20% of years had higher than safe utilisation rates, it does not explain the much larger difference in percent perennials when utilisation rates in the majority of years were higher than safe (Figure 7-126). Also, four of the Burdekin herds had more years with higher than safe utilisation than the Barkly. For example, the maximum proportion of years with higher than safe utilisation rates for Burdekin herds was 76%, while that for Barkly herds was 64%.

To further investigate the extent that differences in land condition parameters influenced differences between regions in the responses of percent perennial grass composition to pasture utilisation we compared the proportions of years with bands of annual utilisation rates relevant to those in Figure 7-126. The rates of recovery of land condition with annual pasture utilisation rates ≤15% were very similar for the Burdekin and Barkly properties (Table 7-27, Figure 7-126). Then, at

utilisation rates between 25 and 55%, land condition of the Barkly land type declined at a faster rate than did that of the Burdekin land type. In contrast to this, at utilisation rates >55%, land condition of the Burdekin land type declined at faster rates than the Barkly, and even more so at utilisation rates >70%.

In interpreting the changes in average annual perennial grass composition in response to a range of bands of utilisation rates shown in the Figures below it is important to note that the individual herd values for perennial grasses are the same for all graphs, and are a response to the magnitude and sequence of all annual utilisation rates of simulation periods. So, for example, in Figure 7-127 below, the decline in average annual percent perennials with decreasing proportions of years with utilisation rates <15% is due to all annual utilisation rates, and not just those <15%. Of more value for interpretation of regional differences in responses of percent perennial grasses to utilisation are differences between Barkly and Burdekin herds in their proportions of years with the different bands of utilisation rates.

Nearly half of the simulated Burdekin herds had less than 30% of years when utilisation rates were <15% (with the highest potential rate of land condition recovery at 1.4 - 5.9% increase per year) and consequently this contributed to their lower average annual perennial grass composition compared with Barkly herds (Figure 7-127). Where the proportions of years with <15% utilisation rates were similar, the Barkly and Burdekin herds tended to have similar percentages of perennial grasses, which is consistent with the parameter values of Figure 126. The four smallest Barkly herds which had by far the highest proportions of years with utilisation rates <15% did not have more perennial grasses than Burdekin herds with much lower proportions of years with this band of pasture utilisation. This is because the lower maximum land condition limit for the Barkly simulations prevented these herds from achieving close to 90% perennial grasses, as was possible with the Burdekin herds (Table 7-27). The Burdekin land condition was a lot more sensitive to the proportion of years when utilisation was < 15% than the Barkly. The rate of decline in percent perennials with decreasing proportions of years with utilisation rates <15% in the Burdekin was 3.7 times that of Barkly herds.

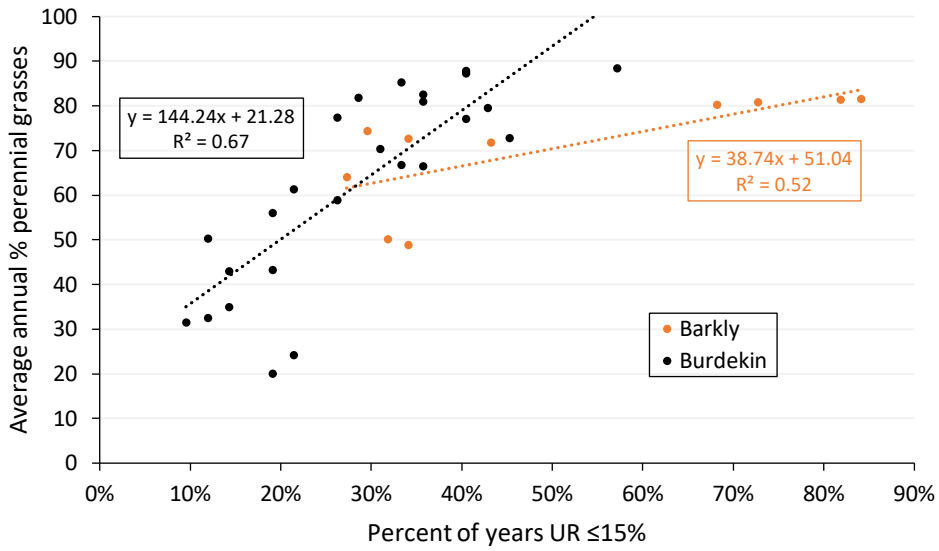


Figure 7-127: Relationship between the proportion of years within simulation periods with annual pasture utilisation rates (UR) that promote the highest rate of land condition recovery (≤15%) and average annual percent perennial grass composition for Burdekin and Barkly herds (fitted lines are linear). Average of 42 / 44 years

Ten of the 25 Burdekin herds had higher proportions of years with moderately high utilisation rates between 25 and 55% (Figure 7-128) than the Barkly herds. This range of utilisation led to declines in land condition between 0 to -3% perennial grasses decline per year. Burdekin herds with <25% of years with 25 to 55% utilisation rates tended to have higher percentages of perennial grasses than did Barkly herds with the same proportions of years. This aligns with the parameters for a lower rate of decline in percent perennials for the Burdekin compared with Barkly herds for this band of utilisation rates as well as the lower permitted maximum in the Barkly (Figure 7-126). The rate of decline in percent perennials as the proportions of years with 25 to 55% utilisation rates increased for Burdekin herds was steeper than that for Barkly herds. This is because the Barkly maximum % perennials was limited to 84%. If the Barkly maximum was 88% the trends would be very similar.

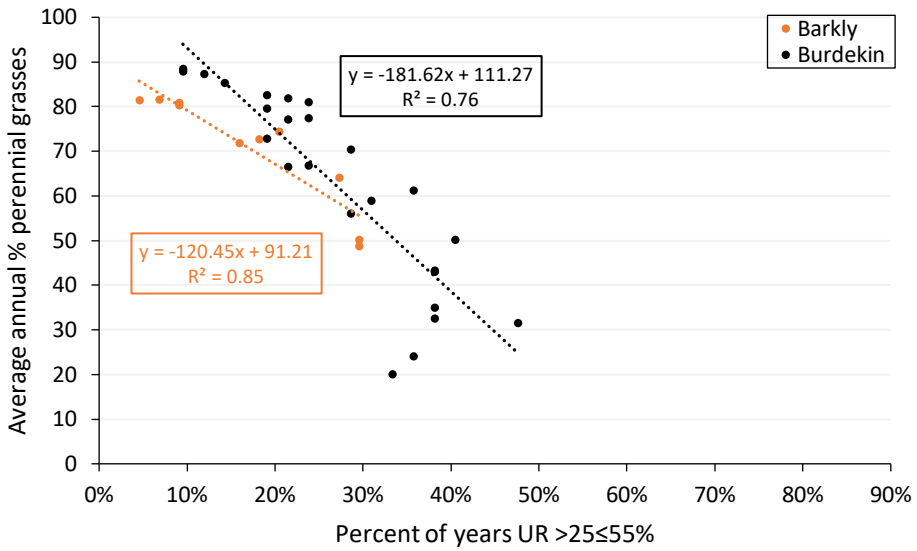


Figure 7-128: Relationship between the proportion of years within simulation periods with annual pasture utilisation rates (UR) of 25≤55% and average annual percent perennial grass composition for Burdekin and Barkly herds (fitted lines are linear). Average of 42 / 44 years

Apart from five Burdekin herds which had no years with utilisation rates >55%, the Barkly and Burdekin property locations had the same proportions of years with this band of utilisation (Figure 7-129). However, while percent perennial grasses decreased rapidly as the proportion of years with utilisation rates >55% increased, the rate of decrease was steeper in the Burdekin. For example, when 25% of years had utilisation rates >55%, Burdekin simulations had 25% perennials compared with 50% in the Barkly. This was consistent with the step changes in percent perennials shown in Figure 7-127, where they declined more quickly in the Burdekin for this band of utilisation rates.

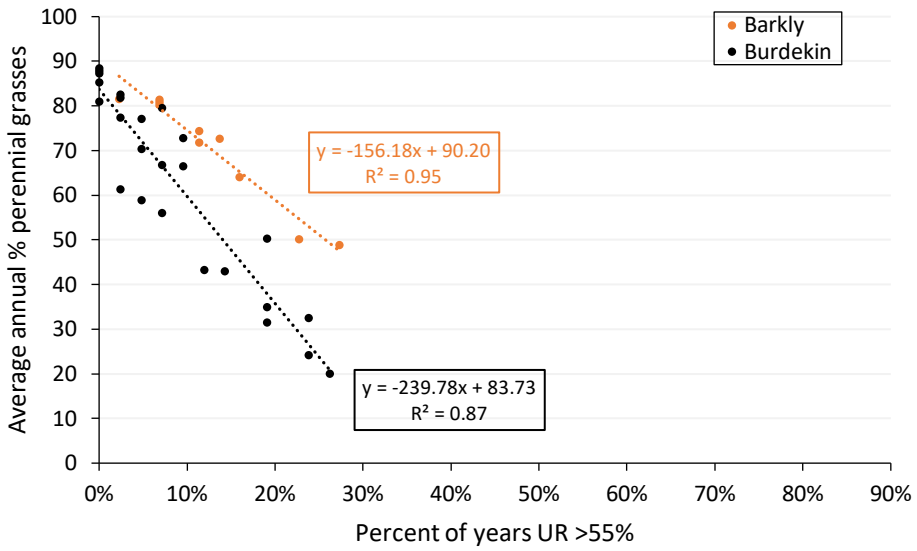


Figure 7-129: Relationship between the proportion of years within simulation periods with annual pasture utilisation rates (UR) >55% and average annual percent perennial grass composition for Burdekin and Barkly herds (fitted lines are linear). Average of 42 / 44 years

The rate of decline in percent perennial grasses that occurred with increasing median utilisation rate for Burdekin herds was much higher than that for Barkly herds. Examination of the proportion of years with utilisation rates relevant to the differences in land condition parameters shown in Figure 126 indicate that the Burdekin herds generally had lower proportions of years with utilisations rates <15%. Years with utilisation rates <15% were responsible for improvements in land condition, and thus there were less opportunities for this during the Burdekin simulation period. While the parameter rates of increase in land condition with utilisation rates <15% were almost the same for Barkly and Burdekin, land condition would have improved more often in the Barkly because it had more years with these low utilisation rates compared with the Burdekin.

Consistent with the differences in proportions of years with <15% utilisation rates shown in Figure 128, where Burdekin herds often had lower proportions than the Barkly, the Burdekin herds also had higher proportions of years with utilisation rates between 25 and 55% (Figure 7-128). While the parameter rates of decline in percent perennials associated with this band of utilisation rates were lower for Burdekin compared with Barkly, the higher proportion of years with these utilisation rates for many of the Burdekin herds likely contributed to their lower average annual values.

The proportions of years with >55% utilisation rates were similar for Barkly and Burdekin herds, but the faster rate of decline in perennial grasses at these high rates of utilisation in the Burdekin would have contributed to their lower perennial grass composition. Of note though, is that many Burdekin herds had no annual utilisation rates >55%, and these included the most productive and profitable herds. They kept utilisation within double the safe levels.

While the regional differences in the parameters used in CLEM to decrease land condition as utilisation rates increased above safe were at least in part responsible for the larger declines in land condition observed in the Burdekin simulations, they do not appear capable of achieving the observed magnitude of decline. Of more importance were the proportions of years with the bands of utilisation rates assessed above. Barkly herds had higher proportions of years with utilisation rates <15% and lower proportions of years with utilisation rates between 25 and 55%. Given that the

Barkly herds generally had similar proportions of years with utilisation rates >55%, it appears that the more rapid decline in perennial grass composition of the Burdekin was due to it possessing less years with utilisation rates <15% and more years with utilisation rates between 25 and 55%. This is also evident in Figure 132, where for the same proportion of years with utilisation rates >55%, the Barkly herds have a higher proportion of years with utilisation rates less than safe.

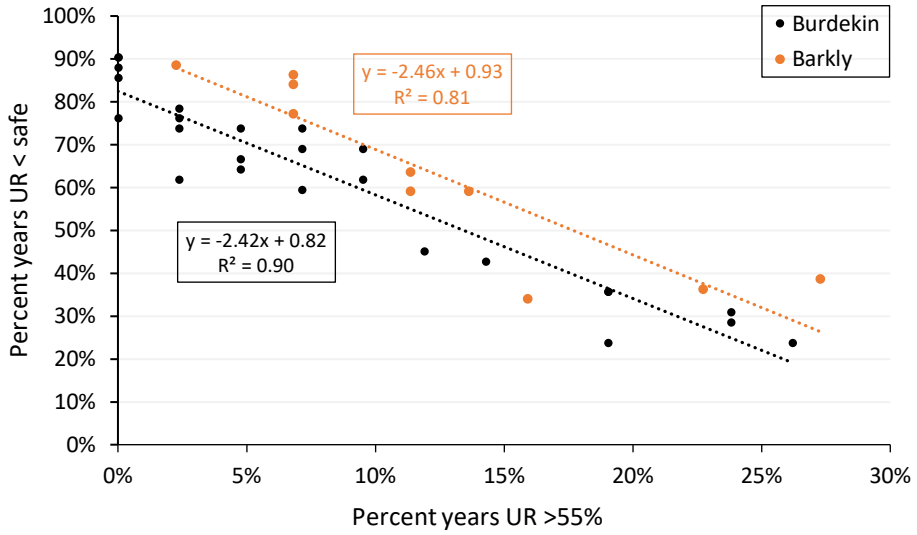


Figure 7-132: Relationship between the proportion of years within simulation periods with annual pasture utilisation rates (UR) <safe and proportion of years with utilisation rates >55% for Burdekin and Barkly herds (fitted lines are linear). Average of 42 / 44 years

Comparisons of annual rainfall within the regional simulation periods identified that Burdekin had four periods of rainfall deficit (annual rainfall relative to average rainfall) compared with two in the Barkly, and during the periods of rainfall deficit, the Burdekin experienced consecutive years of high pasture utilisation rates which were two to seven years in length, whereas those in the Barkly were only one to two years in length It is proposed that the more numerous and longer periods of rainfall deficit in the Burdekin simulation period was responsible for its lower proportions of years with less than safe utilisation rates relative to proportions of years with >55% utilisation rates.

7.8.4 Conclusions

The most profitable herds, at both locations, achieved the highest average annual herd productivity that was possible without causing appreciable and lasting declines in land condition. Additionally, they produced large amounts of beef, over long periods of time, with relatively low variable costs, and relative to other simulated herds in the same region, there were less forced sales during droughts and fewer female breeders purchased to restore herd size when climatic conditions improved.

Profitability/km^2 of the Burdekin property increased almost linearly with increases in the perennial grass composition of pastures (Figure 7-130). In the Burdekin, this improvement in land condition from mid B to A was essential for achieving maximum profit. Herds had to cope with several periods of successive years of rainfall deficit relative to average rainfall of the 42-year simulation period, where there was potential for high utilisation rates and deteriorating land condition. Attempting to maintain relatively high stocking rates early in the simulation period reduced land condition which exacerbated the adverse impacts of later periods of rainfall deficit on pasture productivity, herd

productivity and carrying capacity. When this occurred, forced sales were required to avoid high rates of mortality and utilisation, and then recovery of herd size required purchasing of female breeders when climatic conditions improved. However, recurring periods of rainfall deficit meant that these practices were repeated several times, making it difficult to maintain both high herd size and good land condition.

Challenged by large and unpredictable swings in pasture productivity, the most profitable Burdekin herds were those which had stocking rates, and in particular, numbers of breeders, which could be kept relatively constant throughout the 40+ years of historical climate and still improve land condition. This enabled them to achieve high average annual herd sizes, and combined with high individual animal performance and relatively low variable costs, they were the most profitable of all herds. Increasing stocking rates quickly through purchasing breeders when climatic conditions improved made these herds vulnerable to the next period of dry years when high utilisation rates decreased land condition and forced sales were required.

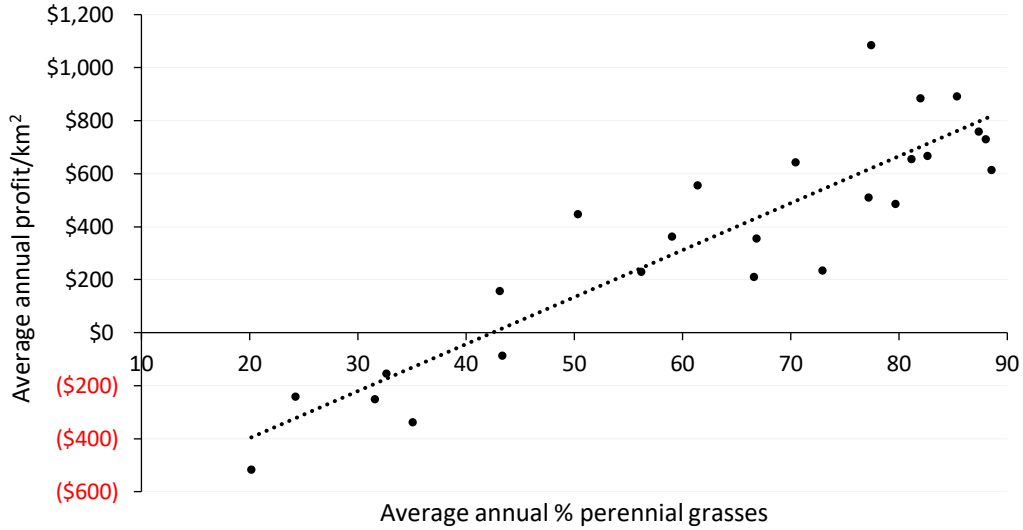


Figure 7-130: Relationship between average annual profit/km^2 and average annual % perennial grass composition for 25 of the 27 simulated Burdekin herds (fitted line is linear). Average of 42 years

The profitability/km^2 of the Barkly property appeared much less dependent on and was quadratically related to land condition (Figure 7-131). Profit/km^2 was low when perennial grass composition was approximately 50% (low B land condition), it was highest when perennial grass composition was 64 to 74% (high B land condition), then declined with further improvements in land condition which were achieved with lower utilisation rates. Barkly herds experienced fewer and shorter periods of rainfall deficit due to an abnormally long period of rainfall surplus in second half of the simulation period. While high stocking rates were maintained during the long period of rainfall surplus, utilisation was mostly at the safe rate of 20%. Very high stocking rates did reduce land condition with subsequent reductions in pasture and herd productivity, but as this occurred near the end of the simulation period it had less impact on overall herd productivity and enterprise profitability. However, this productivity and profitability were achieved at the expense of future herd and enterprise performance. In contrast to this, the Burdekin simulation period possessed earlier periods of rainfall deficit, and therefore, any reductions in land condition and pasture productivity reduced herd productivity for longer periods of time.

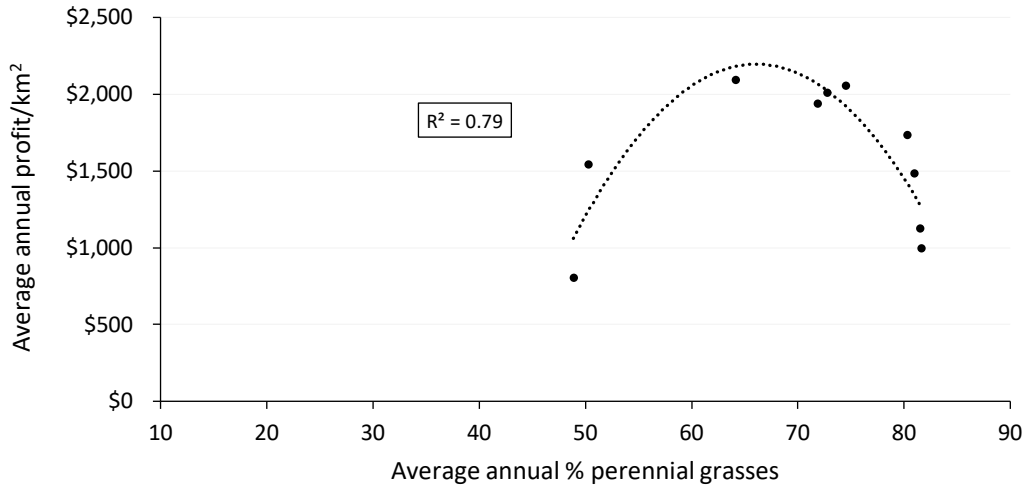


Figure 7-131: Relationship between average annual profit/km^2 and average annual perennial grass composition for the 10 simulated Barkly herds (fitted line is a 2nd order polynomial). Average of 44 years

Given that rangelands are typified by high interannual variability in rainfall, often with alternating periods of successive years with above- and below-average rainfall, it is expected that herd productivity and enterprise profitability could be improved by maximising gains during wet years and minimising losses during dry years. However, unpredictably high variability in annual pasture productivity in the rangelands, combined with less variable cattle stocking rates, makes it difficult to avoid periods of high utilisation rates that reduce land condition. This is a major challenge, as deterioration of land condition from A to B reduces long-term livestock carrying capacity by 25%, and the carrying capacity of land in C condition is only 45% of that in A condition (FutureBeef 2024).

Given the substantial declines in carrying capacity which occur with declining land condition, the most profitable and sustainable beef cattle breeding herds will likely be those which are able to maintain good land condition without needing to substantially reduce stocking rates. Not surprisingly, the simulated most profitable and sustainable herds were those which had the maximum stocking rates possible without causing appreciable and long-term reductions in land condition. It is possible to achieve this with bioeconomic modelling, as hindsight and foresight allow identification of optimal stocking rates over long periods of historical climate. In reality, managers have much more difficulty finding the optimal trade-off between stocking rates and land condition, as they do not know when the next period of rainfall deficit will occur, or for how long. However, the impacts of unpredictable periods of rainfall deficit can be reduced by low utilisation rates during wet years which enable land condition to improve, as high land condition buffers herds against the next period of rainfall deficit. While there may be a short-term opportunity cost in not utilising occasional large amounts of forage available during periods of high rainfall, this can be more than repaid by the land condition buffer that limits or even prevents crashes in herd production when the next drought is encountered. Without this buffer, costly periods of drought feeding, destocking or high mortality rates will be more frequent, and additionally, they limit future herd productivity and profitability. The time required to breed and grow out cattle encompasses considerable variability in pasture production that is largely unpredictable, and consequently, it appears that a conservative or risk-adverse approach to pasture utilisation is more likely to be profitable and sustainable over time.

8.8.4 Future modelling recommendations

As with all modelling exercises, the assumptions and parameters used in this bioeconomic modelling exercise had a large influence on the relative performance of the herd management scenarios investigated. CLEM is a manifestation of contemporary scientific understanding of the rates at which cattle reproduce, grow, lose weight and die in relation to the quantity and quality of forage available to them. Important outputs of CLEM, such as liveweight change, liveweights, reproductive rates and mortality rates should be compared with empirical results before its capacity to accurately mimic herds are known.

Most importantly, included in CLEM were feedbacks between herbivore grazing pressure, land condition and pasture productivity. Rates of change in land condition in response to highly variable grazing pressure over long periods of time have a very large influence on the performance of beef cattle herds in the rangelands. The rates of change in land condition used in simulations of the Barkly and Burdekin herds were based on the best estimate of rates of change derived from previous research (Scanlan *et al.* 2013, Walsh and Cowley 2016), but relative to the large spatial and temporal variability experienced across the rangelands, little is known about the time taken for land condition to deteriorate and improve. The rates of change in land condition and their associated threshold utilisation rates used in these simulations should be reviewed. This should include a sensitivity analysis of the impacts of slower or faster rates of change in land condition on simulation outcomes, as this would enhance our understanding of the study results and how much they hold up under different assumptions. As a start, the simulations for each region could be run with the same rate of change, safe thresholds and minimum and maximum land condition assumptions to see if that changes outcomes and messages.

Consideration also needs to be given to the statistical measures used to summarise annual pasture utilisation rates over long periods of climate variability typical of northern Australia, which are then compared with animal, land and financial performance metrics. A safe pasture utilisation rate has been defined as that which achieves acceptable levels of animal production while maintaining self-sustaining populations of palatable and productive perennial grasses (Hunt 2008, Zhang *et al.* 2021). In their definitions of safe pasture utilisation rates, Hunt (2008) and Zhang *et al.* (2021) both noted that the safe rate was an average of annual utilisation rates which maintained land in good condition over long periods of time. However, average annual utilisation rate may not best represent long periods of annual utilisation rates given their high variability and skewed distribution. Median values are often preferred under these conditions, but they also may not fully predict the impact of different sequences of annual utilisation rates over long periods of high climate variability. This is partly because medians will not fully account for differences in the frequency and length of alternating periods of rainfall deficits and surpluses which appear to have a large influence on the relationship between grazing and land condition. It is also partly because the rates of change in land condition that occur across the full range of utilisation rates are unlikely to be linear. For example, while the amount that land condition changed at zero and 100% utilisation was the same or very similar in our simulations of Barkly and Burdekin herds, land condition improved at a faster rate at utilisation rates less than safe (20 or 25%) compared with rates of decline over the much wider range of higher than safe utilisation rates. Running simulations over more periods of historical climate, in conjunction with further consideration of the rates of land condition change, would provide further insights into the statistical measures which best represent the influence of highly variable pasture utilisation rates on land condition.

All herd simulations in the Barkly and Burdekin commenced with mid to high B pasture condition, corresponding with a perennial grass composition of 60-70%, as this was regarded typical of properties in both regions. Hence, there were considerable benefits for stocking/utilisation rate strategies which improved land condition. This is likely to be even more important for scenarios which commence in C condition, and thus require even more conservative stocking rates during the early parts of simulation periods. In contrast to this, scenarios commencing in A condition may be able to successfully apply more flexible stocking rate approaches. Hence, further insights into the relationships between stocking rate, utilisation rate, land condition, herd productivity and enterprise profitability could be gained by running simulations with different starting land conditions.

Running simulations over more climate windows with different amounts and sequences of rainfall would also be useful to determine the effect of climate on simulation results. We chose the most recent climate window because extensive beef cattle producers would more easily relate to and compare results with their own experiences. Also, running simulations for different periods of time, such as 10 or 20 years, would likely provide further insights into the relationships between stocking rates and measures of herd performance.

Consideration also needs to be given to the methods used to compare the financial performance of herd scenarios. The financial metrics we used were based on averages of annual costs and income. Comparisons of the financial performance of scenarios could be improved by using marginal economic analysis, combined with discounted cash flow and net present value, as recommended in Bowen and Chudleigh (2021).

CLEM can be used in at least two main ways to assess the benefits and costs of factors that potentially influence the performance of extensive cattle herds in northern Australia. One approach is a form of sensitivity analysis, where large numbers of simulations are run with only small incremental changes in one factor, while all others remain constant. For this approach to be practical, it is necessary to enable the herd management functions within the Manage Numbers component of CLEM, so that it automatically controls crucial herd attributes such as herd size and levels of destocking and restocking. Given the recommendations above for several sensitivity analyses, this would be an attractive approach for running CLEM.

However, there appears to be a trade-off between the efficiencies gained by running CLEM with enabled Manage Numbers functions and the extent that simulation outputs are typical of extensive beef cattle enterprises. CLEM is truly a systems model, and changing one factor, such as amount and/or duration of M8U drought feeding, will often have large implications for the dynamics of herds, their relationship with pasture and land condition, and the application and impacts of automated rules within CLEM which sell and buy cattle. In some instances, outcomes relating to land condition, herd size, herd and individual animal productivity, costs and income can be unrealistic or atypical of cattle herds and enterprises.

Another approach, that taken in this project, is to disable the automated Manage Numbers functions within CLEM and manually calibrate each simulation in an attempt to more closely mimic extensive herds and their management. While the outcomes of these simulations may be more acceptable to experienced beef producers and their service providers, parameterisation of CLEM is more subjective, management scenarios compared can have different parameter values, and each simulation requires many iterations which is time consuming. Further consideration needs to be given to the advantages and disadvantages of these two approaches, and the modelling objectives they are best suited to.

CLEM is being continually upgraded to improve its capacity to simulate a wide range of ruminant enterprises. The latest upgrades include a new ruminant growth model, along with new code and new parameters. The results and interpretations using much earlier versions of CLEM in this project should be compared with those using the most recent upgrades.

8. Synthesis

8.1 What's new?

The Sweet Spot project was a major undertaking that has enhanced our understanding of the impact of pasture utilisation on breeder performance in extensive breeder herds in northern Australia and how this flows through to production and profitability over the longer term. The project has created new approaches and new findings.

- This study was the largest pasture growth and utilisation modelling exercise of grazed paddocks in northern Australia that we are aware has ever been undertaken. We modelled 60 paddocks ranging in area from 5 to 500km^2 over 350 paddock-years.
- We worked with GRASP pasture growth model developers from Queensland Department of the Environment, Tourism, Science and Innovation to modify GRASP for use in modelling extensive variable rangeland paddocks and producing pasture growth databases for input into CLEM. GRASP was modified to facilitate calibration with satellite green ground cover, and to read in faecal NIRS data for potential future model development.
- Breeder performance in the Southern NT region has not previously been collated at this scale; the dataset presented here represents the most comprehensive summary of breeder performance that we are aware of. Descriptive analyses were applied to summarise both typical levels and the variation in performance.
- The empirical analysis used pre-existing breeder performance datasets, which meant that more value and insights could be extracted from previous investment in breeder research across northern Australia without any additional field trials.
- After adjustment for key parameters, the multivariable models quantified the impact of pasture utilisation on annual pregnancy rate, foetal and calf loss, pregnancy within four months, and weaning rate. By quantifying both the strength of these associations and magnitude of effect, this work contributes to the very limited existing information on the production consequences of pasture utilisation in northern Australia. These outputs provide critical inputs for future bioeconomic modelling, forming a foundation for future decision-making around infrastructure investment and management strategies to improve reproductive efficiency and herd resilience, while ensuring environmental sustainability.
- This is the first time CLEM has been used to examine enterprise level responses to pasture utilisation in northern Australia. CLEM didn't exist when the project was first conceived, and wasn't written into the original methodology. The project team recognised CLEM as a powerful new tool to model the long-term consequences of pasture utilisation on land condition, production and profitability and adjusted the project methodology and team accordingly. It required considerable investment in developing a new CLEM skill set for the bioeconomic modeller, while it was still being actively developed by CSIRO
- CLEM was able to simulate the long-term impacts of pasture utilisation on land condition and provided insights into how this feeds back to potential pasture productivity, carrying capacity

and ability to carry livestock through drier periods, the increased frequency of the need to destock, and how this leads to lower profitability, demonstrating that getting the stocking rates right allowed higher more stable continuous production over the long-term, helping to mitigate climate variability impacts on production and profitability.

- For breeders with >75% *Bos indicus* content, primarily in northern regions, a competition response was observed even at low pasture utilisation, lower than the safe utilisation rates recommended for maintenance of land condition. This finding highlights the potential influence of forage quality on production and warrants further investigation.
- When analysed at the expected month of calving, the comprehensive climate index was not found to have any association with reproductive wastage, indicating that further research with finer temporal scale is warranted.

8.2 Combining the lessons from across the project

The empirical dataset analysis found relatively muted short-term responses of breeder performance to pasture utilisation. This partly reflects the generally high rainfall experienced for most of the dataset years (65% of modelled site years had higher than median rainfall), which would act to moderate the impacts of high pasture utilisation when pasture growth is high. Supporting this, higher pasture growth and quality were found to be factors enhancing breeder performance in addition to relative pasture utilisation. However, the relatively moderate magnitude of the effect of pasture utilisation found here is consistent with previous reviews of grower liveweight gain responses to pasture utilisation in rangelands systems (Ash and Stafford Smith 1996). Large heterogenous paddocks can have buffers of forage that are not usually highly utilised, in the form of browse, less preferred land types and areas distant from water which provide an inbuilt drought reserve of forage availability in high utilisation years. Hence when utilisation is higher than recommended cattle often can partly offset low forage availability within the watered area by grazing further from water, or utilising areas or forage types that they would usually avoid.

The relatively modest impacts of utilisation on breeder performance means that higher than recommended stocking rates will translate to higher production in the short term (1-10 years). There will be little negative feedback on herd production particularly in average and above average years. If stocking rates are kept fairly stable year to year, producers will still see pasture utilisation fluctuate annually with varying rainfall and pasture growth. In North East Queensland and Southern NT regions, pasture utilisation was most correlated with varying pasture growth, rather than stocking rate, despite the North East Queensland dataset being dominated by stocking rate trials. This means that the impacts of higher utilisation rates will most likely be evident in lower performance and production coming out of a paddock in lower growth years, particularly consecutive lower growth years where cattle can't recover condition after the first high utilisation year, and where all of the reproductive cycle from pregnancy through to weaning and the next pregnancy (more than a 12 month period) is under a period of nutritional stress. In the Barkly and Burdekin modelling scenarios using actual historical climate since 1980, there were five periods of consecutive dry years in 42 years, ranging in duration from 2 to 8 years in the Barkly and 2 to 6 years in the Burdekin, on average at least once a decade. Where stocking rates are too high, there will be more variable performance and production year to year, but in the short-term the higher production in higher pasture growth years still leads to better cumulative production and profitability with utilisation rates that are higher than recommended. This was demonstrated in the bioeconomic modelling over the first decade, and in grazing trials at Wambiana with steers (O'Reagain *et al.* 2022), and with breeders at

Pigeon Hole and Mt Sanford in the VRD (Hunt *et al.* 2013) and at Thalanga and Swan's Lagoon in North East Queensland (Smith *et al.* 2001).

Similarly land condition change can be subtle and difficult to recognise initially, with relatively small annual declines in perennial grasses, that varies spatially across the landscape and that fluctuates up and down year to year, with some recovery in wetter years masking longer-term trends in land condition decline. Mortalities or forced destocking in higher utilisation years will lead to lower stocking rates and pasture utilisation when seasons improve, helping to facilitate land condition recovery until herd numbers are rebuilt through natural increase or purchases. Hence in the short-term both the production and land condition responses to higher utilisation are not a reliable signal of the longer-term potential dangers of overstocking and high pasture utilisation. If producers are not monitoring herd performance, they may be unaware of how poorly their herd is performing compared to the potential for their region or land type. Even if they are, the lack of a response of high *Bos indicus* content breeder herd reproductive performance in northern Australia to higher than safe levels of utilisation measured in the empirical data set analysis explains why producers may see little impacts of over utilisation on breeder performance in the short-term, due to inherent buffers in the extensive rangeland paddocks. This means producers will not be financially penalised by overstocking, and unless utilisation is particularly high, the impact on land condition will be subtle or slight, so that it is entirely rational to continue to overstock based on the outcomes of their management in the first decade, particularly as they may have no counterfactual for what would have happened if they had managed livestock numbers differently.

However, over the longer term (multiple decades) attempting to quickly rebuild stock numbers to higher than recommended levels to increase production in better years can lead to repeated subsequent crashes in forage availability when drier consecutive years return. High pasture utilisation rates can result in low end of season ground cover leading to increased runoff, soil loss and low rainfall use efficiency in the following year, causing death of perennial grasses, and limiting the capacity of the landscape to respond the following wet season. The bioeconomic modelling, consistent with findings at the Wambiana grazing trial with steers in North East Qld (O'Reagain *et al.* 2022) showed how trying to keep stock numbers higher than recommended over the longer term led to more periods of high utilisation driving gradual cumulative decline in land condition, which led to a decreased ability of the landscape to respond to rainfall, declining forage production and more frequent and extended destocking or mortality events. The stock and production losses in drier years can lead to economic losses that could drive producers to try to recoup losses by making the most of better years, to recover economically from poorer years. Previous research has found that you need the right ratio of low to high utilisation years to maintain land condition. For example, at least 70% of years with less than safe utilisation was found to prevent land condition decline in south west Qld (McKeon *et al.* 2004). A strategy to continually make the most of better years by increasing stocking and pasture utilisation could reduce the ratio of low to high utilisation years, and the potential for recovery in better years and lead to an inevitable slide in land condition that is never able to fully recover in wetter years.

The CLEM modelling provided insights into the mechanisms of longer-term impacts of pasture utilisation when it starts to feedback on land condition, production and profitability. In the Burdekin bioeconomic modelling the assumed land condition feedback rates were such that even slightly overstocking could lead to a lower carrying capacity over time, and over the 42-year simulation period, led to a lower average stocking rate due to the more frequent and extended periods of reduced forage availability. Furthermore, there were economic losses when needing to more frequently destock and rebuild at less than optimal market prices, as well as reduced price per kilo

received due to lower body weights and additional supplementation and transport costs. So, trying to carry more than recommended utilisation levels led to lower average stocking rates being able to be carried, and increased costs, making higher than recommended stocking rates uneconomical. Indeed, in the Burdekin, the most profitable median utilisation rates were actually slightly lower than the recognised safe levels of 25%, and at stocking rates that resulted in median utilisation rates between 18 to 20%.

In the Barkly simulations the land type was assumed to be slightly more resilient to grazing, and there was an extended period of above average rainfall in the latter part of the simulation period that drove high land condition and stocking rates, so that over the longer term, although land condition did decline at higher than recommended utilisation rates, it was less severe, and did not lead to lower stocking rates being able to be carried at the highest utilisation rates. Even so production and profitability were still optimal at close to the recommended safe utilisation rate of 20%, at 18-23% median utilisation. At higher utilisation rates the lower pasture growth with poorer land condition exacerbated the poorer performance of breeders/head and led to little additional production, but with the higher costs of the larger herd size, led to reduced profit.

Together the two regional bioeconomic modelling exercises demonstrate how the long-term cumulative impacts of high pasture utilisation resulting from carrying stocking rates higher than recommended levels can lead to lower profits. In the Barkly, the feedbacks on land condition were not as severe, but the combination of higher utilisation and lower growth affected performance such that utilisation rates above safe levels gave no additional production despite larger herds, and hence had poorer economic outcomes. In the Burdekin the effect of higher utilisation led to declines in land condition that didn't just prevent increases in production, but led to dramatic declines in carrying capacity to the degree that on average the herd sizes were smaller due to more frequent and extended forage shortages.

For both regions the most profitable and sustainable utilisation rates were those that maintained good land condition. They had the maximum stocking rate possible without causing appreciable long-term reductions in land condition, or as Ian McLean describes "*run as many as you can, but no more than you should*." Trying to achieve higher stocking rates in wetter years led to subsequent overutilisation and land condition decline when drier years returned. The short-term opportunity cost in not utilising occasional large amounts of forage available during periods of high rainfall, was more than repaid by the land condition buffer that limits or even prevents crashes in herd production when the next drought was encountered. Without this buffer, costly periods of drought feeding, destocking or high mortality rates were more frequent, and additionally, they limited future herd productivity and profitability. Hence the conservative risk adverse approach to manage the unpredictable and variable climate risk was the most profitable and sustainable over the longer term.

Implementing optimal utilisation rates has the potential for multiple benefits. If pasture utilisation is too high, reducing stocking rates will lead to improvement in breeder performance quite quickly. However, in the short term there may be a loss of potential production as land condition can take some time to recover (e.g. d'Abbadie *et al.* 2025). It takes the combination of both appropriate stocking rates and ideally consecutive high rainfall years to promote land condition recovery. Depending on the start condition, it could take multiple years, or decades for recovery of soil and seedbanks, before perennial pastures rebuild to the more productive B or A condition state. Producers who shared their experiences in managing stocking rates to find the Sweet Spot in their breeder herd performance did not report losses in profits, but instead dramatic increases in breeder herd performance that led to similar production with smaller herds, lower costs of production and

similar or higher profits with improving land condition. Some of them were receiving ACCUs through the Federal government Beef Cattle Herd Management Methodology for their reduction in emissions due to lower livestock numbers. Where pasture utilisation rates are currently too high, reducing stocking rates to optimise pasture utilisation has the potential to reduce total livestock emissions and improve land condition, both of which have important implications for demonstrating industry environmental stewardship and provide potential opportunities for carbon and environmental market participation, and to enhance the industry social licence.

8.3 Study limitations

A key limitation of this study is that the dataset was compiled from multiple sources originally collected to address specific research questions, rather than being designed specifically to evaluate pasture utilisation effects on reproductive performance. As such, there is potential for unquantifiable bias arising from differences in study design, management, and data collection methods. Additionally, several factors within the dataset were highly correlated—for example, *Bos indicus* content and geographic region—making it challenging to disentangle their individual effects on reproductive outcomes.

The empirical analysis of the short-term impacts of pasture utilisation on breeder performance was further constrained by the availability of suitable datasets. Much of Northern NT and North East Queensland data was from research projects deliberately designed to test the impacts of a range of grazing intensities, and in the Southern NT much of the dataset was from Old Man Plains research station which ran recommended long-term safe stocking rates. Hence, they are not a measure of actual industry levels. Although a comparison between research and commercial herds in central Australia did suggest that industry often has lower performance than research herds, which are usually in smaller paddocks and more optimally managed. These limitations should be considered when interpreting the results and in planning future studies.

So that the empirical analysis could include data from a range of land types with varying levels of safe utilisation, breeder performance was compared to relative utilisation. Hence the results are expressed in the ratio of utilisation to safe, which requires some interpretation. It could be translated to what this would mean in actual utilisation rates, although relative utilisation allows you to express, x% loss will happen to y performance for a doubling or tripling of recommended utilisation.

The bioeconomic modelling results are dependent on the defined rates of change in land condition with pasture utilisation, and there is a lack of empirical evidence to be certain that they reflect reality (see further examination of this in Chapter 7.8.4, page 252). Despite this, the resulting simulated rates of land condition change were consistent with known rates of land condition change from producer and researcher anecdotal and literature sources. They were also not ‘tweaked’ until we got the outcome we were seeking or anticipated given our understanding of the ecology of rangeland systems and previous research. We were seeking emergent learnings from the modelling exercise and kept the initial expert derived rates of change and let the model tell us what the outcomes would be. We did not realise that the slightly different assumed rates of change for the different land types in the different regions combined with the different climate histories could lead to such different, although not inconsistent outcomes.

8.4 Breeder herd management recommendations

Empirical data set

Statistical analyses of the very large empirical data set enabled identification of factors which were significantly correlated with the reproductive rates of cows. Advantages of this data set was its very large sample size, wide geographical spread across the Northern Territory and Queensland, large temporal spread and a wide range of annual pasture utilisation rates. The standard of management of these research herds and closely monitored commercial herds were likely higher than those of commercial herds generally. This would have included nutrition, health and reproduction-related management practices.

Descriptive summaries of breeder performance across the different regions found significant room for improvement in breeder herd performance across northern Australia. Findings were largely consistent with the North Australian beef fertility project, but additionally this analysis provides new insights, as the Southern NT was not previously included and previous studies have focused on specific animal classes or were conducted on research stations. Overall, regional differences and levels of performance were consistent with existing literature, with lower performance in Northern NT.

Multivariable modelling findings demonstrated that high relative pasture utilisation significantly reduced individual animal performance across all reproductive and weaning outcomes. Pregnancy within 4 months of calving was predicted to decline by approximately 33% from low to high relative utilisation in low *Bos indicus* content cattle while a lesser response was observed in higher *Bos indicus* breed content and foetal/calf loss increased by about 3.4% per incremental step in relative utilisation. Critical nutritional factors, such as pasture growth, available green pasture, and pasture percent nitrogen around calving and in the early dry season, were vital for reproductive success and calf survival. Body condition score at pregnancy testing was also strongly linked to calf loss, decreasing from 22.7% at BCS 1.5 to 3.5% at BCS 5.0.

Analyses of the empirical data set found that reproductive rates of cows tended to increase with:

- higher body condition scores
- lower utilisation rates
- when pasture quality and quantity around calving and in the early dry season were higher
- higher available soil phosphorous.

Bioeconomic modelling

Bioeconomic modelling was used to assess relationships between pasture utilisation rate and measures of individual and herd performance. Individual or per head performance, such as reproductive rate and liveweight gain, increased with decreasing utilisation rate. The lowest utilisation rates resulted in the highest reproductive and growth rates, and the highest perennial grass composition (index of pasture and land condition).

Consistently highest individual animal performance and land condition were achieved at the expense of herd performance. Bioeconomic modelling demonstrated that small herds which had the lowest pasture utilisation rates and highest individual animal performance were often less productive and less profitable than larger herds. Conversely, maintaining large herds throughout simulation periods

resulted in high initial herd productivity and high pasture utilisation rates, but as this was at the expense of land condition, future herd productivity declined, costs of production were relatively high, and profits declined. As long-term carrying capacity of land in A condition is 33% higher than that in B condition and around 100% higher than that in C condition (FutureBeef 2022, 2024), maintaining high land condition is a necessary requirement of productive and profitable herds. Somewhere between herds that are too small and herds that are too large, are herd sizes and associated pasture utilisation rates which achieve an optimal long-term balance between pasture productivity and herd productivity. The most profitable simulated Barkly and Burdekin herds achieved the highest average annual herd productivity with relatively low production costs, without causing appreciable and lasting declines in land condition. If median annual utilisation rate defined this sweet spot of breeder herd productivity and profitability for the Barkly property, then it would have been 18-23%, comparable with the safe rate of 20%. For the Burdekin herds, those which were most profitable had median annual utilisation rates of 18 to 20%, which is lower than the safe rate of 25%.

The climate of the Barkly property, during the simulation period and since 1886, was characterised by long periods of low rainfall followed by several years with unusually high rainfall. Simulations based on the climate during the past 44 years found that average annual profitability was increased by allowing herds to grow quickly, including enabling this through purchasing breeders, when climatic conditions improved and there was a large surplus of forage. However, this often makes herds vulnerable to inevitable unpredictable and sudden declines in rainfall, requiring rapid decreases in herd size. As there were only one or two long periods of consecutive years with very high rainfall during the past 130+ years of historical Barkly climate, purchasing large numbers of breeders when there is a surplus of feed is likely to result in a financial loss and deterioration in land condition. On most occasions, it would be more likely that long-term herd productivity would be increased by allowing land condition to improve.

The herd management approaches that were most profitable on the Burdekin property were also likely to be equally successful in the Barkly region, considering that the climate of the Barkly simulation had an atypically long period of above-average rainfall. The most profitable Burdekin herds possessed numbers of female breeders which were close to the maximum number which could be maintained at relatively constant levels throughout the simulation period, while improving land from mid B to A condition. These herds had amongst the highest levels of individual animal and herd productivity, with relatively low costs of production. Destocking of cattle was not needed during droughts when cattle were poor, herd productivity during droughts was high relative to that of more dynamic herds, very little drought feeding was required, land condition deterioration was minor and purchasing female breeders was not needed to restore herd size after droughts. Overall, they were highly efficient herds.

A fundamental feature of these most productive and profitable herds were median annual pasture utilisation rates which were similar to or slightly lower than those regarded as safe. However, accurate measurement of the proportion of annual growth consumed and tracking changes in this over time by station managers is not practical. Monitoring changes in the condition of pastures and land may be more practical and effective. Furthermore, indices of pasture and/or land condition can be customised to land and pasture types, land and pasture condition, and to herd and land management objectives. Examples of indices of pasture and land condition that could be used are

proportions of total standing dry matter consumed, proportions of key pasture plants consumed, height of grazed pastures or key pasture plants, the size and number of patches of bare ground and the proportion of pastures that are undesirable plants.

However, the easiest way to ensure safe utilisation in most years is to apply stocking rates based on the long-term safe stocking rates for a paddock taking into account the watered area, land types and land condition. In Queensland the FORAGE website provides modelled long-term safe carrying capacity for every land parcel in the state, with the effect of different land types and land conditions also calculated. In the NT there are some available resources to assist calculation of carrying capacity in some but not all regions (e.g. the Land Condition Guides for the Barkly, VRD and Sturt Plateau), and consistent mapping at the relevant scale is also variable between regions, which can make estimation of safe carrying capacity challenging.

Achieving the most productive balance between herd productivity and land condition will always be challenging, and particularly under continuous grazing. Dry season forage budgeting will help align demand for forage with forage supply, but as the length of the dry season is unpredictably variable, overgrazing can occur. This could be avoided if stocking rates could be adjusted on one or more occasions during the second half of the dry season.

Rotational grazing, where mobs of cattle graze paddocks for short periods of time, may provide greater control of grazing pressure. Rotations could cease when indices of pasture and land condition have reached their target or threshold values. However, it is still likely that at some time the entire property will run out of feed, making it necessary to have a strategy for substantially reducing herd size or grazing pressure when that occurs. Sales, agistment, moving cattle between stations in different regions and drought feeding are options for achieving this, but their appropriateness will vary with the circumstance of each drought. For example, drought feeding is not usually an option in the NT due to the large station and herds sizes and the lack of available drought forage options. Being forced to take these actions should be avoided, as they will be costly in terms of finances, land condition and animal welfare. Target or threshold values that signal the cessation of rotations should leave paddocks with some amount of emergency forage supplies. Managing grazing to leave target end of year residual yields also helps to increase the rainfall use efficiency and pasture growth in the following growing season.

Producer recommendations from meetings and workshops

Queensland

Key recommendations provided by Queensland beef producers at a Sweet Spot project workshop at Charters Towers in July 2024 are provided below.

Grazing land management should be focused on maintaining good land condition and improving poor land condition, as this was conducive to high herd productivity. The key to a successful grazing enterprise was to eat as much grass as possible without damaging the ongoing or long-term productivity of land and pastures. They emphasized the need to avoid reductions in land condition as it takes a long time for it to improve and cattle productivity during that time is low.

Paddocks should be flexibly and rotationally rather than continuously grazed. Paddocks were often grazed on three separate occasions each year, by different classes of cattle, and with the duration and number of rotations dependent on pasture condition and availability. Rotational grazing gave them the ability to increase pasture yield and quality when good seasons allowed it, but to also

protect land condition as much as possible during years with well below average rainfall. When climatic conditions were poor and forage supplies were low, they would act quickly to reduce herd size in ways which varied with circumstances at the time. It was noted that in many places pasture condition would run down if it wasn't completely spelled routinely. Even a few head in a paddock impacts growth and denudes areas due to the selective grazing of preferred species and areas.

Land and pasture condition was of primary importance. Make decisions based on the condition of the country, not the stock. The better the condition of pastures at the end of the dry season the sooner they would be back in full production when the wet season resumed.

The beef producers noted how important it was for management to be proactive rather than reactive with regards to high climate variability, and particularly leading up to droughts. Proactive management limits the occasions when businesses must suffer losses in herd productivity and land condition. The latter could include situations such:

- weakness in market prices that are not acceptable to the business when forced to destock
- agistment not available or too expensive when forced to destock
- molasses and other drought feeds are not available or are too expensive
- cattle are too poor or too weak to sell
- market prices too expensive to re-stock when climatic conditions improve.

In dry years and early in droughts, when it appears that there will not be enough forage available for the herd:

- Sell steers and aged and empty breeders
- Agist cattle
- Providing supplements or rations to address energy and mineral deficiencies (e.g., M8U, formulated rations)In extreme situations, start to destock other breeders

It is important to have a well thought out drought management strategy which is written down and kept up to date. It should include critical dates that have trigger actions, such as early weaning, first sales or early agistment. During droughts, rely on your plan, but be adaptable. Move early by first selling stock which are the least productive and which have least market potential, which may then make it possible for more valuable stock to reach weights and condition scores suitable for sale. Be ready to supplement feed, but never substitute feed.

Maintaining efficient and productive herds, together with land in very good condition, is essential for establishing resilience and coping effectively with droughts. This can be achieved by culling non-productive and underperforming animals, maintaining a young age profile of breeding females, as older aged breeders are at-risk of mortality. It is recommended that the breeding proportion (breeding cows and heifers) of an enterprise not exceed 40%, to provide flexibility for tactical selling decisions throughout the year, which can be particularly challenging if sales coincide with calving or other critical periods. However, if the enterprise consists solely of breeders, some flexibility can be achieved by segregating breeders based on expected calving windows. Improving land condition and keeping it there builds resilience through improved soil health, perennial grass basal area and seed banks.

After droughts it is important to keep the stocking rate at a level that will allow grass to grow and recover fully. If at a later date there is not enough cattle for the available grass, agist in some stock or buy some stock in.

Northern Territory

Approaches to optimise breeder herd performance through pasture utilisation rates arising from the Katherine workshop are listed in Table 8-1.

Table 8-1: Practical options to manage climate variability from the Katherine Sweet spot workshop

Strategic (long-term, preventative)	Tactical (Short-term, responsive)
Structuring the herd age to be younger	In dry times dropping culling age to 7 or 8 years of age
Herd segregation on pregnancy and/or lactation allows fast selling down to priority core herd with the least mustering costs	Having groups of animals that can easily be mustered and marketed altogether
Decide on a core breeder number to not exceed safe utilisation in 70% of years (as per McKeon *et al.* 2004 page 232) and using other strategies i.e. Trading to more easily move numbers up and down.	
The threshold after the Sweet Spot – with such a steep curve, if the strategic action is to maintain conservative stocking rates	A strategically low SR to the "left of the sweet spot" can reduce the need for drastic culling policies. Segregation or having a trading component of the total AE's - including weaning lighter, selling more heifers, selling PTIC cows.
If operating right on the line of the sweet spot being prepared to vary stocking rates in runs of drier years	CIBO SOP's clearly to define decision dates to trigger sales for each location and some objective measures for regions as to what that is. Understand the numbers if animals are taken out of the herd to be production fed or sold

9. Communications and adoption pathways

9.1 Communications

The Sweet Spot project results have been presented to industry at 2 industry workshops, 4 expert workshops, 1 field day, 1 FutureBeef Webinar, 2 Beefups, 7 Industry meetings and in 9 conference presentations.

9.1.1 Conference presentations

R.A. Cowley, J.O. Carter, G.W. Fraser, G. Whish and K.D. McCosker (2019) Using cedar GRASP to simulate pasture utilisation in historical grazing trials in northern Australia. In: MODSIM2019 23rd International Congress on Modelling and Simulation Society of Australia and New Zealand, December 2019, Canberra, ACT, Australia.

Robyn Cowley, Kieren McCosker, Lester Pahl, Dave Smith, Giselle Whish, Melissa Wooderson, Geoffry Fordyce, Chris Holloway, Dale Jenner, Chris Materne (2019) Finding the 'Sweet Spot' for reproductive performance in north Australian beef herds. p. 94. Proceedings Northern Beef Research Update Conference, Brisbane, Qld 19-22 August 2019.

Materne C, Cowley R (2023) Defining safe: utilisation rates to improve land condition in central Australia. Proceedings of the 22nd Biennial Australian Rangeland Society Conference, 18-22 September 2023, p. 92, Broome, Western Australia.

R.A. Cowley, G. Whish, C. Materne, C.L. Pettit, K.D. McCosker, J. O. Carter, Mayer, D.G., Pahl, L.I., B.J. Wirf (2023) Modelling SchMOOodelling – What's grass got to do with it? Getting the most out of your animal production datasets. Proceedings North Australian Beef Update Research Conference, p. 82, Darwin, NT, 22-25 August 2023.

KD McCosker, RA Cowley, G Whish, C Materne, CL Pettit, JO Carter, DG Mayer, C Holloway, LI Pahl, BJ Wirf (2023) The Sweet Spot: Impact of pasture utilisation on the fertility of female cattle. North Australian Beef Update Research Conference, Darwin, NT, August 2023.

R.A. Cowley, G. Whish, C. Materne, C.L. Pettit, K.D. McCosker, J. O. Carter, Mayer, D.G., Pahl, L.I., B.J. Wirf (2023) Modelling SchMOOodelling – What's grass got to do with it? Getting the most out of your animal production datasets. Australian Rangeland Society Conference, Broome, WA, September 2023.

R.A. Cowley, G. Whish, C. Materne, C.L. Pettit, K.D. McCosker, J. O. Carter, Mayer, D.G., Pahl, L.I., B.J. Wirf (2024) Finding the Sweet Spot: Improving breeder herd performance through optimal pasture utilisation. NTCA Conference, March 2024, Alice Springs, NT.

R.A. Cowley, G. Whish, Hearnden, M.H., C. Materne, C.L. Pettit, K.D. McCosker, J. O. Carter, B.J. Wirf, Holloway, C., Pahl, L.I., Mayer, D.G. (2025) Factors influencing pasture utilisation in northern Australian rangelands. In Proceedings of the International Rangeland Congress, pp. 1704-1708. June 2-6, 2025, Adelaide.

McCosker, KD; Cowley, RA; Wooderson, M; Whish, G; Materne, C; Smith, D; Fordyce, G; Mayer, D; Holloway, C; Wirf, B; Pettit, C; Oxley, T; Carter, T (2025) Feeling the heat: a retrospective investigation of thermal load impacts on calf loss. In Proceedings of the International Rangeland Congress, pp. 1493-1497. June 2-6, 2025, Adelaide.

9.1.2 Workshops

Workshops were held with experts (Table 9-1) and industry (Table 9-2) to get input into and feedback on the bioeconomic modelling assumptions and results.

Table 9-1: Meetings seeking expert input and feedback on the bioeconomic modelling

Activity	Date	Location	Attendees	Purpose
Meeting with experts experienced in NT breeding enterprises to get input into Barkly modelling	18 October 2023	Ecosciences precinct	Geoffe Niethe and Geoff Murrell met with Lester Pahl, Robyn Cowley and Kieren McCosker	Feedback and input into the CLEM Barkly modelling assumptions, herd management and results

Meeting with DAF staff to discuss Burdekin modelling	26 October 2023	Teams meeting 1 hr	Lester Pahl, Robyn Cowley, Giselle Whish, Charters Towers DAF, Glenn Miller	Get feedback and input into the CLEM Burdekin modelling results and assumptions
Sweet Spot CLEM modelling review workshop	31 October 2023	Ecosciences precinct 1 day	Andrew Ash, Adam Leidloff, James Dougharty, Di Prestwidge, Ian Watson, Robyn Cowley, David Mayer, Giselle Whish, Lester Pahl, Trudi Oxley, Kieren McCosker, Dennis Poppi, Geoffry Fordyce	Feedback and input into the CLEM modelling approach, assumptions, parameters and results.
DAF workshop to review Burdekin modelling	8 Dec 2023	Charters Towers ¾ day workshop	Lester Pahl, Robyn Cowley, Peter O'Reagain, Dave Smith, Karl McKeller, Peter Smith, Bob Shepherd	Present Sweet Spot results and get feedback and input into the CLEM Burdekin modelling results and assumptions

Table 9-2: Sweet Spot Industry workshops

Region	Location	Date	Meeting
Sturt Plateau//Katherine	Daly Waters	20 November 2023	KPIAC Planning and Sweet Spot Feedback Workshop
Burdekin catchment	Charters Towers	1 July 2024	Producer workshop dedicated to review of bioeconomic modelling results

Qld Burdekin DAF extension and research staff workshop – 8th December 2023

Queensland DAF staff at the workshop valued the capacity of CLEM to simulate and provide results for a wide range of factors which influence the condition and performance of individual animals, herds, pastures, land and finances. Also, staff were satisfied that the results of CLEM simulations were generally representative of breeder herds on this land type in the Burdekin region. For example, the ranges in the live weights of steers and breeders and reproductive rates such as weaning were considered indicative of those in the region. Staff thought that in some respects the simulated reproductive rates were closer to regional rates than were the rates obtained from the empirical data sets. The reproductive performance of breeders in the empirical data set was considered high, but this is likely due to them arising from closely managed herds in grazing trials, rather than being averages from the commercial industry. Improvements in the simulations of herds suggested at the workshop were:

- Sell or destock less breeders during successive dry years and droughts. Generally, beef producers would at most reduce the breeder herd by 30%.

- Feed more M8U to cattle during droughts to enable more of them to be kept on the property. This will also reduce breeder mortality.
- Reduce conception rates to around 75% for mature breeders for average years. Foetal and calf losses combined are often around 9%, which should be reflected in calving and weaning rates.
- Feed M8U earlier to breeders, when their body condition score is 2, rather than wait until they have become very poor (body condition score 1 or lower). Feed M8U when pasture is still available in order to maintain animal condition.
- Turn-off age for steers should be between 3 and 4 years, rather than between 2 and 3 years.
- Change the current controlled mating season of December – March to January – April.
- Keep the branding muster in April and remove bulls at this time. Consider moving weaning and pregnancy testing from June to July or August.
- Beef producers often do not sell empty breeders, so this needs to be limited in further simulations.
- Review the amount of browse that classes of cattle eat daily. Currently set at 5 kg for breeders.

The workshop also provided suggestions for future CLEM simulation approaches:

- Simulate herds for a range of climate windows to assess the influences of differences in climate at the start of and during simulation periods.
- Undertake sensitivity analyses of the influence that a range of 'safe' utilisation rates have on land condition and herd productivity. Do the same using a limited range of rate changes in land condition and grass basal in response to variation in annual utilisation rate.
- Include discounts in price due to low body condition scores.
- Evaluate the capacity of CLEM to simulate changes in land condition, percent perennial grasses and animal productivity which have occurred during the Wambiana grazing trial.
- Use CLEM to investigate the cost-benefit of feeding supplements and drought rations.

Burdekin catchment workshop

A workshop with six beef producers and two DAF extension staff was conducted at Charters Towers on the 1st of July 2024. The purpose of this workshop was to gain beef producer feedback on the bioeconomic modelling assessment of the impacts of a range of pasture utilisation rates on the productivity and profitability of a hypothetical but representative breeding property in the rangelands of the Burdekin catchment.

The workshop was undertaken with the presenter and all but one producer in the conference room at the DAF office at Charters Towers. The remaining beef producer participated online through Microsoft Teams. Comments and discussion occurred throughout the PowerPoint presentation, over a period of three hours. The beef producers were all actively engaged in discussions and were happy to continue these for three hours even though the workshop was scheduled to take between 1.5 and 2 hours.

The participating beef producers were in agreement with the main finding of the bioeconomic modelling, which was that herd and grazing land management should be focused on maintaining good land condition and improving poor land condition, and that this was conducive to high herd productivity. The key to a successful grazing enterprise was to eat as much grass as possible without damaging the ongoing or long-term productivity of land and pastures. They emphasized the need to avoid reductions in land condition as it takes a long time for it to improve and that cattle productivity during that time is low.

The beef producers frequently commented that they used indicators of land condition, such as ground cover and the presence of palatable perennial grasses, to manage grazing pressure. In most cases they did not know annual pasture utilisation rate. Instead, they rotationally grazed paddocks, often on three occasions each year, with the duration and number of rotations dependent on pasture condition. A criticism of the modelling was that it was based on continuous grazing and that they believed this was detrimental to land and pasture condition. Rotational grazing gave them the ability to increase pasture yield and quality when the good seasons allowed it, but to also protect land condition as much as possible during years with well below average rainfall. When climatic conditions were poor and forage supplies were low, they would act quickly to reduce herd size in ways which varied with circumstances at the time.

It was noted that in many places pasture condition would run down if it wasn't completely spelled routinely. Even a few head in a paddock impacts growth and denudes areas. Light stocking slows degradation but will change the pasture over time to one not as productive with bare areas and erosion, while regular rest will cycle the pasture up and add lots of diversity.

Land and pasture condition was of primary importance. The better the condition of pastures at the end of the dry season the sooner they would be back in full production when the wet season resumed.

The beef producers noted how important it was for management to be proactive rather than reactive with regards to high climate variability, and particularly leading up to droughts. It is important to have a well thought out drought management strategy which is written down and kept up to date. It should include critical dates that have trigger actions, such as early weaning, first sales or early agistment.

Having efficient and productive herds and land in very good condition are important for coping with droughts. Make sure herds are efficient by culling bad doers, keeping the age of breeders down and getting rid of slow breeders. It was recommended that the breeder and heifer component of the total herd should be no more than 40%, as that makes it easier to get through droughts by progressively selling down steers. Strive to improve land condition and keep it there, which will build soil health and seed banks. Make decisions based on the condition of the country, not the stock. The better condition the country is in at the end of the dry the sooner it will be in full production again.

During droughts, rely on your plan, but be adaptable. Move early by first selling stock which have least market potential, which may then make it possible for more valuable stock to reach weights and condition scores suitable for sale. Be ready to supplement feed, but never substitute feed.

After droughts it is important to keep the stocking rate at a level that will allow grass to grow and recover fully. If at a later date there is not enough cattle for the grass which is available, agist in some stock or buy some stock in.

Proactive management limits the occasions when businesses must suffer losses in herd productivity and land condition. The latter could include situations such:

- weakness in market prices that are not acceptable to the business when forced to destock,
- agistment not available or too expensive when forced to destock,
- molasses and other drought feeds are not available or are too expensive,
- cattle are too poor or too weak to sell,
- market prices too expensive to buy cattle back in when re-stocking when climatic conditions improve.

In dry years and early in droughts when it appears that there will not be enough forage available for the herd:

- Sell steers and empty breeders,
- Agist cattle
- Feed M8U
- In extreme situations, start to destock other breeders

Feedback on modelling methods included:

- Liveweights and liveweight gains for growing animals were too low
- Need two weaning events, with the first in May and second in July
- Sell 2-3 yr old steers rather than 3-4 yr olds
- Reproductive rates too high
- Kg of beef produced annually and per breeder were too high
- Variable costs were too high

Katherine Sweet Spot workshop

Producers attending the KPIAC Sweet Spot workshop were generally more interested in the bioeconomic modelling results than the empirical research results. They thought the ability to link land condition and production was critical, and important to understanding the profitability of good management. They liked the ability to show the longer-term impacts via modelling compared to the short-term gains of higher stocking rates and though that this was needed. They thought it was a good demonstration of how lower stocking rates can increase profitability over the longer term, and wanted to be able to use this to take to financiers and corporate management to get support for implementing safe stocking rates.

Recommendations arising from the producer workshops and meetings:

- Cash Cow style summary of the project results, producer summary manuals online and hardcopy
- Producers wanted longer to consider the project results
- A user friendly version of CLEM that can be used by producers
- CLEM Regional baseline herd files be made available for others to use to model scenarios
- KPIAC producers wanted the CLEM modelling done for additional regions such as the Katherine and VRD regions
- To add the impacts of heat load into the empirical data analysis – this was subsequently done for foetal and calf loss

- They wanted to have a long-term demonstration site of the impacts of stocking rates similar to Wambiana but with breeders, long enough to get feedbacks on pasture condition and to experience runs of drier years
- They wanted to use CLEM to model real life scenarios where producers have reduced stocking rates and found they still get the same production
- Need more CLEM user capacity
- Sensitivity analysis of model assumptions such as
    - safe utilisation rates
    - rates of change at low and high pasture utilisation
    - to better understand the contributing factors to the modelled sweet spot, how much was land condition feedbacks vs costs of running out of feed more and needing to buy and sell more when prices are not optimal
    - how cattle numbers adjusted to varying pasture availability
    - effect of different starting points in land condition and stocking rates
- Producers were interested in using CLEM to answer other management questions such as
    - Early weaning, controlled vs continuous mating, herd segregation based on calving date, number of musters, use to justify finance for development, supplementation

9.1.3 Industry meetings where Sweet Spot results presented

Sweet Spot results were presented at industry meetings across the NT and Queensland (Table 9-3). Producers at the meetings were invited to provide feedback about the project results and relevance to industry, and next steps.

Table 9-3: Industry gatherings where Sweet Spot results were presented

Region	Location	Date	Meeting
Alice Springs	Old Man Plains Research Station	18 July 2025	Alice Springs Beefup Forum
VRD	Kidman Springs	21 August 2024	Kidman Springs Field Day and Beefup Forum
NT	Alice Springs	21 March 2024	NTCA conference
Southern Qld	Toowoomba	18 July 2024	Combined meeting of the southern and south-east Regional Beef Research Committees
Barkly	Barkly Homestead	14 November 2023	Barkly NTCA meeting
VRD/Sturt Plateau	Katherine Research Station	13 November 2023	Katherine Grazing Land Management Course
Qld Northern Gulf//NT Barkly	Mt Isa	8 November 2023	Calf Alive Forum

Calf Alive Forum Station Rocklands station visit

The Sweet Spot results were to the Calf Alive Forum in November 2023, which produced a lot of discussion amongst attending producers who were very receptive to the concept of finding a sweet spot for breeder performance, production and profits. On day two of the Mt Isa Calf Alive Forum, at the Rocklands station visit there was a lot of unprompted discussion from Paraway managers telling

their own experiences about they have managed to find the Sweet Spot for their stations. Rocklands approach was to add waters to double the watered area, but only increase stock numbers by 30%. They still have 30% further than 3km from water which can act as buffer in dry years. This means their stock are now spread across a larger area and they effectively decreased stocking rates and pasture utilisation. This allowed them to get through the dry years in 2018-2020 without having to reduce stock numbers. Their liveweight production has increased per head and per area as a result. This is in contrast to other stations in the Barkly that had to massively reduce cattle numbers and or had high mortalities through the 2018 to 2022 period. Paraway Armraynald station manager told how they reduced stock numbers from 30,000 to 15,000 head and got the same animal production. The recovery of country that the reduced stocking rates facilitated increased their carrying capacity and allowed them to subsequently then increase numbers to 20,000.

Kidman Springs Beefup Sweet Spot in Action Panel Session

At the Kidman Springs field day in August 2024 the Sweet Spot project results were presented followed by a *Sweet Spot in Action* panel of producers discussing their own experiences on station in the VRD working towards optimising stocking rates and utilisation to improve breeder performance, production and profits.

Producers were provided with the following prompts for discussion:

- How did things used to be done?
- What precipitated the change in management?
- What adjustments did you make and how did you come to the new numbers?
- What did you have to do the make the changes?
- What happened to breeder / herd performance after stocking rates were changed?
- How long did it take to see improvements?
- How did this affect production coming out of those paddocks (e.g. total kg weaned, or total kilos sold)?
- How did this affect the cost of running those paddocks and profit coming from them?
- How did it affect other things?
- What were the opportunities / unexpected outcomes of this?
- What advice do you have for others thinking about this?
- Other thoughts?

The panel consisted of Dan Chapman, Rangelands Officer for AACo discussing AACo's experiences on their VRD stations, Mike Bailey, Manager at Newry Station in the VRD, and Steve Petty, General Manager of CAIT, discussing their experiences at Newry and Auvergne Stations in the VRD. See the full transcript of the Sweet Spot in Action panel discussion in Appendix 14.9, page 441.

Highlights from the panel

Both companies said that stocking rates were high after two decades of unusually high rainfall in the VRD, and when the more normal rainfall years returned these stock numbers were causing poor animal performance.

AACo

- AACo reduced their herd numbers by 44% during the drier years across their three VRD stations by removing older and non performing animals

- They got an immediate response in animal performance to the lower stocking rates
- Their branding rate increased from around 45% to 77%
- Land condition recovery took longer
- They got a really good land condition recovery response with wetter years
- The lower stock numbers gives then the flexibility to pro-actively burn and spell for pasture management to further promote land condition recovery which will help them to increase their carrying capacity over the longer term
- Supplementation costs reduced because the pasture quality stayed higher for longer with lower stocking rates
- Reducing their herd numbers made them eligible for participation in the Herd Management Methodology which provides an income stream for AACo from ACCUs received due to reduced methane emissions with a smaller more productive herd

CAIT

- CAIT bought Newry and Auvergne Stations in 2019 and they had low weaning rates and low turnoff weights
- They tried implementing lots of recommended herd management such as segregating, supplementing with P, good bulls, etc, but they did not get real improvements until they addressed pasture utilisation through managing their stocking rates
- Newry reduced stock numbers by 20% but also further reduced effective stocking rates by adding waters to spread the grazing pressure across more of the station
- Weaning rate went from low 50s to 70%
- Heifer turnoff weight went from high 200s to mid 300kg
- They now have less cows producing more calves
- This helped Newry lower their cost of production from $1.90 to $1.60 per kg produced
- They have more pasture for cattle to eat, and supplement costs have come down
- Land condition is improving which they expect to help increase the carrying capacity of the stations
- They are now doing the same at Auvergne station, adding waters to reduce pasture utilisation and increase animal performance
- Currently they have 400 head per water point at Auvergne and aim to get that down to 300hd/waterpoint
- For every extra water they add they're not increasing numbers, but spreading a lot more cattle out to drive the average stocking rate down
- "The take home message for us is that, we can spend a lot of time talking about productivity and you know have we got the EBV tested bulls, are we vaccinating, we wet/dry draft and we supplement our dry cows and we do all that sort of stuff; but the most basic thing that we should all know is what really is having the biggest impact in our herd. And that's stocking rate. Stocking rate's driving the big changes in in productivity."

Alice Springs Beefup at Old Man Plains

The Sweet Spot project headlined the July 2025 Alice Springs Beefup. Sweet Spot breeder performance data from the Alice region was separated into the commercial stations vs. Old Man Plains Research Station for the first time. The differences in utilisation and how that played out in breeder performance were used to demonstrate how applying recommended utilisation rates on

Old Man Plains led to much better breeder performance and land condition recovery, and how reducing stocking rates on the stations could lead to the same number of calves produced due to better breeder performance (see presentation slides below (Figure 9-1 to Figure 9-3).

Pasture utilisation impacts on mature breeder performance in central Australia

	n	Median Utilisation (%)	Median Stocking rate (AE/km^2)	Median annual preg (%)	Median calf loss (%)	Median weaning rate (%)
Commercial stations	19	22	5.2	73	7	56
Old Man Plains	55	12	4.2	92	3	89

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Figure 9-1: Slide from the Alice Springs Sweet Spot presentation showing differences in pasture utilisation and breeder performance between the commercial stations and Old Man Plains research station

Pasture utilisation impacts on production in central Australia

	Watered area (km²)	Stocking Rate (AE/km²)	No. Breeders	Weaning rate (%)	No. calves
Commercial	1000	5.2	3355	56	1879
OMP	1000	4.2	2710	89	2412
Benefit of lower pasture utilisation			645 fewer breeders		533 more calves

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Figure 9-2: Slide from the Alice Springs Sweet Spot presentation showing how the difference in breeder performance would affect production of weaners

Pasture utilisation impacts on production in central Australia

	Paddock watered area (km²)	Stocking Rate (AE/km²)	No. Breeders	Weaning rate (%)	No. calves
Commercial	1000	5.2	3355	56	1879
OMP	1000	4.2	2710	89	2412
Commercial scenario	1000	4	2581	75	1935

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Figure 9-3: Slide from the Alice Springs Sweet Spot presentation showing a scenario where industry reduced the stocking rates and how this could affect weaner production if breeder performance improved by 20%

9.2 Adoption pathways

The following is a list of current northern beef industry adoption programs which could benefit from the key findings of the Sweet Spot project.

9.2.1 Practical steps to manage pasture utilisation to enhance breeder performance

It is recommended that guidelines be developed for producers to identify and take steps to manage when pasture utilisation is a factor affecting their herd performance. Below is an example of what is envisioned.

The first step is to identify if the breeder herd is already achieving optimal performance or if there is potential for improvement. Comparison of herd breeder performance to regional benchmarks requires assessing the true breeder performance. This requires accurately measuring weaning percentages that is the total weaners vs. the total number of breeders that were originally exposed to bulls, including any breeders culled for non-pregnancy. Calculating this data over as many years as possible will provide an indication of average performance over the long-term and how this fluctuates with seasonal conditions. This requires measuring and keeping records of breeder numbers going in and out of paddocks and their pregnancy and lactation status when they come through the yards and the total number of weaners; and then the skill set to analyse these records to target nonperforming animals for culling. Another simple indicator is if there are excess females to sell. If not, this is a strong indicator that breeder performance can be lifted.

If breeder performance is below potential for a land type or region, there are many factors that affect breeder performance, so identifying if pasture utilisation rates are currently limiting to breeder performance is the next step. This requires calculating the stocking rates in the watered area in paddocks and comparing this to the recommended long-term safe carrying capacity for the paddock, taking into account watered area, land type, pasture condition and rainfall deciles. If stocking rates within the watered area are within recommended levels, then other factors may be affecting breeder herd performance. Are other recommended herd management strategies already in place, including vaccination and supplementation?

If stocking rates are higher than recommended for the rainfall deciles experienced, and the breeder performance is low for the region, then it is likely breeder performance will be enhanced by reducing pasture utilisation.

There are two main ways to decrease pasture utilisation - by adjusting stocking rates, or by increasing pasture growth or forage availability, and these can be linked if reducing stocking rates leads to improvements in land condition.

- Pasture growth can be enhanced in the short-term by adjusting stocking rates to leave enough ground cover to get better pasture response to rainfall the following year, and over the longer term by managing to improve land condition or adding legumes or improved pastures.
- Stocking rates can be reduced by reducing total stock numbers, and in regions that are not fully developed, by adding waters to unwatered areas without adding commensurate stock numbers, so that the stocking rate per watered area and hence pasture utilisation rate declines.

Some measures require significant time and capital investment to achieve, including adding improved pastures and legumes or adding stock waters. The fastest way to reduce high pasture utilisation rates is to reduce stock numbers. Identifying and removing older and non performing animals from the herd is the first step.

Once stocking rates are aligned with recommended levels, other pasture management options such as wet season spelling, prescribed fire to manage the tree-grass balance and weeds and post fire spelling become more viable ways to improve pasture growth through land condition recovery. Herd

structure can be adjusted to allow easier selling and rebuilding strategies to respond to poorer seasons. For example, having a target market for two-year and older steers would provide an opportunity to destock young steers in preference to breeders during exceptionally dry years.

9.2.2 MLA

MLA have a number of online and in-person training programs that are suitable for encouraging adoption of the key findings of the Sweet Spot project by the extensive beef industry of northern Australia.

Grazing fundamentals EDGE

https://www.mla.com.au/extension-training-and-tools/edge-network-hub/grazing-fundamentals-edge/

Grazing fundamentals EDGE is a one-day workshop designed to give you a broad understanding of the components of the grazing production system and the core principles behind optimising grazing land productivity. The one-day Grazing fundamentals workshop is a perfect introduction before stepping into the three-day Grazing Land Management EDGE program.

Grazing Land Management (GLM) EDGE

https://www.mla.com.au/extension-training-and-tools/edge-network-hub/grazing-land-management-glm-edge/

Grazing land management (GLM) EDGE is a three-day workshop to give you a thorough understanding of the grazing land environment in which you operate – learn how to strategically manage your grazing business, so you can optimise your land condition and productivity in the long-term.

BredWell FedWell

https://www.mla.com.au/extension-training-and-tools/bredwell-fedwell/

BredWell FedWell (BWFW) is a practical, one-day introductory workshop on how productivity and profitability can be improved through good breeding and feeding over the livestock production cycle, with a specific focus on profit drivers. It is also a precursor to the more intensive Nutrition EDGE and Breeding EDGE three-day workshops.

Nutrition EDGE

https://www.mla.com.au/extension-training-and-tools/edge-network-hub/nutrition-edge/

Nutrition EDGE is a three-day workshop covering all aspects of ruminant nutrition. Participants will be able to make better decisions to achieve their herd performance targets through improved breeder fertility, weight gains, reduced mortality, optimal use of supplements and overall management.

Breeding EDGE

https://www.mla.com.au/extension-training-and-tools/edge-network-hub/breeding-edge/

Breeding EDGE is a three-day workshop designed to assist producers improve and refine their breeder herd management and genetic improvement plans to achieve desired production targets.

BeefUp forums

https://www.mla.com.au/extension-training-and-tools/beefup-forums/

BeefUp forums bring producers, advisors, researchers and other experts together to share information and ideas that help grow beef businesses throughout northern Australia. BeefUp forums are held at many locations throughout Qld, NT and WA. Presentations of key findings from the Sweet Spot project would be suitable for BeefUp forums.

Profitable Grazing Systems

https://www.mla.com.au/extension-training-and-tools/profitable-grazing-systems/

Profitable Grazing Systems (PGS) is a group-based training program which uses supported learning packages to deliver training and coaching over several months and up to a year to improve producer skills and knowledge. Through PGS, participants have the opportunity to develop and practice skills with small groups of like-minded producers to improve business performance.

Livestock Advisor Updates

https://www.mla.com.au/extension-training-and-tools/livestock-advisor-updates/

Livestock Advisor Updates are regionally relevant, one-day technical workshops held in northern, southern and western Australia. The workshops provide opportunities for livestock advisors, leading producers and professional extension consultants to:

- learn about the latest red meat R&D
- gain skills, tools and knowledge to increase their offering to clients
- network with their peers.

The Toolbox – online training, tools and resources

https://elearning.mla.com.au/

Contains a wide range of tools, calculators and training packages.

e.g. Northern forage budgeting

9.2.3 Qld Department of Primary Industries

Stocktake

https://stocktakeglm.com.au/about.html

Stocktake GLM is a production decision support app developed by the Department of Agriculture and Fisheries, Queensland (DAF). It helps beef producers identify land types, monitor grazing land condition, estimate long-term carrying capacity, convert animal classes to adult equivalents and develop detailed forage budgets.

FutureBeef

https://futurebeef.com.au/

FutureBeef is a collaborative program of the Queensland Department of Primary Industries, Northern Territory Department of Agriculture and Fisheries, Western Australia Department of Primary Industries and Regional Development, and Meat & Livestock Australia.

The FutureBeef website contains a vast number of resources cover a vast number of grazing industry topics. Some of these resources could be updated with the key findings of the Sweet Spot project, and new more detailed resources could be added to the site. The Future Beef project site will be updated and key resources added.

9.2.4 NT Department of Agriculture and Fisheries

Producers in the Alice, Barkly, and Victoria River District (Appendix 14.9, page 441) shared their experiences with the Sweet Spot Team about how they had found the Sweet Spot in their own enterprises. There was more than one way to achieve this outcome and it varied depending on the region, scale of enterprises, access to production feeding options and proximity to markets, current level of infrastructure development and production system.

NTDAF have been collecting real life examples of where cattle producers have adjusted stocking rates to enhance breeder performance and profits. This has been incorporated into our producer communications, producer demonstration site activities and planned retrospective modelling of producer case studies, as was suggested in the NT Daly Waters KPIAC producer workshop. Producers we have had initial discussions about doing retrospective modelling of pasture utilisation and breeder performance, animal production and economics are shown in Table 9-4. The development of the Newry case study with CAIT is already underway in the current Station Smart project funded by the Northern Hub. We are actively applying for funding to do the other case studies. The plan is to create videos and glossy written case studies that can be placed on Future Beef and used as content in Edge courses.

Table 9-4: Potential *Sweet Spot in Action* producer case studies in the NT

Region	Station	Managers	Case study
Alice	Woodgreen	Bob Purvis	Reduction in stocking rates in the 1970s and how that flowed through to improved land condition, increased carrying capacity, enhanced climate resilience and more stable high animal performance and production
Alice	Mt Riddock	Cadzows	Reduction in stocking rates in the 1990s and how that flowed through to improved land condition, increased carrying capacity, enhanced climate resilience and more stable high animal performance and production
Alice	Lindavale	Staines	Reduction in stocking rates in the 2000s and how that flowed through to improved land condition, increased carrying capacity, enhanced climate resilience and more stable high animal performance and production
VRD	Newry	Mike Bailey and Steve Petty, CAIT	Reduction in stocking rates after 2020 and how that flowed through to improved land condition, higher breeder performance, higher liveweight gains, higher weaner weights, shorter time to turnoff, less supplement costs and same or better profits
VRD	Camfield, Delamere and Montejinni AACo	Dan Chapman	Reduction in stocking rates after 2020 and how that flowed through to improved land condition, higher breeder performance, lower supplement costs, more flexibility to apply spelling and burning, reduced FTE requirements, enhanced staff morale and same or better profits

9.2.5 Commercial consultants to the beef industry

Several private consulting companies have extensive materials and programs which encourage adoption of beef industry best practices.

RCS

RCS Farm Management Professional Development Australia – Resource Consulting Services (rcsaustralia.com.au)

Grazing for profit

https://www.rcsaustralia.com.au/farming-grazing-for-profit-programs/

Grazing clinics

https://www.rcsaustralia.com.au/grazing-clinics/

Cibolabs

https://www.cibolabs.com.au/

MaiaGrazing

https://www.maiagrazing.com/

AgriWebb

https://www.agriwebb.com/

10. Conclusion

The northern Australian extensive beef herd has significant potential to improve breeder performance through better management of pasture utilisation. Key reproductive measures, including annual pregnancy, pregnancy within 4 months, foetal and calf loss and weaning rates varied between and within regions, highlighting background variation in potential performance due to regional environmental constraints but also substantial potential for improvement in many herds. This study demonstrated clear negative impacts of short-term high pasture utilisation on breeder performance through an analysis of existing breeder herd datasets, with all reproductive outcomes declining as pasture utilisation increased.

Bioeconomic modelling of the Barkly and Burdekin herds over 40 years with historical climate data illustrated regionally specific optimal utilisation rates for long-term production and profitability. These typically were equal to or less than recommended safe levels. In the Barkly, the optimal median annual utilisation rate for profitability was 18-23%, aligning with its safe rate of 20%. In the Burdekin, with lower land resilience, the highest profitability was achieved at 18-20% median utilisation, which is lower than its assumed safe rate of 25%.

These findings highlight the importance of maintaining land condition to sustain productive capacity, often requiring conservative utilisation rates, that avoid having to destock at great expense. Case studies and guidelines should be developed to facilitate producers to identify when their breeder herd performance could benefit from better management of pasture utilisation, without compromising herd production and profitability. This includes how to accurately assess breeder performance on farm, comparing this to regional breeder performance benchmarks, comparing

stocking rates to recommended rates, and potential approaches to reducing pasture utilisation through management of stocking rates, targeting and removing old and non-performing animals, and development to increase pasture growth or watered area where relevant.

Overall, this study provides critical evidence supporting balanced grazing management in northern Australian beef enterprises, optimizing both economic returns and long-term sustainability.

10.1 Key findings

- Pasture growth and utilisation was retrospectively modelled for 350 site-years in 60 paddocks for the breeder herd datasets (Chapter 4, page 35). Estimated paddock level safe pasture utilisation rates varied between 9 and 30%. Simulated annual pasture utilisation of annual pasture growth varied from very low to very high (0.5% to 114%). The ratio of annual to estimated safe utilisation - relative pasture utilisation, varied from 0.03 to 7.4. This provided a wide range of pasture utilisation to model the short-term (1-10 years) impacts of relative utilisation on breeder performance.
- This is the largest pasture growth and utilisation modelling exercise to have been undertaken in northern Australia. Existing modelling methodology was modified to facilitate modelling at the paddock scale across multiple land types, with the incorporation of satellite green cover data to guide model calibration for research site years. This methodology can and should be applied to all cattle research trials in extensive rangeland systems to help estimate and adjust for pasture utilisation in research paddocks, which could be influencing herd performance in addition to any other treatment being demonstrated / researched.
- Descriptive analyses summarised typical levels and variation in performance for beef breeding females in four regions across Northern Australia including Northern NT, Central NT, Southern NT and North East Qld, using standardised reproductive measures (Chapter 5, page 76). Beef breeding females in the Southern NT showed moderate to high performance, comparable to or exceeding Central NT, but with substantial variability reflecting management and environmental differences within this arid region. This analysis provides new insights, as the Southern NT was not included in the North Australian beef fertility project and previous studies have focused on specific animal classes or were conducted on research stations. Overall, regional differences and levels of performance were consistent with existing literature, with lower performance in Northern NT.
- Multivariable modelling findings (Chapter 6, page 92) demonstrated that relative pasture utilisation significantly reduced individual animal performance across all reproductive and weaning outcomes. Pregnancy within 4 months of calving was predicted to decline by approximately 33% from low to high relative utilisation in low *Bos indicus* content cattle while a lesser response was observed in higher *Bos indicus* breed content. Foetal/calf loss increased by about 2.3% per incremental step in relative utilisation. Critical nutritional factors, such as pasture growth, available green pasture, and pasture percent nitrogen around calving and in the early dry season, were vital for reproductive success and calf survival. Body condition score at pregnancy testing was also strongly linked to calf loss, decreasing from 22.7% at BCS 1.5 to 8% at the recommended score of 3.5 at calving.
- Bioeconomic modelling (Chapter 7, page 118) highlighted a trade-off between individual animal performance and herd-level productivity. In both regions the utilisation rates that maintained land condition were the most productive and profitable over the longer term. This was primarily

due to feedbacks of higher pasture utilisation leading to reduced land condition and pasture growth which led to decreased climate resilience, needing to destock sooner and more often during dry periods, and increased costs with more destocking and rebuilding required to maintain herd numbers. In the Barkly, the optimal median annual utilisation rate for profitability was 18-23%, aligning with its safe rate of 20%. In the Burdekin, with lower land resilience, highest profitability was achieved at 18-20% utilisation, which is lower than its assumed safe rate of 25%. This underscored the importance of maintaining high land condition as a buffer against climatic variability, often requiring conservative utilisation rates.

- Anecdotal evidence from producers who have reduced pasture utilisation to increase breeder performance was collated incidentally as part of the project. Although not part of the project objectives, producers would often share their experiences with the project team after hearing about the Sweet Spot project. This provided a lot of insights into the potential ways to implement optimal pasture utilisation, and the flow on effects to other parts of the business, including more options for pasture management, improvement in land condition, enhanced breeder performance and consistent paddock production with lower supplement and other costs with the same or higher profits. Producers in the Victoria River District at the 2024 Kidman Springs BeefUp Forum (see transcript Chapter 14.8, page 441) discussed how after the dry years in 2019 reductions in stocking rates on their stations led to 20-30% increases in weaning rates, reduced mortalities, higher growth rates, shorter turnoff times, with similar paddock level production, reduced supplementation costs, and enhanced profitability, better pasture growth response to rainfall, recovering land condition, and enhanced their flexibility to manage stock to incorporate wet season spelling and fire for vegetation management. Furthermore, they anticipated that the improved land condition would lead to enhanced carrying capacity so that additional stock may be sustainably carried in the future. Similarly, a large Barkly station increased the watered area to reduce stocking rates which enabled them to get through the very dry years of 2018-2020 without having to destock, with the lower pasture utilisation rates leading to increased production / head, making their herd numbers and production more resilient to drier years, and allowing them to wet season spell without overgrazing other paddocks.

10.2 Benefits to industry

The findings provide clear evidence that pasture utilisation, nutritional availability, and strategic management, such as management of body condition score and lactation, are critical determinants of reproductive performance and long-term herd sustainability in northern Australian beef systems. This report provides an evidence base for economic evaluations of different pasture utilisation rates, enabling more balanced management decisions that consider both short-term productivity and long-term sustainability, optimising overall long-term enterprise profitability and resilience.

11. Future research and recommendations

11.1 Related datasets/ other things to with data

The data compiled for the Sweet Spot project was interrogated to meet the direct objectives of this study, focusing on breeder performance. A useful next step is to conceptually map the production system and use tools such as DAGitty to identify the direct effects of each parameter within the system. This approach would allow the dataset to be subjected to further targeted analyses, improving understanding of causal relationships and informing management decisions. Although the project focused on breeders, additional data—such as weaner weights and steer liveweight gains were collected from the same paddocks at the same time and are potentially available to be analysed. The pasture growth and utilisation modelling for this project could be used for additional analyses of the impacts of pasture utilisation on other classes of animals and production of liveweight/area (Table 11-1).

The Kidman Springs dataset that was deemed suitable for inclusion in the study but was not modelled due to time constraints, could be analysed in a future study using the same methodology. The land types at Kidman Springs are not currently represented in the Sweet Spot dataset, and would provide a useful complement and contrast to the existing study. It would make sense to combine this with CLEM modelling of the long-term land condition and economic impact of pasture utilisation in the VRD region as recommended by producers at the NT Sweet Spot bioeconomic modelling workshop.

Table 11-1: Future potential analyses with empirical datasets

Related/accompanying Dataset	Sites have for	Notes
Weaning weight data	Pigeon Hole, Cash Cow sites	Could potentially calculate weaner production, and total LWG production / area vs. utilisation, rather than just performance
Indicator steer data	Mt Sanford and Pigeon Hole, Old Man Plains,	Many of the paddocks we modelled had indicator steers in them as well. It would be a useful exercise to compare utilisation effects on steers vs. breeders. The existing pasture growth and utilisation modelling could be used for this exercise
Grazing trials	Mt Sanford, Pigeon Hole, Swans Lagoon, Thalanga	Re-analyse the stocking rate and utilisation trials taking into account modelled utilisation
Faecal NIRS data	Cash Cow sites, Mt Sanford, Pigeon Hole, Thalanga, Swan's Lagoon, Old Man Plains, Katherine Research Station lease, Lake Nash, Brunchilly, Rocklands, Mt Riddock	Where available faecal NIRS was collated and Rob Dixon revised the predictions using the latest regional algorithms. NIRS data was added to all GRASP pasture growth model

		paddock parameter files for potential future use, but not used as part of this project, because it was only available for a subset of the sites
Kidman Springs / Victoria River Research Station in the Victoria River District, NT	Lots of studies and paddocks over several decades	This very large, dataset was identified as suitable for the Sweet Spot project, but time constraints prevented its inclusion. Kidman Springs has many land types not represented in the current Sweet Spot project dataset, and would provide a useful contrast / complement to the existing work completed here

The pasture utilisation modelling revealed that there is little empirical data to support recommended safe utilisation rates in the Alice Springs region. Safe utilisation rates can be retrospectively modelled (sensu Walsh and Cowley 2011, Johnston *et al.* 1996) where producers have land in good condition (hence the utilisation was safe) and good stocking rate records. We recommend retrospectively modelling of safe pasture utilisation rates for different land types across the NT. This is research we are actively sourcing funding to do.

Many of the breeder datasets that were reviewed for inclusion in the Sweet Spot project were unable to be used for this purpose, usually because there was either no/or inadequate information on stocking rates in the trial paddocks. Given that this study has demonstrated the impact that pasture utilisation can have on breeder performance it is possible that previous study findings have been compromised or had spurious results or interpretation because the impact of pasture utilisation was not accounted and adjusted for. This is particularly relevant to paired paddock studies, where different treatments are applied in different paddocks without sufficient replication to account for paddock-level heterogeneity. Because no two paddocks are identical due to varying infrastructure and spatial variability in land type composition, even applying the same stocking rates, or recommended carrying capacity does not ensure that paired paddocks are receiving the same pasture utilisation. Pasture utilisation also affects liveweight gain (Hunt *et al.* 2013) and distance walked from water in large paddocks (Materne *et al.* 2025). Additionally, many pasture trials were confounded by differences in animal class without considering their distinct physiological responses to lactation, calving, and growth. Hence it is strongly recommended that future cattle research in rangelands paddocks include a minimum dataset requirement that facilitates the modelling of pasture utilisation in research paddocks for the duration of the research or apply replication across multiple properties and paddocks to account for the heterogeneity documented in the present study. The minimum dataset to determine pasture utilisation would include recording the numbers of all classes of cattle and other animals in the research paddocks so that pasture utilisation can be retrospectively modelled and accounted for in statistical analyses of treatment effects. Ideally weights of each class would also be recorded at each muster to enable more accurate estimation of intake and AE based on paddock level performance.

11.2 Recommended additional CLEM modelling

- CLEM modelling with grower data
- Bioeconomic modelling of the impacts of pasture utilisation using CLEM for additional regions
- Bioeconomic modelling using CLEM case studies such as Lindavale, Montejinni, Mt Riddock, Newry, Rocklands and other stations that have reduced animal numbers or increased the watered area to reduce effective stocking rates to increase performance, and get the same production and/or higher profits
- Sensitivity analyses effect of CLEM assumptions on rates of land condition change, and safe utilisation levels and thresholds for change on modelling results
- Make the parameter sets and input databases of pasture growth used for CLEM modelling assumptions publicly available
- There is a lack of expertise in using CLEM to model northern Australian systems. It is recommended that the number of skilled users be increased

11.3 Other

- Producers at the Katherine Pastoral Industry Advisory Group Workshop suggested we develop a breeder risk management game

11.4 Future use of Sweet Spot empirical collated dataset

- Make available to public after published Sweet Spot work
- Use the empirical dataset effect of utilisation on breeder performance to test the accuracy of CLEM model predictions of the impacts of utilisation on breeder performance in the short-term

12. Draft papers

The report has been written into chapters that represent the draft of separate journal papers (Table 12-1).

Table 12-1: Proposed journal papers arising from the Sweet Spot project

Chapter	Papers	Target Journal	Cost to publish open access	Authors
Chapter 3 – General Methodology	Introduction to study and Descriptive summaries of breeder performance dataset	Animal Production Science	$3300 no cost if KM corresponding author	Cowley, McCosker, *et al.*
Chapter 4 - Pasture Utilisation	Method and analysis of factors influencing pasture utilisation in dataset	The Rangeland Journal	$3300	Cowley, Whish, *et al.*
Chapter 5 - Reproductive performance of females	Descriptive analyses of herd and pasture factors influencing breeder performance in northern Australia	Animal Production Science	$3300 or no cost if KM corresponding author	Cowley, McCosker, *et al.*
Chapter 6 - Quantifying the impact of pasture utilisation on breeder performance	Impact of Pasture Utilisation on likelihood of pregnancy and weaning for beef breeding females in northern Australia Rangelands	Journal Animal Science / Animal production Science	No cost	McCosker, Cowley Mayer, *et al.*
Chapter 6 - Quantifying the impact of pasture utilisation on breeder performance	Impact of Pasture Utilisation on occurrence of foetal and calf loss in beef breeding females in northern Australian Rangelands	Journal Animal Science / Animal production Science	No cost	McCosker, Cowley Mayer, *et al.*

Chapter 6 - Quantifying the impact of pasture utilisation on breeder performance	Analyses of factors influencing body condition score prior to calving in beef breeding females in northern Australia rangelands	Animal Production Science	$3300 no cost if KM corresponding author	McCosker, Cowley Mayer, *et al.*
Chapter 7 - Bioeconomic analysis of the impacts of pasture utilisation on breeder performance, production and profit	Barkly	The Rangeland Journal	$3300 or No cost if LM corresponding author	Pahl *et al.*
	Burdekin	The Rangeland Journal	$3300 or No cost if LM corresponding author	Pahl *et al.*
Reference dataset – combined pasture utilisation breeder performance, and predictors dataset used for all analyses		Anim Prod Sci? Published after / accompanying the Intro to study paper	?	Cowley, McCosker et al
CLEM models		Accompanying the journal publications		Pahl *et al.*

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14. Appendix

14.1 Datasets reviewed for suitability for inclusion in study

Table 14-1: Datasets reviewed for suitability for inclusion in study

Study	Location	State/Territory	Region	Date	Dataset suitability	Dataset	Cattle data received	Data prepared for import	Animal ID	No production supplement	Stocking rate - Animal numbers by class throughout year	Steer LWG from breeder paddock	Faecal NIRS in paddock	Breeders in one paddock all year round
Benchmarking	Hamilton Downs	NT	Alice Springs	1970-1975	OLD		NA	NA	Y	Y	Y	Y	N	Y
Benchmarking	Mt Riddock	NT	Alice Springs	1991-1996	suitable	DS08	Y	Y	Y	Y	Y	N	N	Y
Benchmarking	Narweitooma	NT	Alice Springs	1970-1975	OLD		NA	NA						
Benchmarking	Todd River	NT	Alice Springs	1970-1975	OLD		NA	NA	Yes	Y	probably	Y	n	Y
Breeder herd	Swans Lagoon	Qld	North Qld	1987-1994	not suitable	DS14	NA	NA	Y		Y	N	N	Y
Breeder Herd Efficiency	Lake Nash	NT	Barkly	2000-2002	ideal	DS03	Y	Y	Y	Y	Y	N		
Breeder study	Swans Lagoon	Qld	North Qld	2000-2004	might be suitable	DS14		N	Y	Y, except when dry molasses and urea	Y	Heifers	Y	Y
Bull Breeding PDS	Brunchilly/Helen Springs	NT	Barkly	2010-2012	suitable	DS07		N	Y	Y	Y			
Cash Cow	CC03P	NT	Barkly	2008-2010	not suitable	DS02	Y	N	Yes	Y	Attempts made	N		
Cash Cow	CC05M	Qld	North Qld	2008-2013	suitable	DS02	Y	Y	Y	Y	Y	N	?	N

Cash Cow	CC06M	Qld	opposite Barkly	2008-2010	suitable	DS02	Y	Y	Y	Y	Attempts made			
Cash Cow	CC09P	NT	Barkly	2008-2010	suitable but < 3 years	DS02	Y	Y	Yes	Y	Attempts made	N		
Cash Cow	CC13P	NT	Darwin	2008-2010	not suitable	DS02	NA	NA	Yes	Y	Attempts made	N		
Cash Cow	CC17M	Qld	North Qld	2008-2012	suitable	DS02	Y	Y	Y	Y	Y	N	?	N
Cash Cow	CC28M	NT	Sturt Plateau	2008-2010	suitable	DS02	Y	Y	Yes	Y	Attempts made	N		
Cash Cow	CC28M	NT	Sturt Plateau	2008-2010	suitable	DS02	Y	Y	Yes	Y	Attempts made	N		
Cash Cow	CC34M	NT	Barkly	2008-2010	suitable	DS02	Y	Y	Yes	Y	Attempts made	N		
Cash Cow	CC44M	NT	VRD	2008-2010	suitable	DS02	Y	Y	Yes	Y	Attempts made	N		
Cash Cow	CC45M	NT	Sturt Plateau	2008-2010	not suitable	DS02	NA	NA	Yes	Y	Attempts made	N		
Cash Cow	CC46M	NT	Sturt Plateau	2008-2010	suitable	DS02	Y	Y	Yes	Y	Attempts made	N		
Cash Cow	CC54M	NT	VRD	2008-2010	not suitable	DS02	NA	NA	Yes	Y	Attempts made	N		
Cash Cow	CC65M	Qld	North Qld	2008-2011	suitable	DS02	Y	Y	Y	Y	Y	N	?	N
Cash Cow	CC66M	WA	Pilbara	2008-2010	not suitable	DS02	NA	NA	Y	Y	Attempts made			
Cash Cow	CC81M	NT	Roper	2008-2010	not suitable	DS02	NA	NA	Yes	Y	Attempts made	N		
Cash Cow	CC84M	NT	Roper	2008-2010	not suitable	DS02	NA	NA	Yes	Y	Attempts made	N		
Cash Cow	CC87M	NT	Katherine	2008-2010	suitable	DS02	Y	Y	Yes	Y	Attempts made	N		
Cash Cow	CC97M	WA	Pilbara	2008-2010	not suitable	DS02	NA	NA	Y	Y	Attempts made			
Cash Cow	CC99M	NT	VRD	2008-2010	not suitable	DS02	NA	NA	Yes	Y	Attempts made	N		

CRC Program 4	Toorak	Qld	Western Qld	2005-2012	might be suitable			N	Y	Not production feeding but fed a fair bit when very dry	Y	N	Y	N
Genomics/Northern Grazing Demo	Greenvale, Mt Garnet, Bowen	Qld	North Qld	2017+	not suitable		NA	NA	Y		Y	Y	N	N
Grazing systems	Old Man Plains	NT	Alice Springs	2010-2018	ideal	DS11	some,more to be provided	N	Y	Y	Y	Y	some for steers 2014-2016 monthly in 2 paddock rotation	3 continuous, 2 rotated
Heifer study	Avago	NT	Sturt Plateau	2006-10	suitable	DS06		N	Y	Y	Y	N	N	Y
Heifer study	Avon Downs	NT	Barkly	2006-7	suitable	DS06	Y	Y	Y	Y	Y	N	N	Y
Heifer study	Benmara	NT	Barkly	2004-6	not suitable	DS06	NA	NA				N	N	Y
Heifer study	Killarney	NT	VRD	2005-6	not suitable	DS06	NA	NA			N	N	N	Y
Heifer study	Newry	NT	VRD	2004-8	suitable	DS06		N	Y	Y	Y	N	N	Y
Heifer study	Riveren	NT	VRD	2005-8	not suitable	DS06	NA	NA	Y	Y	probably	N	N	Y
Heifer study	Rockhampton Downs	NT	Barkly	2004-5	not suitable	DS06	NA	NA			N	N	N	Y
Heifer study	Tieyon	NT/SA	Alice Springs	2004-12	suitable	DS06	Y	Y	Y	Y	Assume 500 breeders + 20 bulls	N	N	Y

Heifer study	Willeroo	NT	Katherine	2004	not suitable	DS06	NA	NA			N	N	N	Y
Nutrition effects on breeders	Alexandria	NT	Barkly	1997-2001	suitable	DS01	Y	N	Y	Y	Y	N	Y	Y
O'Rourke thesis	Swans Lagoon	Qld	North Qld	1972-1986	not suitable		NA	NA						
Paddock Power	Rocklands					DS12								
PDS	various	Qld		Unlikely	not suitable		NA	NA						
Phosphorus	Brunchilly	NT	Barkly	2011-13	suitable	DS04	Y	Y	Y	Y	Y	N	N	Y
Reducing calf loss from exposure	Avon Downs	NT	Barkly			DS05								
Repronomics	Brian Pastures, Spyglass, Douglas Daly	Qld	North Qld, Darwin, Southern Qld	2015+?	might be suitable			N	Y	N	Y	N	Y BP but not sure Spyglass	N
Senepol	Katherine Research Station lease	NT	Katherine	2012-18	suitable	DS07	Y	Y	Y	Y	Y	N	N	Y
Stocking Rate	Mt Sanford	NT	VRD	1994-2000	ideal	DS09	Y	Y		Y	Y	Y	N	Y
Stocking rate Demo	Swans Lagoon	Qld	North Qld	1994-1999	ideal	DS14	Y	N	Y		Y	Y	Y	Y
Stocking rate Demo	Namuel	Qld	North Qld	1994-1998	not suitable		NA	NA	N		Y	Y	N	Y
Stocking rate Demo	Thalanga	Qld	North Qld	1994-1999	ideal	DS15	Y	N	Y		Y	Y	N	Y
Utilisation	Mt Sanford	NT	VRD	2001-2006	ideal	DS09	Y	Y		Y	Y	Y	some	Y
Utilisation	Pigeon Hole	NT	VRD	2003-2007	ideal	DS13	Y	Y		Y	Y	Y	Y	Y

Various	Belmont	Qld	Central Qld	2000-2011	might be suitable			N	Y	Not production feeding but fed a fair bit when very dry	Y	N	Y	N
Various	Belmont	Qld	Central Qld	1969	not suitable		NA	NA						
Various	Brian Pastures	Qld	Southern Qld	2000-2011	might be suitable			N	Y	Not usually production feeding but fed a fair bit when very dry, cotton seed and molasses	Y	N	Y	N
Various	Brian Pastures	Qld	Southern Qld		not suitable		NA	NA						
Various	Brigalow	Qld	Central Qld	1979-1985	not suitable		NA	NA	?	?	?	N	N	?
Various	Fletcherview	Qld	North Qld	1981-1987	not suitable		NA	NA						
various	Kidman Springs	NT	VRD	1997-2018	ideal		Y	N	Y	Y	Y	Y - some		
Various	Kidman Springs	NT	VRD	1981-1989	not suitable		NA	NA	N		N			
Various	Spyglass	Qld	North Qld	N	not suitable		NA	NA						
Various	Swan's Lagoon	Qld	North Qld	2000-2011	might be suitable	DS14		N	Y	Not production feeding but fed a fair bit when very dry	Y	N	Y	N

Water medication, Keith Hill	Narweitooma	NT	Alice Springs	1998 to 2001	suitable	DS10	Y	N	Y	Y	Y	N	N	2 paddocks - check
Wet Season Supplementation	Mt Bundy	NT	Darwin	1980-1984	OLD		NA	NA		probably	Y	Y - 10 steers/paddock	Faecal % N and P	Y

14.2 Assumed safe pasture utilisation

Table 14-2: Assumed safe level of pasture utilisation for modelled Sweet Spot sites

Cattle analysis region	Sub Region	Station	Paddock	Safe pasture utilisation (%)
Central NT	**Barkly**	STN1	Paddock 1	22
			Paddock 2	22
			Paddock 5	22
			Paddock 3	22
			Paddock 4	22
		STN2	Paddock 19	22
			Paddock 20	22
			Paddock 21	22
			Paddock 18	22
		STN4	Paddock 23	22
		STN8	Paddock 14	22
			Paddock 16	22
		STN7	Paddock 31	22
			Paddock 30	22
			Paddock 12	22
North East Queensland	**Central Queensland**	CC17M	Paddock 11	23
	Far north Queensland	CC65M	Paddock 7	15
	North Queensland	CC05M	Paddock 8	25

Cattle analysis region	Sub Region	Station	Paddock	Safe pasture utilisation (%)
		Swans Lagoon	Allingham	28.1
			Burns	30
			Burns/Holroyd	27.5
			Holroyd	25
			Sandalwood	30
		Thalanga	Dingo	25
			JSW	25
			Toms	25
Northern NT	**Katherine**	KRS_Lease	North Queens	12.5
			South Queens	12.5
	Sturt Plateau	CC28M	Paddock not used for cattle analysis	15
		CC46M	Paddock 10	12.5
	VRD	CC44M	Paddock 6	18
		Mt Sanford	Budgie	22
			Galah	22
			Larry Macs	22
			Parrot Creek	22
			Pigeon	22
			Quail	22
			Quarrion	22
			Wedgetail	22
		Pigeon Hole	Barra	22
			Bauhinia	22
			Brolga	22
			Bullock	22
			Cell Grazing	22
			Dead Cat	22
			No13	22
			North Stevens Creek	22

Cattle analysis region	Sub Region	Station	Paddock	Safe pasture utilisation (%)
			Racecourse	22
			Sandstone	22
			South Stevens Creek	22
			Villiers	22
Southern NT	**Alice**	Station 5	Paddock 24	12
		Station 6	Paddock 27	9
			Paddock 25	11
		Old Man Plains	2 Paddock Rotation	16.1
			4 Paddock Rotation	16.1
			Pine Gap	17.5
			Waterhouse	16.3
			Western	15.0
		Station 3	Paddock 22	12.5

14.3 Individual site description, GRASP calibration and modelling of pasture utilisation

14.3.1 Alice

Alice region sites were modelled by Chris Materne and Robyn Cowley. Pasture utilisation varied widely in this highly variable and low rainfall region (long-term median rainfall at the Alice sites ranged from 125 to 229mm).

Station 5

The Station 5 site was a large paddock (558km^2) where breeder performance was measured in the 1990s (Coventry 2013). The paddock was predominantly composed of the mountains and hills of Harts Range (78%), with palatable shrubs witchetty bush (*Acacia kempeana*), and mulga (*Acacia aneura*) over woollyoat, mulga and kerosene grasses. 17% of the paddock was alluvial plains of open woodlands and gidyea over grasses and forbs.

TSDM of long-term monitoring points in the paddock was visually estimated by an experienced operator. TSDM was then weighted by land type to give a paddock wide estimate. The paddock was calibrated for the period of interest for the Sweet Spot study between 1990 and 1996. This model underestimated pasture TSDM and growth (green cover) after the double La Nina of 2000/2001 (dashed line in Figure 14-1, Figure 14-2). After this time buffel increased on the station. To better simulate TSDM and cover after this time GRASP parameter values were adjusted to better reflect the higher grass basal area, lower detachment, changed pasture structure and higher nitrogen dilution characteristics of buffel dominated pastures. Hence an unintended finding of the Sweet Spot modelling for this site was evidence of improved pasture condition and a methodology to accurately represent this with GRASP parameter adjustments. There was a high confidence in modelling assumptions (81%).

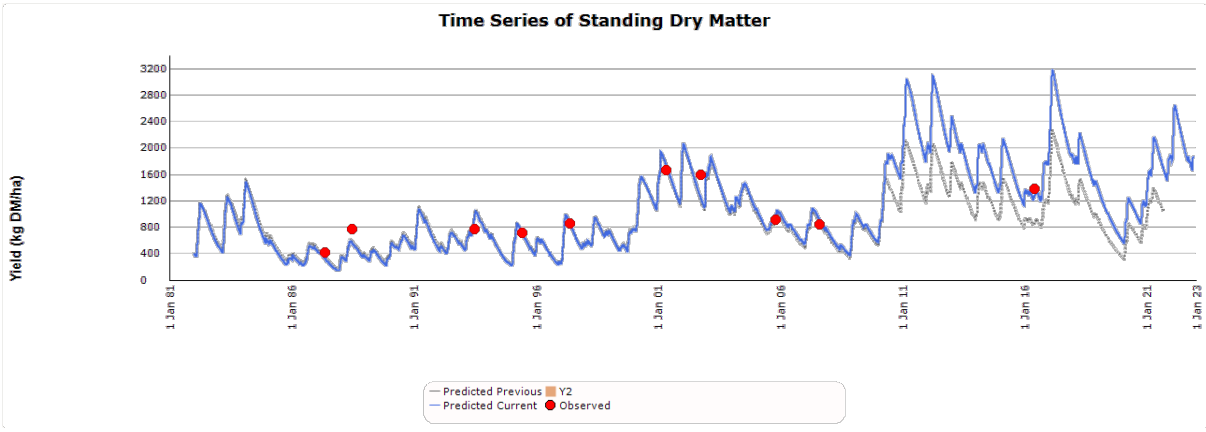


Figure 14-1: Final GRASP calibration fit between simulated and field TSDM at Paddock 24, Station 5 . The grey dashed line is before model adjustments were made to account for improved land

condition/buffel colonisation following 2001/2002 and 2010/2011 double La Nina events of high rainfall and pasture growth

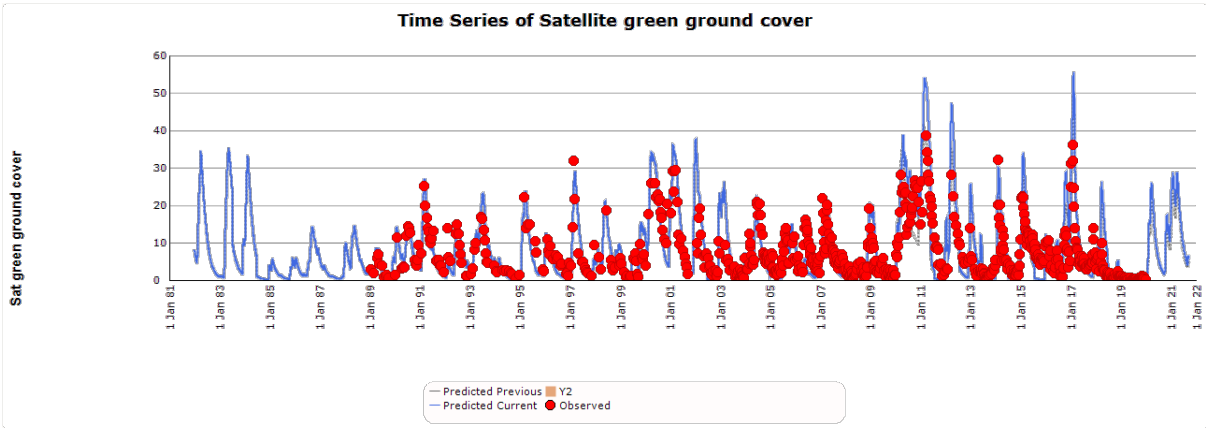


Figure 14-2: Final GRASP calibration fit between simulated and satellite derived green ground cover at Paddock 24 , Station 5. The grey dashed line is before model adjustments were made to account for improved land condition/buffel colonisation following 2001/2002 and 2010/2011 double La Nina events of high rainfall and pasture growth

Station 5 managers indicated that stocking rates have stayed similar in that paddock until current day. Despite stable stocking rates, the improving land condition and buffel colonisation has led to increased growth, leading to declining utilisation rates through time. Long-term pasture utilisation was ≤ 22% in 70% years (Figure 14-3) and 18% or less in half the years. Since 2010 utilisation was less than or close to 20% except for one very dry year.

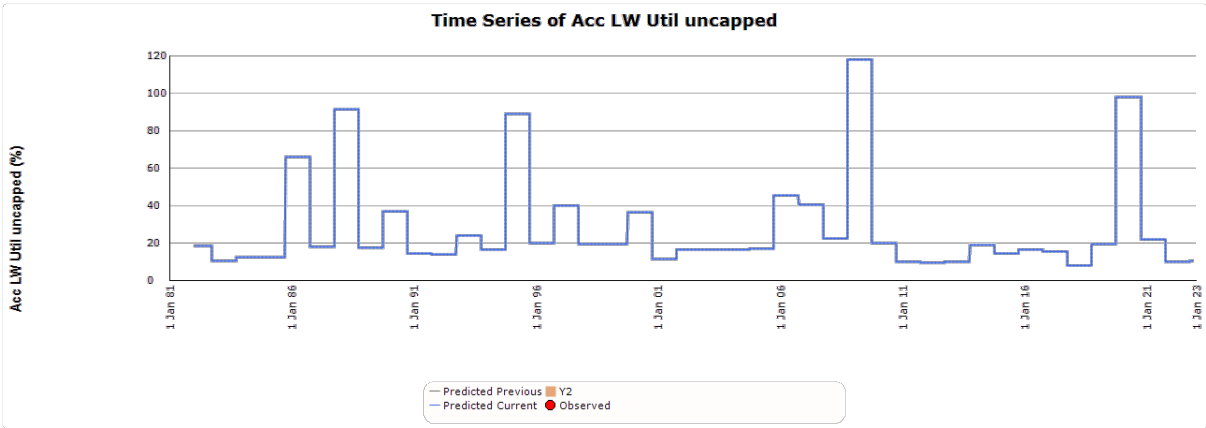


Figure 14-3: Longer-term pasture utilisation rates at Station 5 assuming stocking rates were the same as during the study period

Given the improvement in land condition at the Station 5 site, we can assume that the utilisation rates were safe. However, they are higher than what we previously assumed was safe (12.5%) for those land types and ranged from 14 to 89%, averaging 33% over the study period, but 23% if 1994 is excluded (Figure 14-4). The longer-term modelling suggests that in the order of 20% utilisation is probably safe for this site. It is also possible that the safe level of utilisation has increased due to the colonisation of buffel.

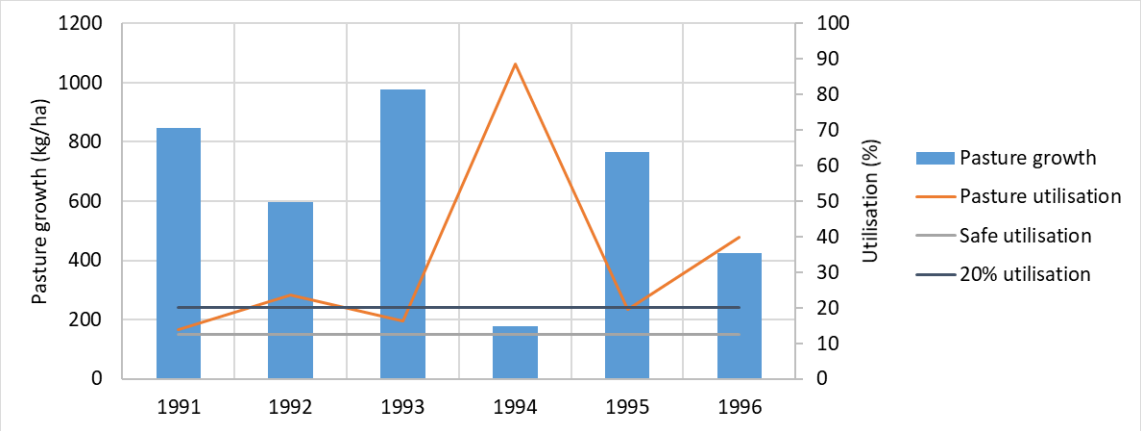


Figure 14-4: Simulated pasture growth and utilisation at Station 5

Station 6

Breeder performance was monitored in two paddocks of mixed spinifex sandplains and calcareous shrublands with and without water medication at Station 6 (Hill 2003). TSDM was visually estimated by an experienced operator from images of permanent monitoring points. Only 1 of the monitoring sites was located in the paddocks, hence estimated TSDM was used as a guide, but not calibrated to. There was a moderate confidence in modelling assumptions (51%).

Assumed safe pasture utilisation for these paddocks was very low (9-11%) due to the low palatability and resilience of the land types in the paddocks (spinifex safe utilisation = 5% and calcareous earths safe utilisation = 15%). The sites had very high utilisation rates (in the order of three times the assumed safe levels, Figure 14-5 - Figure 14-10) and will provide an example of the upper range of utilisation impacts on breeder performance in the Alice region.

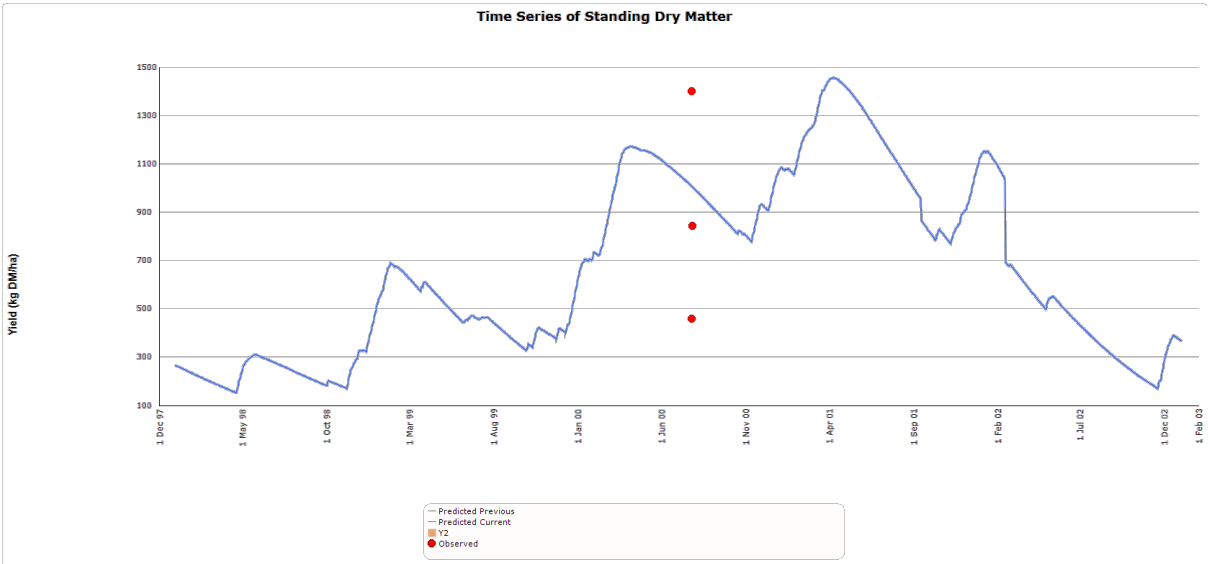


Figure 14-5: Simulated TSDM at Paddock 25, Station 6 (blue line) and TSDM observations from surrounding monitoring locations (red dots)

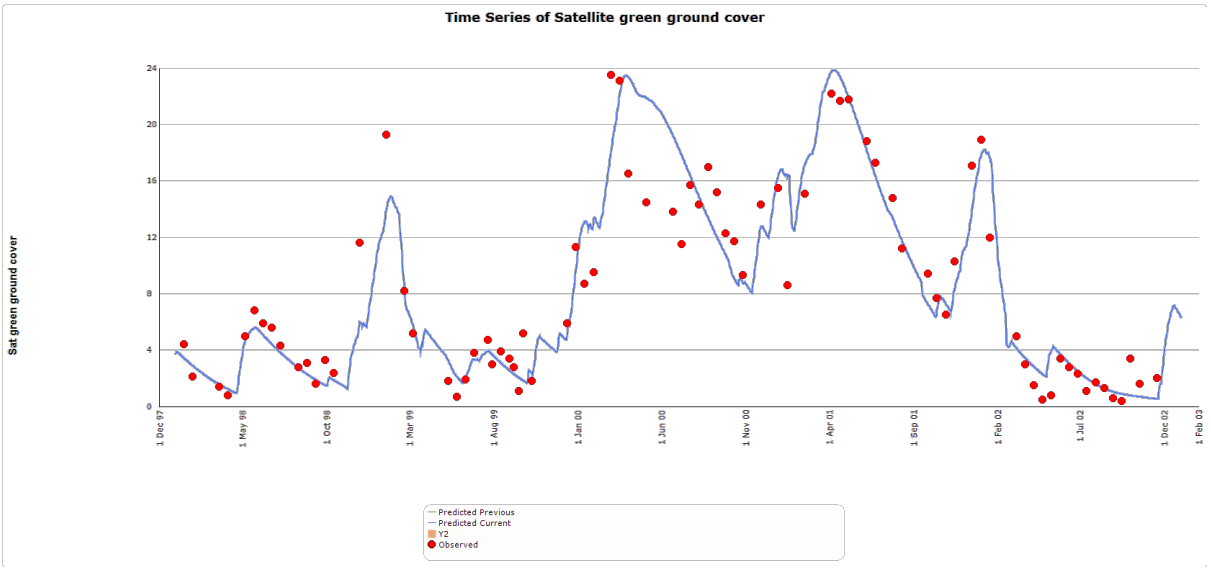


Figure 14-6: Simulated green ground cover at Paddock 25, Station 6 (blue line) and satellite derived green ground cover observations from within the 5km watered area of the paddock

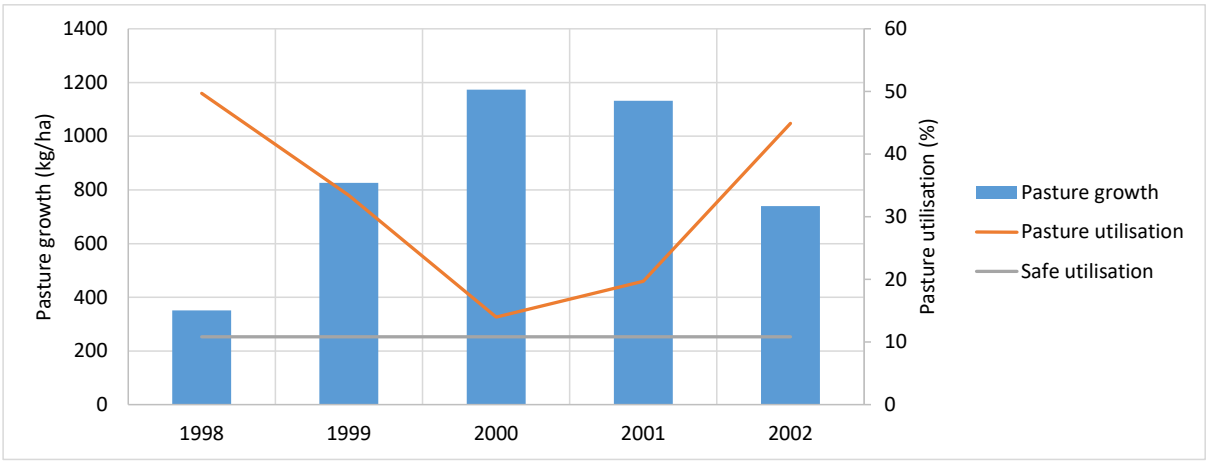


Figure 14-7: Simulated pasture growth and utilisation in Paddock 25, Station 6

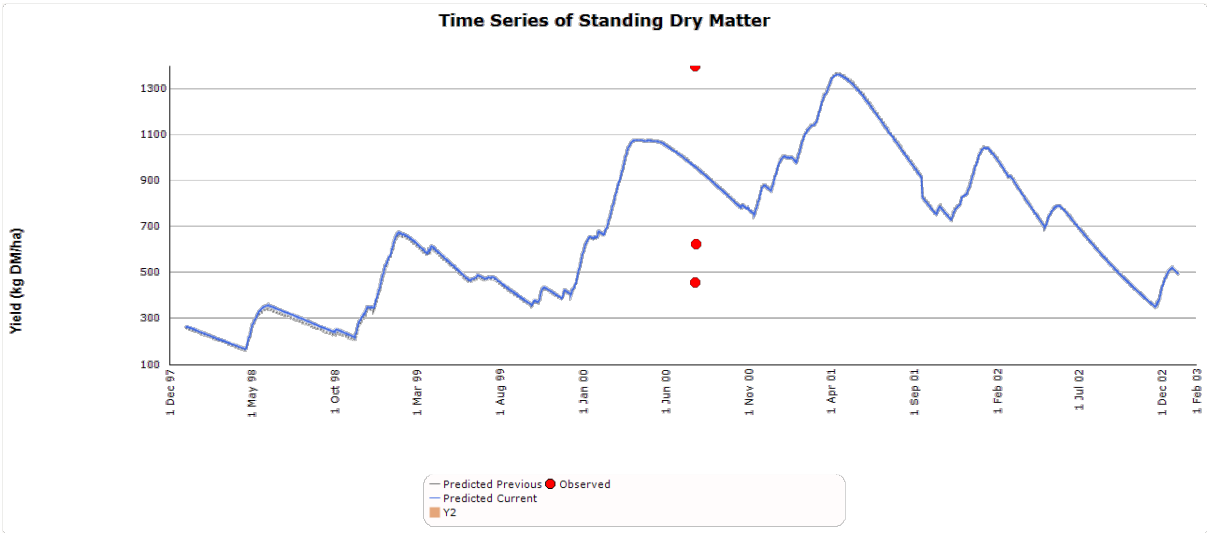


Figure 14-8: Simulated TSDM at Paddock 27, Station 6 (blue line) and TSDM observations from surrounding monitoring locations (red dots)

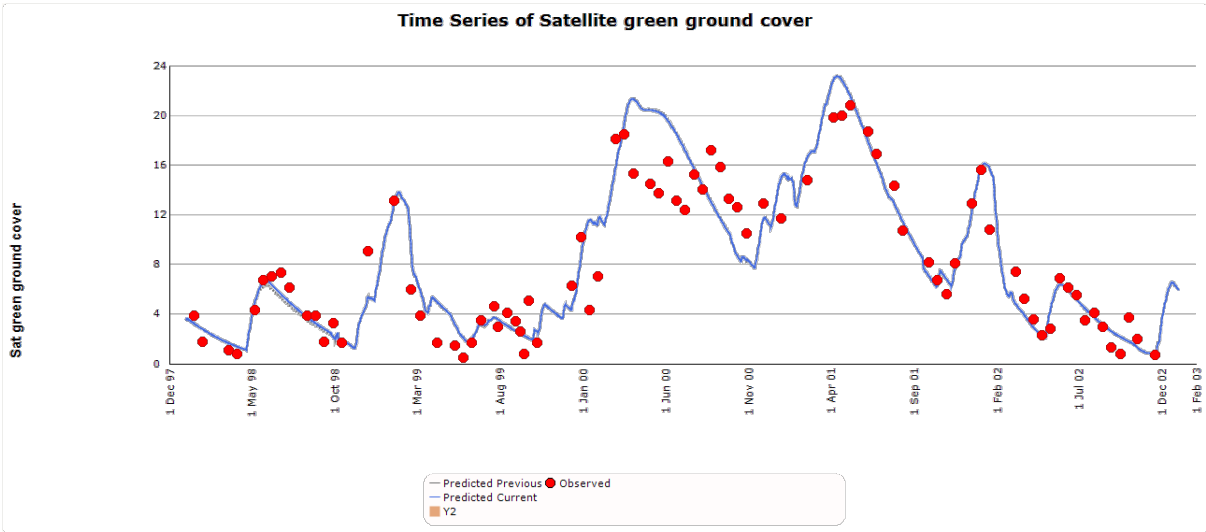


Figure 14-9: Simulated green ground cover at Paddock 27, Station 6 (blue line) and satellite derived green ground cover observations from within the 5km watered area of the paddock

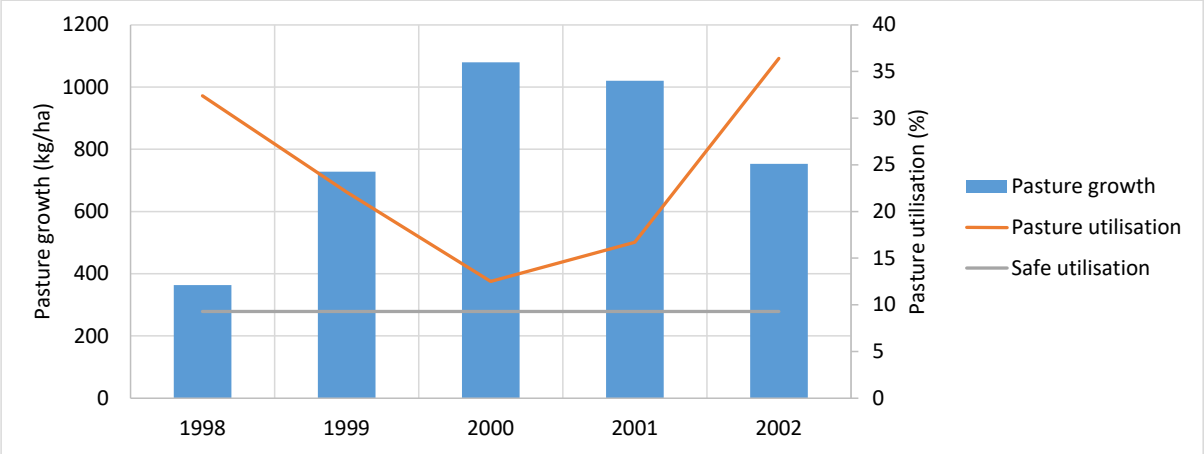


Figure 14-10: Simulated pasture growth and utilisation in Paddock 27 , Station 6

Old Man Plains

Old Man Plains (OMP) is a research station managed by NT DAF. Vegetation is dominated by witchetty bush over oatgrasses on shallow gravelly calcareous clay loams, mulga over kerosene grass and woollybutt on sandy loam red earths and smaller areas of alluvial loamy sands dominated by buffel grass. Three paddocks and two rotationally grazed systems were modelled. TSDM and ground cover were calibrated and weighted for distance to water and land type. There was a high confidence in modelling assumptions (81%).

Breeder data is from 2012 top 2021, but stocking rates are known prior to then, hence longer-term simulations were run. Similar to Station 5, land condition improvement during the 2010/2011 La Nina led to increased pasture growth. Longer-term simulations informed the GRASP parameter changes required to simulate the observed land condition improvement (grass basal area was increased). Because stock numbers were set according to recommended carrying capacity, average utilisation rates were usually close to recommended levels at OMP. However, set stocking across variable rainfall years did lead to inter-annual variation in utilisation that may assist the detection of threshold levels of utilisation for optimal breeder performance.

2 Paddock Rotation

GRASP simulated TSDM and green cover well in the 2 Paddock Rotation at OMP (Figure 14-11 - Figure 14-12). Pasture growth varied fivefold, leading to average annual pasture utilisation of 19% (varying between 8 and 33%, Figure 14-13).

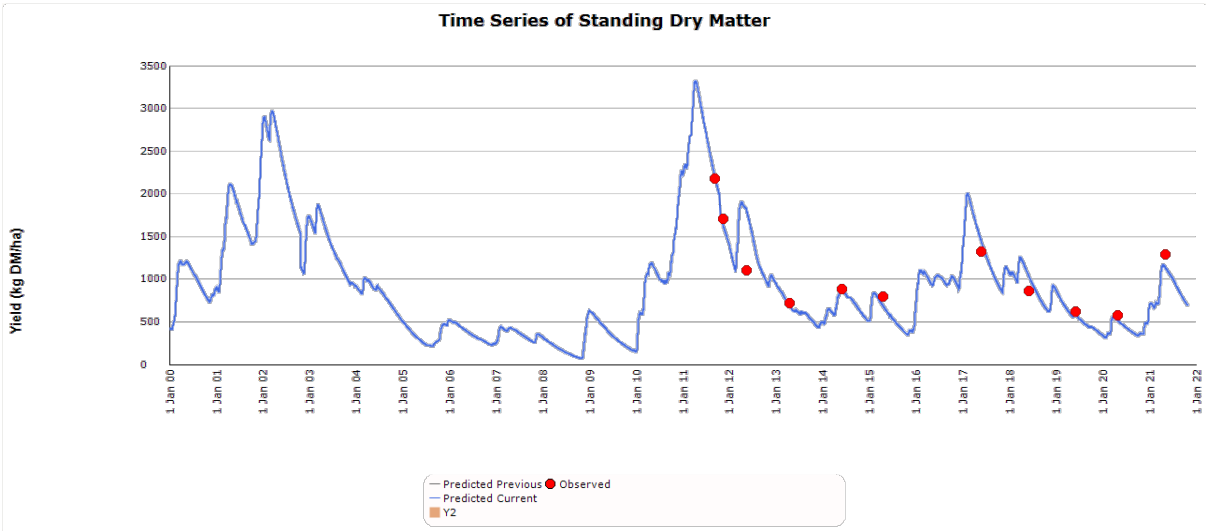


Figure 14-11: Simulated TSDM in the 2 paddock Rotation at Old Man Plains Research Station, (blue line) and TSDM observations (red dots)

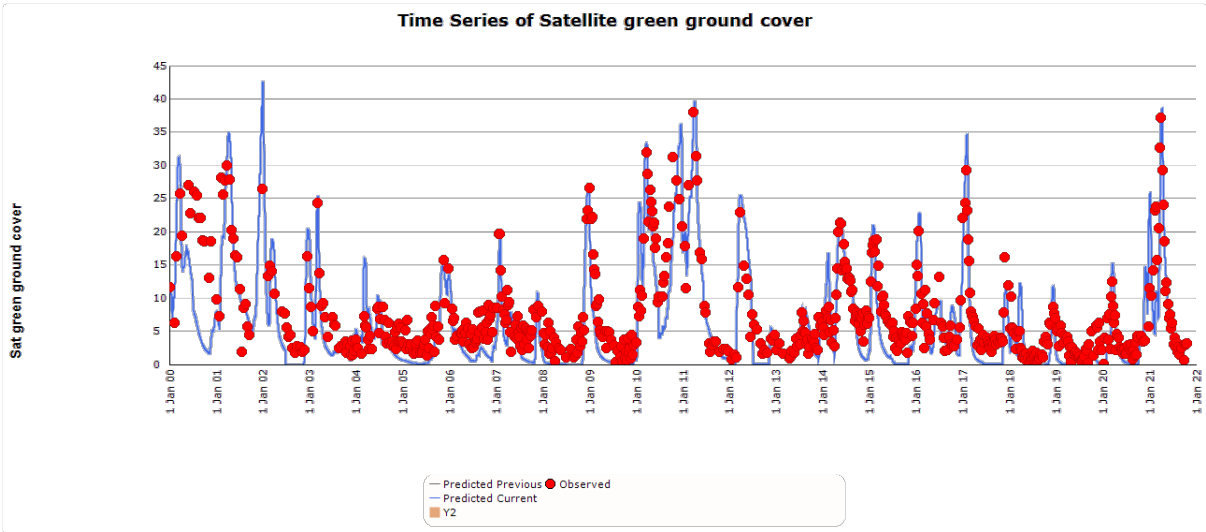


Figure 14-12: Simulated green ground cover in the 2 paddock Rotation at Old Man Plains Research Station, (blue line) and satellite derived green ground cover observations (red dots)

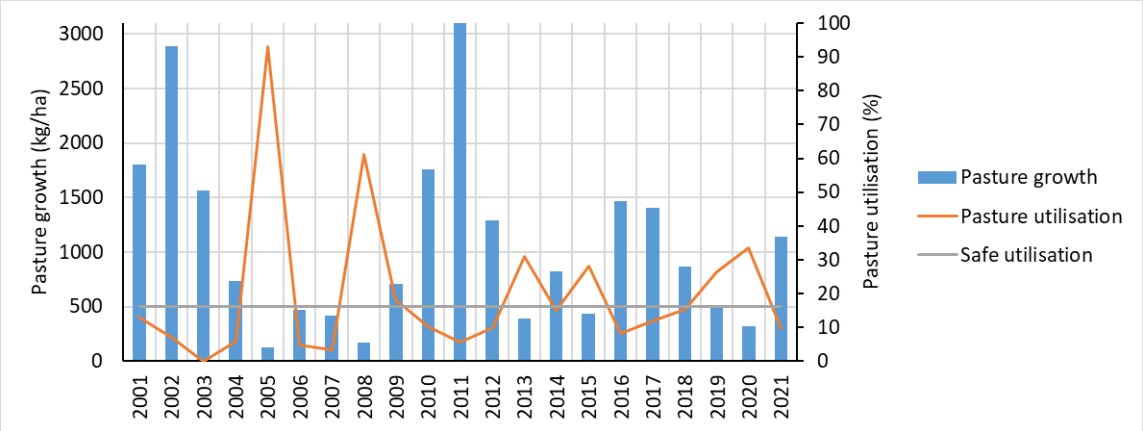


Figure 14-13: Simulated pasture growth and utilisation in the 2 Paddock Rotation at Old Man Plains Research Station

4 Paddock Rotation

GRASP simulated TSDM and green cover well in the 4 Paddock Rotation at OMP (Figure 14-14 - Figure 14-15). Pasture growth varied four-fold, leading to average annual pasture utilisation of 12% (varying between 5 and 22%, Figure 14-16).

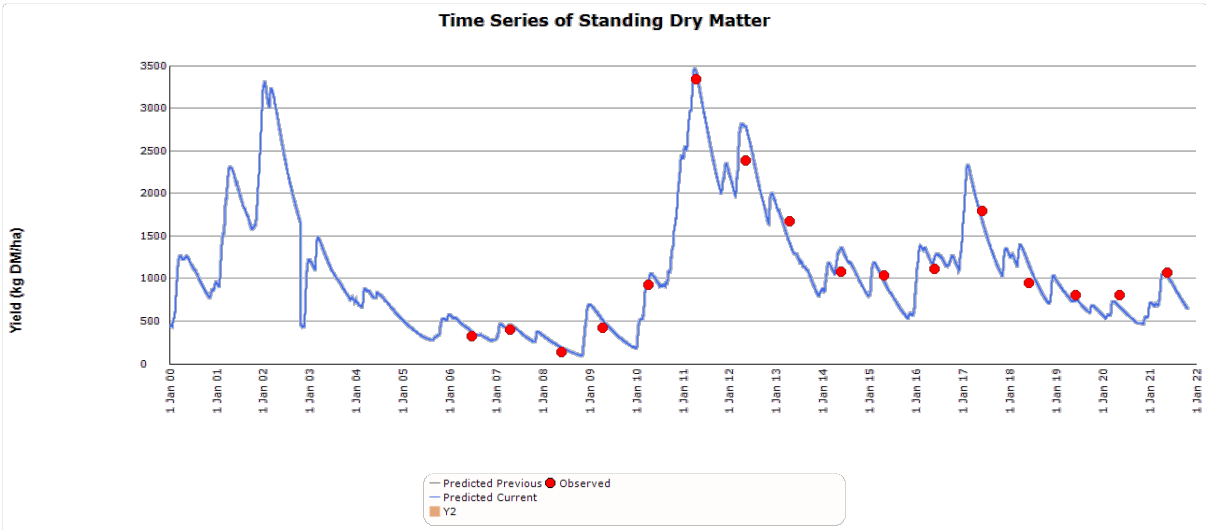


Figure 14-14: Simulated TSDM in the 4 paddock Rotation at Old Man Plains Research Station, (blue line) and TSDM observations (red dots)

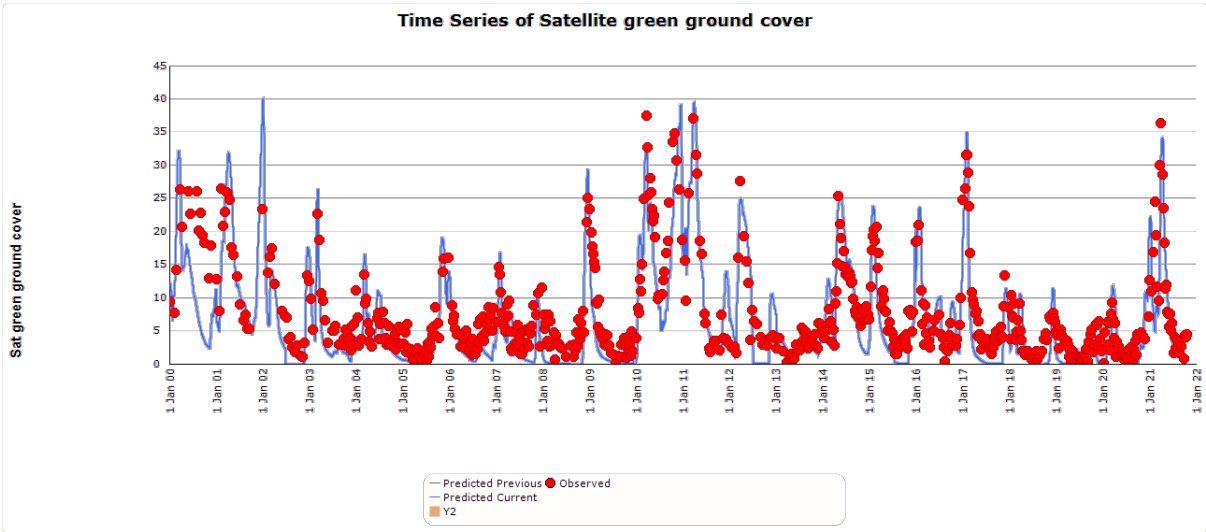


Figure 14-15: Simulated green ground cover in the 4 paddock Rotation at Old Man Plains Research Station, (blue line) and satellite derived green ground cover observations (red dots)

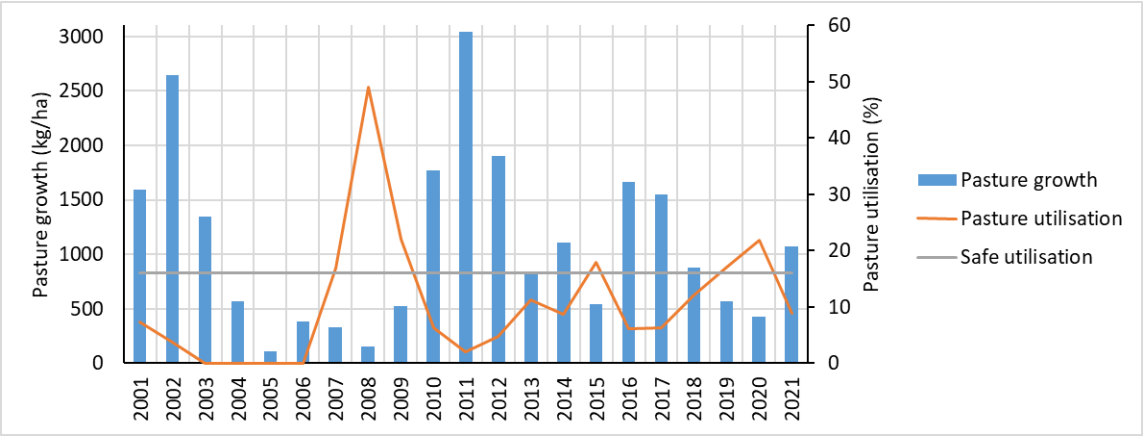


Figure 14-16: Simulated pasture growth and utilisation in the 4 Paddock Rotation at Old Man Plains Research Station

Pine Gap Paddock - continuous variable stocking

GRASP simulated TSDM and green cover well in Pine Gap Paddock at OMP (Figure 14-17 - Figure 14-18). Pasture growth varied three-fold, leading to average annual pasture utilisation 15% (varying between 6 and 23%, Figure 14-19).

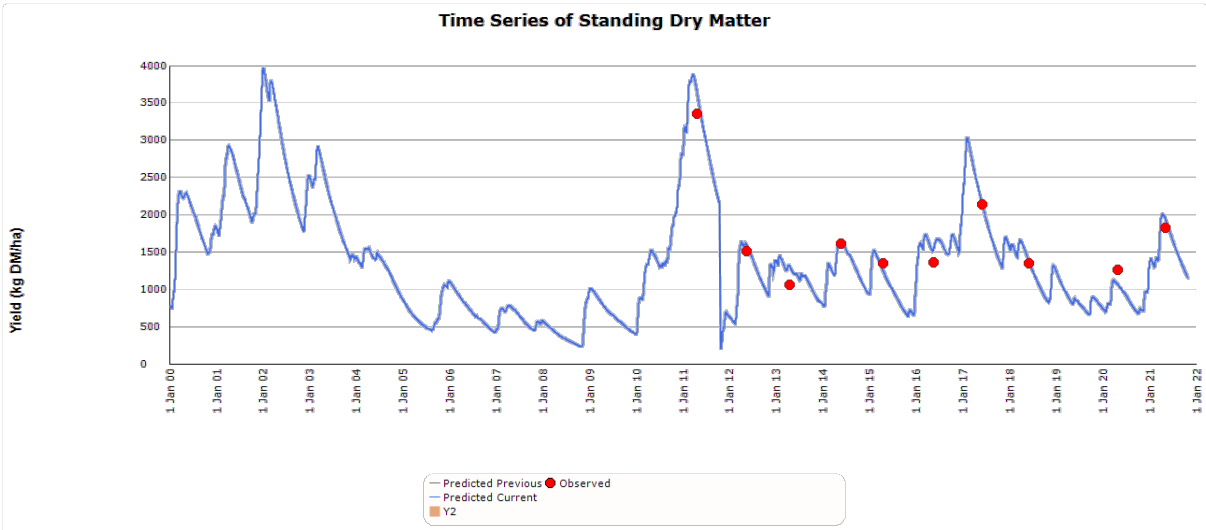


Figure 14-17: Simulated TSDM in Pine Gap Paddock at Old Man Plains Research Station, (blue line) and TSDM observations (red dots)

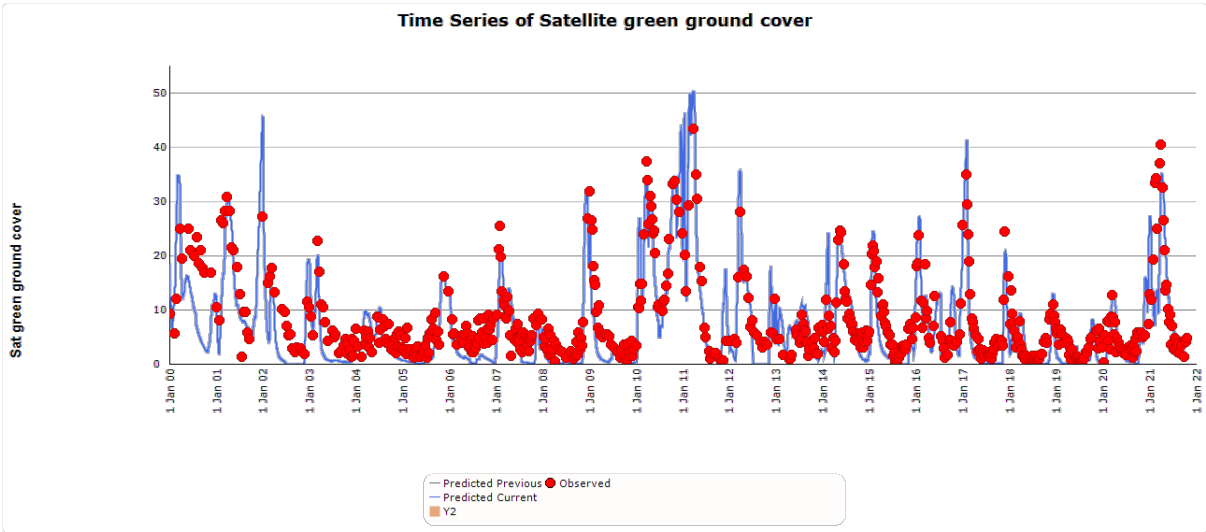


Figure 14-18: Simulated green ground cover in Pine Gap Paddock at Old Man Plains Research Station, (blue line) and satellite derived green ground cover observations (red dots)

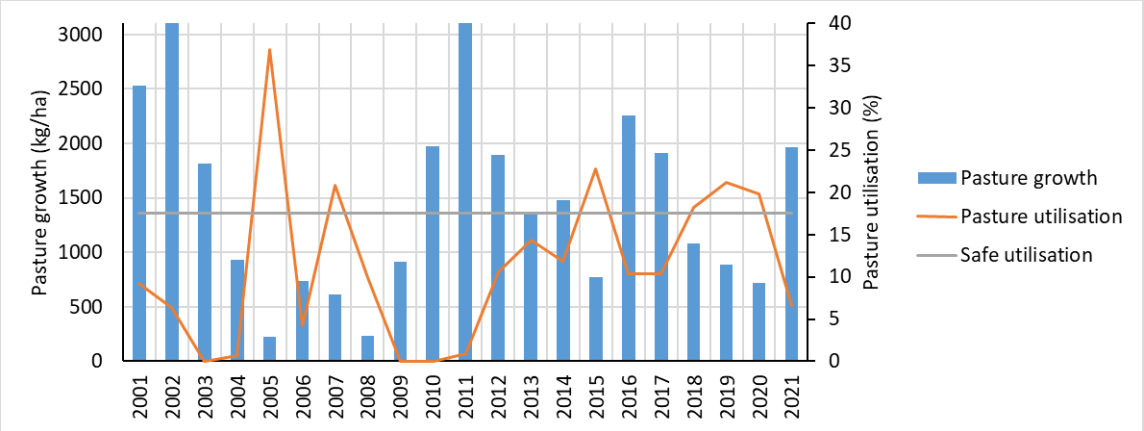


Figure 14-19: Simulated pasture growth and utilisation in Pine Gap Paddock at Old Man Plains Research Station

Waterhouse Paddock - continuous set stocking

GRASP simulated TSDM and green cover well in Waterhouse Paddock at OMP (Figure 14-20 - Figure 14-21). Pasture growth varied fivefold (between 8 and 33%), with an average annual pasture utilisation of 18% (Figure 14-22).

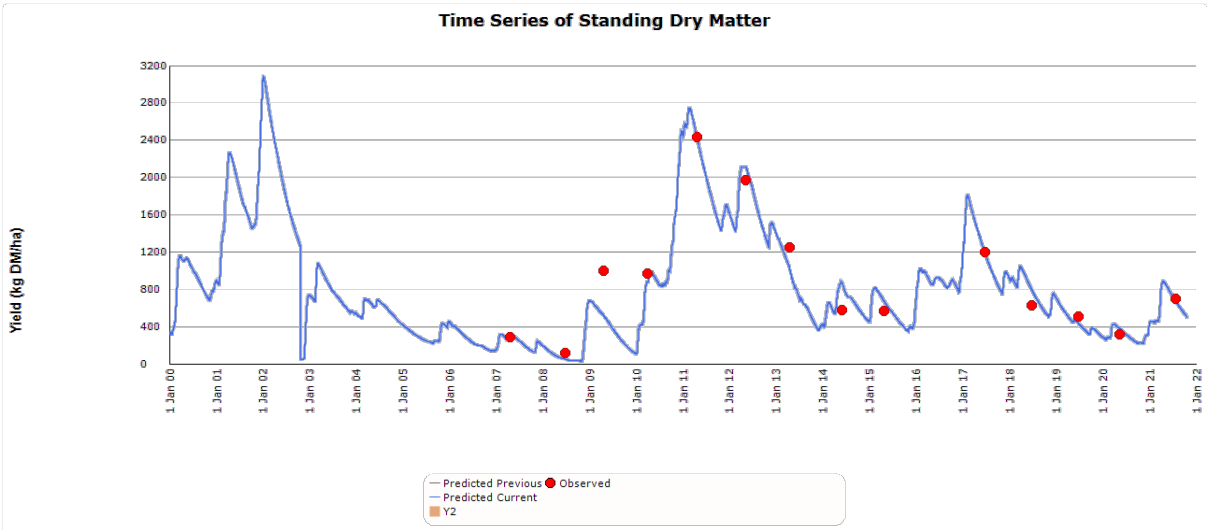


Figure 14-20: Simulated TSDM in Waterhouse Paddock at Old Man Plains Research Station, (blue line) and TSDM observations (red dots)

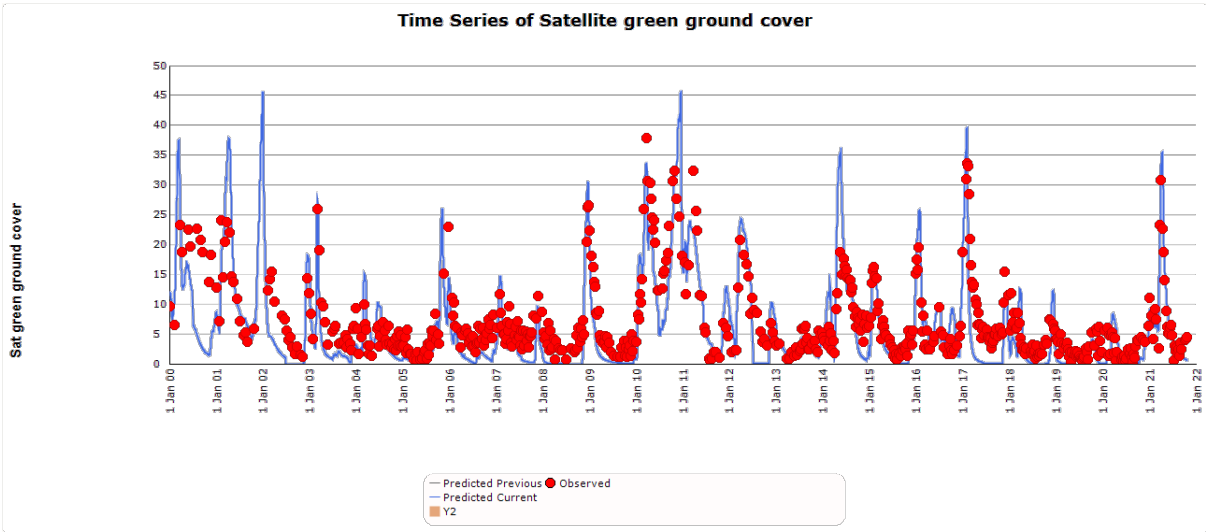


Figure 14-21: Simulated green ground cover in Waterhouse Paddock at Old Man Plains Research Station, (blue line) and satellite derived green ground cover observations (red dots)

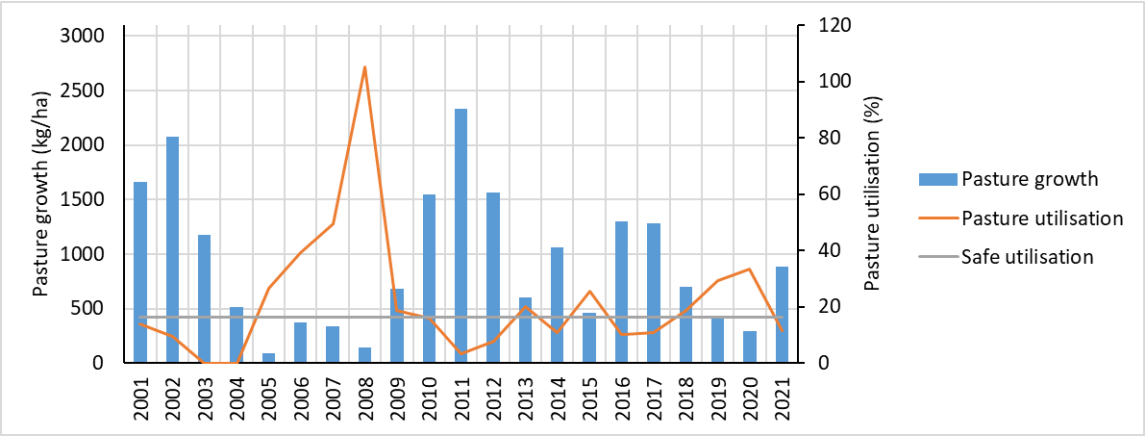


Figure 14-22: Simulated pasture growth and utilisation in Waterhouse Paddock at Old Man Plains Research Station

Western Paddock - continuous set stocking

GRASP simulated TSDM and green cover well in Western Paddock at OMP (Figure 14-23 - Figure 14-24). Pasture growth varied nine-fold, leading to average annual pasture utilisation 16% (varying between 5 and 39%, Figure 14-25).

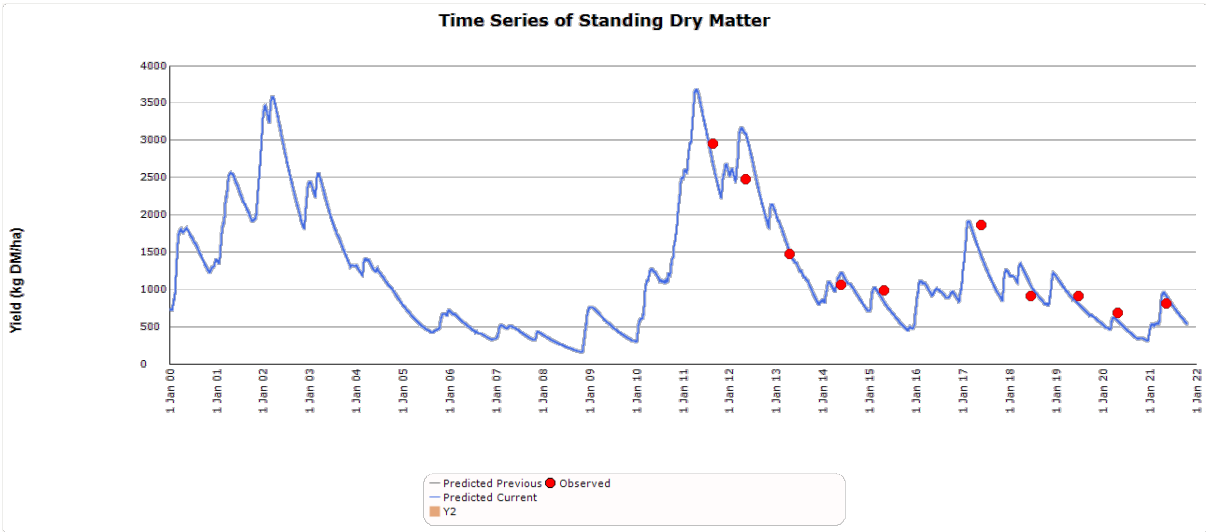


Figure 14-23: Simulated TSDM in Western Paddock at Old Man Plains Research Station, (blue line) and TSDM observations (red dots)

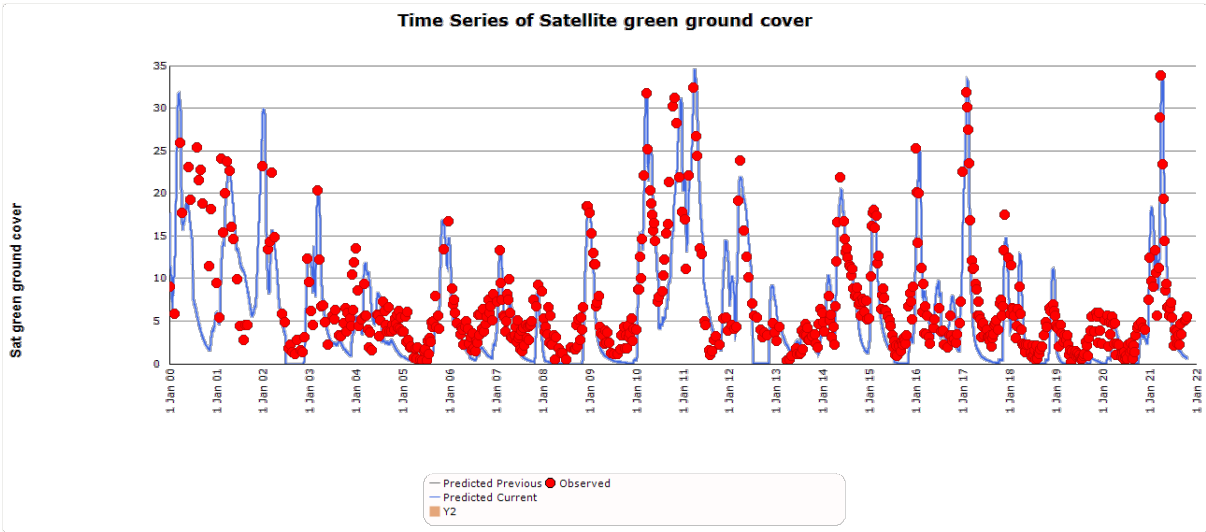


Figure 14-24: Simulated green ground cover in Western Paddock at Old Man Plains Research Station, (blue line) and satellite derived green ground cover observations (red dots)

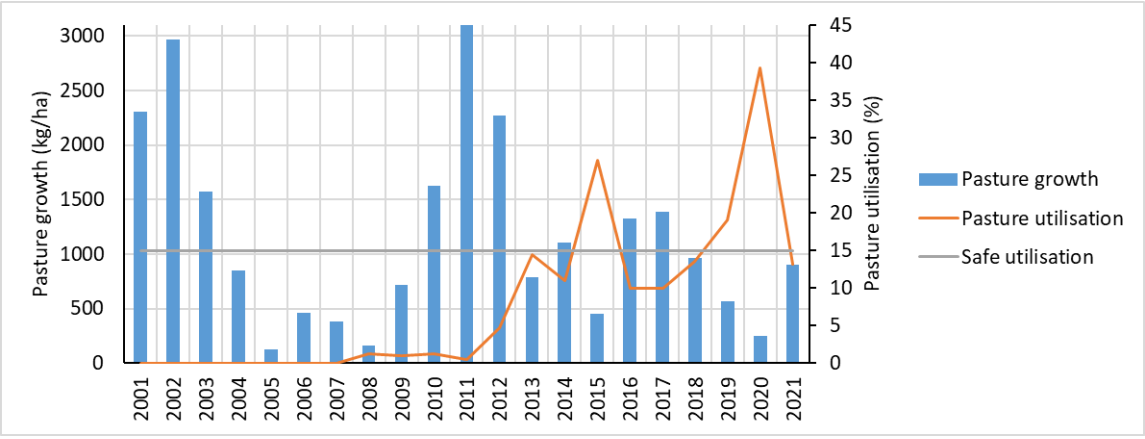


Figure 14-25: Simulated pasture growth and utilisation in Western Paddock at Old Man Plains Research Station

Station 3

Heifer performance was monitored at in a 486km^2 mulga and open shrubland paddock at Station 3 between 2005 and 2012. TSDM on Station 3 was visually estimated by an experienced operator from images of the paddock, and other sites of similar land types outside the paddock. TSDM was weighted by land type but not distance to water. GRASP simulated TSDM and green cover moderately well (Figure 14-26 - Figure 14-27). Pasture growth varied tenfold, leading to annual pasture utilisations between 10 and 82% (Figure 14-28). There was a moderate confidence in modelling assumptions (51%). %). There were 2 very low pasture growth years in the study when simulated pasture utilisation was very high, although mulga and other tree and shrub browse may have been accessed by the herd, which would reduce pasture utilisation to below that assumed here.

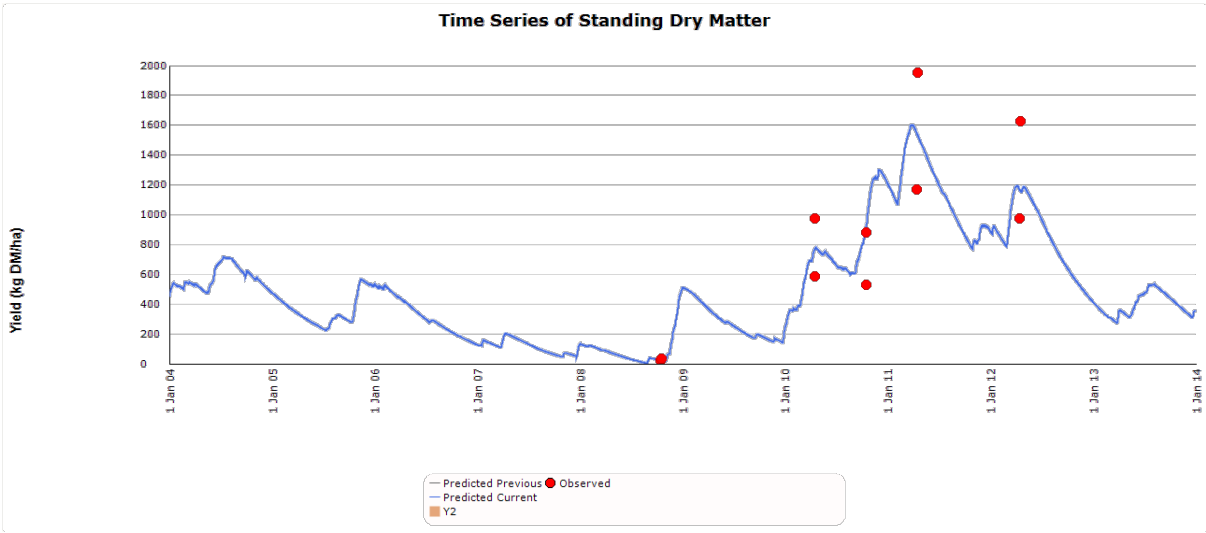


Figure 14-26: Simulated TSDM at Station 3, (blue line) and TSDM observations (red dots)

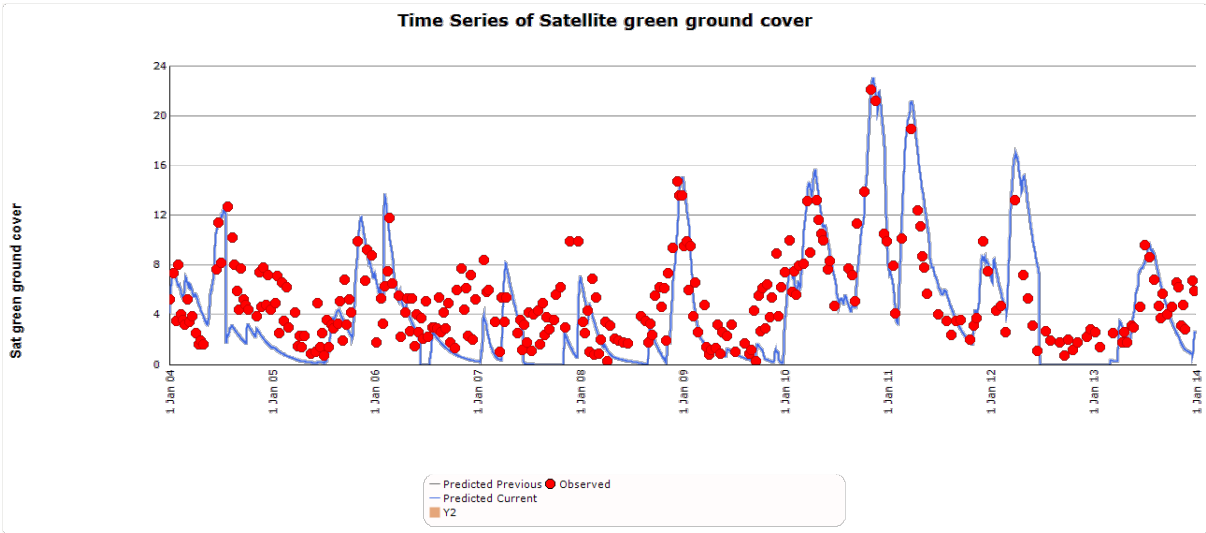


Figure 14-27: Simulated green cover at Station 3, (blue line) and satellite derived green ground cover observations (red dots)

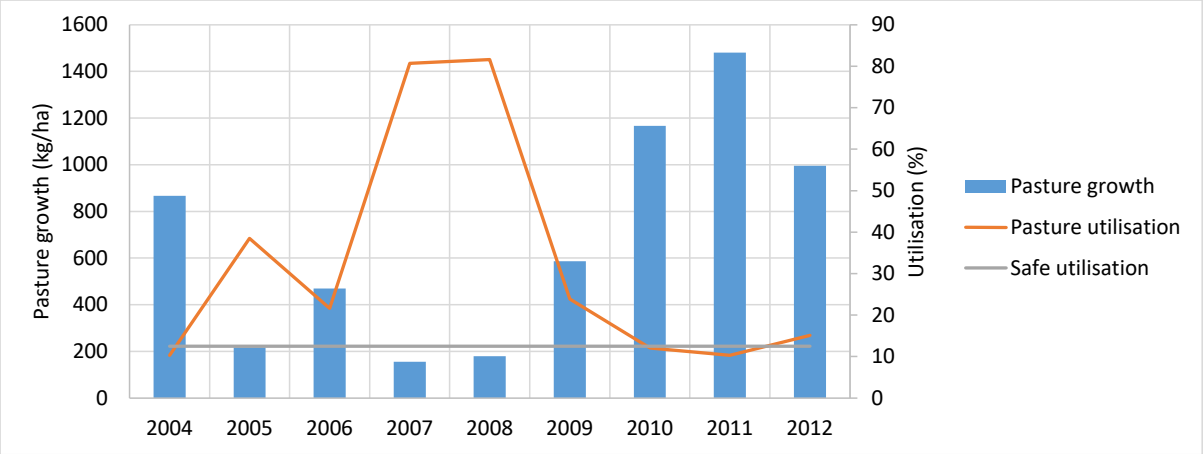


Figure 14-28: Simulated pasture growth and utilisation at Station 3

14.3.2 Barkly

Barkly region sites were modelled by Robyn Cowley with input from Chris Materne.

There were 12 sites across the Barkly Mitchell grasslands bioregion from 5 different studies. The sites were all within the Mitchell grass bioregion and were predominantly Mitchell grass dominated grasslands. Together they provide a good range of years and pasture utilisations to test the effect of utilisation on breeder herd performance in this region and land type. A further 2 sites could possibly be added from the current Paddock Power study as data become available.

Station 1

Two separate breeder herd studies were modelled on 5 sites on Station 1. They were a Cash Cow site between 2009 and 2011 (McGowan *et al.* 2014) and a study of the effects of nutrition on breeders between 1997 and 2001 (Savage 2004).

Calibrated TSDM was available for some paddocks in some years, and uncalibrated estimates by producers in one paddock, and by experts from images of long-term monitoring sites in some paddocks. TSDM (Figure 14-29, Figure 14-32, Figure 14-35) and green cover (Figure 14-30, Figure 14-33, Figure 14-36, Figure 14-38, Figure 14-40) were simulated very well by GRASP which was calibrated and validated on Station 1 land types and hence the confidence in model assumptions was high (86%).

Pasture utilisation ranged between 10 and 35% across all sites and years at Station 1 (Figure 14-31, Figure 14-34, Figure 14-37, Figure 14-39, Figure 14-41), but was usually close to safe levels at Station 1 sites except for Paddock 4 in the first 2 years.

Paddock 1

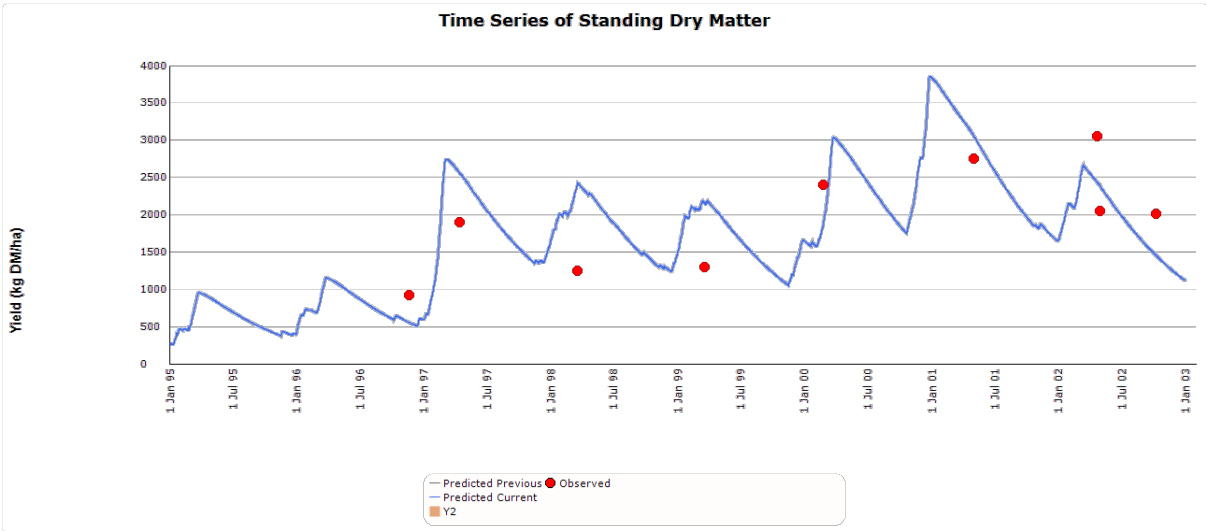


Figure 14-29: Simulated TSDM at Paddock 1 , Station 1 (blue line) and TSDM observations (red dots)

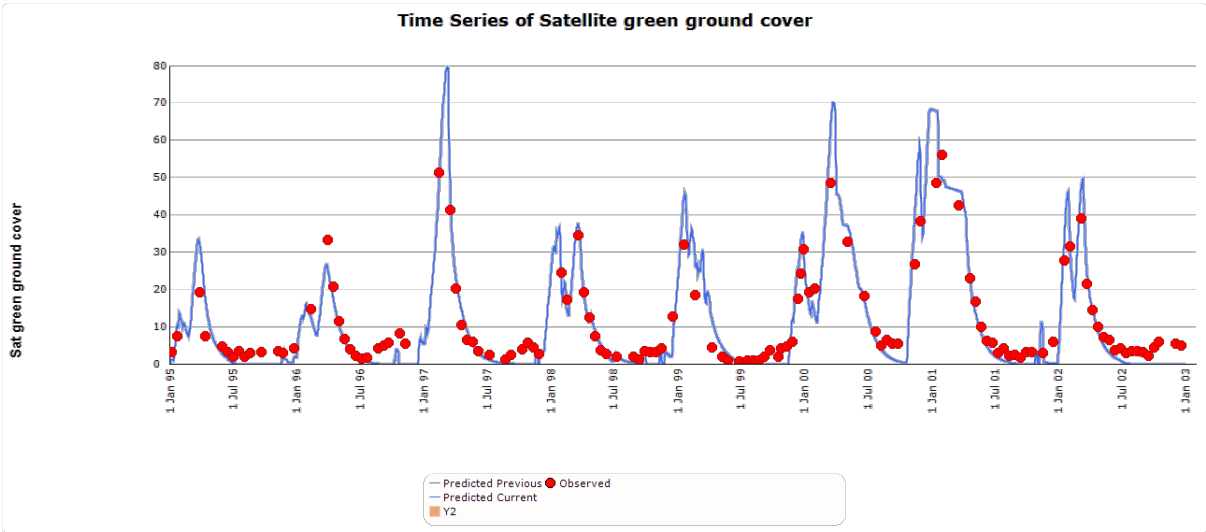


Figure 14-30: Simulated green cover at Paddock 1, Station 1 (blue line) and satellite derived green ground cover observations (red dots)

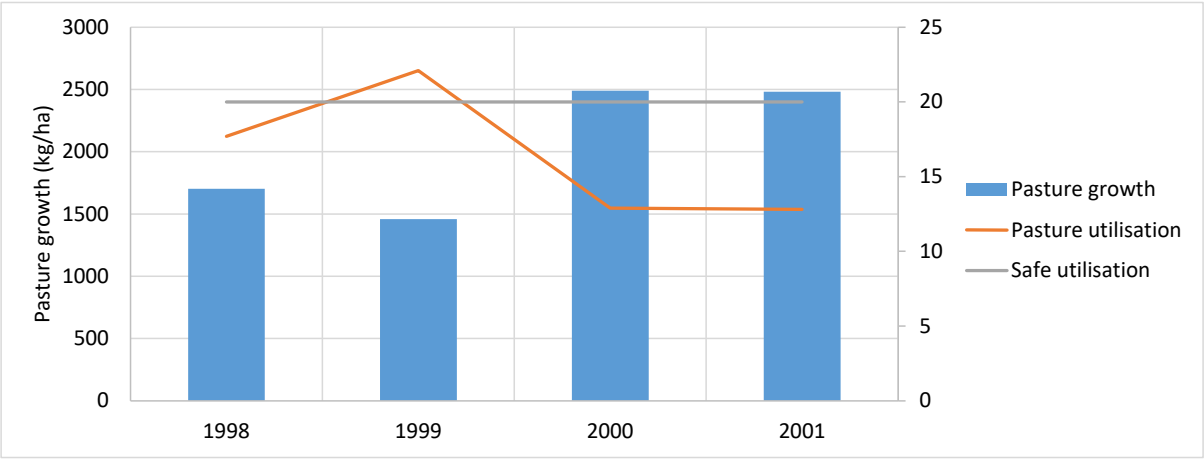


Figure 14-31: Simulated pasture growth and utilisation at Paddock 1, Station 1

Paddock 2

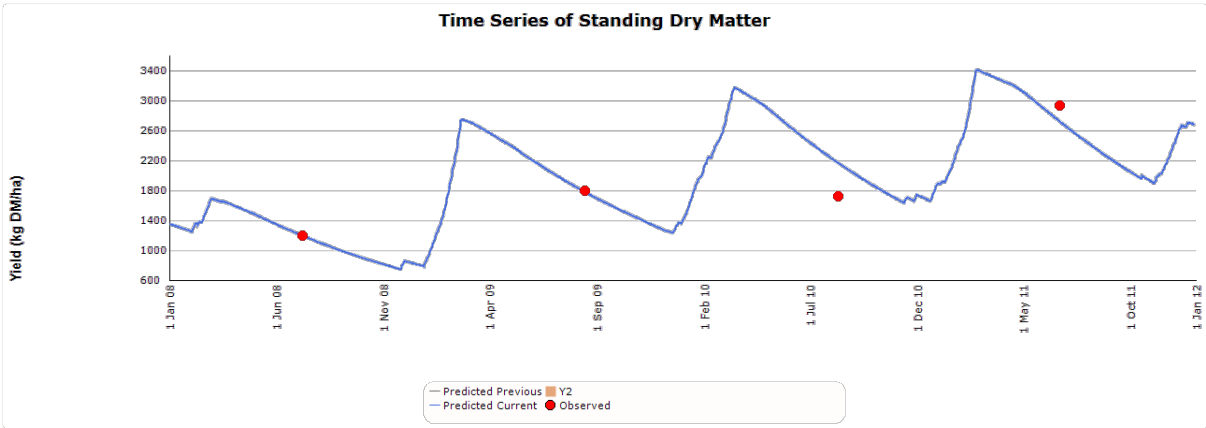


Figure 14-32: Simulated TSDM at Paddock 2, Station 1 (blue line) and TSDM observations (red dots)

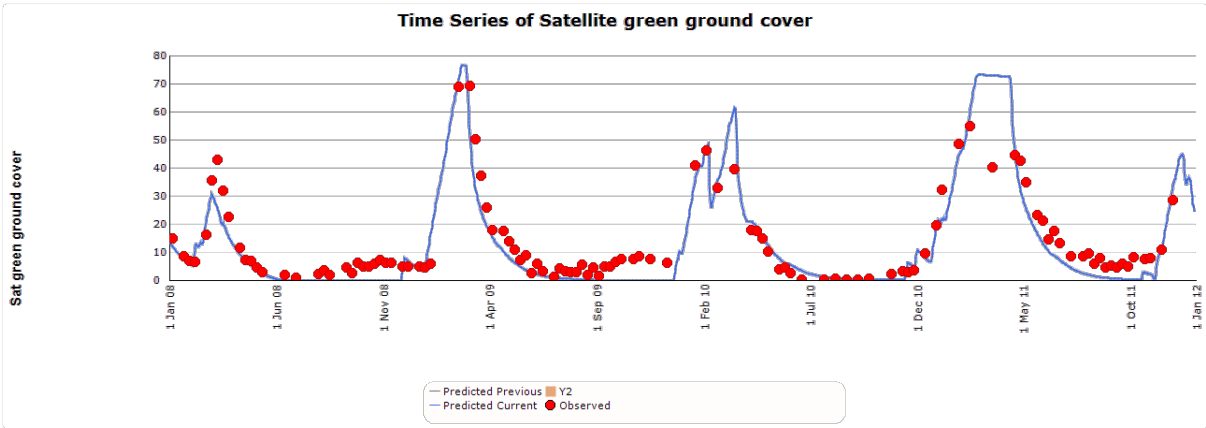


Figure 14-33: Simulated green cover at Paddock 2, Station 1 (blue line) and satellite derived green ground cover observations (red dots)

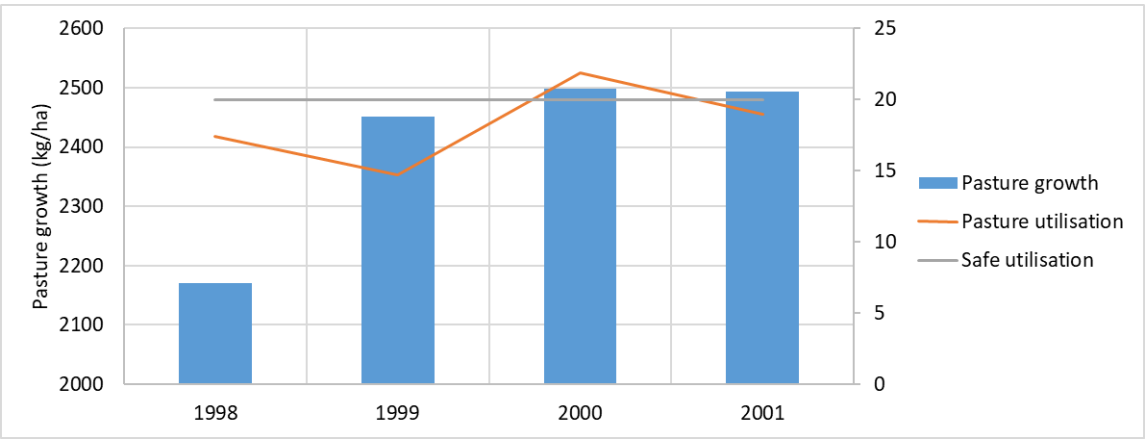


Figure 14-34: Simulated pasture growth and utilisation at Paddock 2, Station 1

Paddock 5

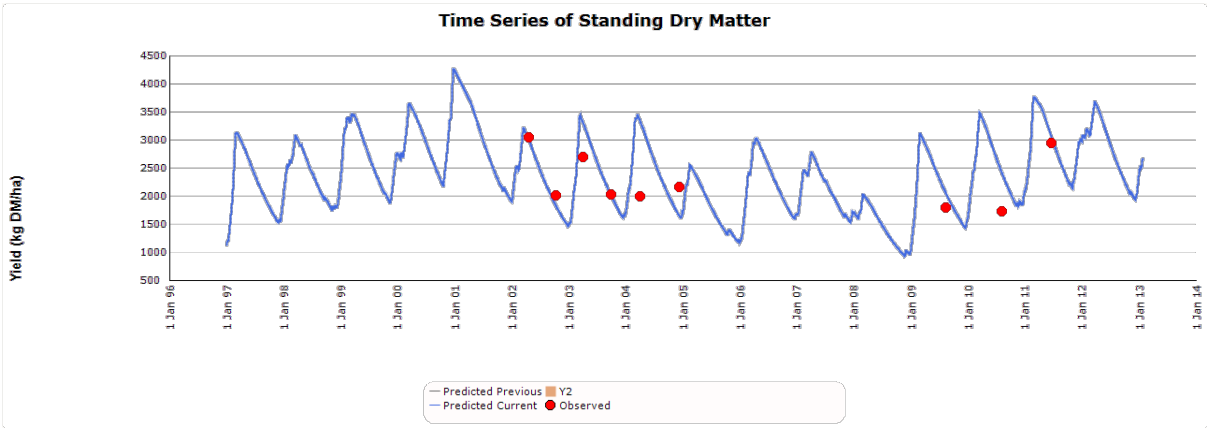


Figure 14-35: Simulated TSDM at Paddock 5, Station 1 (blue line) and TSDM observations (red dots)

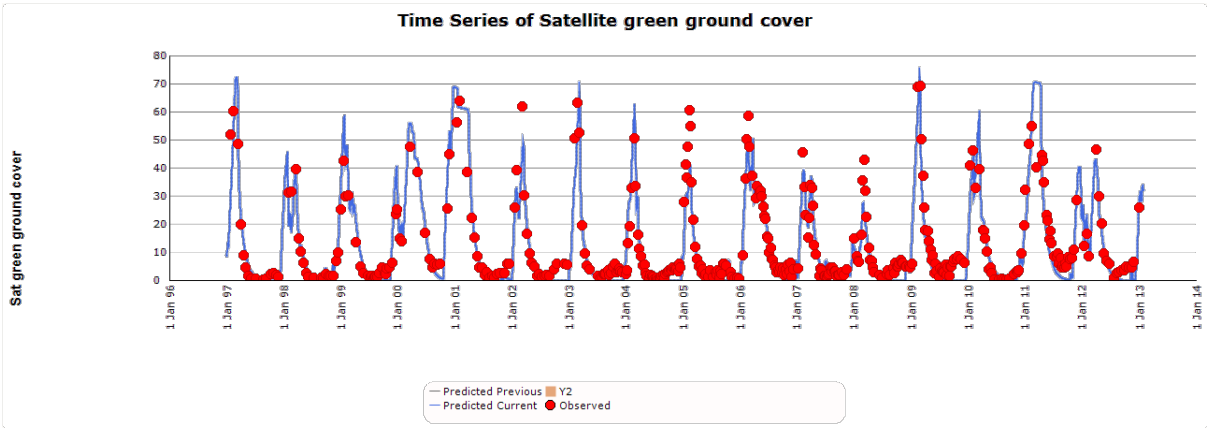


Figure 14-36: Simulated green cover at Paddock 5 , Station 1 (blue line) and satellite derived green ground cover observations (red dots)

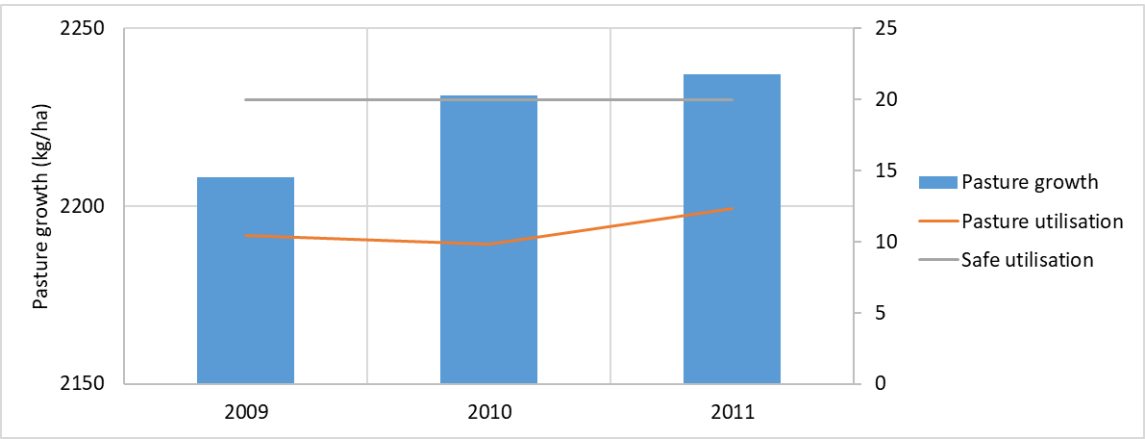


Figure 14-37: Simulated pasture growth and utilisation at Paddock 5, Station 1

Paddock 3

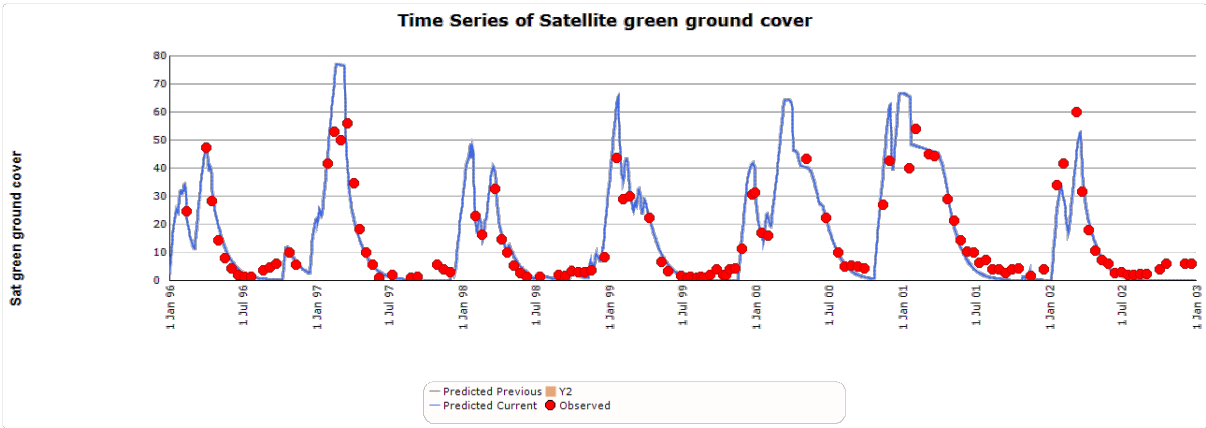


Figure 14-38: Simulated green cover at Paddock 3, Station 1 (blue line) and satellite derived green ground cover observations (red dots)

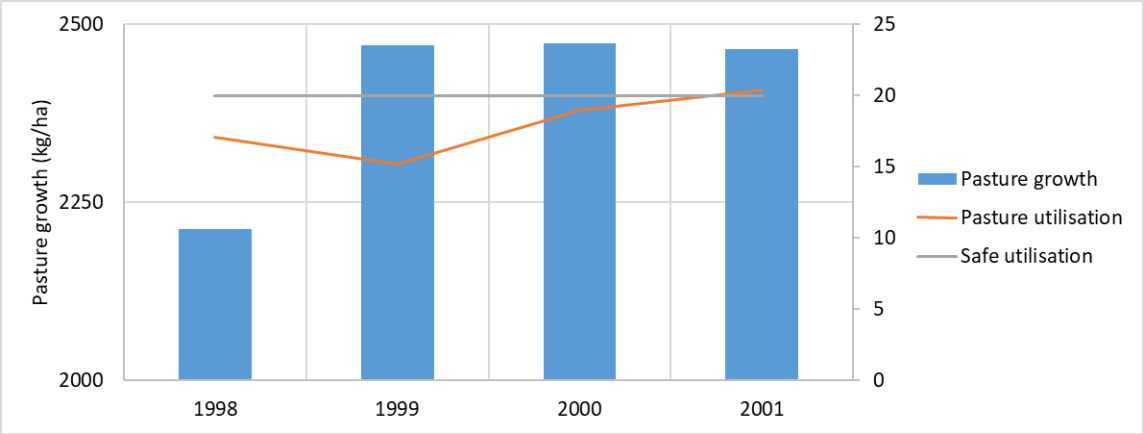


Figure 14-39: Simulated pasture growth and utilisation at Paddock 3, Station 1

Paddock 4

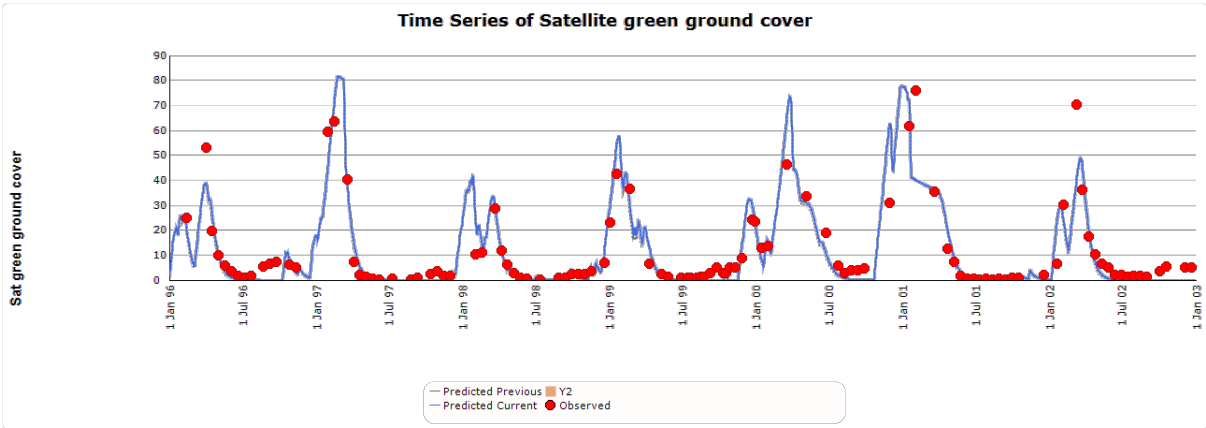


Figure 14-40: Simulated green cover at Paddock 4, Station 1 (blue line) and satellite derived green ground cover observations (red dots)

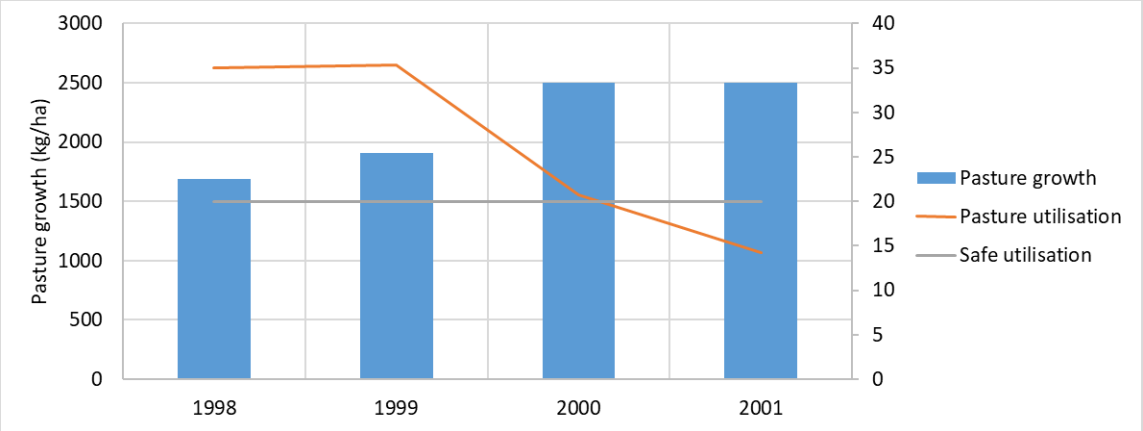


Figure 14-41: Simulated pasture growth and utilisation at Paddock 4, Station 1

Station 2

There were 4 sites from 2 studies at Station 2, a heifer study from 2006 to 2007 (Schatz and Hearnden 2008) and the Reducing Calf Loss from Exposure study 2019 -2023. TSDM estimates included uncalibrated visual estimates by producers in the paddock and experts looking at images of permanent monitoring sites inside, and also outside but near the paddock. Hence, they were not used for calibration, but were used as a guide.

TSDM (Figure 14-42, Figure 14-45, Figure 14-48, Figure 14-51) and green cover (Figure 14-43, Figure 14-46, Figure 14-49, Figure 14-52) were very well simulated at all sites, with a high confidence level in model assumptions (79-81%). Simulated pasture utilisation was usually close to or less than safe levels (Figure 14-44, Figure 14-47, Figure 14-50, Figure 14-53) and ranged from 4 to 39%.

Paddock 21

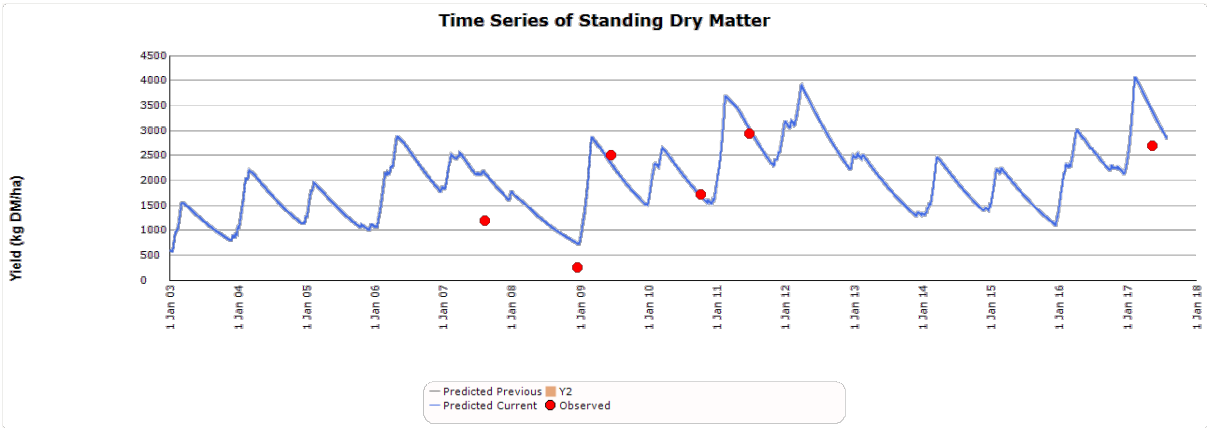


Figure 14-42: Simulated TSDM at Paddock 21, Station 2, (blue line) and TSDM observations (red dots)

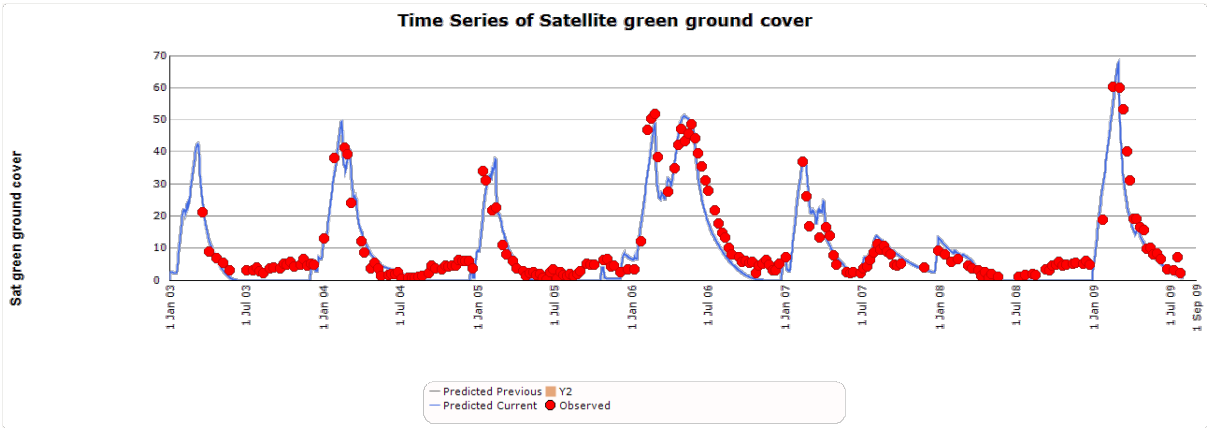


Figure 14-43: Simulated green cover at Paddock 21, Station 2, (blue line) and satellite derived green ground cover observations (red dots)

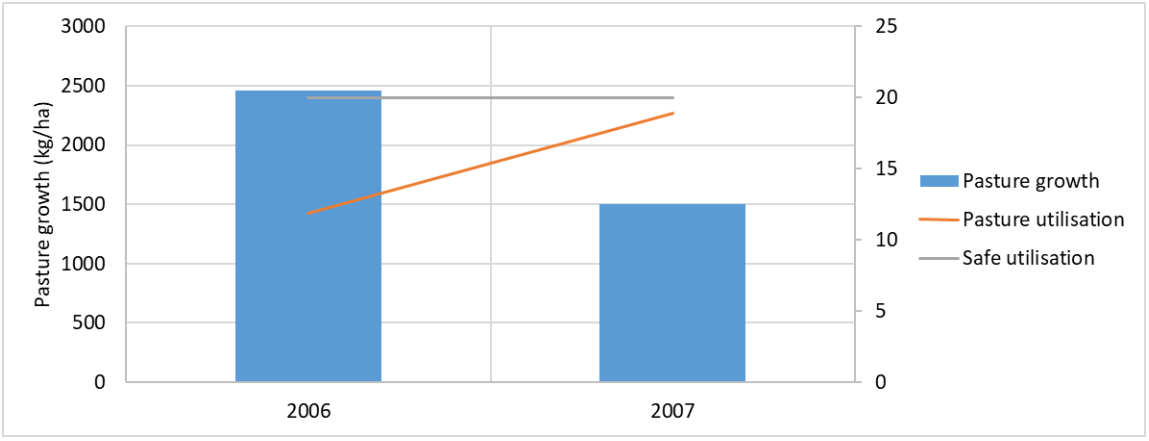


Figure 14-44: Simulated pasture growth and utilisation at Paddock 21, Station 2

Paddock 20

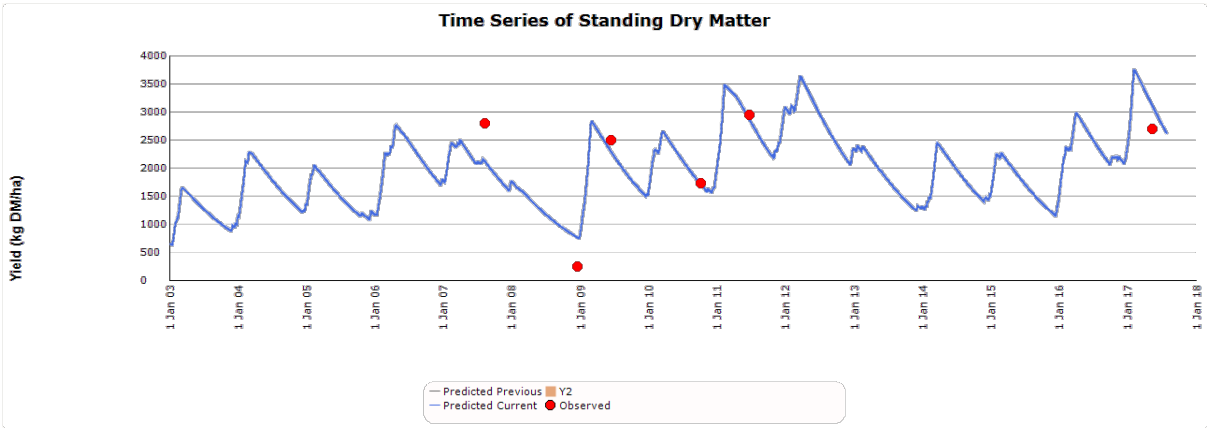


Figure 14-45: Simulated TSDM at Paddock 20, Station 2, (blue line) and TSDM observations (red dots)

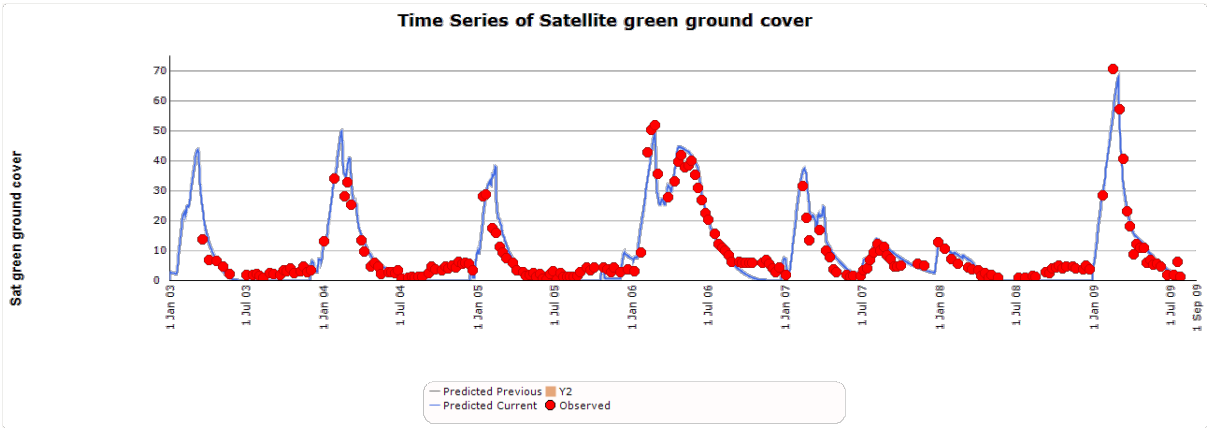


Figure 14-46: Simulated green cover at Paddock 20, Station 2, (blue line) and satellite derived green ground cover observations (red dots)

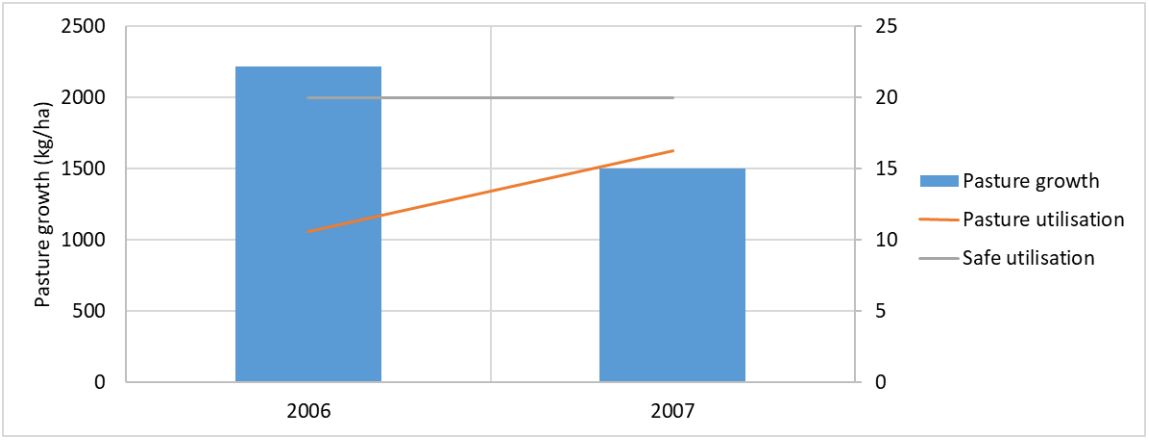


Figure 14-47: Simulated pasture growth and utilisation at Paddock 20, Station 2

Paddock 19

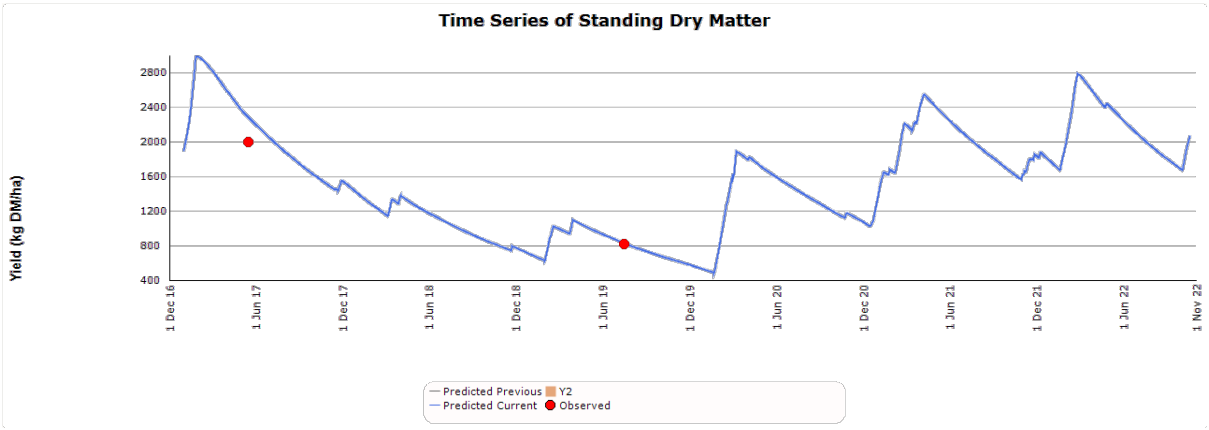


Figure 14-48: Simulated TSDM at Paddock 19, Station 2, (blue line) and TSDM observations (red dots)

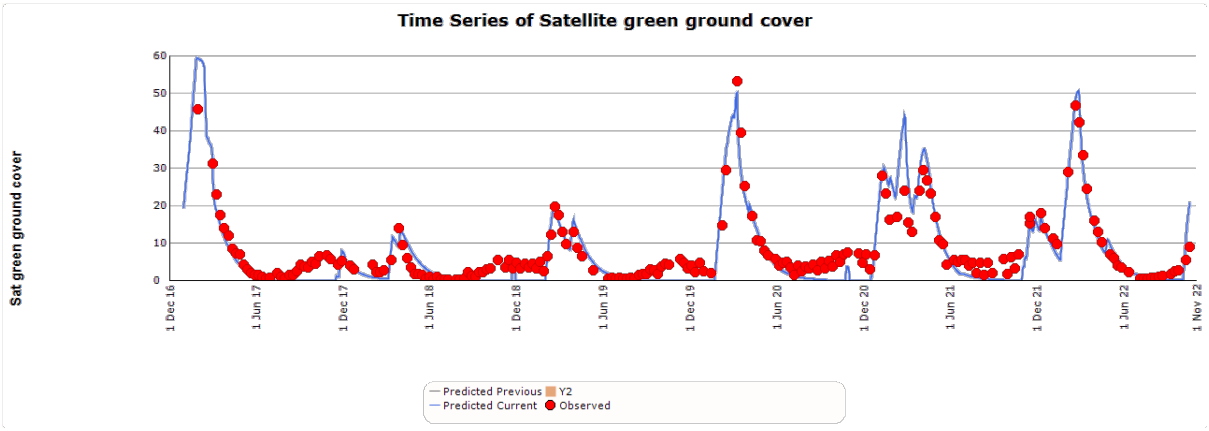


Figure 14-49: Simulated green cover at Paddock 19, Station 2 (blue line) and satellite derived green ground cover observations (red dots)

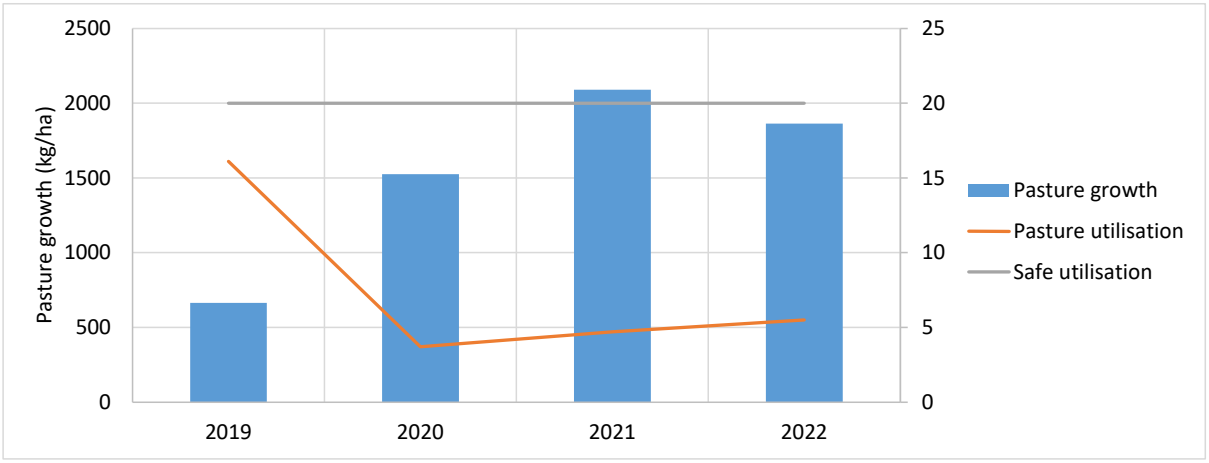


Figure 14-50: Simulated pasture growth and utilisation at Paddock 19, Station 2

Paddock 18

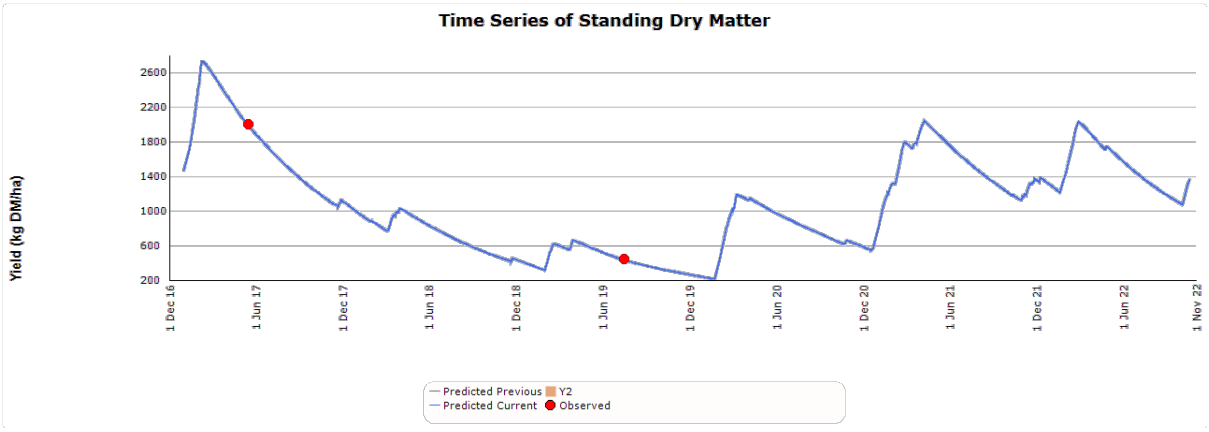


Figure 14-51: Simulated TSDM at Paddock 18, Station 2, (blue line) and TSDM observations (red dots)

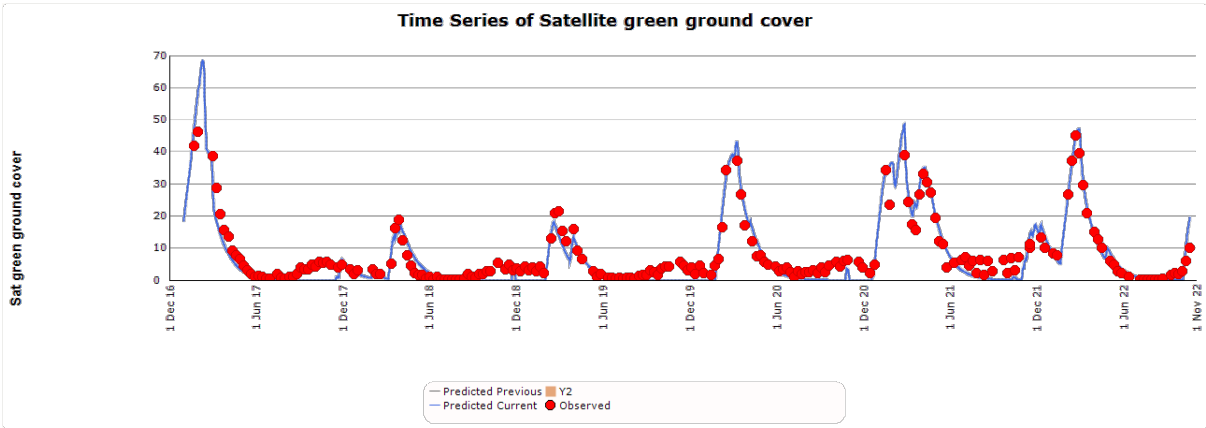


Figure 14-52: Simulated green cover at Paddock 18, Station 2, (blue line) and satellite derived green ground cover observations (red dots)

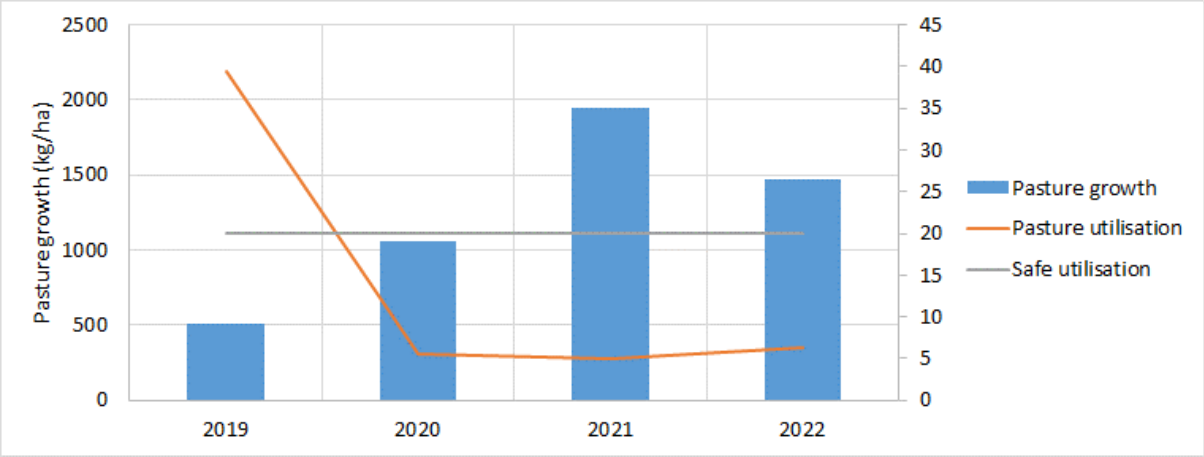


Figure 14-53: Simulated pasture growth and utilisation at Paddock 18, Station 2

Station 4

There was no TSDM available for this site during the Phosphorus trial study (Quigley *et al.* 2015) period. Data that was available was not closely calibrated due to uncertainty re stocking rates and paddock representativeness due to distance to water and fires outside of the study period (Figure 14-54). However, the GRASP land type model was calibrated and validated at the paddock scale on the same land type nearby, so was judged to be very representative of the site. GRASP simulated green cover reasonably well during the study period (Figure 14-55). There was a moderately good confidence in modelling assumptions (71%).

The paddock was a mix of Mitchell grass (73% of paddock, 20% safe utilisation rate) and Wonorah (27% of paddock, woodland and shrubland with a safe utilisation rate of 15%) land types, hence the weighted safe utilisation rate is 18.6%. There was a wide range in utilisation (between 10 and 45%) due to varying pasture growth at the site (Figure 14-56).

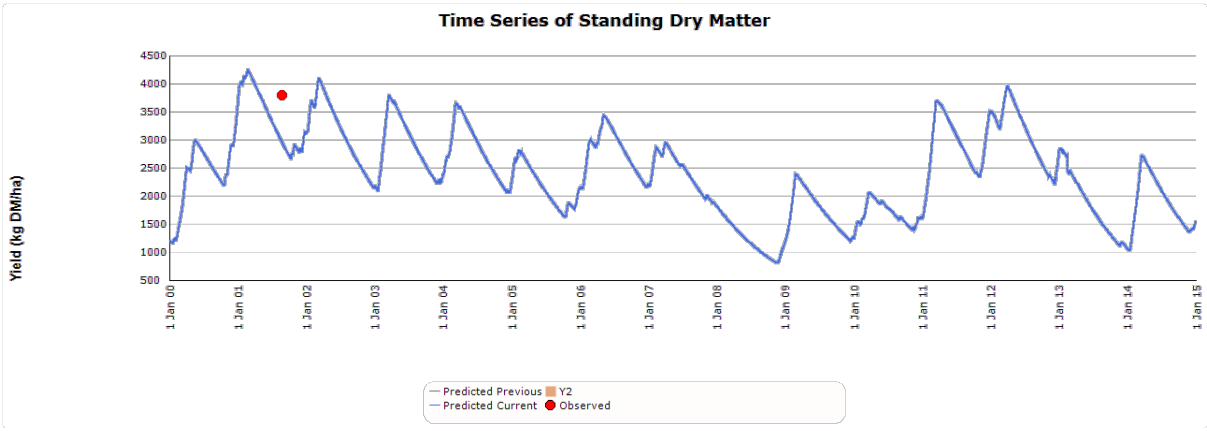


Figure 14-54: Simulated TSDM at Station 4, (blue line) and TSDM observations (red dots)

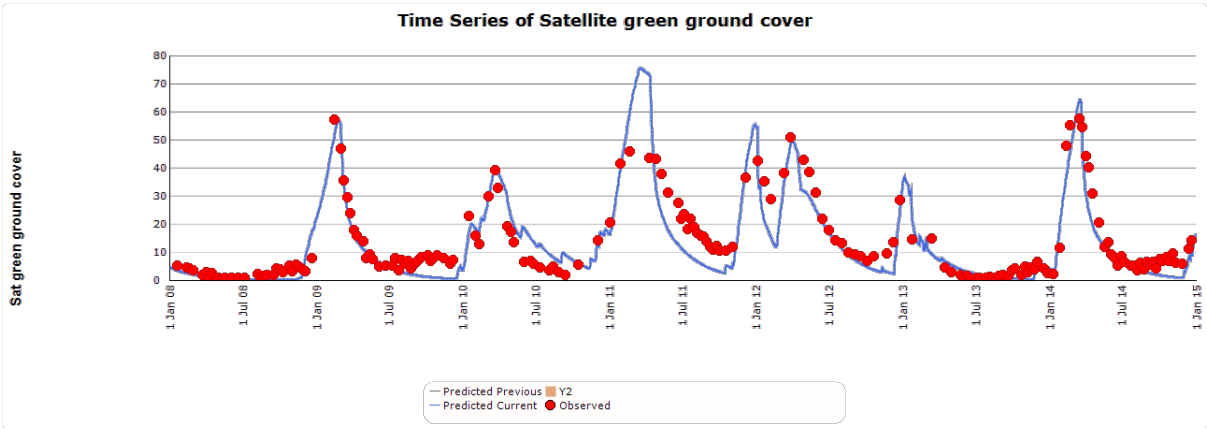


Figure 14-55: Simulated green cover at Station 4, (blue line) and satellite derived green ground cover observations (red dots)

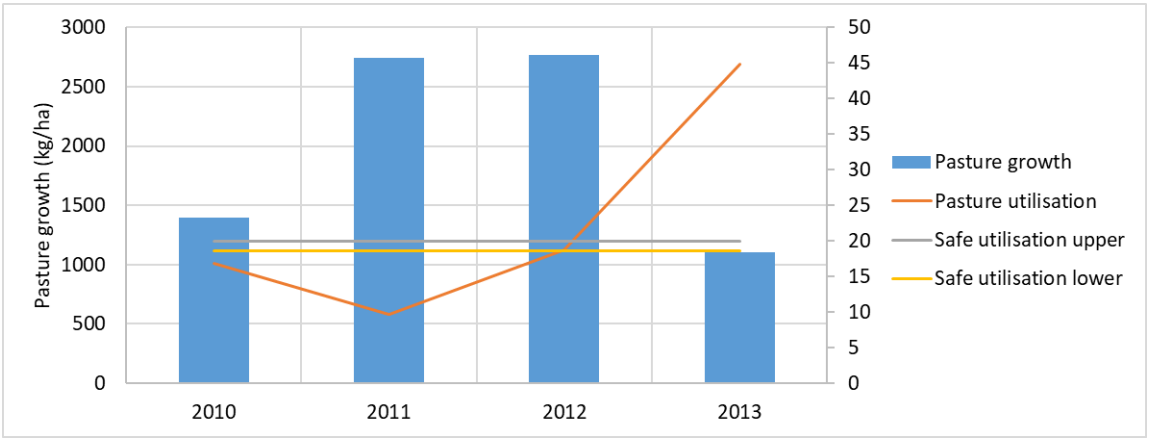


Figure 14-56: Simulated pasture growth and utilisation at Station 4

Station 8

The Station 8 Breeder Herd Efficiency study tested the effect of supplementation on breeder performance during a period that included the 2000-2002 double La Nina (DPIFM 2007). There was high quality calibrated and weighted botanal pasture data collected during the study, contributing to a high level of confidence in modelling assumptions (86%). There were two grazing systems

modelled. One was a single paddock (Paddock 16 paddock which was supplemented and grazed all year round) and one was a rotationally grazed 2 paddock system (Paddock 14 which was not supplemented, one paddock grazed in the wet, one in the dry season) to keep cattle off Georgina Gidgee when it was poisonous. Both paddocks were predominantly Mitchell grasslands with about 20% spinifex sandplains that were excluded from analysis because cattle don't graze them (Chris Materne pers. comm.). Hence satellite green cover and watered area was based only on the 5km grazed area within the non-spinifex land types of the modelling units.

TSDM and green cover were very well simulated at these sites (Figure 14-57 - Figure 14-58, Figure 14-60 - Figure 14-61).

Station 8 is on the southern end of the Barkly Mitchell grasslands and has the lowest median rainfall (271mm) of all the Barkly sites. The high rainfall (558mm) during the study led to very high pasture growth and low pasture utilisation rates (2.5 to 14%) during the study years (Figure 14-59, Figure 14-62).

Paddock 14 - 2 paddock rotation

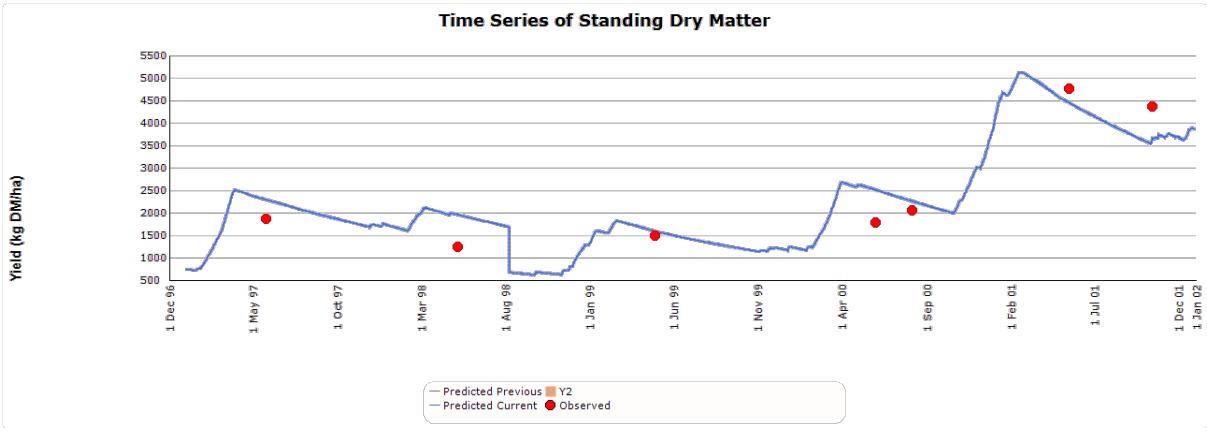


Figure 14-57: Simulated TSDM at Paddock 14, Station 8, (blue line) and field observations (red dots)

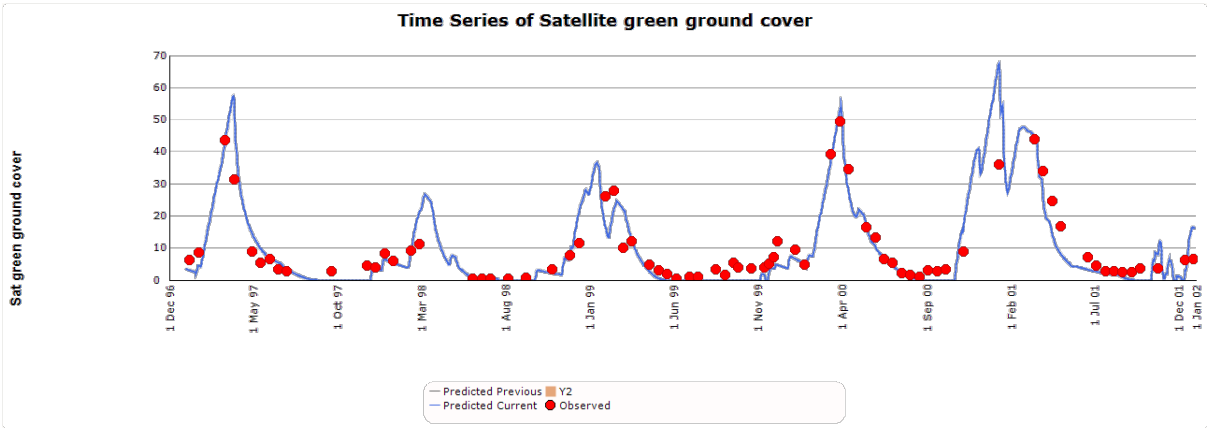


Figure 14-58: Simulated green cover at Paddock 14, Station 8, (blue line) and satellite derived green ground cover observations (red dots)

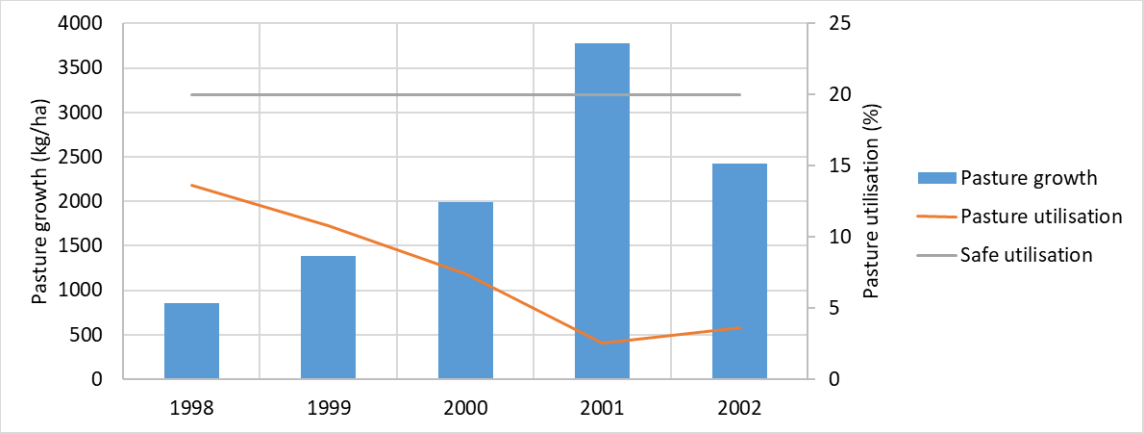


Figure 14-59: Simulated pasture growth and utilisation at Paddock 14, Station 8

Paddock 16

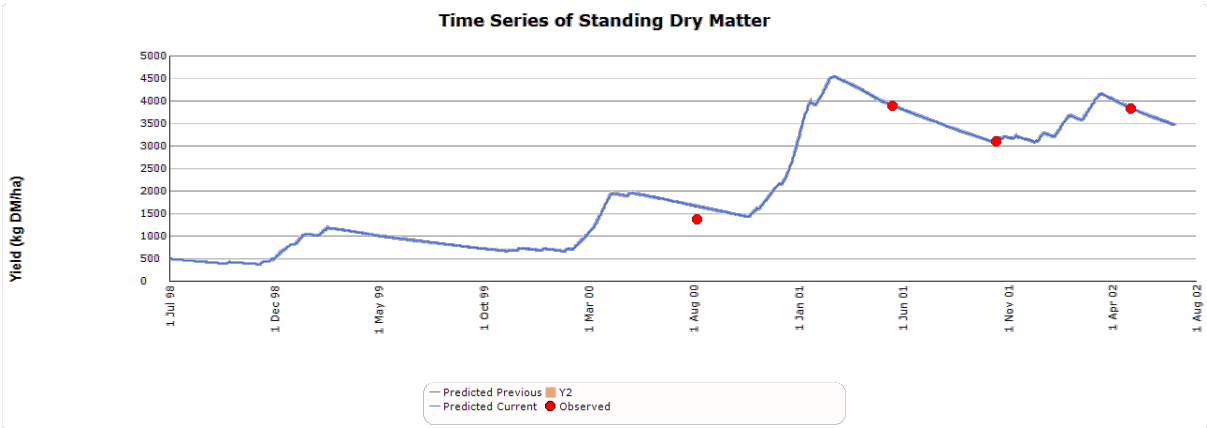


Figure 14-60: Simulated TSDM in Paddock 16, Station 8, (blue line) and TSDM observations (red dots)

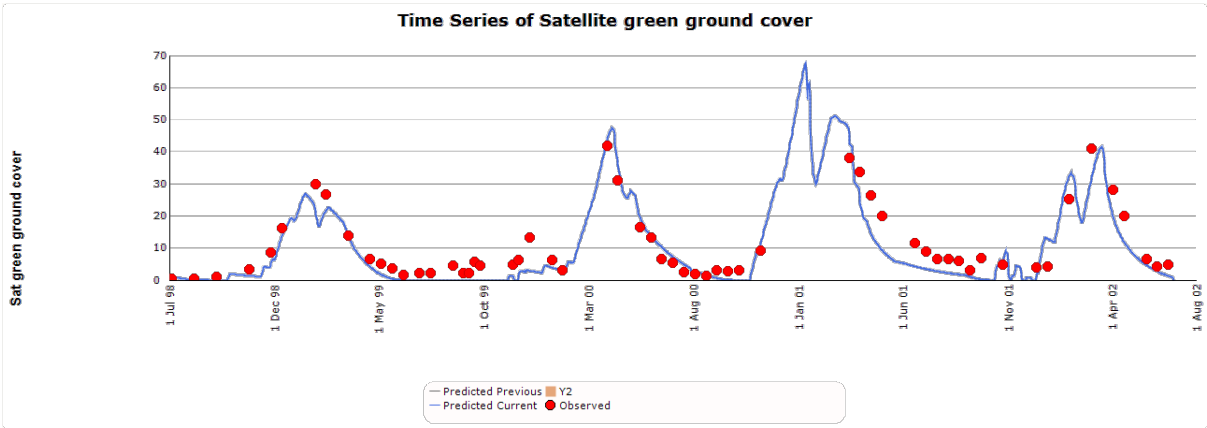


Figure 14-61: Simulated green cover in Paddock 16, Station 8, (blue line) and satellite derived green ground cover observations (red dots)

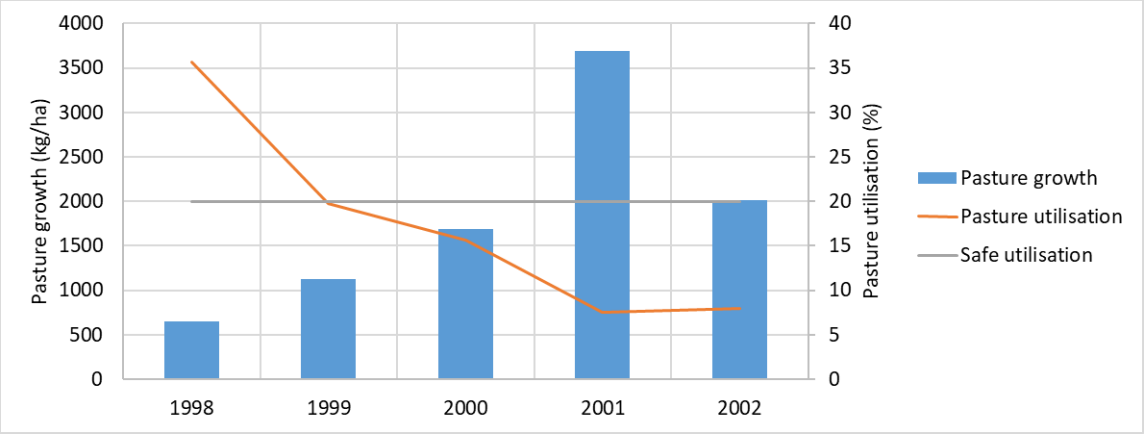


Figure 14-62: Simulated pasture growth and utilisation at Paddock 16, Station 8

Station 7

Paddock 31

TSDM estimates from this Paddock Power site was based on 8-9 visual estimates by experienced observers taken from across the paddock in 2020 and 2021. These were weighted for distance from water. TSDM and green cover were well simulated by GRASP (Figure 14-63 - Figure 14-64). There was a moderate confidence in modelling assumptions (69%).

Pasture utilisation at the Station 7 site was within safe levels (<20%) for the duration of the breeder herd dataset (Figure 14-65).

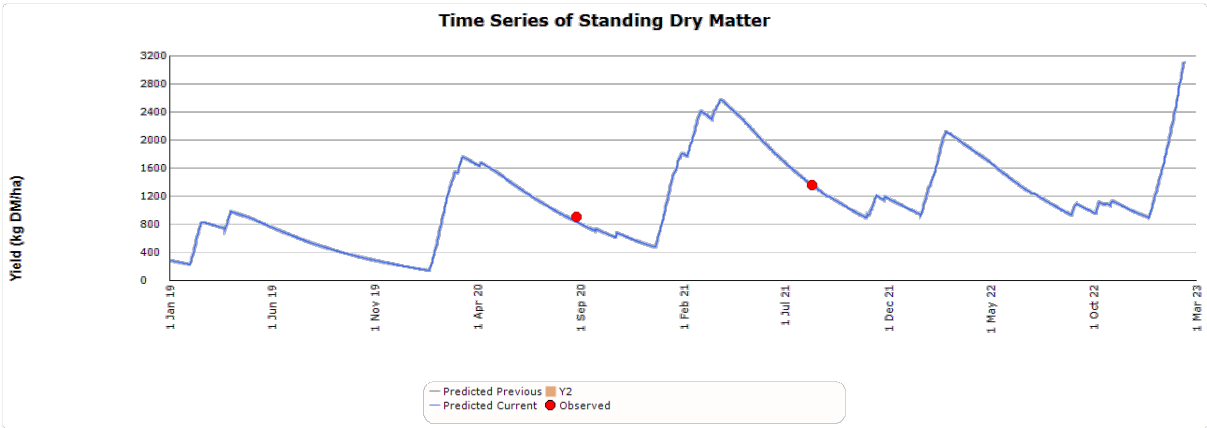


Figure 14-63: Simulated TSDM in Paddock 31, Station 7, (blue line) and observed TSDM observations (red dots)

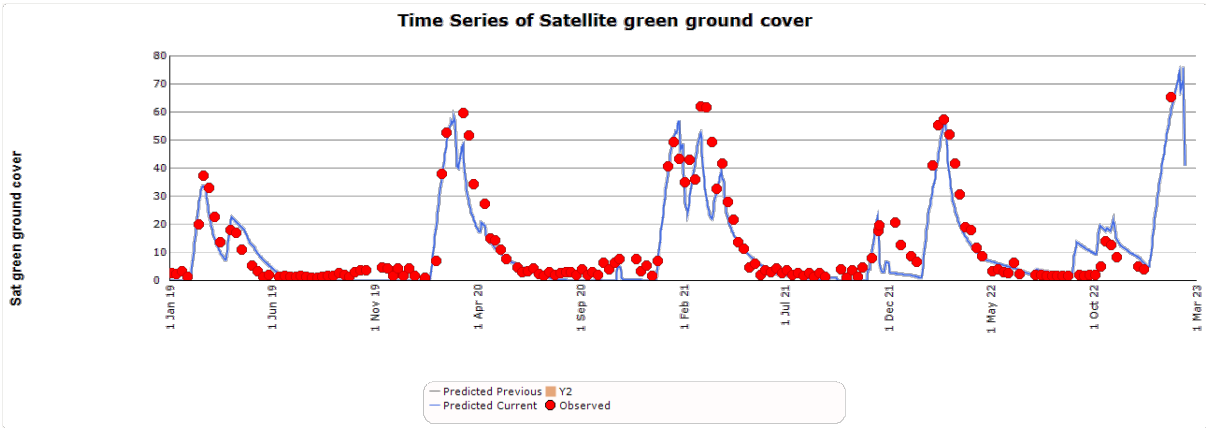


Figure 14-64: Simulated green cover in Paddock 31, Station 7, (blue line) and satellite derived green ground cover observations (red dots)

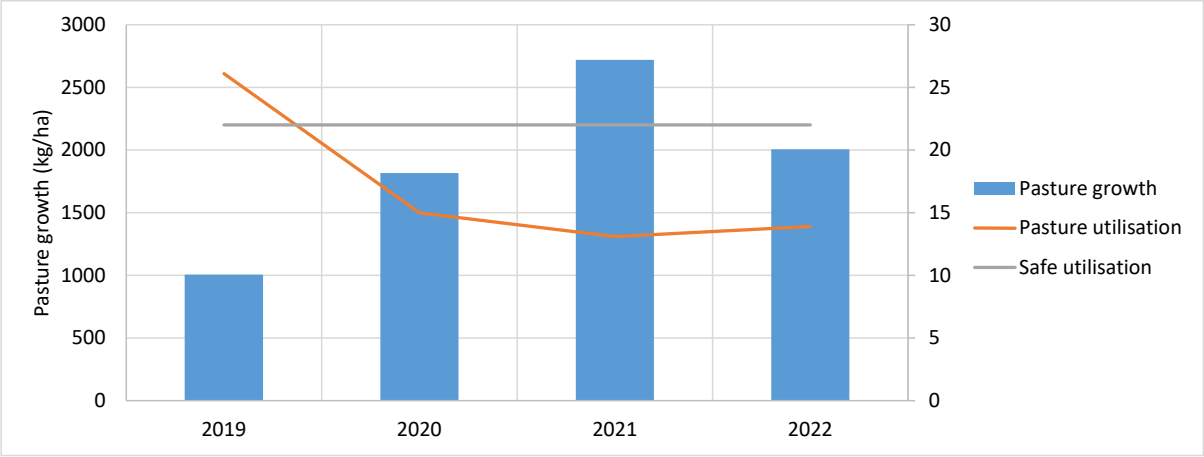


Figure 14-65: Simulated pasture growth and utilisation at Paddock 31, Station 7

Paddock 30

TSDM estimates from this Paddock Power site was based on 7-10 visual estimates by experienced observers taken from across the paddock in 2020 and 2021. These were weighted for distance from water. TSDM and green cover were well simulated by GRASP (Figure 14-66 - Figure 14-67).

Pasture utilisation at the Station 7 site was within safe levels (<20%) for the duration of the breeder herd dataset (Figure 14-68).

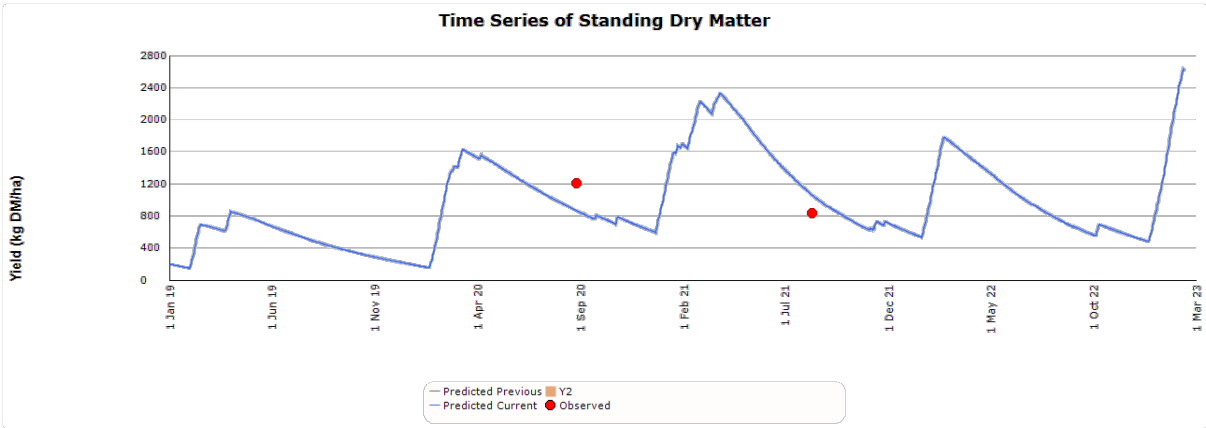


Figure 14-66: Simulated TSDM in Paddock 30, Station 7, (blue line) and observed TSDM observations (red dots)

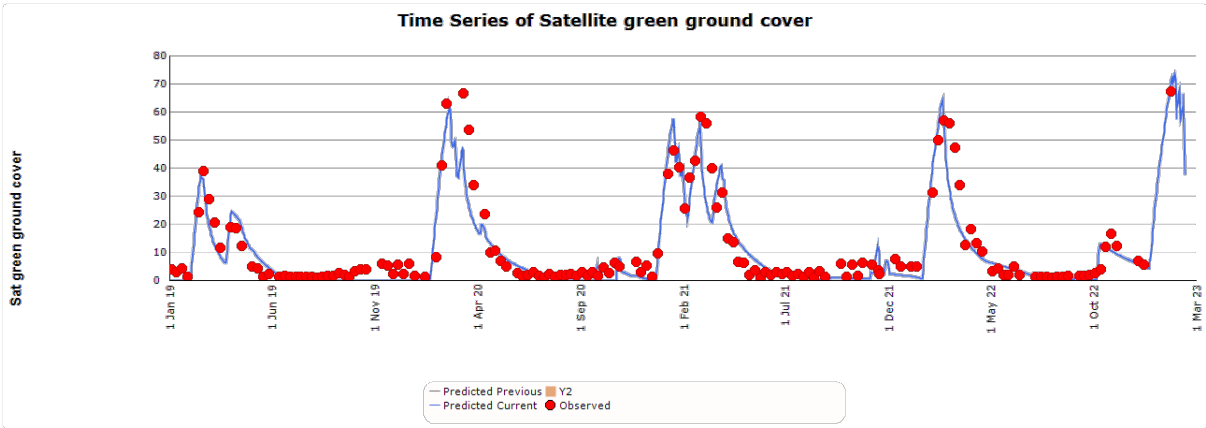


Figure 14-67: Simulated green cover in Paddock 30, Station 7, (blue line) and satellite derived green ground cover observations (red dots)

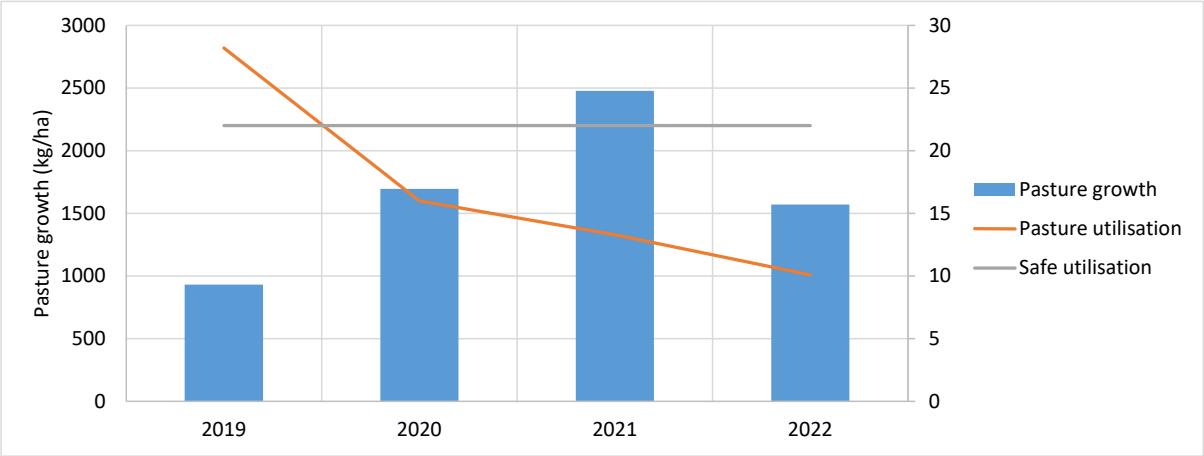


Figure 14-68: Simulated pasture growth and utilisation at Paddock 30, Station 7

Paddock 12

TSDM estimates of this Cash Cow site were a combination of uncalibrated visual estimates by the producer and visual estimates by an experienced observer referencing photo standards of images from photo monitoring sites in the paddock, which were weighted for distance to water. TSDM and green cover were well simulated by GRASP (Figure 14-69 - Figure 14-70). There was a moderately high confidence in modelling assumptions (78%), which will be improved when AEs are recalculated based on site herd performance.

Pasture utilisation at the Station 7 site was within safe levels (<20%) for the duration of the breeder herd dataset between 2009 to 2010 (Figure 14-71).

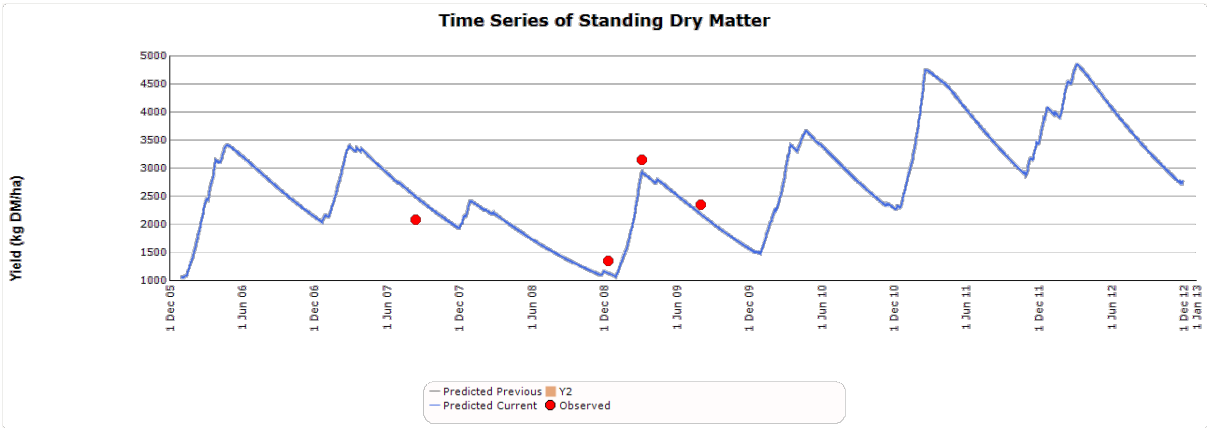


Figure 14-69: Simulated TSDM at Station 7, (blue line) and TSDM observations (red dots)

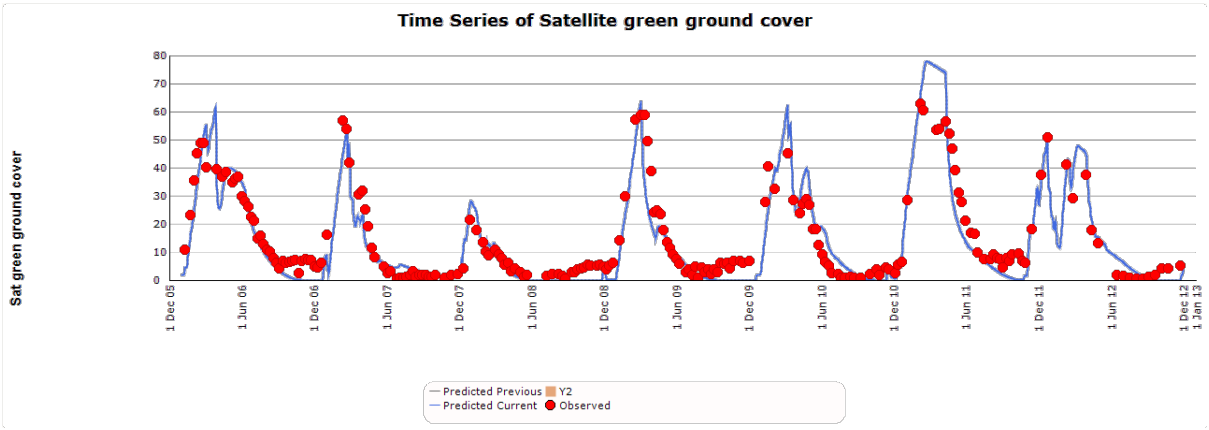


Figure 14-70: Simulated green cover at Station 7, (blue line) and satellite derived green ground cover observations (red dots)

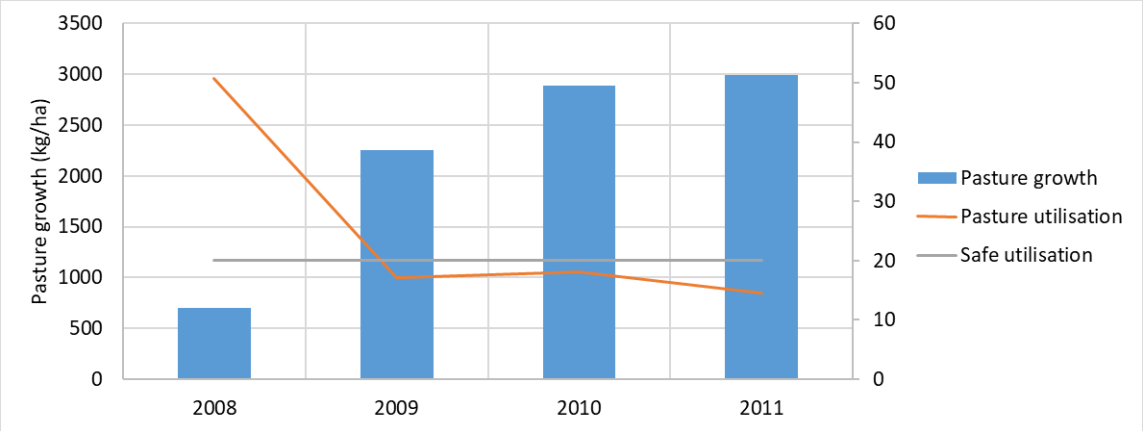


Figure 14-71: Simulated pasture growth and utilisation at Paddock 12, Station 7

14.3.3 Central Queensland

This site was modelled by Giselle Whish with input from Robyn Cowley.

Station CC17M

Station CC17M property is located between Emerald and Aramac bordering the Burdekin and Fitzroy Grazing Land Management regions. Animal and pasture data for the breeder herd on Paddock 11 was collected during the Cash Cow Project 2008-2011 (McGowan *et al.* 2014). Pastures were described as Buffel (*Cenchrus ciliaris*) and Mitchell (*Astrebla* spp.) grass dominant with bauhinia, bendee and dead finish woody vegetation browse. There were uncalibrated visual estimates of TSDM done by the producer at the site, so observations were used more as a guide than deliberately calibrated to (Figure 14-72). Green cover was well simulated at this Buffel and Mitchell grass site (Figure 14-73). This buffel and Mitchell grass pasture is only a moderately productive site, however, the study occurred during a high rainfall period hence pasture growth was also high. The highest stocking rates of any Sweet Spot site (average 31AE/km^2) meant that annual pasture utilisations were above safe levels for this improved pasture land type (27-35%, Figure 14-74). There was a moderate confidence in modelling assumptions (57%).

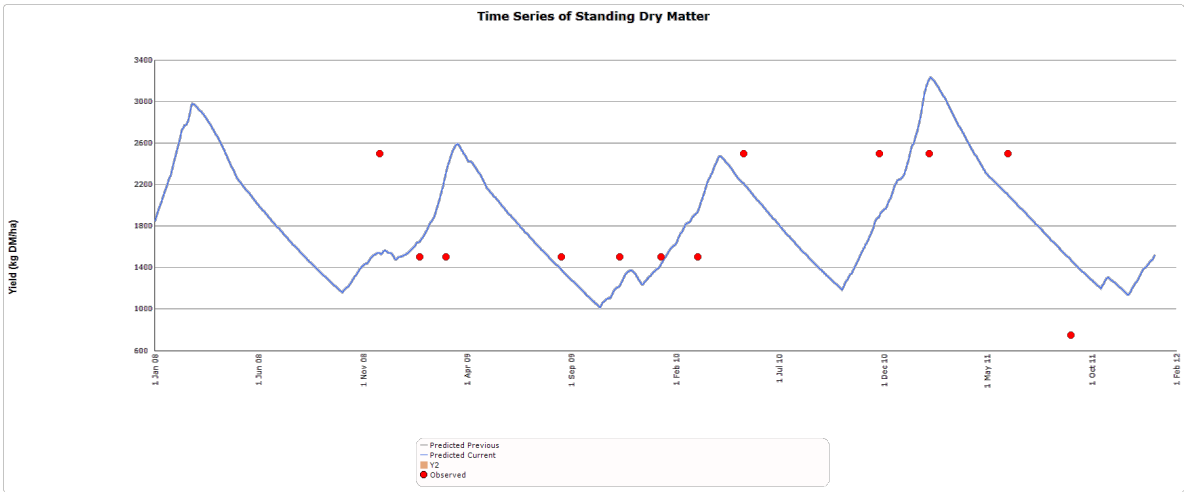


Figure 14-72: Simulated TSDM at Station CC17M, (blue line) and TSDM observations (red dots)

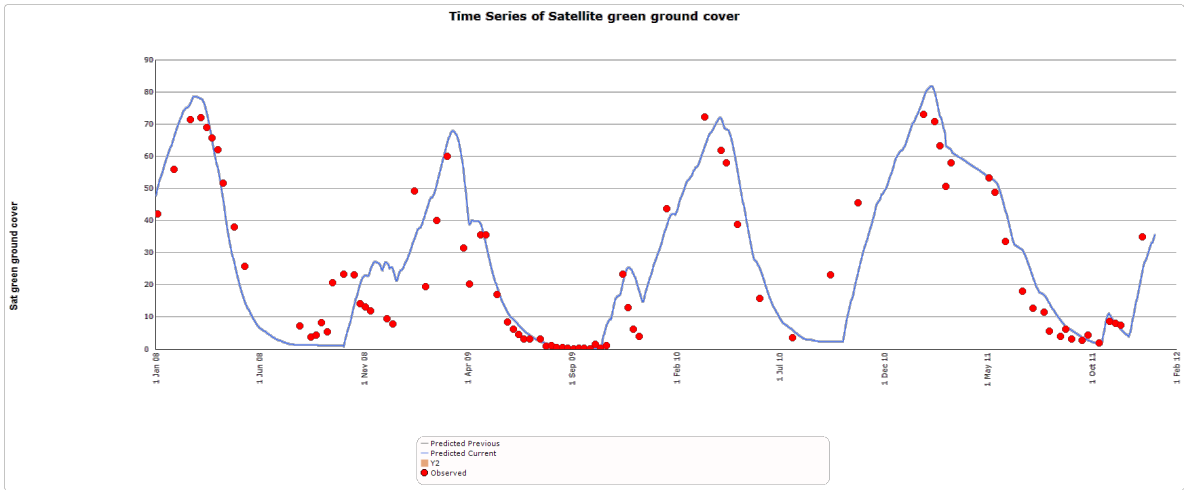


Figure 14-73: Simulated green cover at Station CC17M, (blue line) and satellite derived green ground cover observations (red dots)

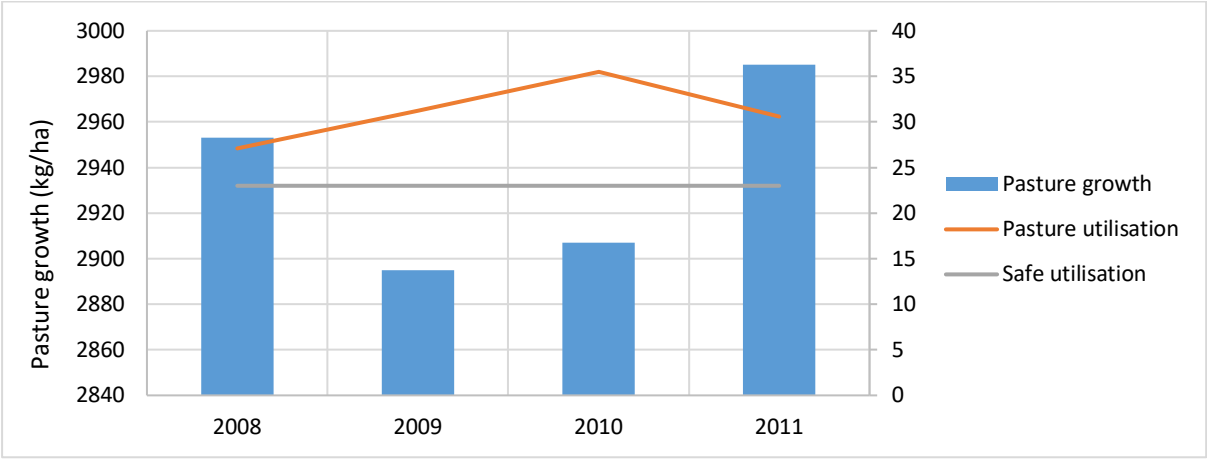


Figure 14-74: Simulated pasture growth and utilisation at Station CC17M

14.3.4 Far North Queensland

All North Queensland sites were modelled by Giselle Whish with input by Robyn Cowley for the Cash Cow sites.

Station CC65M

Station CC65M is located north of Cairns in Cape York near Herbertvale and Laura BOM stations. Animal and pasture data for breeder herd on Paddock 7 End paddock was collected during Cash Cow Project 2008-2011 (McGowan *et al.* 2014). Pastures were described as native Black spear grass (*Heteropogon contortus*) with *Urochloa* grass and Verano and Seca Stylos. There were no calibrated TSDM estimates. There were uncalibrated visual estimates of TSDM done by the producer at the site, so observations were used more as a guide than deliberately calibrated to (Figure 14-724). Green cover was well simulated (Figure). In this low productivity but high rainfall site (median rainfall 972mm), growth was usually nitrogen limited with little inter-annual variation in growth except for very dry years (Figure). Pasture utilisation was consistently higher than assumed safe levels of 15% at around 20%. There was a moderate confidence in modelling assumptions (56%).

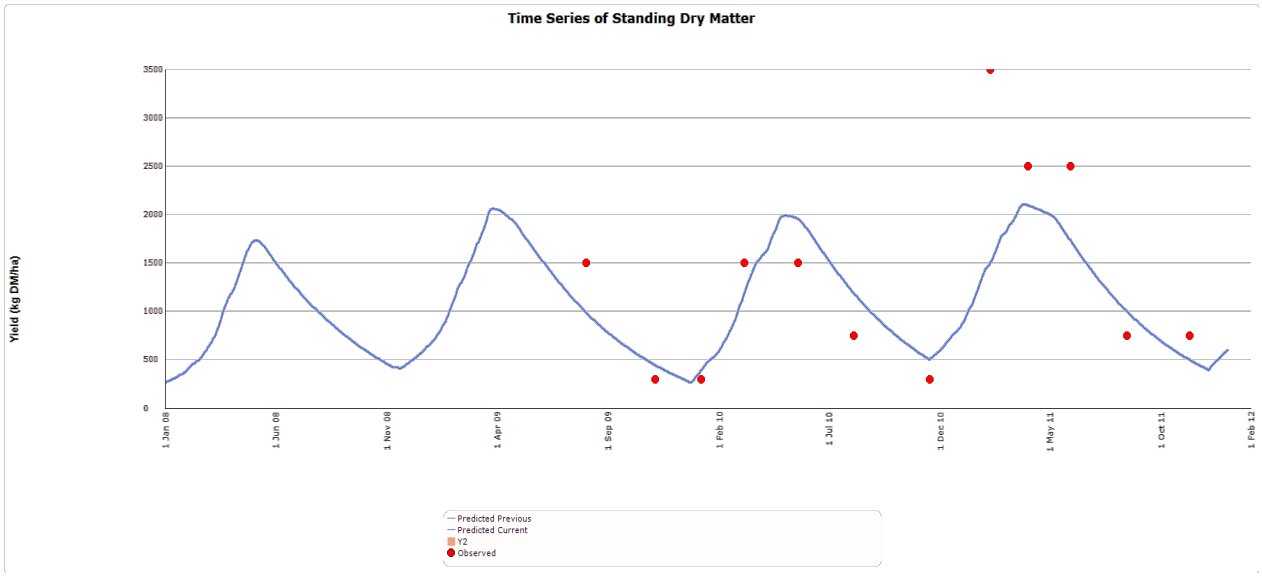


Figure 14-75: Simulated TSDM at Station CC65M, (blue line) and satellite derived green ground cover observations (red dots)

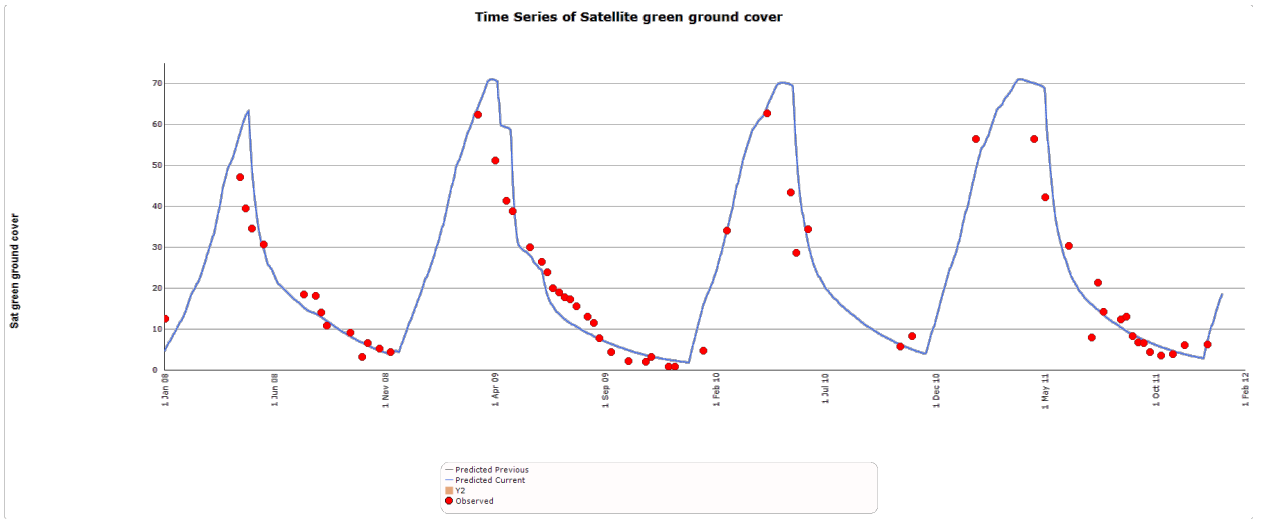


Figure 145: Simulated green cover at Station CC65M, (blue line) and satellite derived green ground cover observations (red dots)

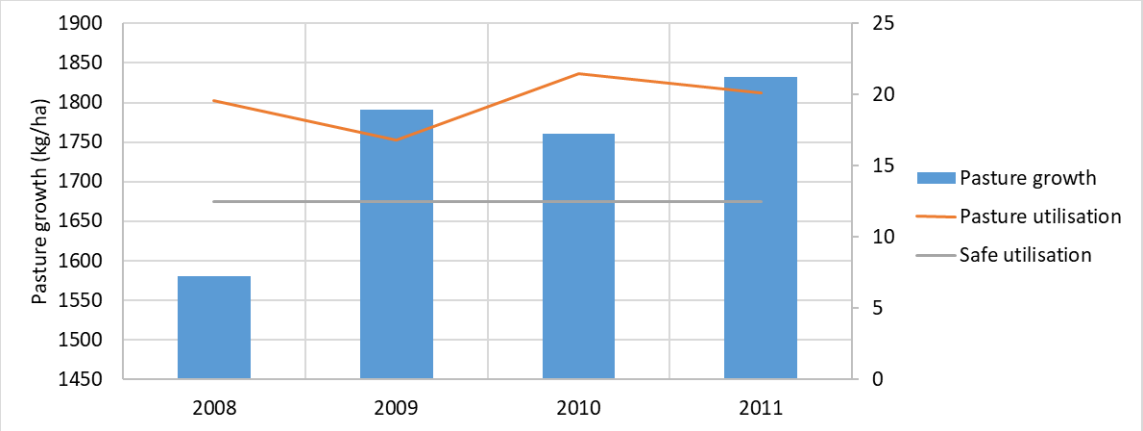


Figure 146: Simulated pasture growth and utilisation at Station CC65M

14.3.5 Katherine Research Station Lease (KRS_Lease)

An example of the modelling process is shown below for Katherine Lease North Queens (NQ) and South Queens (SQ) paddocks (960mm median rainfall) (Figure 14-76). In a tale of two Tippera Tall Grass paddocks, one well and one poorly watered, the stocking rates, pasture growth and utilisation rate outcomes were quite different (Figure 14-80 - Figure 14-84). South Queens was a Cash Cow site from 2008 to 2011 and then used for the NTDAF Senepol and Brahman breeder herds to current day. The North Queens paddock complex was added in 2015 for the Senepol and Brahman herds. Only 38% of South Queens was within 3km of permanent water. A natural semi-permanent waterhole increased the watered area to 100% when available, but the proportion of the year that it was available varied annually from only a couple of months to up to 9 months, and there was uncertainty about how much it contributed to watered area in the paddock in a typical year. We assumed it was available for 9 months of the year, so the stocking rates and utilisation are a conservative estimate and may have been higher if the semipermanent water was available for less of the year. Even with this generous assumption of semipermanent water availability in South Queens, stocking rates within the watered area (all of the area within 3km and half the area within 3 to 5km) were higher than for North Queens (Figure 14-77). (Note that North Queens was not used by NTDAF until 2015, so stocking rates prior to this are a conservative estimate.) North Queens had more fires, lower tree cover (Figure 14-78), higher grass basal area (Figure 14-79) and higher growth (Figure 14-83) than South Queens. The combined impacts of higher stocking rates and lower growth of south Queens led to higher intake and pasture utilisation (Figure 14-82 - Figure 14-84).

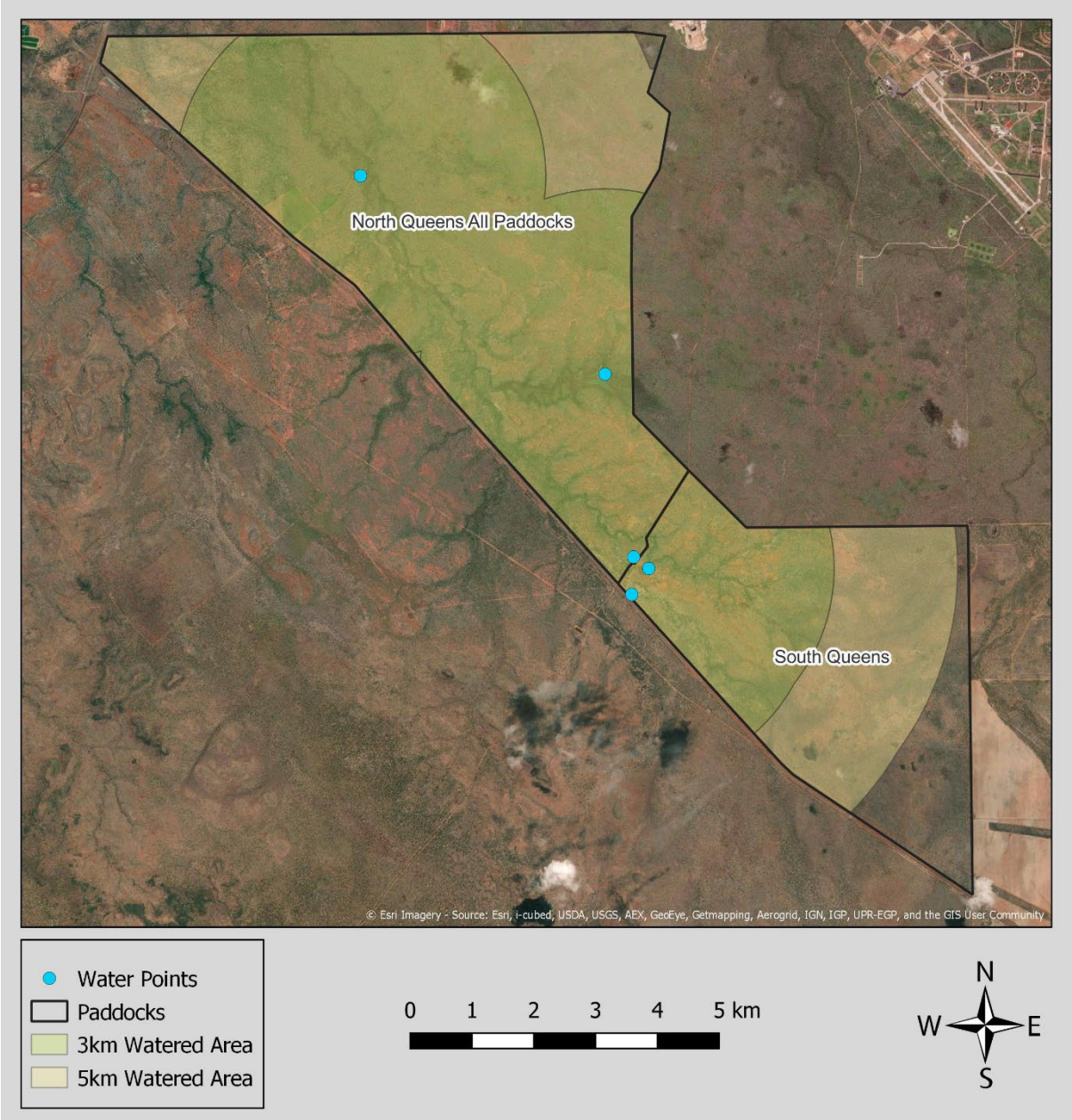


Figure 14-76: KRS Lease Paddocks

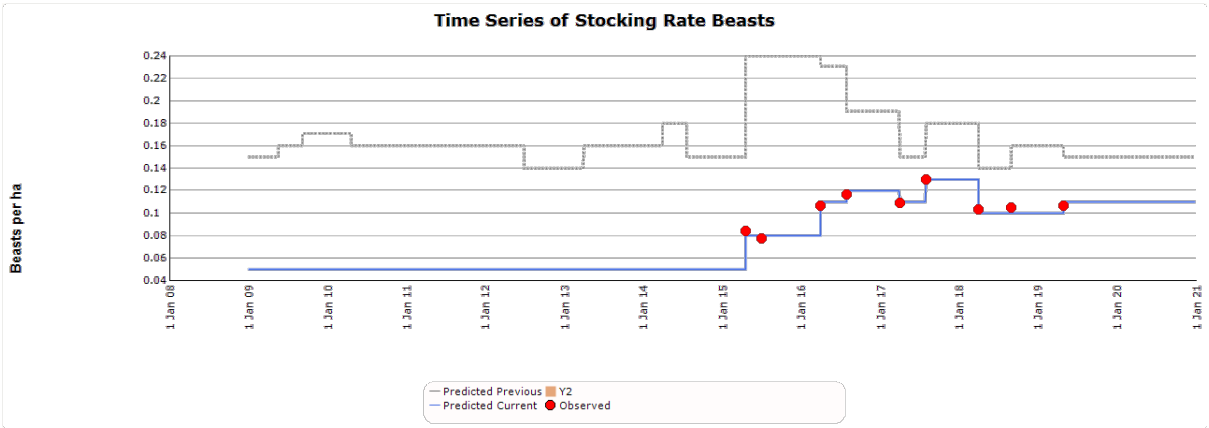


Figure 14-77: Stocking rate within watered area at North (blue line) and South (dashed line) Queens paddocks. Red dots are stocking rate observations for North Queens

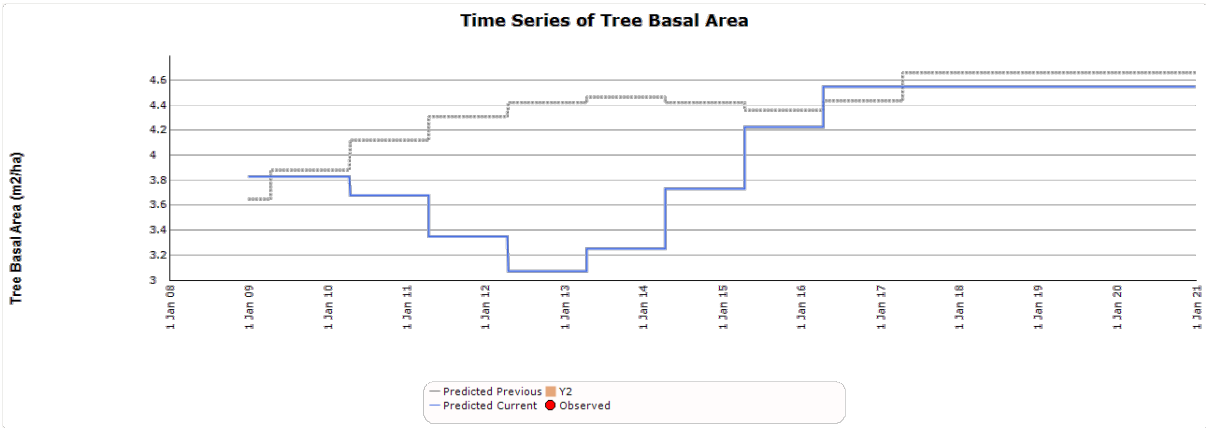


Figure 14-78: Tree basal area at North (blue line) and South (dashed line) Queens paddocks. Derived from satellite persistent green observations

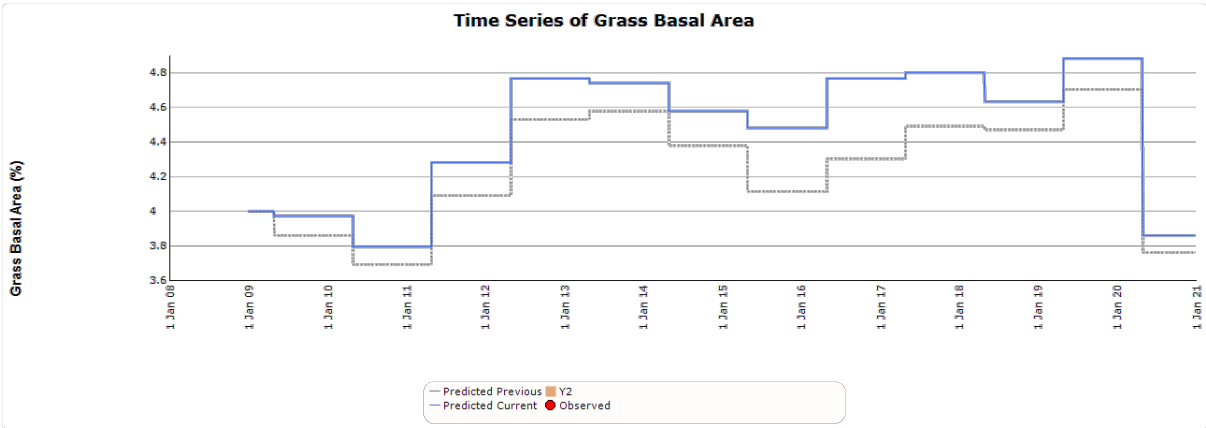


Figure 14-79: Simulated grass basal area at North (blue line) and South (dashed line) Queens paddocks

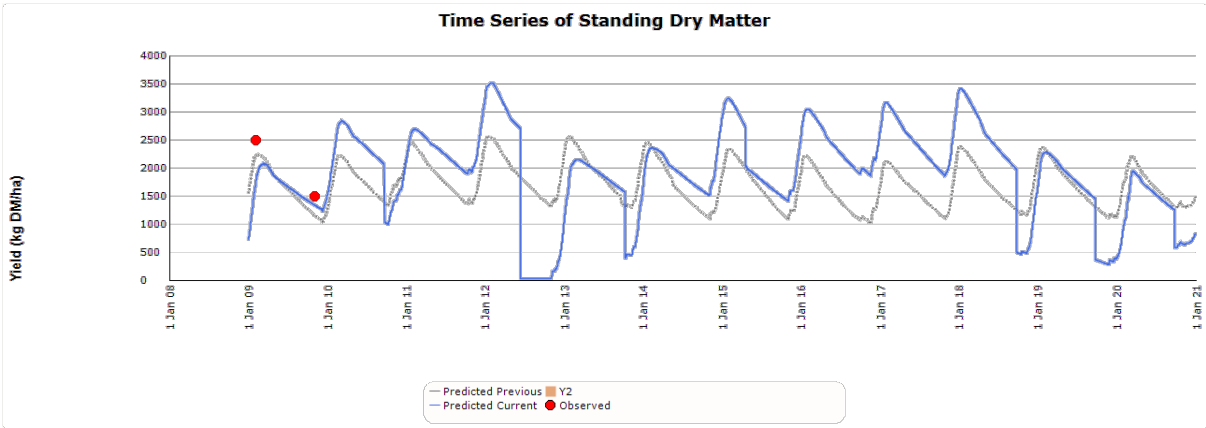


Figure 14-80: Simulated total standing dry matter at North (blue line) and South (dashed line) Queens paddocks. Red dots are uncalibrated yield observations

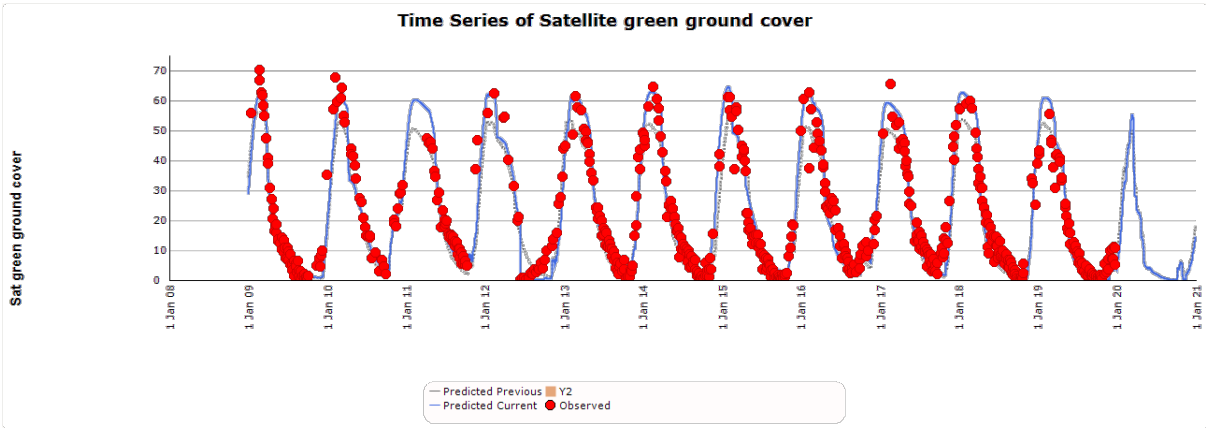


Figure 14-81: Simulated green cover at North (blue line) and South (dashed line) Queens paddocks. Red dots are satellite derived green ground cover observations

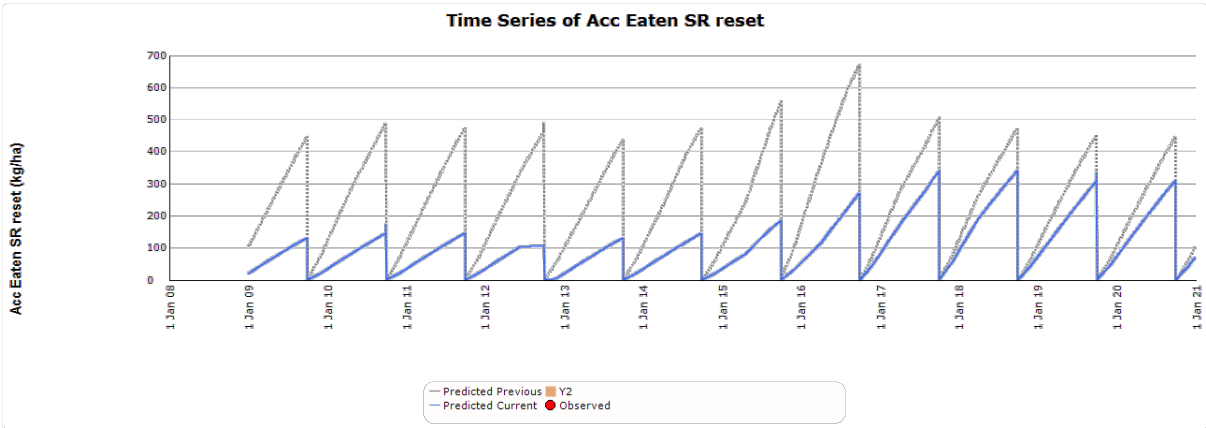


Figure 14-82: Simulated intake by cattle at North (blue line) and South (dashed line) Queens paddocks

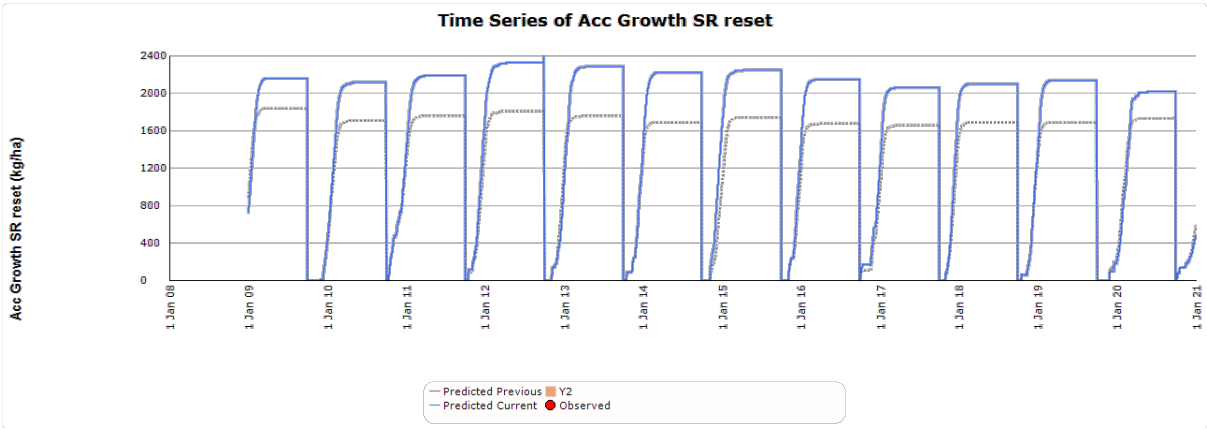


Figure 14-83: Simulated pasture growth at North (blue line) and South (dashed line) Queens paddocks

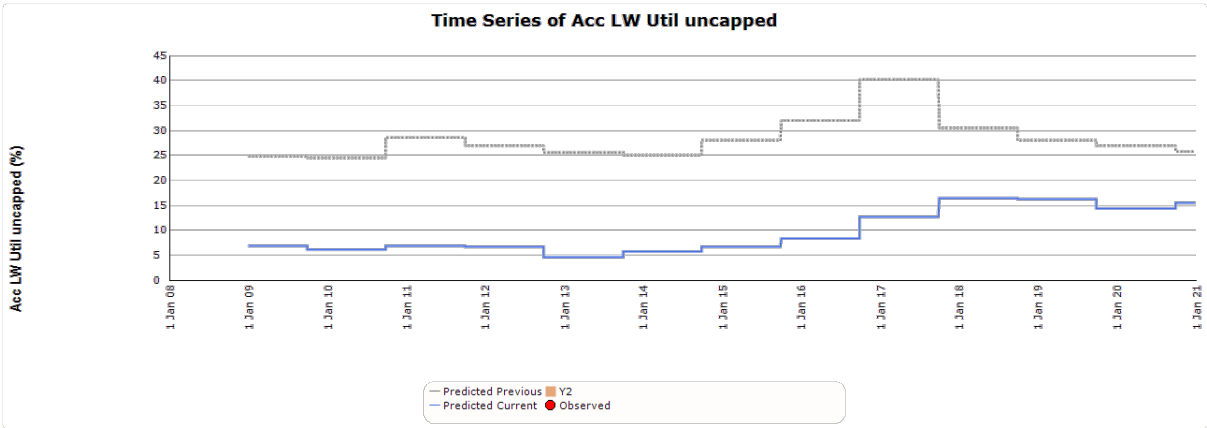


Figure 14-84: Simulated pasture utilisation at North (blue line) and South (dashed line) Queens paddocks

14.3.6 North Queensland

Station CC05M

Station CC05M property is located between Ayr and Bowen in the Burdekin Grazing Land Management region. Animal and pasture data for breeder herd on Paddock 8 was collected during Cash Cow Project 2008-2011 (McGowan *et al.* 2014). Pastures were described as black spear grass (*Heteropogon contortus*) and kangaroo grass (*Themeda triandra*) with Indian couch (*Bothriochloa pertusa*) and Verano and Seca Stylos. There were uncalibrated visual estimates of TSDM done by the producer at the site, but additional pasture yields were collected during 2018-2020 from two other Indian couch dominated paddocks from Station CC05M property. Combined, they guided the calibration of TSDM at Paddock 8, although they were not calibrated to (Figure 14-85). Green cover was moderately well simulated (Figure 14-86). There was a moderately high confidence in modelling assumptions (69%). Simulated pasture growth was nutrient limited at this high rainfall site (rainfall median 781mm, average during study 1138mm) and did not vary year to year. All variation in utilisation was due to fluctuating intake with varying stocking rate (24-32AE/km^2) (Figure 14-87). Utilisation was always higher than recommended levels.

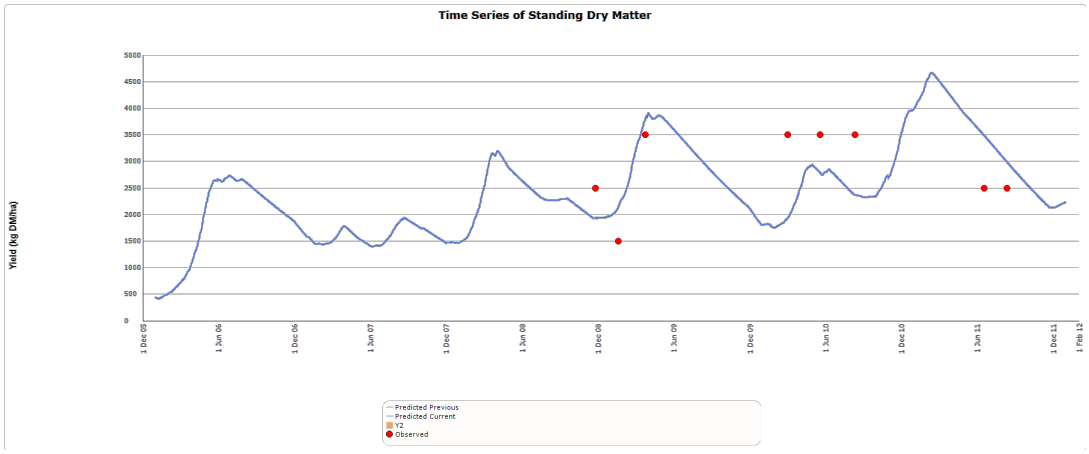


Figure 14-85: Simulated TSDM at Station CC05M, (blue line) and TSDM observations (red dots)

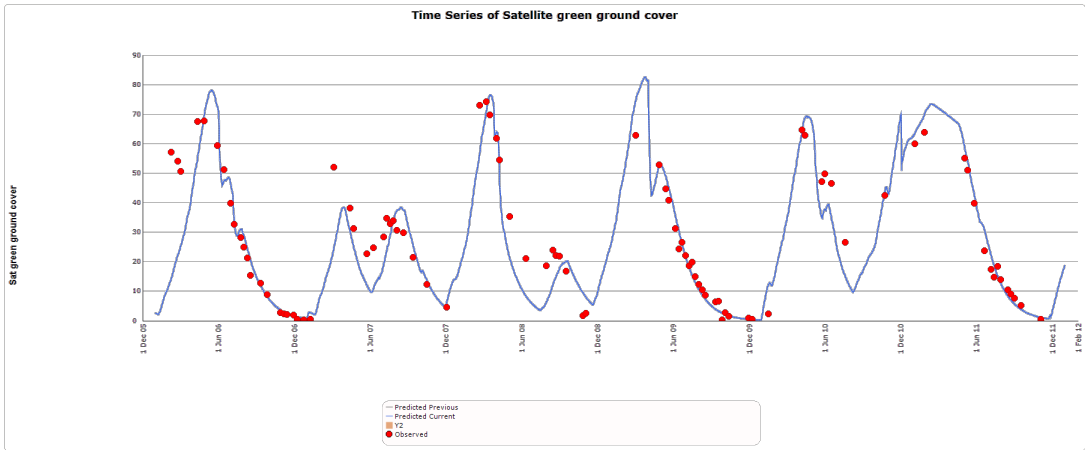


Figure 14-86: Simulated green cover at Station CC05M, (blue line) and satellite derived green ground cover observations (red dots)

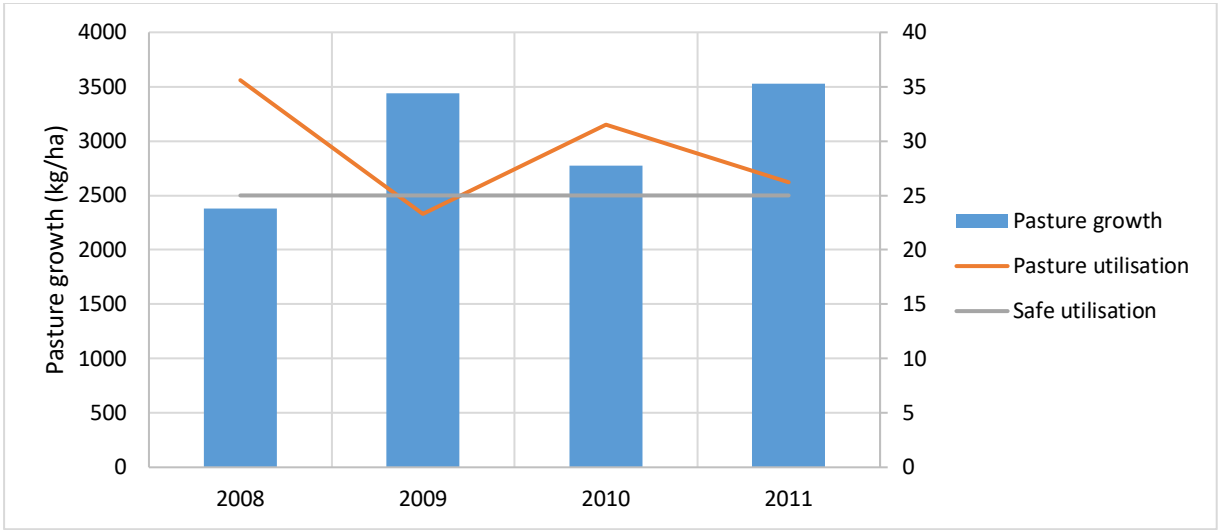


Figure 14-87: Simulated pasture growth and utilisation at Station CC05M

Swan's Lagoon

Swan's Lagoon property is located in the subcoastal spear grass region of the Burdekin Grazing Land Management region. Pastures are dominated by Black spear grass (*Heteropogon contortus*), Golden beard grass (*Chrysopogon fallax*), wiregrasses (*Aristida* spp.) and Indian couch (*Bothriochloa pertusa*). Animal and pasture data for breeder herds on Allingham, Burns, Holroyd and Sandalwood paddocks were collected during Northern Stocking Rate Demonstration Project 1994-1999 (Figure 14-88).

Calibrated TSDM at this stocking rate demonstration was well simulated by GRASP (Figure 14-89, Figure 14-93, Figure 14-97, Figure 14-101). Rainfall was close to the long-term median during the study, although rain was below to well-below median in first years of study and well-above in the last three years of study. Green cover was moderately well simulated by GRASP (Figure 14-90, Figure 14-94, Figure 14-98, Figure 164). There was a high confidence in modelling assumptions (75-78%). There was a wide range in pasture utilisation at Swans Lagoon (between 20 and 54% across all the paddocks and years, Figure 14-92, Figure 14-96, Figure 14-100, Figure 14-104) which is suited to find thresholds for optimal breeder performance.

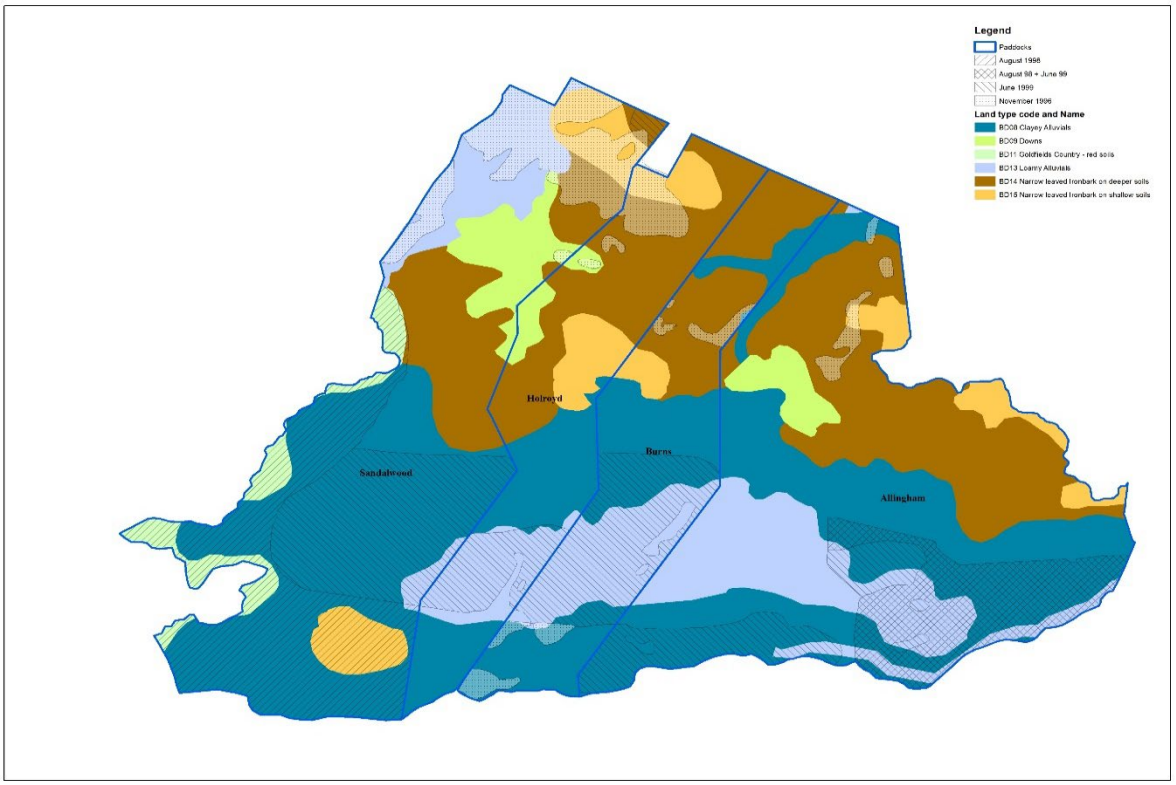


Figure 14-88: Map of Swans Lagoon stocking rate demonstration sites

Allingham - continuous set stocking

Pasture utilisation was close to recommended levels at the continuous set stocked Allingham Paddock (Figure 14-92).

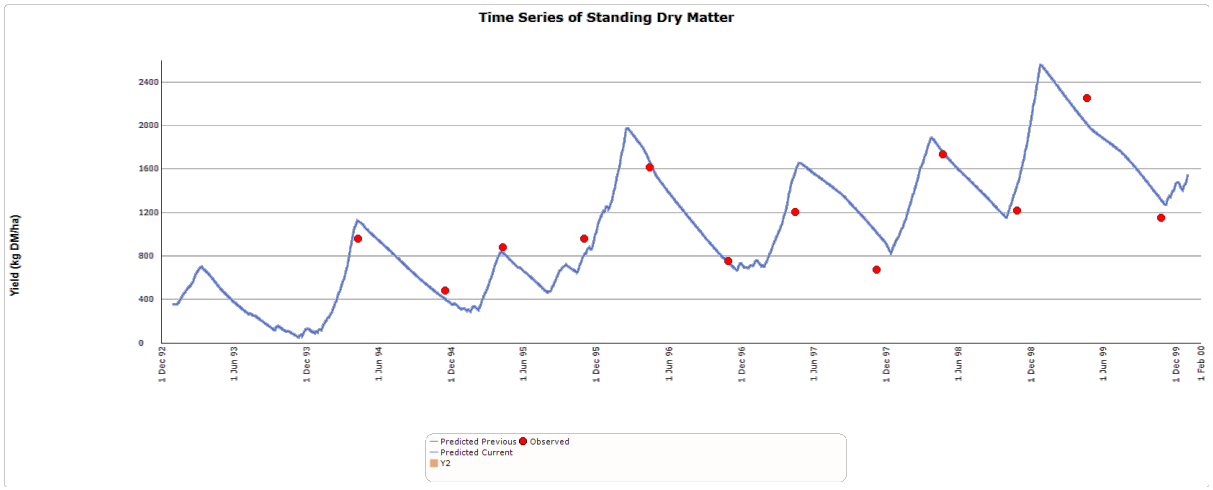


Figure 14-89: Simulated TSDM at Allingham Paddock, Swans Lagoon, (blue line) and TSDM observations (red dots)

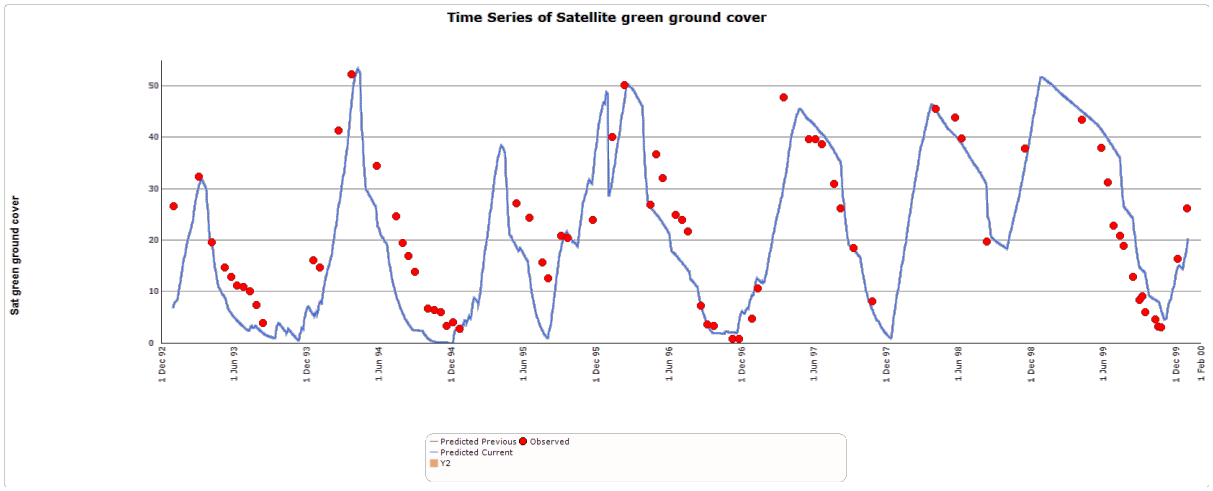


Figure 14-90: Simulated green cover at Allingham Paddock, Swans Lagoon (blue line) and satellite derived green ground cover observations (red dots)

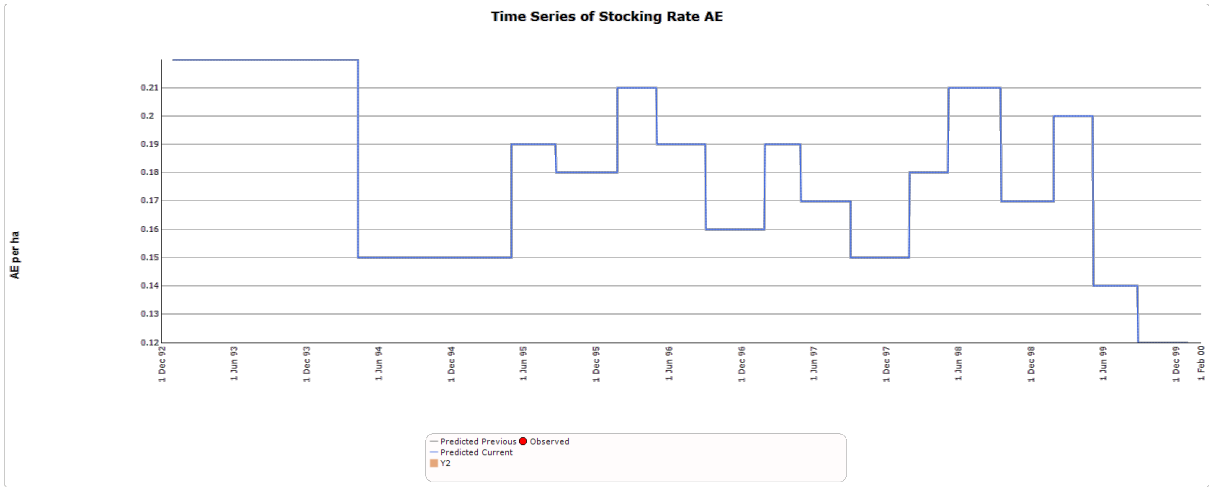


Figure 14-91: Stocking rate during the stocking rate demonstration at Allingham Paddock, Swans Lagoon

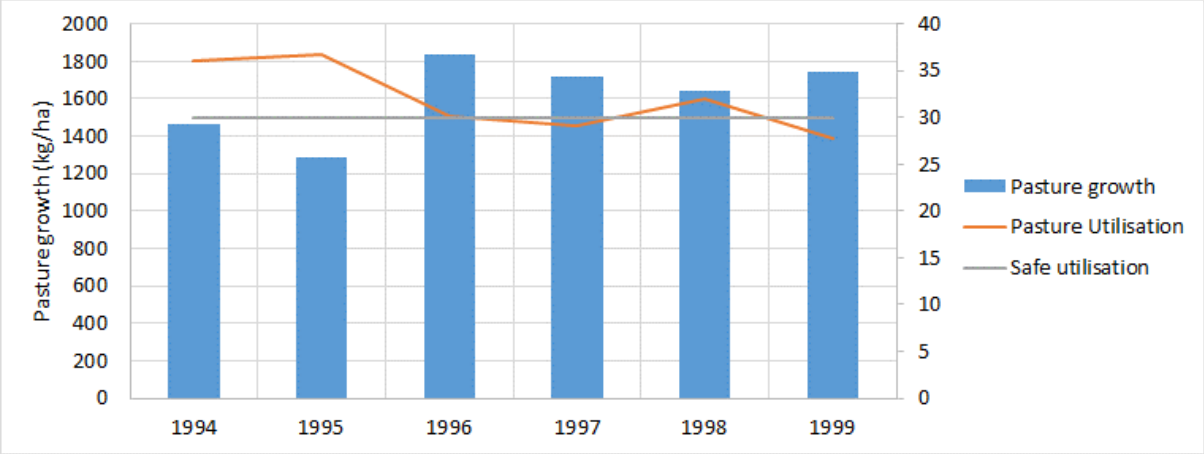


Figure 14-92: Simulated pasture growth and utilisation at Allingham Paddock, Swans Lagoon

Burns - continuous variable stocking

Pasture utilisation was always slightly higher than recommended levels at the continuous variable stocked Burns Paddock (Figure 14-96).

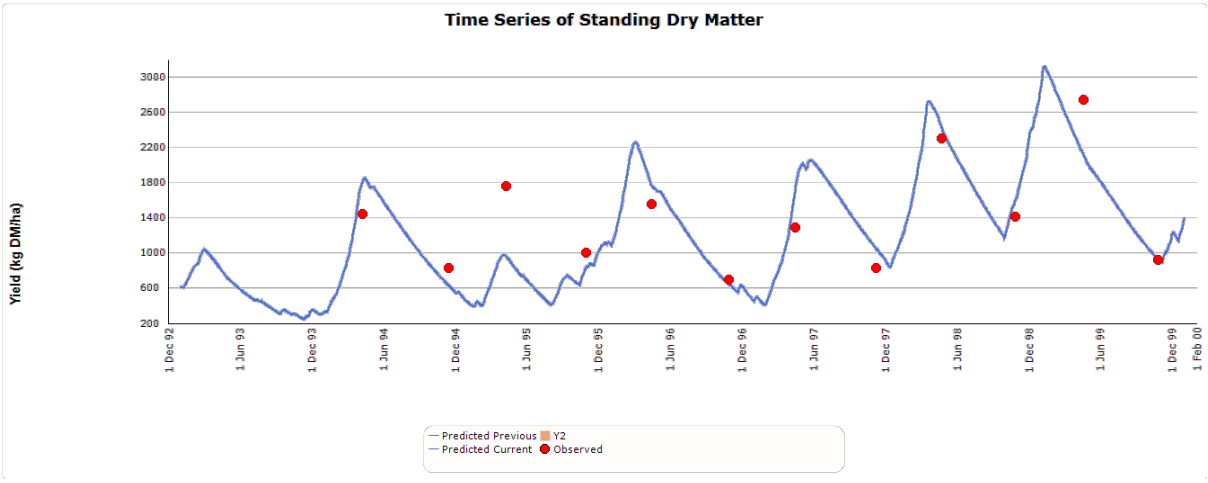


Figure 14-93: Simulated TSDM at Burns Paddock, Swans Lagoon, (blue line) and TSDM observations (red dots)

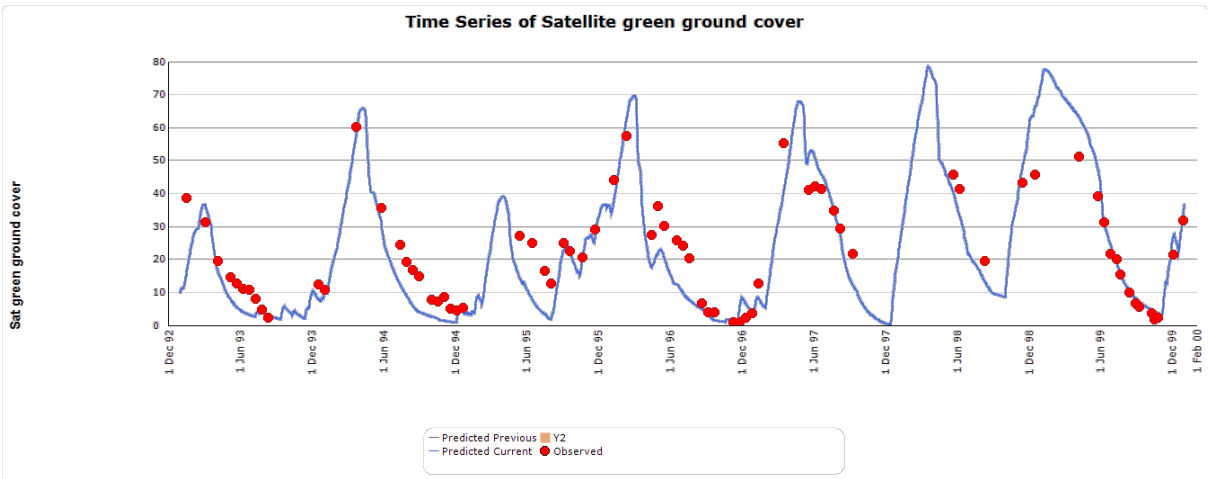


Figure 14-94: Simulated green cover at Burns Paddock, Swans Lagoon (blue line) and satellite derived green ground cover observations (red dots)

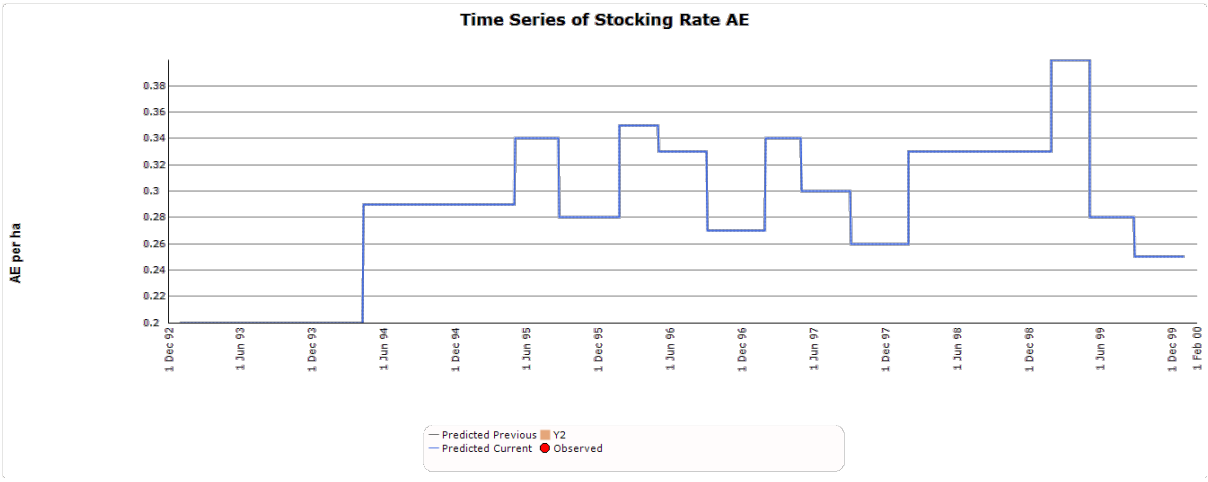


Figure 14-95: Stocking rate during the stocking rate demonstration at Burns Paddock, Swans Lagoon

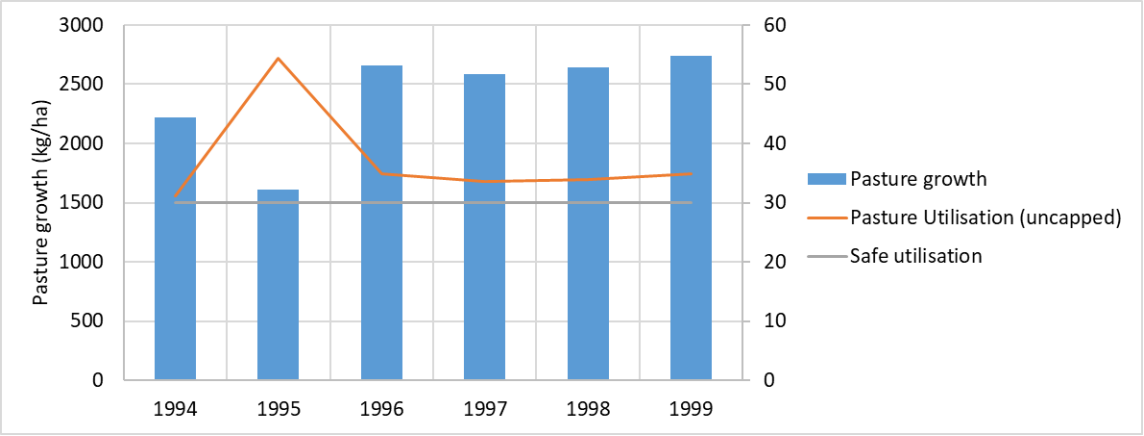


Figure 14-96: Simulated pasture growth and utilisation at Burns Paddock, Swans Lagoon

Holroyd - continuous set high stocking

Pasture utilisation was always higher and up to double recommended levels with continuous set high stocking at Holroyd Paddock (Figure 14-100).

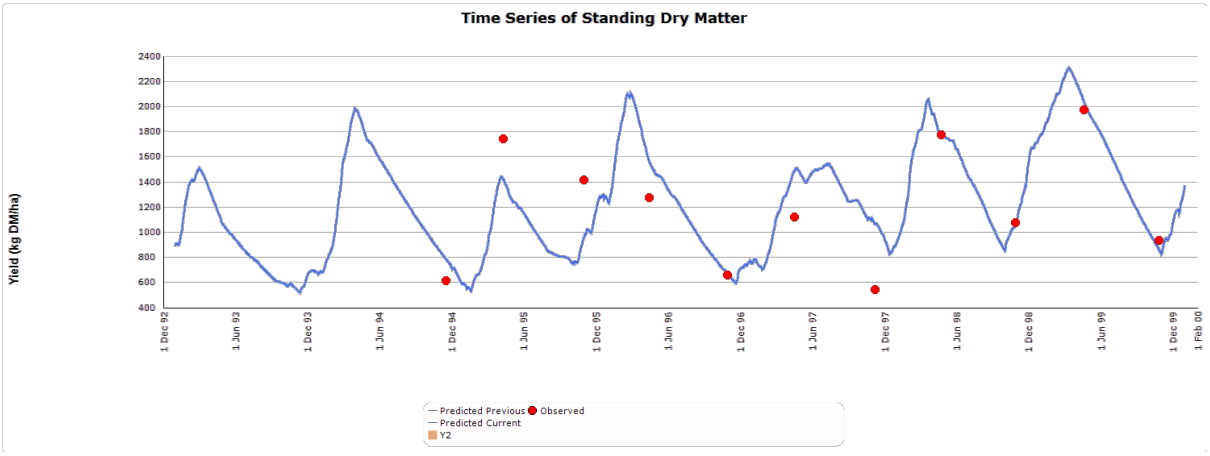


Figure 14-97: Simulated TSDM at Holroyd Paddock, Swans Lagoon, (blue line) and TSDM observations (red dots)

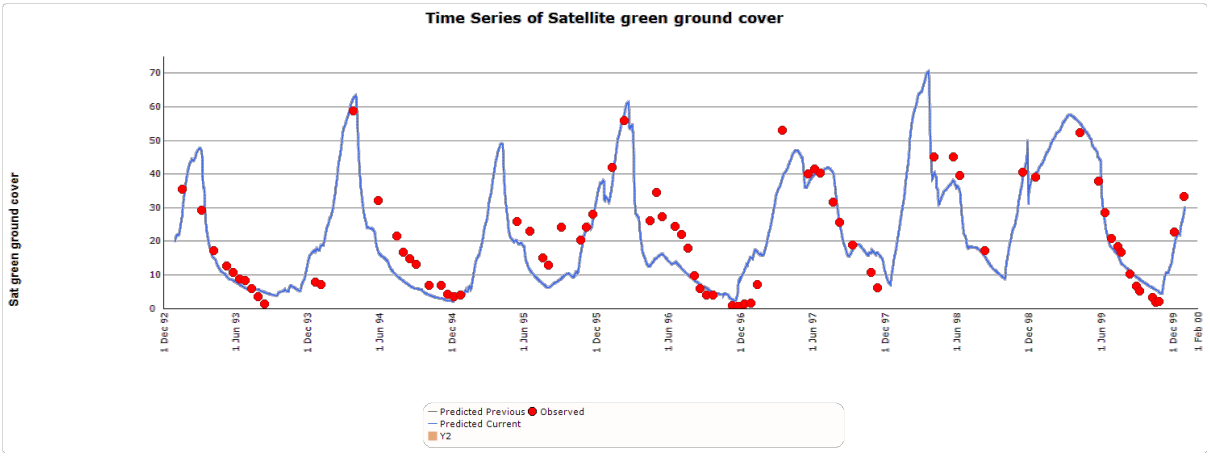


Figure 14-98: Simulated green cover at Holroyd Paddock, Swans Lagoon (blue line) and satellite derived green ground cover observations (red dots)

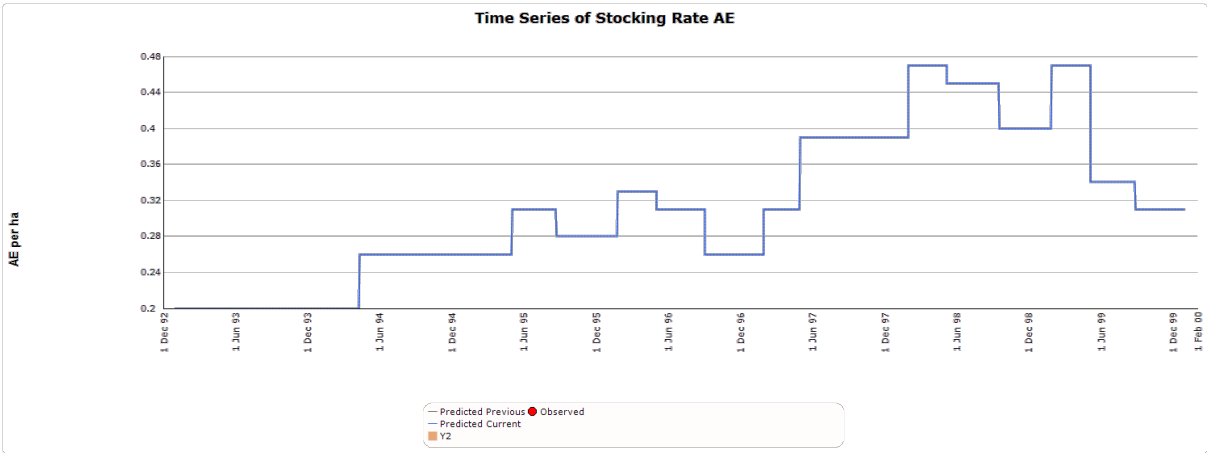


Figure 14-99: Stocking rate during the high stocking rate demonstration at Holroyd Paddock, Swans Lagoon

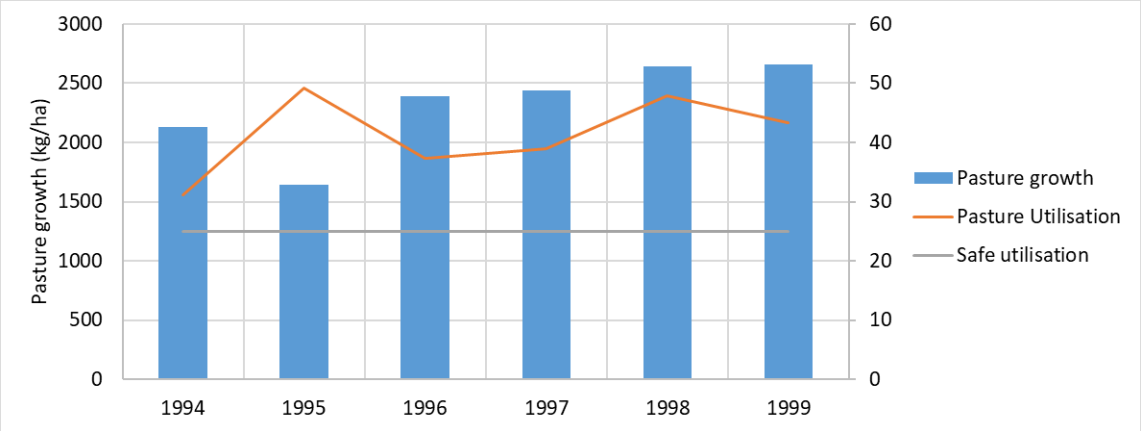


Figure 14-100: Simulated pasture growth and utilisation at Holroyd Paddock, Swans Lagoon

Sandalwood - continuous set stocking

Pasture utilisation was close to or less than recommended levels at the continuous set stocked Sandalwood Paddock (Figure 14-104).

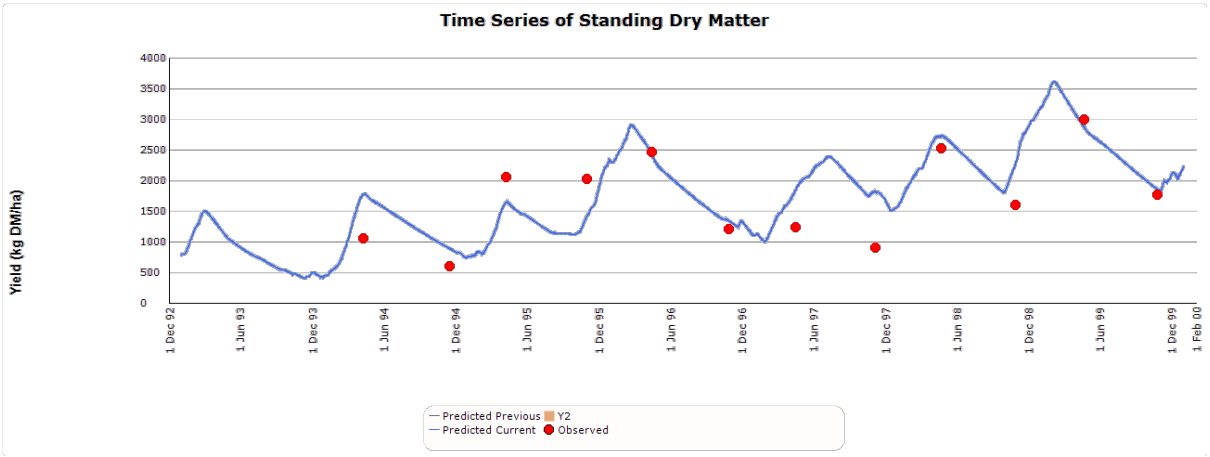


Figure 14-101: Simulated TSDM at Sandalwood Paddock, Swans Lagoon, (blue line) and TSDM observations (red dots)

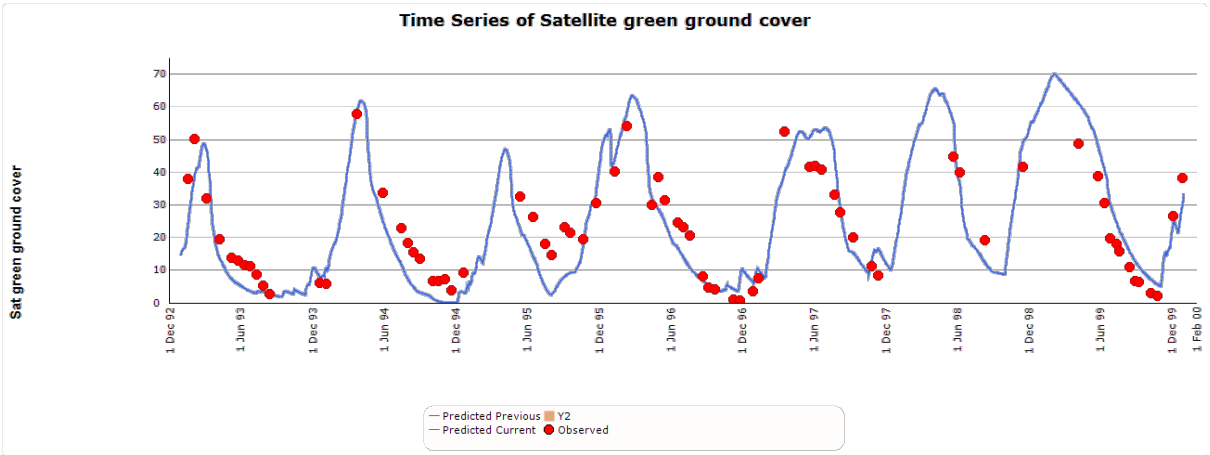


Figure 14-102: Simulated green cover at Sandalwood Paddock, Swans Lagoon (blue line) and satellite derived green ground cover observations (red dots)

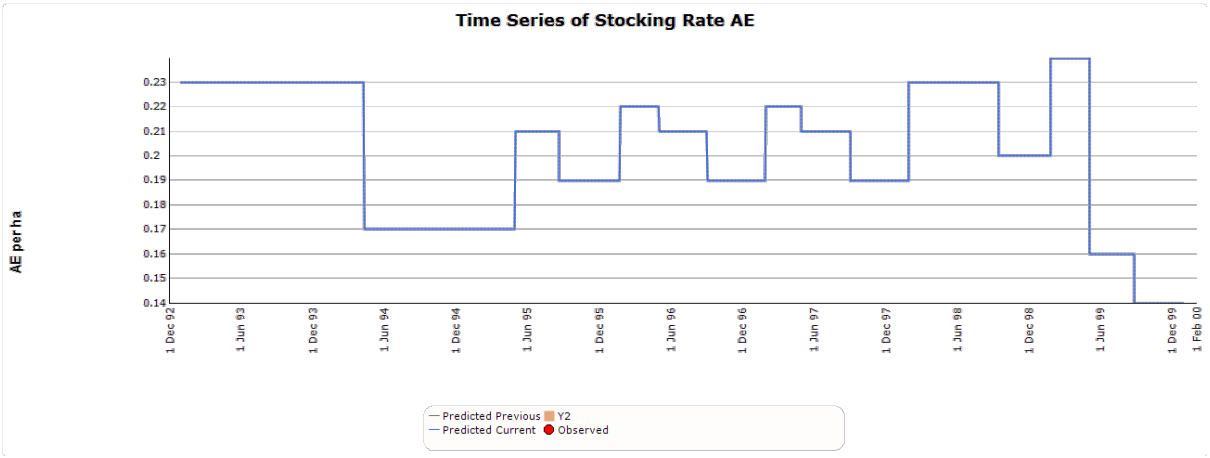


Figure 14-103: Stocking rate during the stocking rate demonstration at Sandalwood Paddock, Swans Lagoon

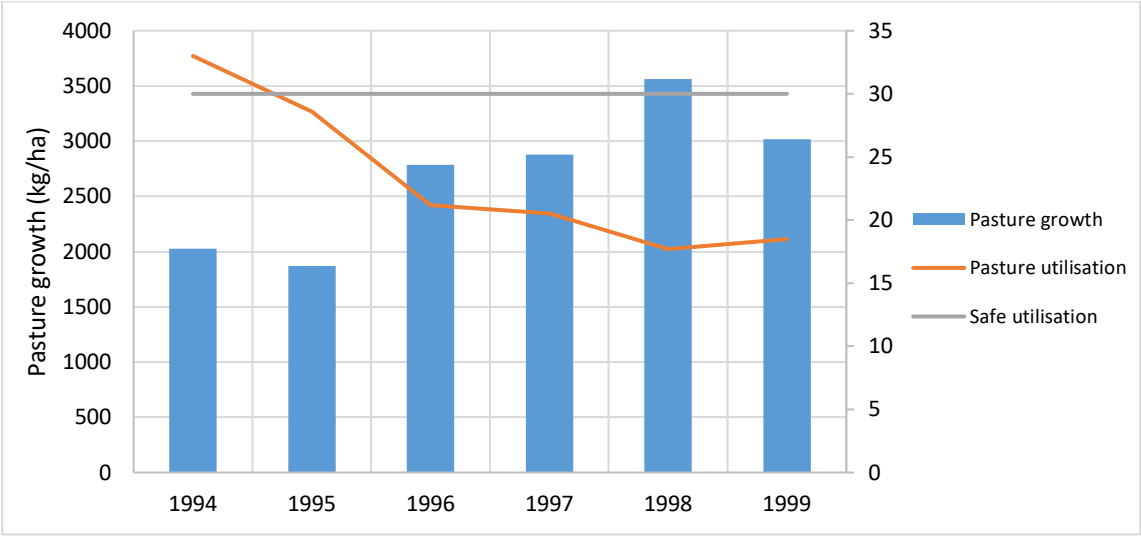


Figure 14-104: Simulated pasture growth and utilisation at Sandalwood Paddock, Swans Lagoon

Thalanga

Thalanga property is located near Balfes Creek 55 km west of Charters Towers in the Burdekin Grazing Land Management region. Animal and pasture data for breeder herds on Dingo, JSW and Toms/Fiat paddocks were collected during Northern Stocking Rate Demonstration Project 1994-1999 (Figure 14-105). The subcoastal spear grass pastures were dominated by Golden beard grass Black spear grass (*Heteropogon contortus*), (*Chrysopogon fallax*) and wiregrasses (*Aristida* spp.).

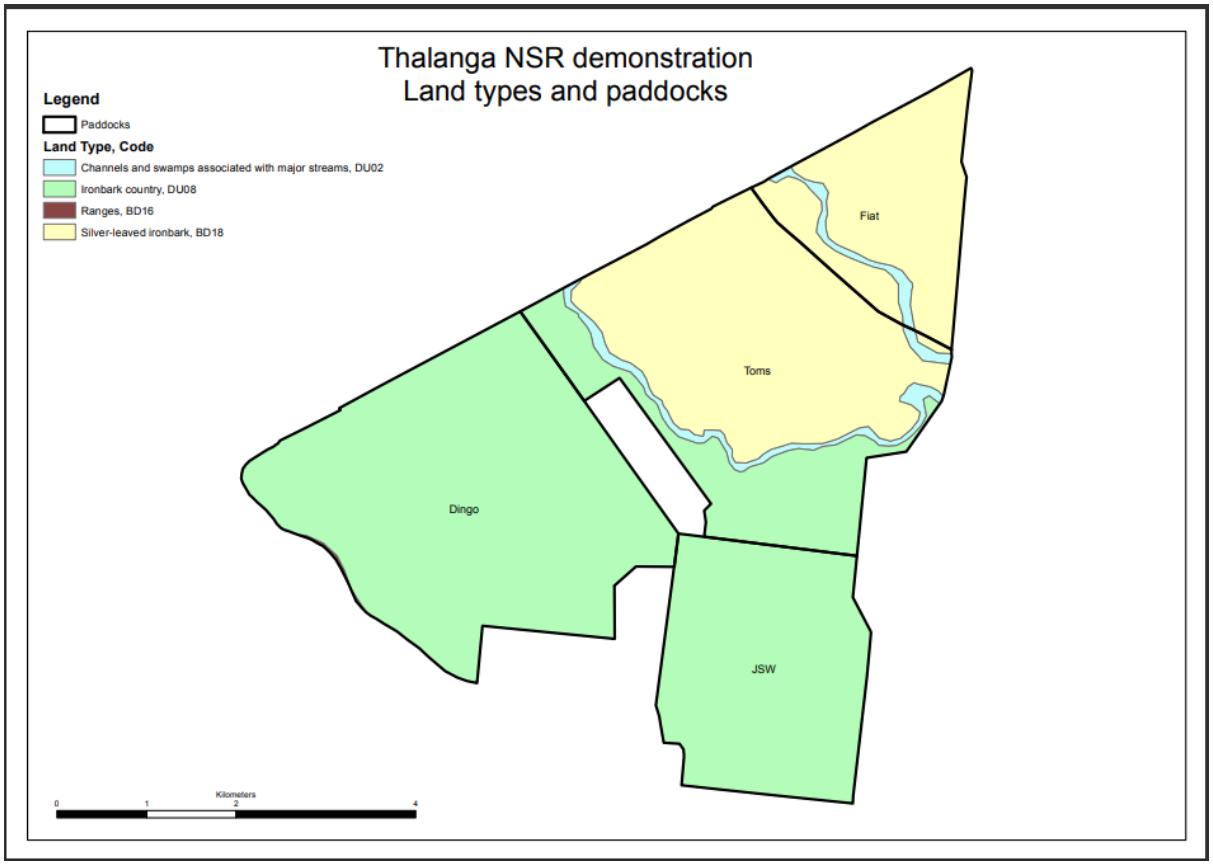


Figure 14-105: Thalanga stocking rate demonstration

Calibrated TSDM was well simulated by GRASP (Figure 14-107, Figure 14-111, Figure 14-115). Green cover was moderately well simulated by GRASP (Figure 14-108, Figure 14-112, Figure 14-116). There was a high confidence in modelling assumptions (78%).

Rainfall was lower than the long-term average during the study (Figure 14-106) which led to destocking even in the continuously set stocked treatments (Figure 14-109, Figure 14-113, Figure 14-117). There was a very wide range in pasture utilisation at Thalanga between 4 and 113% across all the paddocks and years (Figure 14-110, Figure 14-114, Figure 14-118) which provided a good range to detect thresholds for optimal breeder performance. Across all treatments simulated pasture utilisation was higher than recommended for the first three years and then close to or lower than recommended for the last three years.

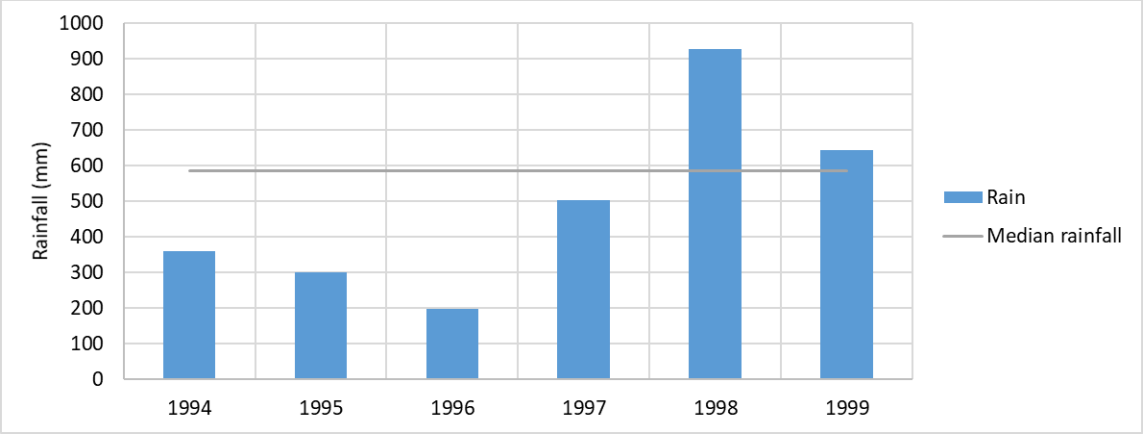


Figure 14-106: Rainfall during the Thalanga stocking rate demonstration

Dingo - continuous set stocking

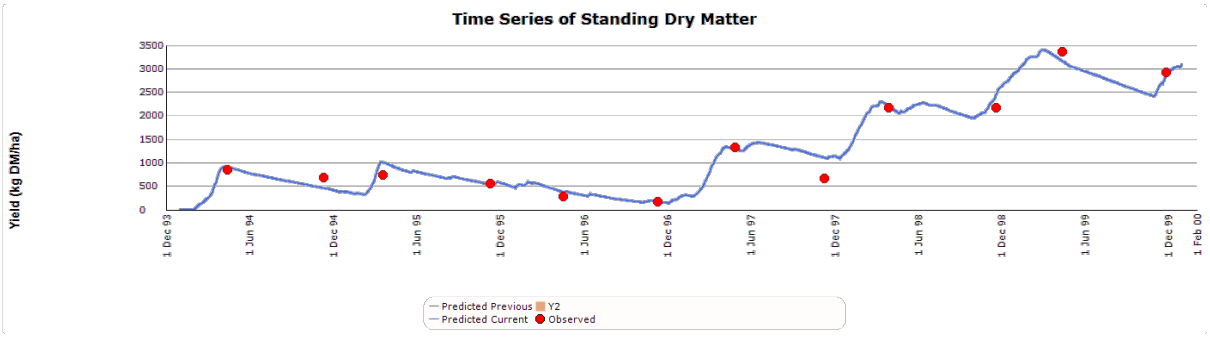


Figure 14-107: Simulated TSDM at Dingo Paddock, Thalanga, (blue line) and TSDM observations (red dots)

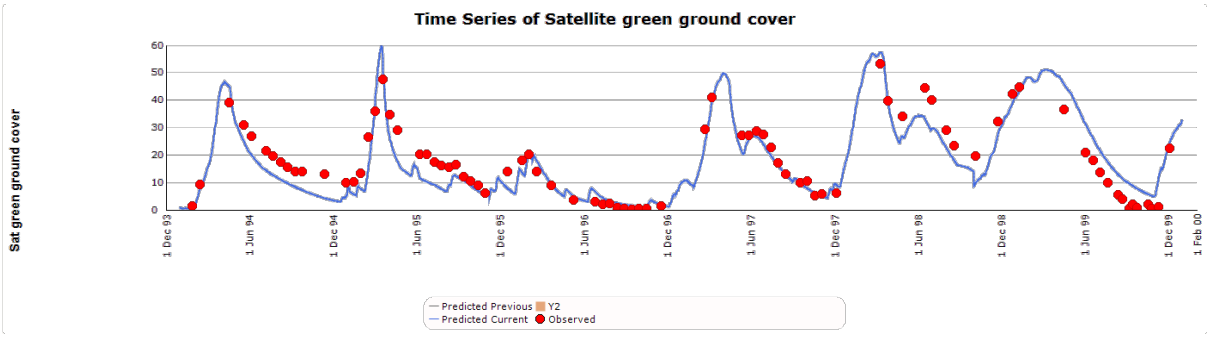


Figure 14-108: Simulated green cover at Dingo Paddock, Thalanga (blue line) and satellite derived green ground cover observations (red dots)

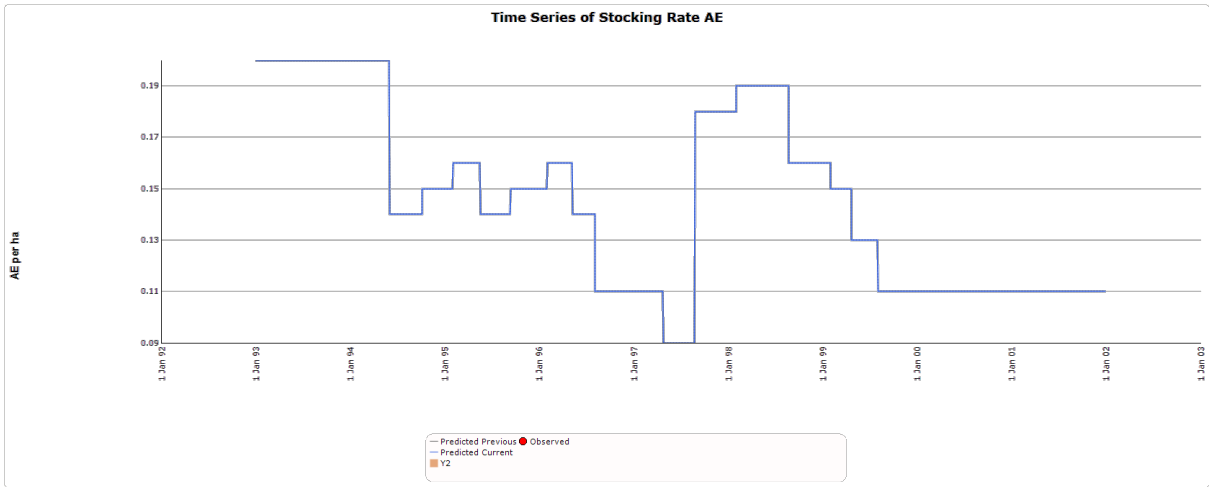


Figure 14-109: Stocking rate during the stocking rate demonstration at Dingo Paddock, Thalanga

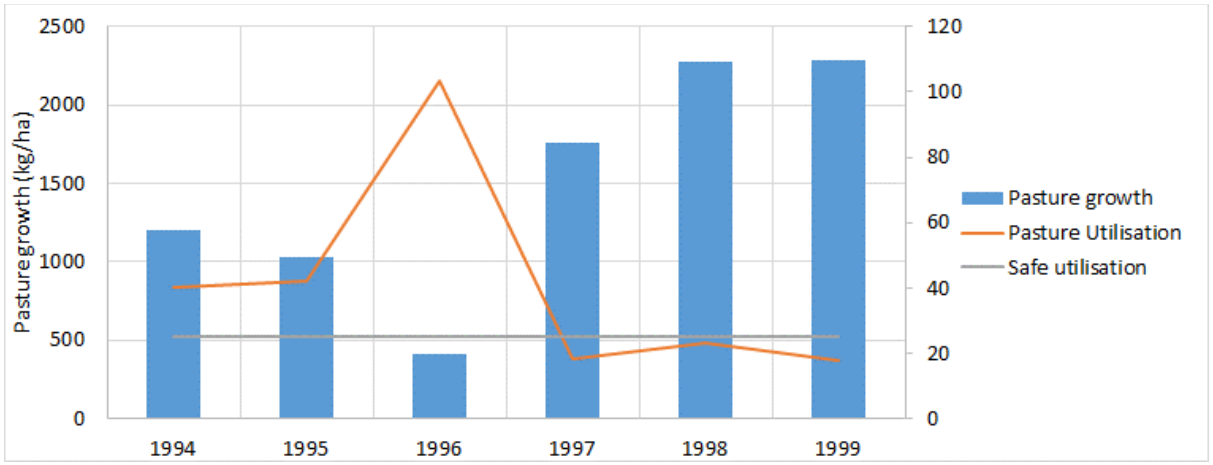


Figure 14-110: Simulated pasture growth and utilisation at Dingo Paddock, Thalanga

JSW - continuous variable stocking

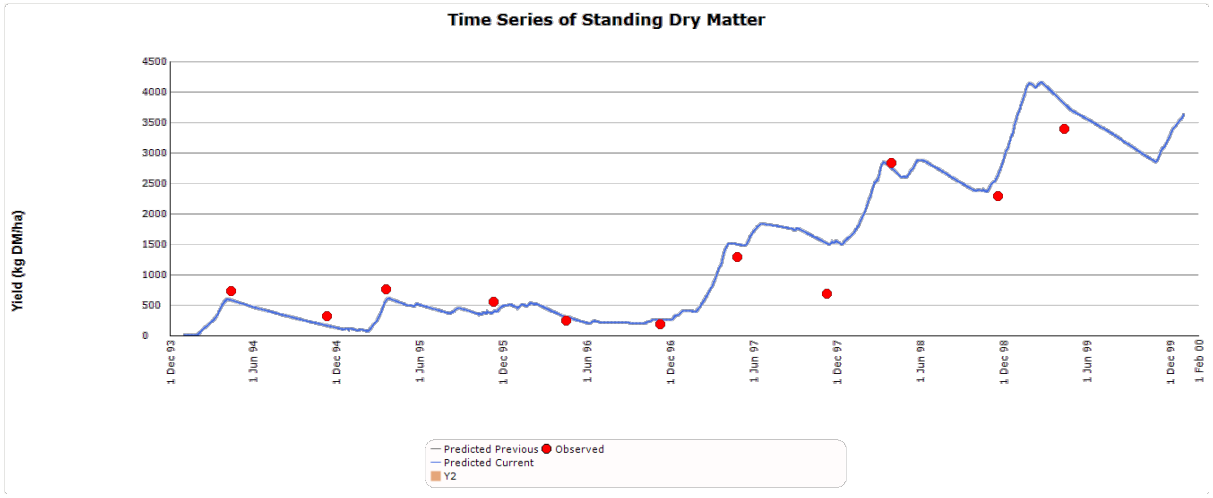


Figure 14-111: Simulated TSDM at JSW Paddock, Thalanga, (blue line) and TSDM observations (red dots)

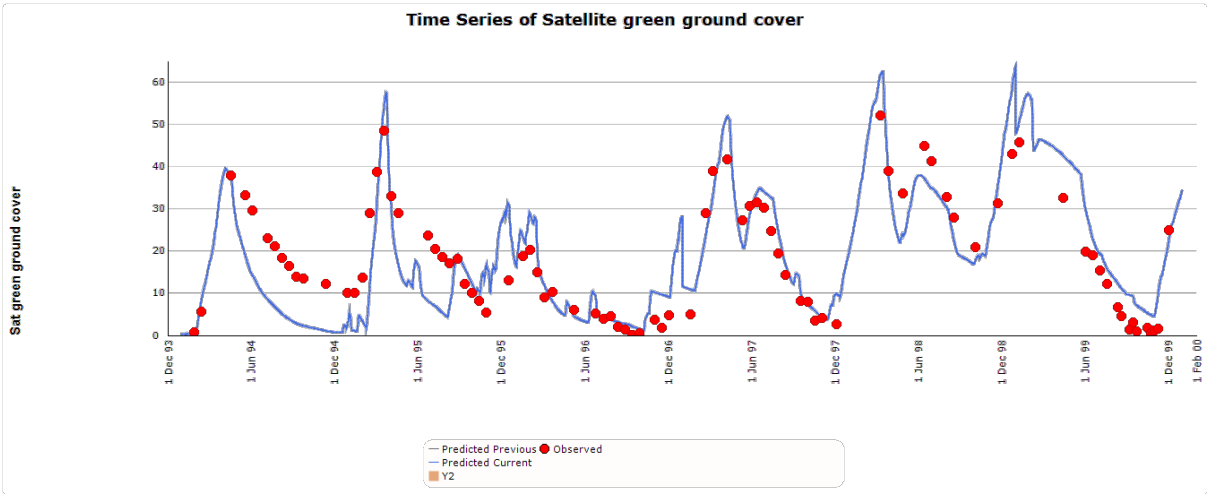


Figure 14-112: Simulated green cover at JSW Paddock, Thalanga (blue line) and satellite derived green ground cover observations (red dots)

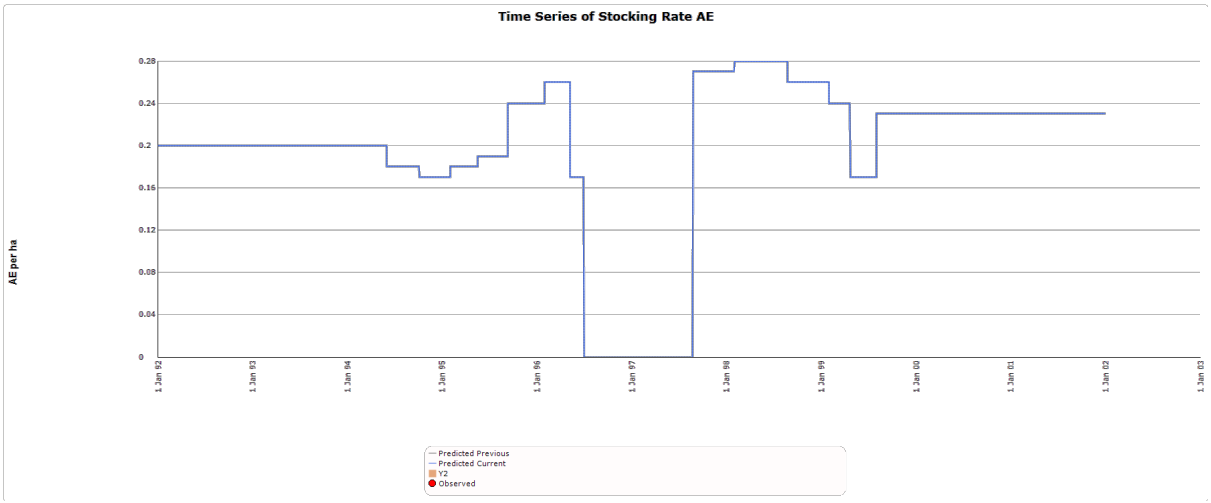


Figure 14-113: Stocking rate during the stocking rate demonstration at JSW Paddock, Thalanga

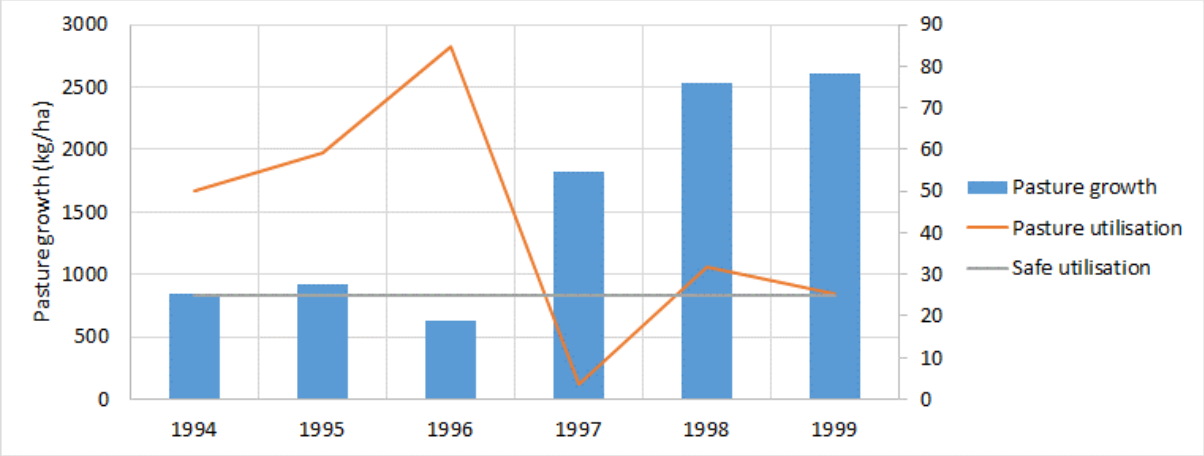


Figure 14-114: Simulated pasture growth and utilisation at JSW Paddock, Thalanga

Toms - continuous set high stocking

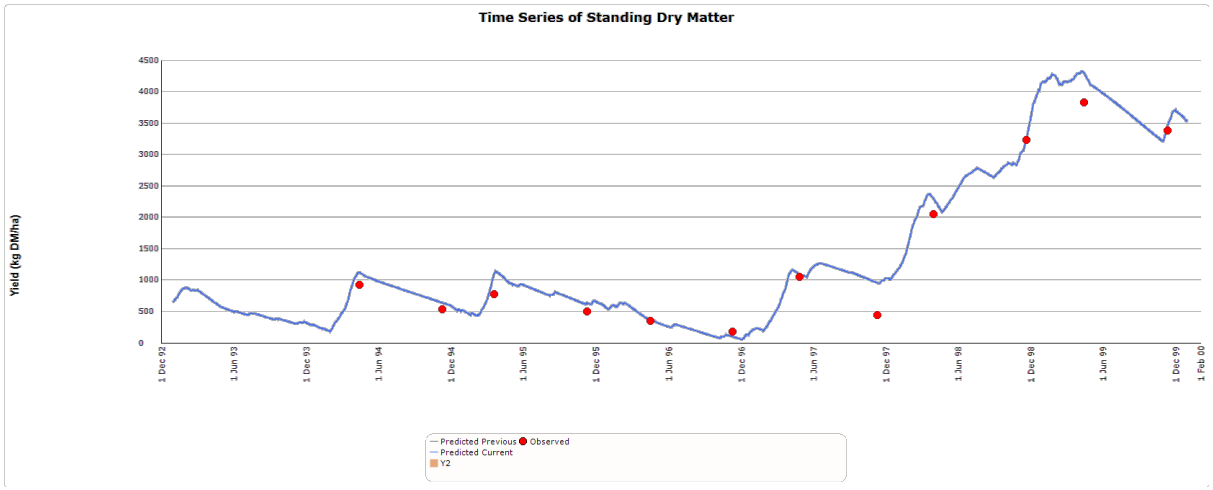


Figure 14-115: Simulated TSDM at Toms Paddock, Thalanga, (blue line) and TSDM observations (red dots)

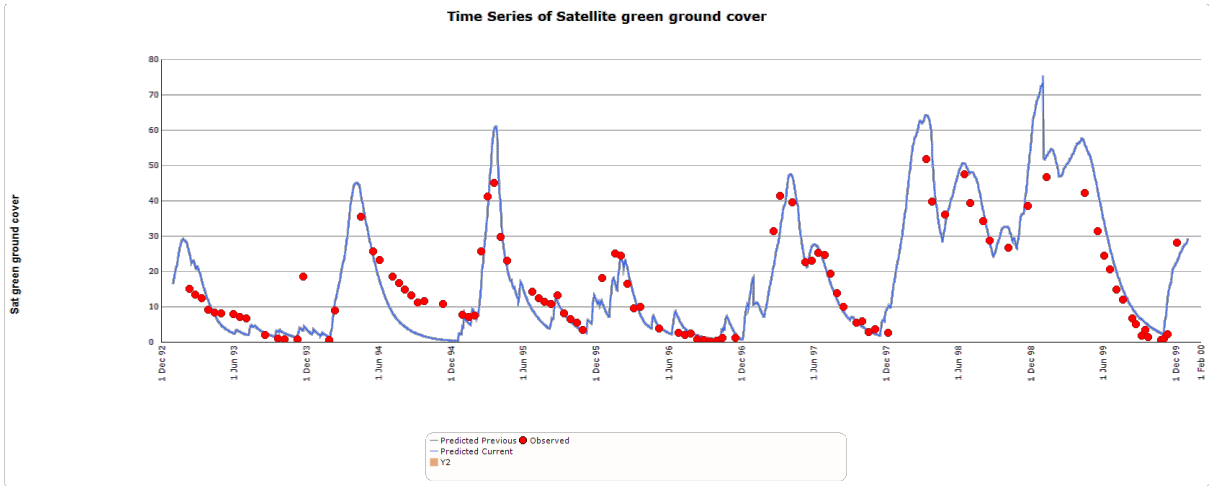


Figure 14-116: Simulated green cover at Toms Paddock, Thalanga (blue line) and satellite derived green ground cover observations (red dots)

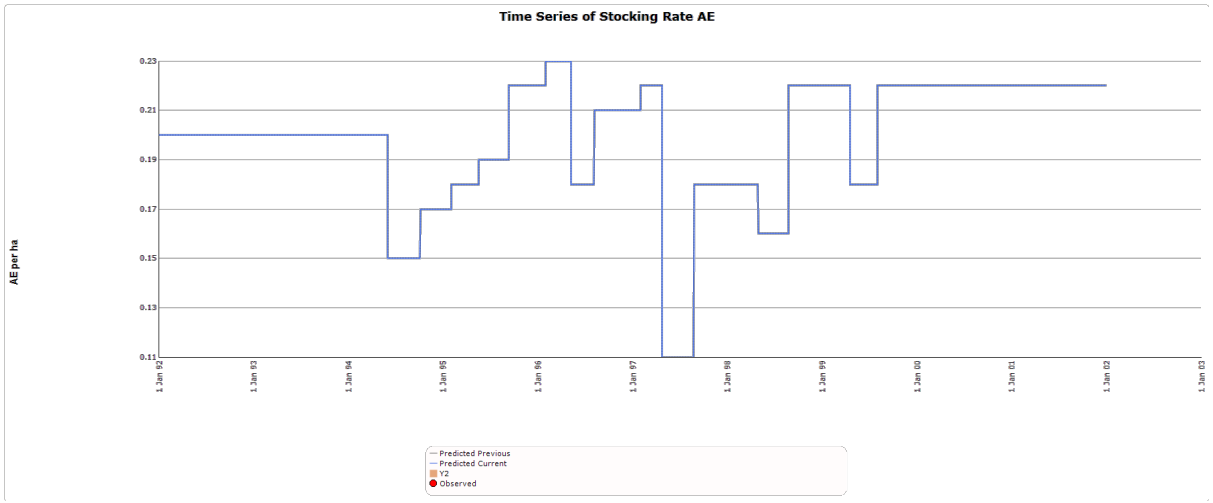


Figure 14-117: Stocking rate during the stocking rate demonstration at Toms Paddock, Thalanga

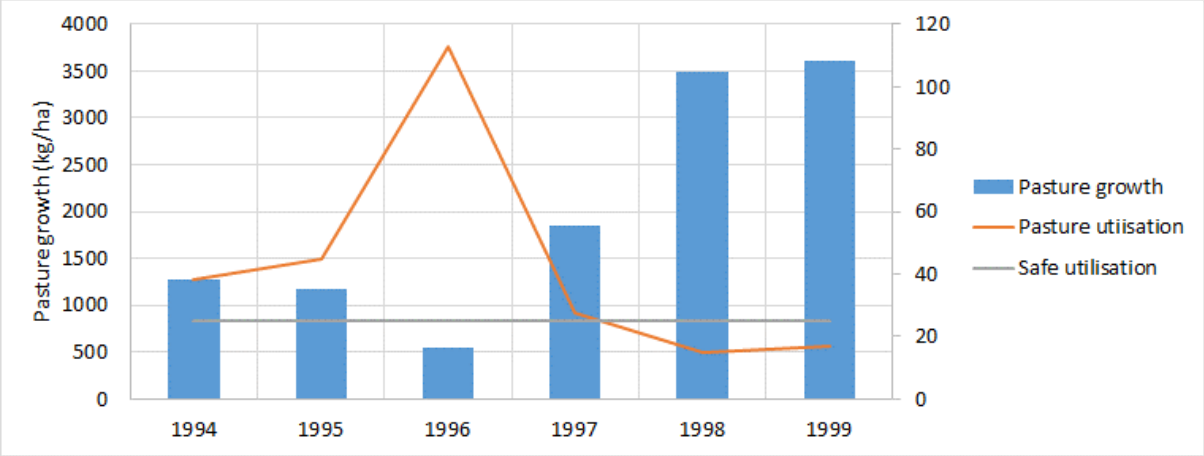


Figure 14-118: Simulated pasture growth and utilisation at Toms Paddock, Thalanga

14.3.7 Sturt Plateau

Sturt Plateau were modelled by Caroline Pettit and Robyn Cowley. Sturt Plateau sites were Eucalypt woodlands on shallow to deep red earths dominated by a grassy understorey of *Chrysopogon, Sorghum plumosum* and *Sehima nervosum*.

Station CC28M

TSDM was visually estimated by the producer for this Cash Cow site (McGowan *et al.* 2014) (Figure 14-119). Green cover was moderately well simulated (Figure 14-120). Pasture growth was generally high during this high rainfall period of the study and varied little year to year. Pasture utilisation was similar to safe levels (Figure 14-121). There was a moderately high confidence in modelling assumptions (72%).

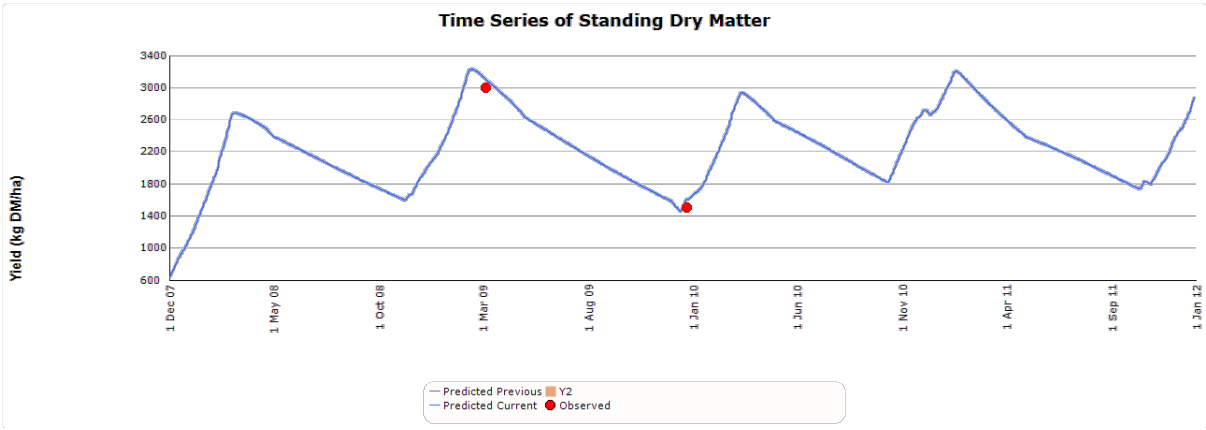


Figure 14-119: Simulated TSDM at Station CC28M, (blue line) and TSDM observations (red dots)

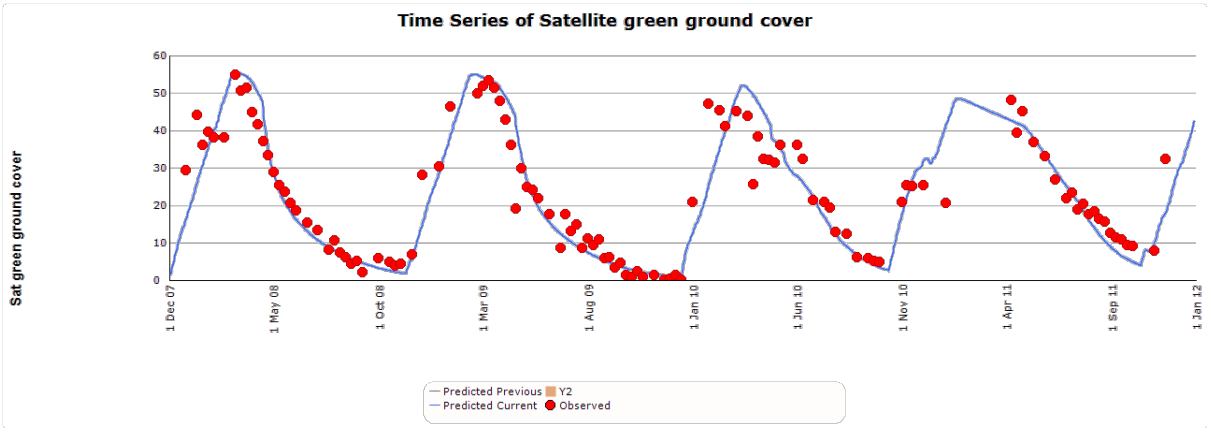


Figure 14-120: Simulated green cover at Station CC28M, (blue line) and satellite derived green ground cover observations (red dots)

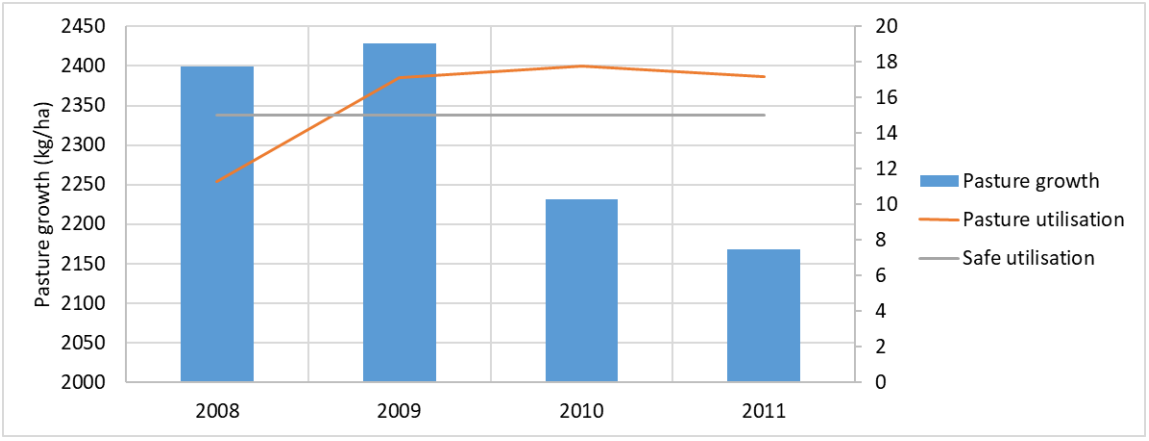


Figure 14-121: Simulated pasture growth and utilisation at Station CC28M

Station CC46M

There were uncalibrated visual estimates of TSDM done by the producer and also a more experienced operator at this Cash Cow site (McGowan *et al.* 2014) (Figure 14-122). Pasture growth was usually nutrient limited and varied little year to year at this high rainfall site in high rainfall years (average 1321mm during the study). Green cover was well simulated (Figure 14-123). There was a moderately high confidence in modelling assumptions (69%).

Utilisation declined from higher than recommended levels in the first years, to within safe levels through the study as additional waters increased the watered area available to stock, and stocking rate was halved in the last year (Figure 14-124).

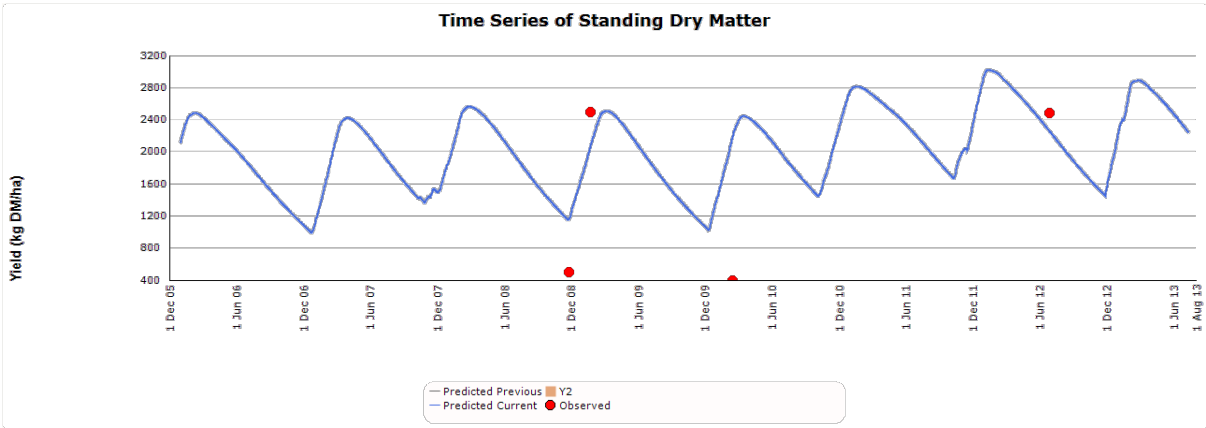


Figure 14-122: Simulated TSDM at Station CC46M, (blue line) and TSDM observations (red dots)

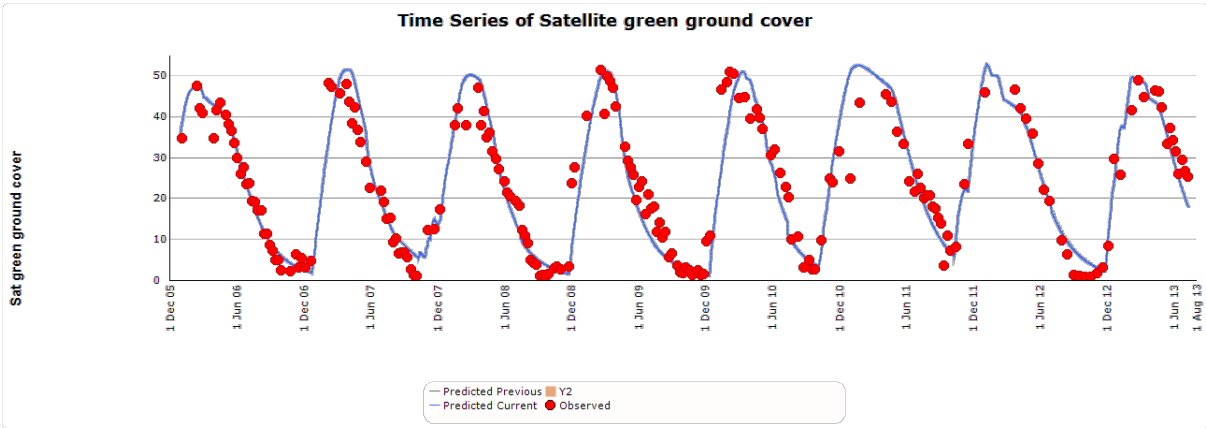


Figure 14-123: Simulated green cover at Station CC46M (blue line) and satellite derived green ground cover observations (red dots)

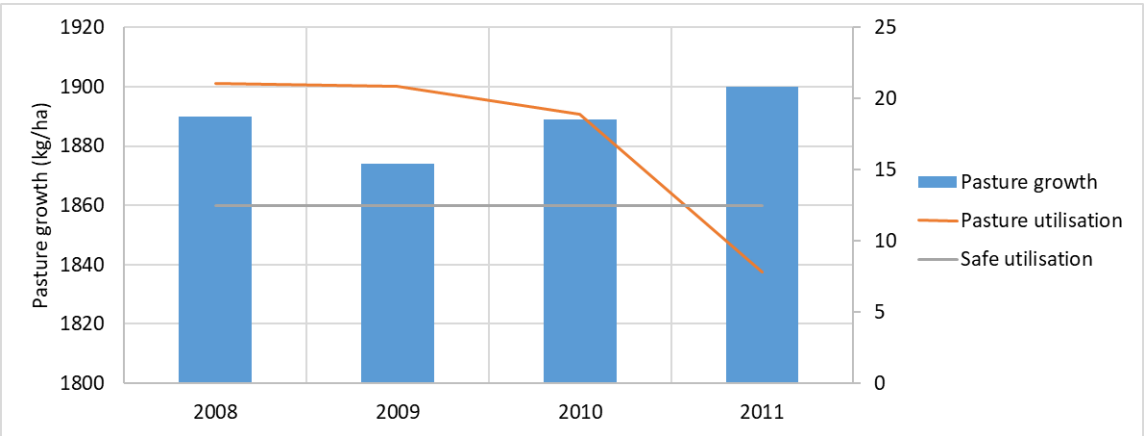


Figure 14-124: Simulated pasture growth and utilisation at Station CC46M

14.3.8 Victoria River District

All VRD sites were modelled by Robyn Cowley with input from Caroline Pettit for Station CC44M.

Station CC44M

There was a single uncalibrated visual estimate of TSDM by an expert observer, that was not weighted for distance to water and was not representative of all land types at this Cash Cow

(McGowan *et al.* 2014) site. Hence the TSDM observation was used more as a guide than deliberately calibrated to (Figure 14-125). There were two SWIFTSYND sites on Station CC44M in the main alluvial land type (Ivanhoe land system) that was found in the paddock that were used to base the GRASP calibration on. Green cover was moderately well simulated (Figure 14-126). There was a moderately high confidence in modelling assumptions (69%). Rainfall was generally high and not limiting to growth during the study, so there was little variation in pasture growth and utilisation during the study (Figure 14-127, Figure 14-128). Utilisation was always higher than recommended levels.



Figure 14-125: Simulated TSDM at Station CC44M, (blue line) and TSDM observations (red dots)

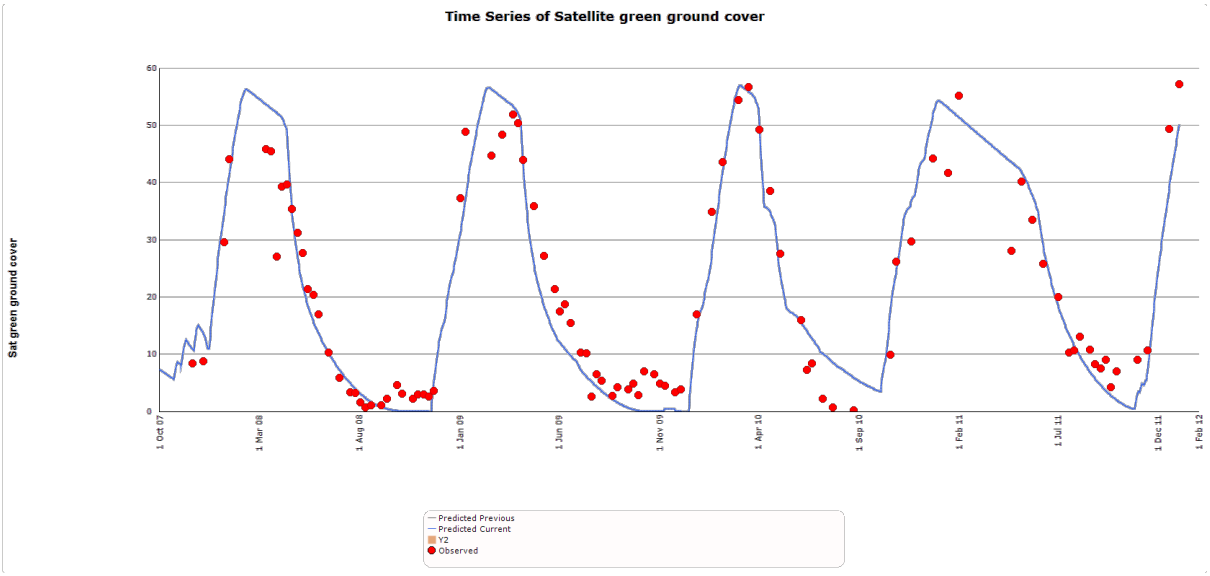


Figure 14-126: Simulated green cover at Station CC44M, (blue line) and satellite derived green ground cover observations (red dots)

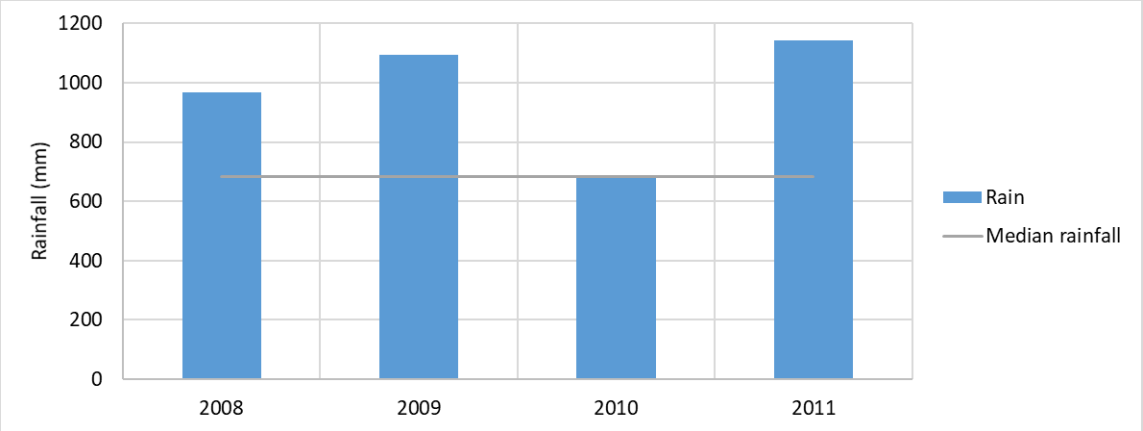


Figure 14-127: Annual and median rainfall at Station CC44M

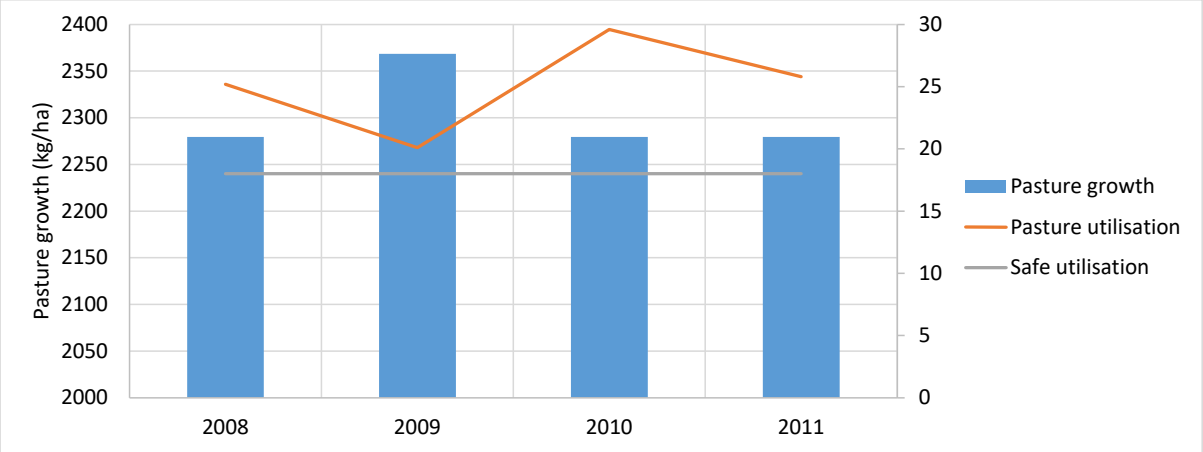


Figure 14-128: Simulated pasture growth and utilisation at Station CC44M

Mt Sanford

The Mt Sanford site 350km southwest of Katherine in the NT, had two separate consecutive grazing trials with breeder herds (Cowley *et al.* 2007). The site is an open savanna grassland dominated by (in order of decreasing average yield) *Dichanthium* spp., *Iseilema* spp., *Aristida latifolia*, *Astrebla* spp., and *Chrysopogon fallax* on basalt derived vertosols. A set stocking rate demonstration ran between 1993 and 1999 in 6 paddocks with stocking rates ranging between 5 and 15 breeders per km^2. This was followed by a set utilisation (variable stocking rate) demonstration between 2001 and 2006 in 6 paddocks with target utilisations ranging from 12 to 45%. Calibrated TSDM collected twice yearly at the end of the growing season and the end of the dry season, weighted for distance to water, was used to calibrate GRASP for each paddock in the trial. There were six SWIFTSYND sites across the grazing trial complex (Cobiac 2006). These were used to calibrate pasture growth for the grazing trial paddocks. Generally GRASP was able to simulate observed TSDMs well, except for in April 2003, which was a moderate rainfall but low pasture growth year, as two thirds of the annual rainfall fell late in the wet season within three weeks between mid Feb and the first week of March 2003, and there was very little pasture growth until February 2003. The growth in 2003 was reduced by reducing the grass basal area at the beginning of 2003.

Parrot Creek – 5 breeders/km^2 set stocked and 12% utilisation target variable stocked

GRASP simulated TSDM and green cover well at Parrot Creek (Figure 14-129 - Figure 14-130). There was a very high confidence in modelling assumptions (93%).

Rainfall was at or above average during the trial (Figure 14-131) and pasture growth was often nutrient limited (Figure 14-133). Due to relatively uniform pasture growth and stocking rates (Figure 14-132), pasture utilisation was usually around 15%, but varied between 10 and 28% (Figure 14-133).

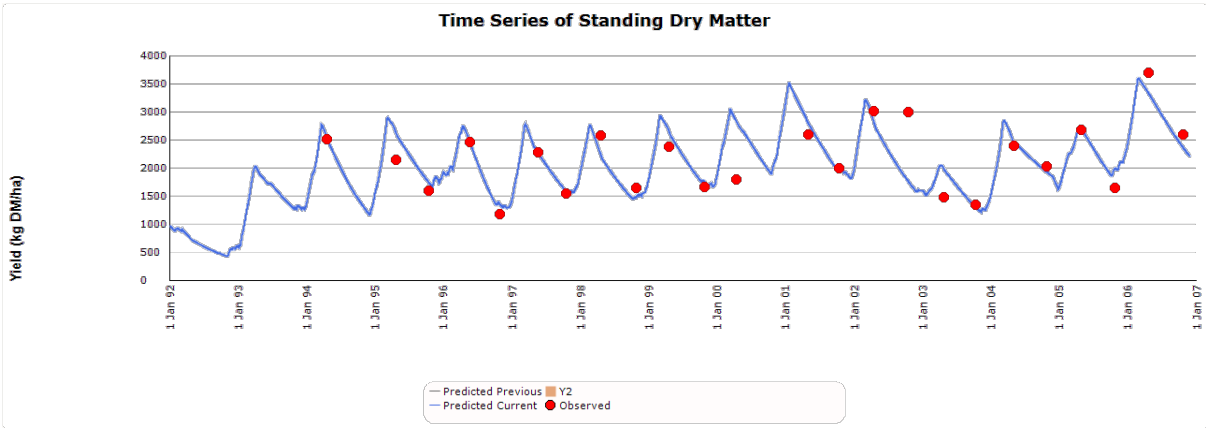


Figure 14-129: Simulated TSDM in Parrot Creek paddock, Mt Sanford (blue line) and TSDM observations (red dots)

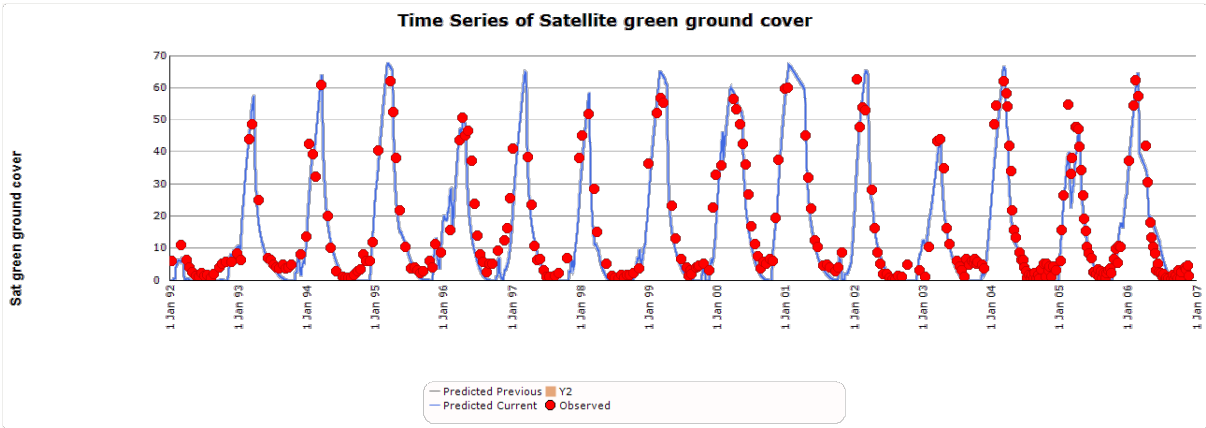


Figure 14-130: Simulated green cover in Parrot Creek paddock, Mt Sanford, (blue line) and satellite derived green ground cover observations (red dots)

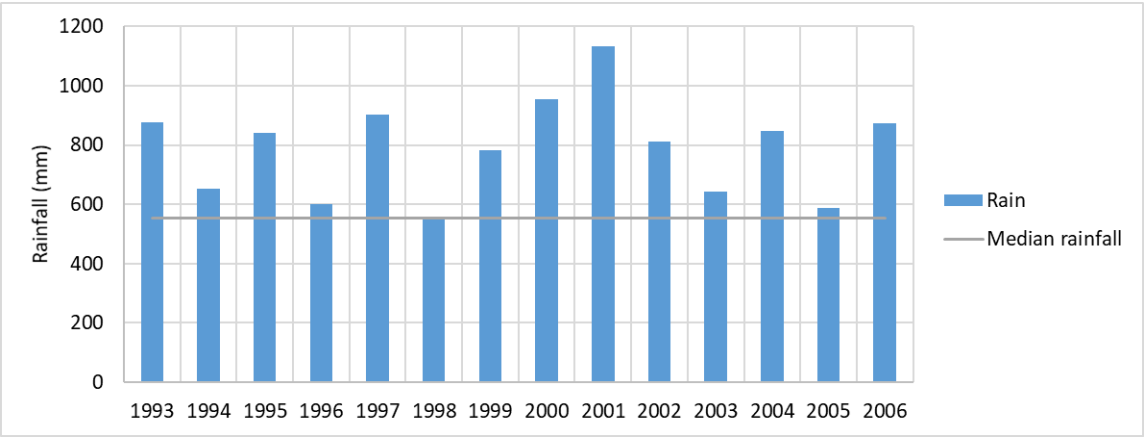


Figure 14-131: Rainfall at Parrot Creek, Mt Sanford

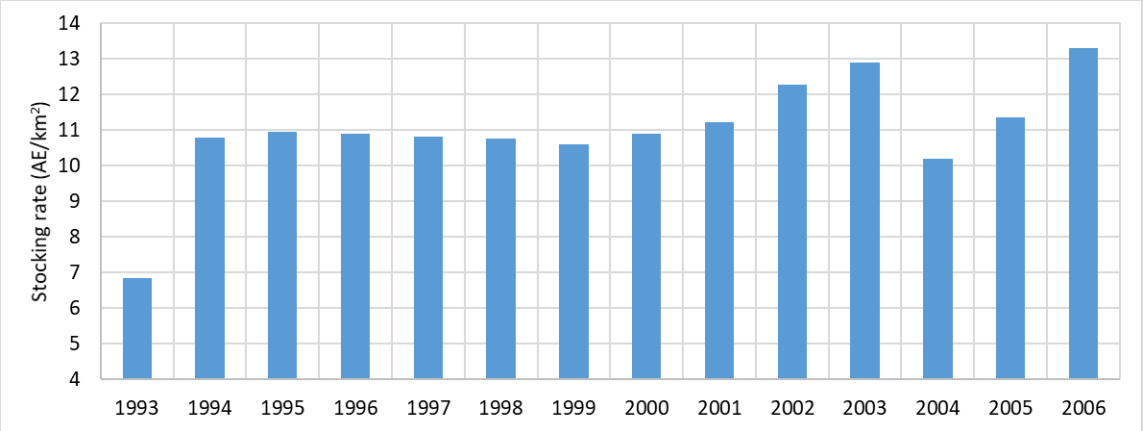


Figure 14-132: Stocking rates at Parrot Creek, Mt Sanford

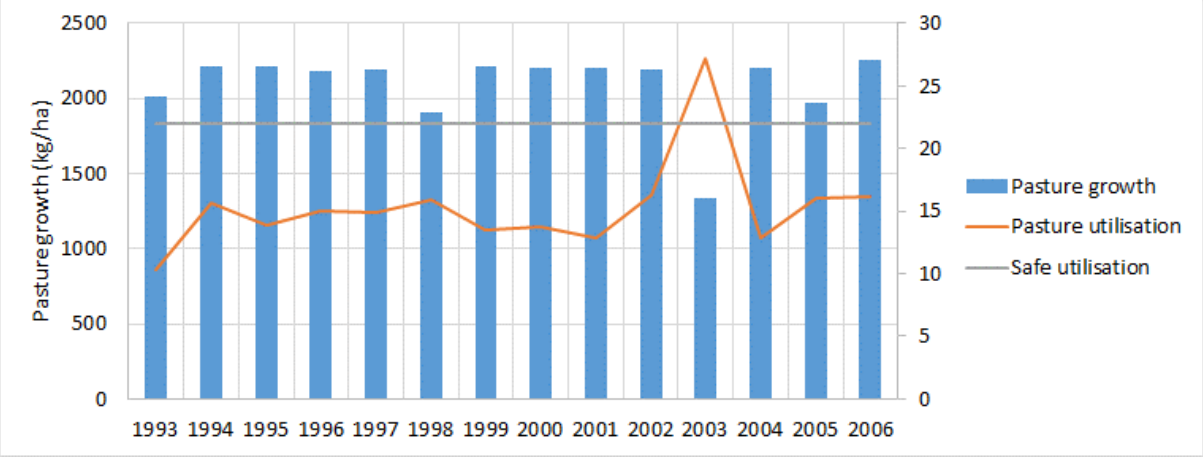


Figure 14-133: Simulated pasture growth and utilisation at Parrot Creek, Mt Sanford

Budgie – 15 breeders/km^2 set stocked supplemented and 22% utilisation target variable stocked

GRASP simulated TSDM and green cover well at Budgie (Figure 14-134 - Figure 14-135). There was a very high confidence in modelling assumptions (93%).

Pasture growth was often nutrient limited (Figure 14-136). Pasture utilisation averaged 24%, but varied between 12 and 31% (Figure 14-133).

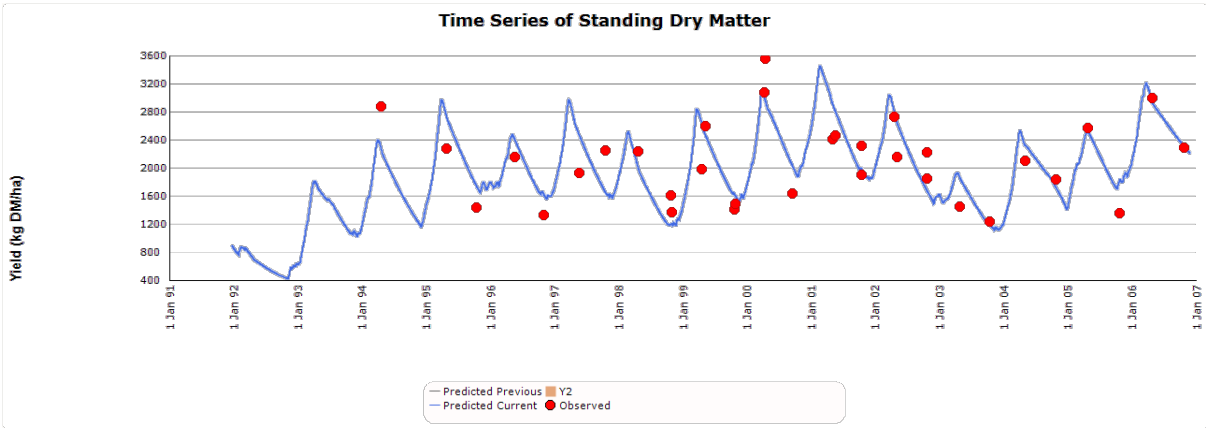


Figure 14-134: Simulated TSDM in Budgie paddock, Mt Sanford (blue line) and TSDM observations (red dots)

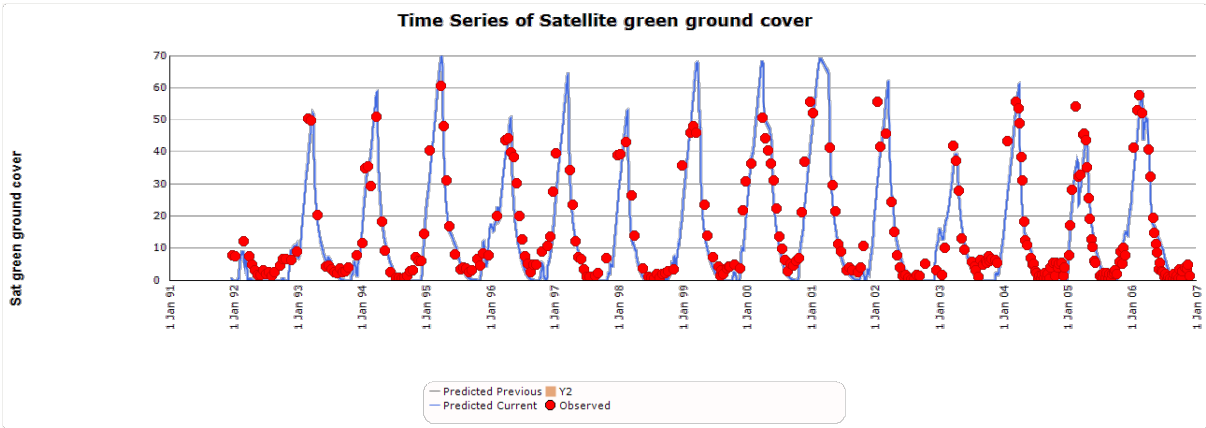


Figure 14-135: Simulated green cover in Budgie paddock, Mt Sanford, (blue line) and satellite derived green ground cover observations (red dots)

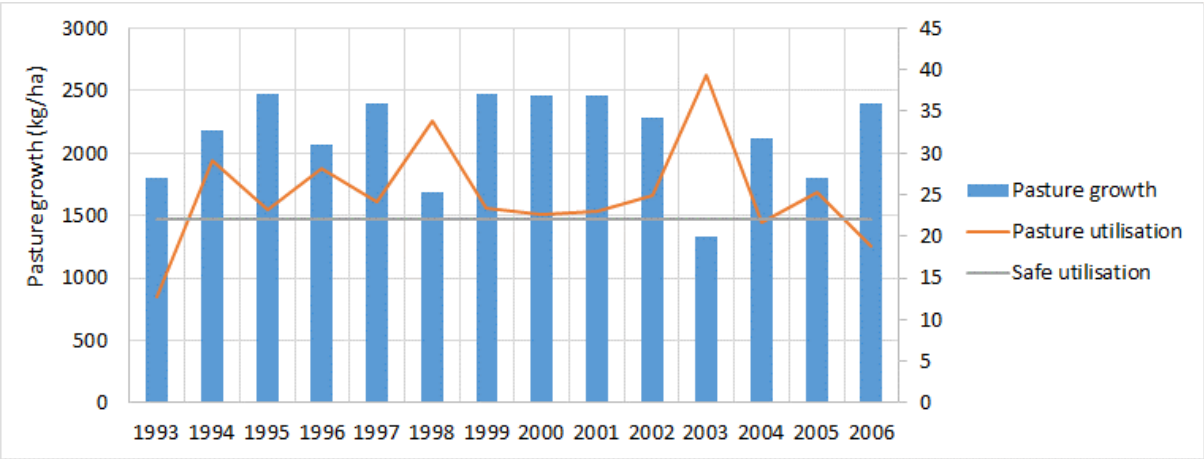


Figure 14-136: Simulated pasture growth and utilisation at Budgie, Mt Sanford

Galah - 5 breeders/km^2 set stocked supplemented

GRASP simulated green cover well at Galah paddock (Figure 14-138). It is unclear why there was lower TSDM in May 1999 and May 2000 than the surrounding October measurements, possibly reflecting errors in measurement or variable detachment through time (Figure 14-137). Detachment between April and October field varied between 0.0007 in 1995 to 0.003 in 1997. Given the lack of confidence in the field measured TSDM after 1998, and as green cover suggested growth was well calibrated, detachment was not adjusted year to year to try to matched observed TSDM. There was a high confidence in modelling assumptions (87%).

The low stocking rates led to consistently low pasture utilisation, averaging 11%, only varying between 9 and 12% (Figure 14-139).

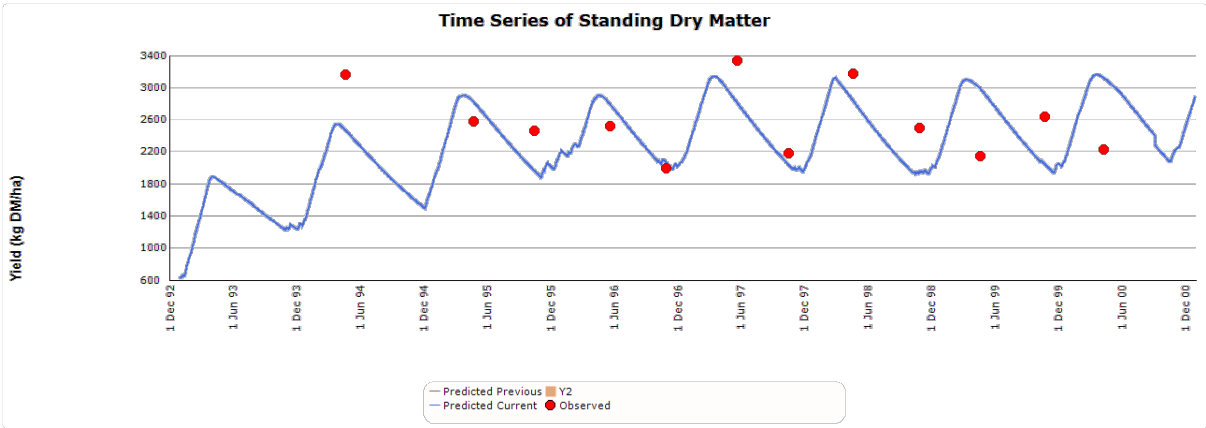


Figure 14-137: Simulated TSDM in Galah paddock, Mt Sanford (blue line) and TSDM observations (red dots)

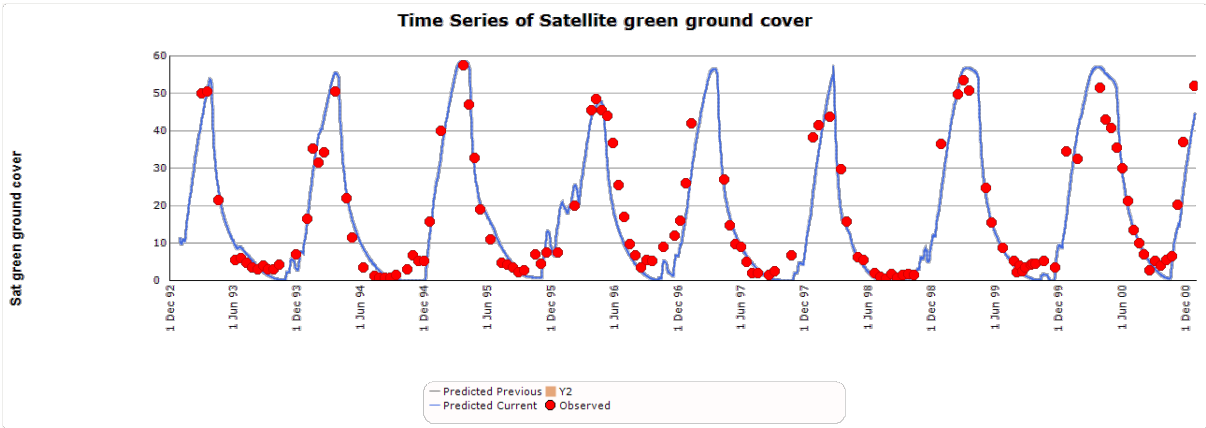


Figure 14-138: Simulated green cover in Galah paddock, Mt Sanford, (blue line) and satellite derived green ground cover observations (red dots)

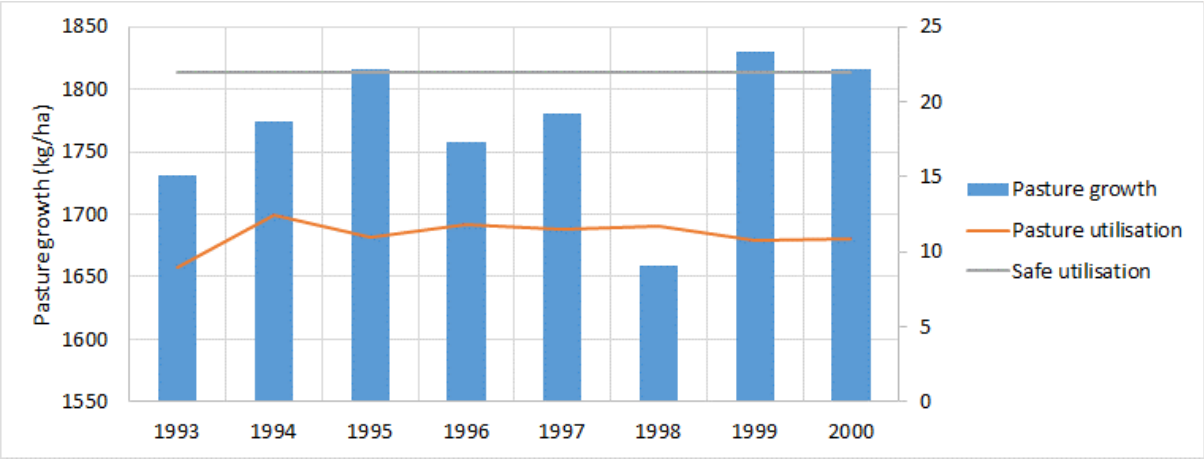


Figure 14-139: Simulated pasture growth and utilisation at Galah, Mt Sanford

Larry Mac – 45% utilisation target variable stocked

GRASP simulated TSDM and green cover well at Larry Mac (Figure 14-140 - Figure 14-141). There was a very high confidence in modelling assumptions (93%).

The high stocking rates led to high pasture utilisation, averaging 45%, varying between 23 and 62% (Figure 14-142).

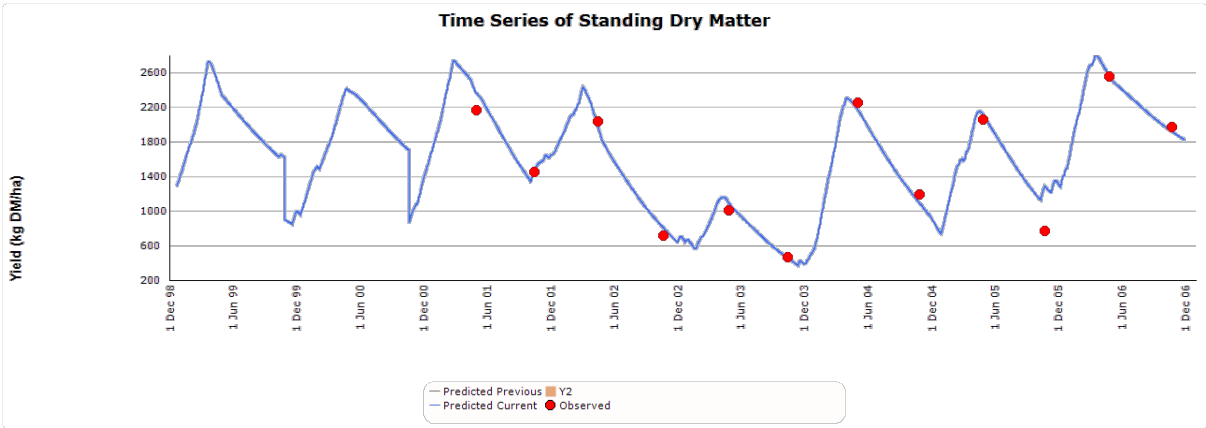


Figure 14-140: Simulated TSDM in Larry Mac paddock, Mt Sanford (blue line) and TSDM observations (red dots)

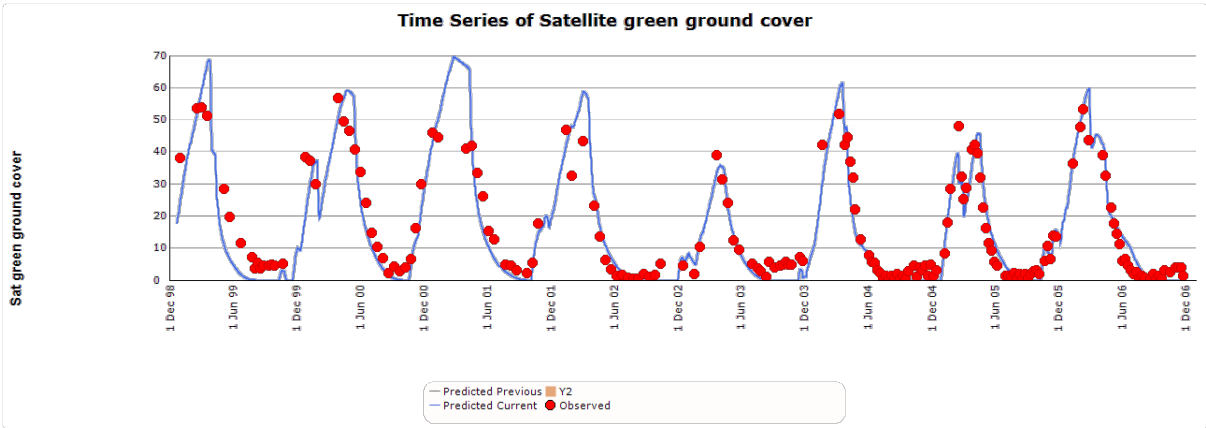


Figure 14-141: Simulated green cover in Larry Mac paddock, Mt Sanford, (blue line) and satellite derived green ground cover observations (red dots)

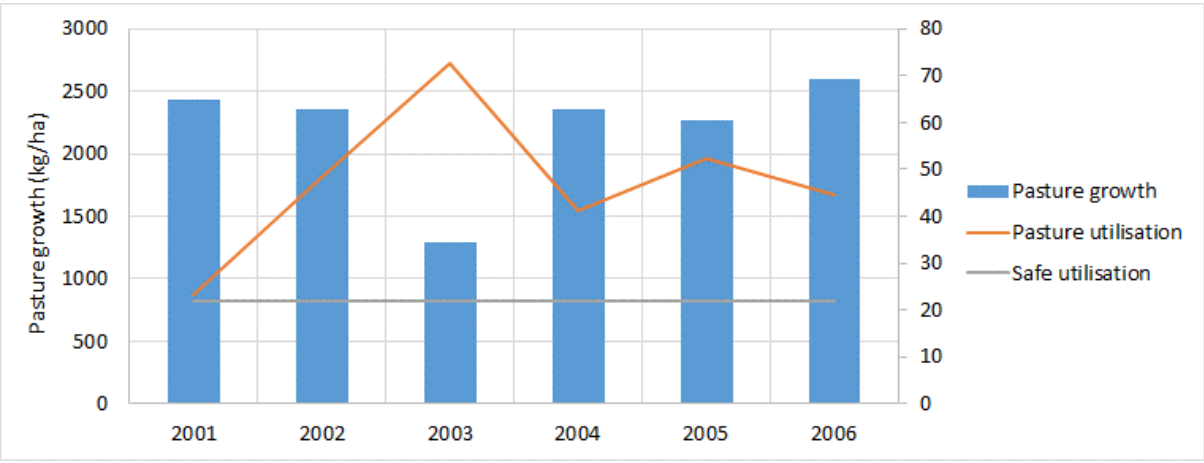


Figure 14-142: Simulated pasture growth and utilisation at Larry Mac, Mt Sanford

Pigeon – 10 breeders/km^2 set stocked supplemented and 16% utilisation target variable stocked

GRASP simulated TSDM and green cover well at Pigeon (Figure 14-143 - Figure 14-144). There was a very high confidence in modelling assumptions (93%).

The moderate stocking rates (15.6 AE km^2) led to close to recommended pasture utilisation except in low growth years, but higher than target utilisation of 16%, averaging 22%, but varied between 16 and 38% (Figure 14-145).

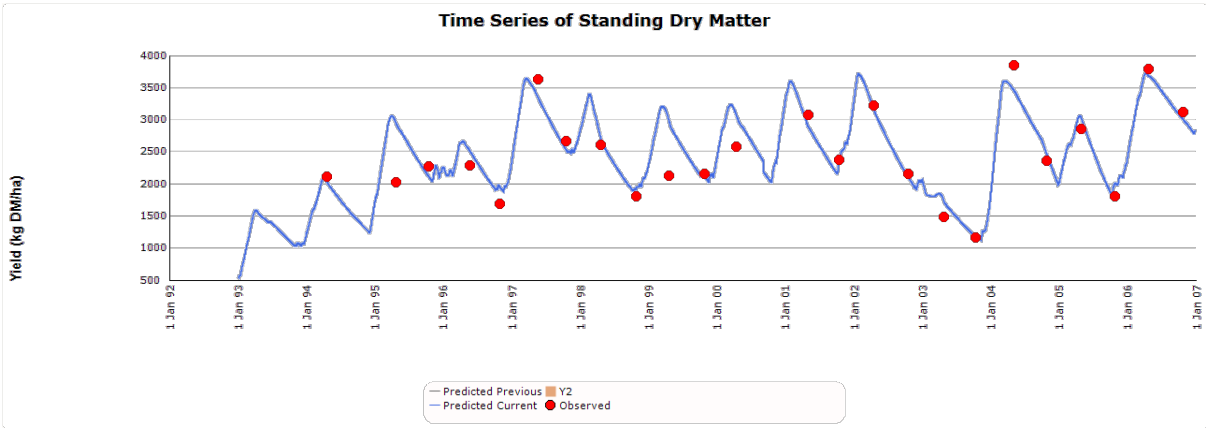


Figure 14-143: Simulated TSDM in Pigeon paddock, Mt Sanford (blue line) and TSDM observations (red dots)

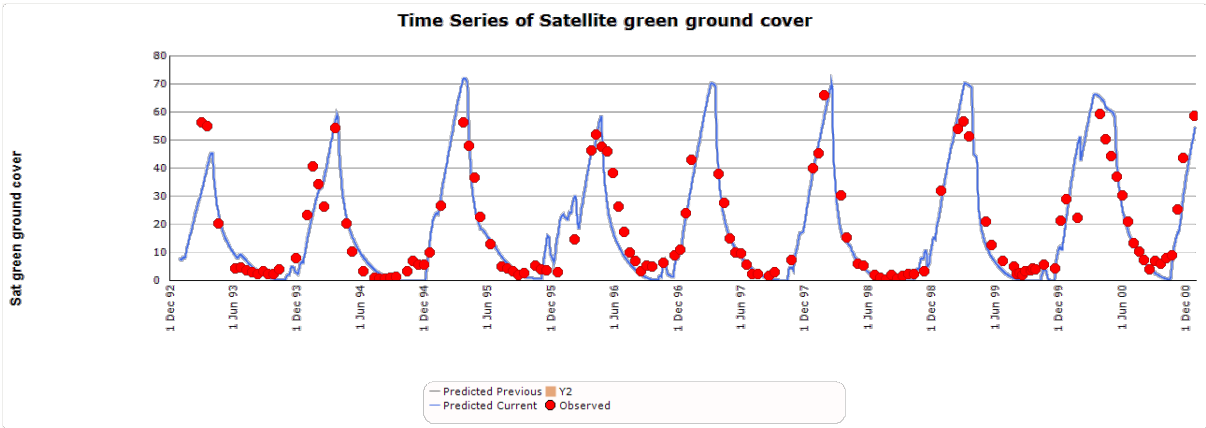


Figure 14-144: Simulated green cover in Pigeon paddock, Mt Sanford, (blue line) and satellite derived green ground cover observations (red dots)

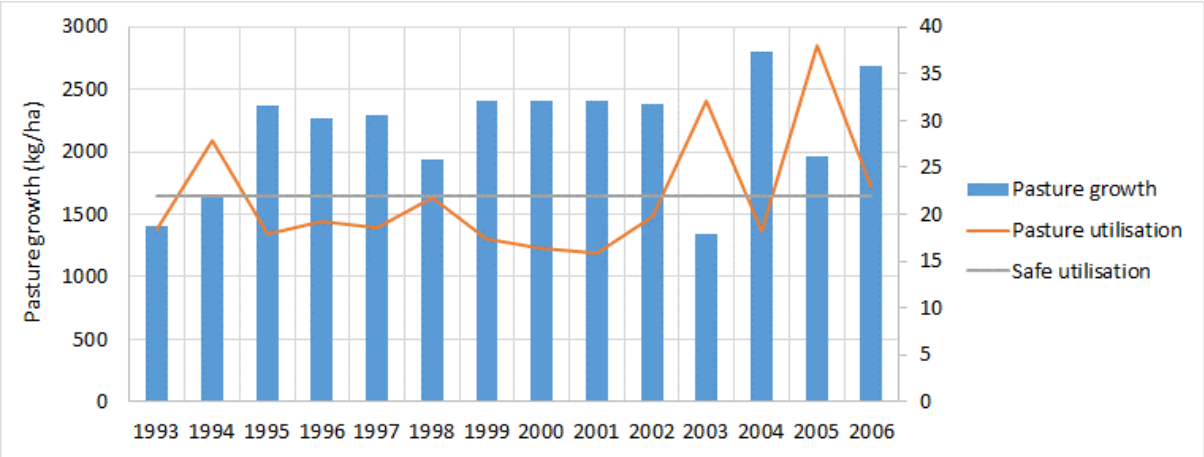


Figure 14-145: Simulated pasture growth and utilisation at Pigeon, Mt Sanford

Quail – 5 breeders/km^2 set stocked unsupplemented

GRASP simulated TSDM and green cover well at Quail (Figure 14-146 - Figure 14-147). There was a very high confidence in modelling assumptions (93%).

The low stocking rates (6-7 AE km^2) led to low pasture utilisation, averaging 11%, (varying between 9 to 16%,Figure 14-148).

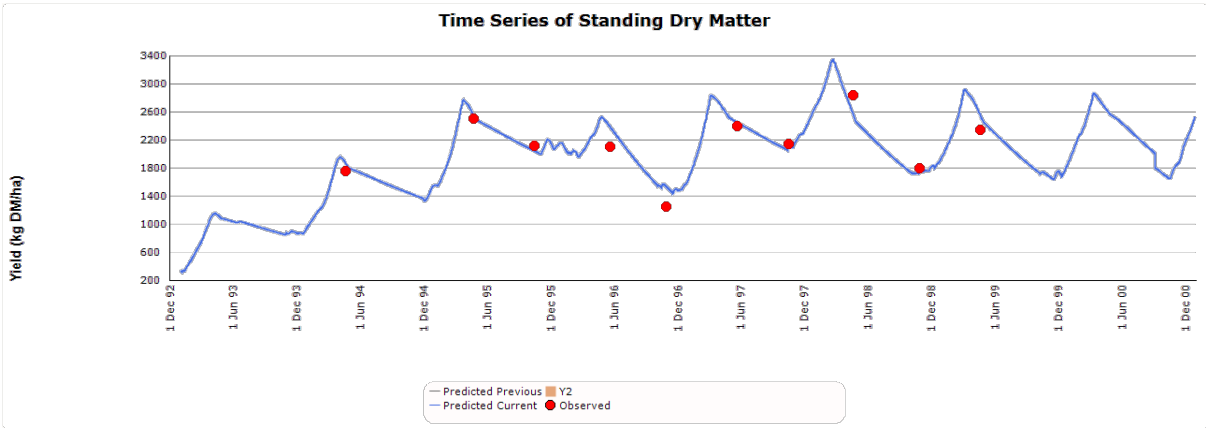


Figure 14-146: Simulated TSDM in Quail paddock, Mt Sanford (blue line) and TSDM observations (red dots)

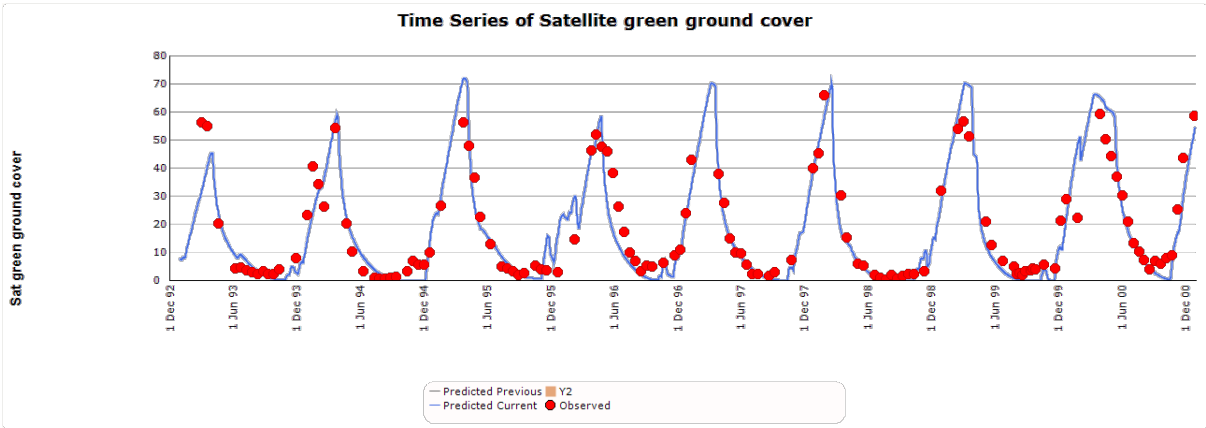


Figure 14-147: Simulated green cover in Quail paddock, Mt Sanford, (blue line) and satellite derived green ground cover observations (red dots)

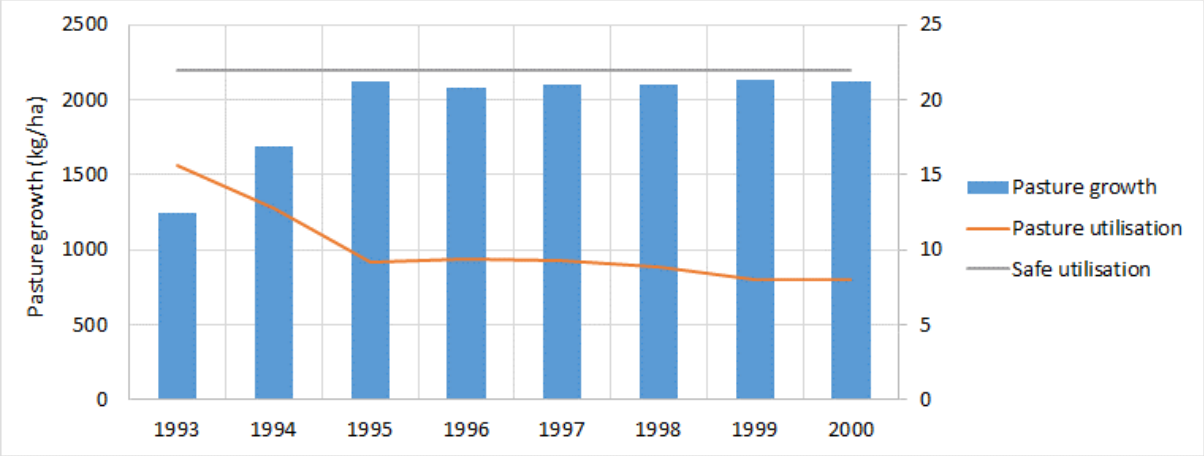


Figure 14-148: Simulated pasture growth and utilisation at Quail, Mt Sanford

Quarrion – 7.5 breeders/km^2 set stocked unsupplemented and 35% utilisation target variable stocked

GRASP simulated TSDM and green cover well at Quarrion (Figure 14-149 - Figure 14-150). There was a very high confidence in modelling assumptions (91%).

The paddock started with low stocking rates (6 AE km^2) and moderate pasture utilisation (average 15%), but higher stocking rates in the second half of the study (25 AE km^2) led to an average 40% utilisation. There was a wide variation in pasture utilisation through time from 10 to 56% (Figure 14-151).

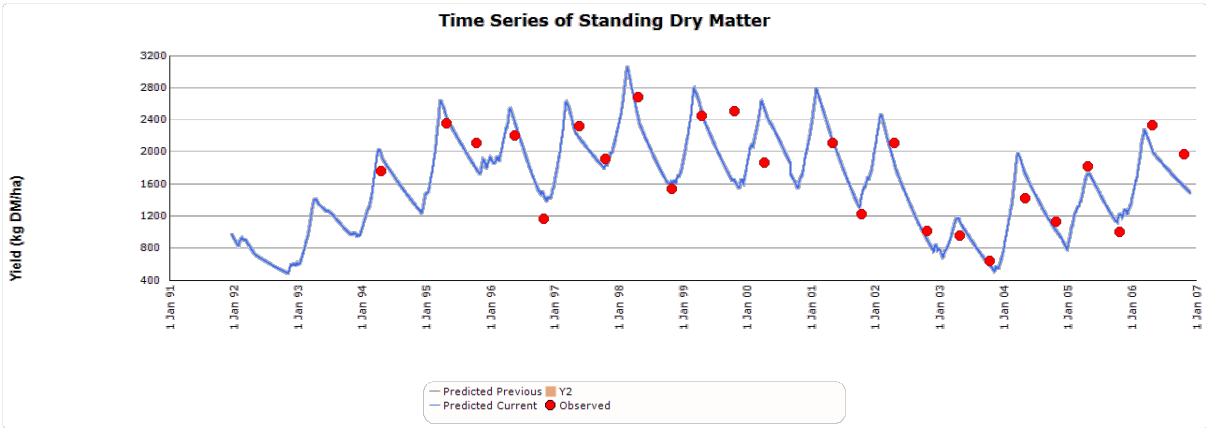


Figure 14-149: Simulated TSDM in Quarrion paddock, Mt Sanford (blue line) and TSDM observations (red dots)

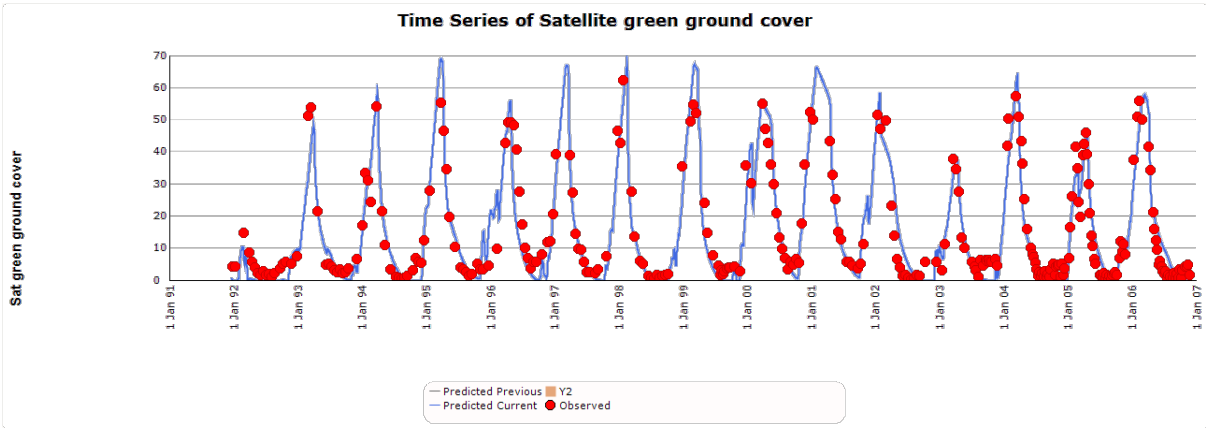


Figure 14-150: Simulated green cover in Quarrion paddock, Mt Sanford, (blue line) and satellite derived green ground cover observations (red dots)

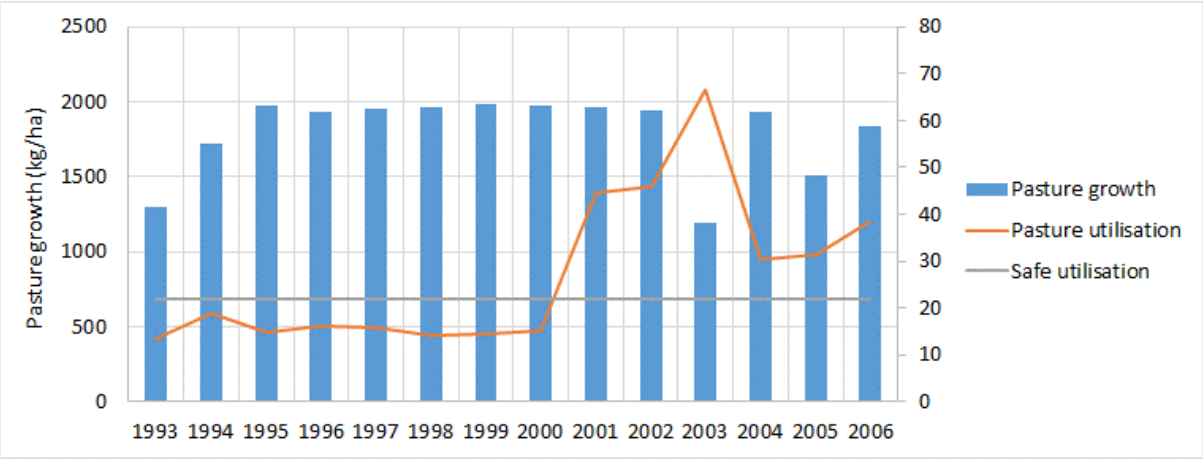


Figure 14-151: Simulated pasture growth and utilisation at Wedgetail, Mt Sanford

Wedgetail –28% utilisation target variable stocked

GRASP simulated TSDM and green cover moderately well at Wedgetail (Figure 14-152 - Figure 14-153). There was a rotational fire trial in the paddock until 2001, and a large proportion of the paddock was spinifex hills which were assumed to be inaccessible and ungrazed. Confidence in modelling assumptions was slightly lower compared to the other paddocks, due to uncertainties in stocking rates before 2002 (81%).

The relatively high stocking rates led to higher than recommended pasture utilisation, averaging 43%, varying between 33 and 57% (Figure 14-154), which was higher than targeted utilisation.

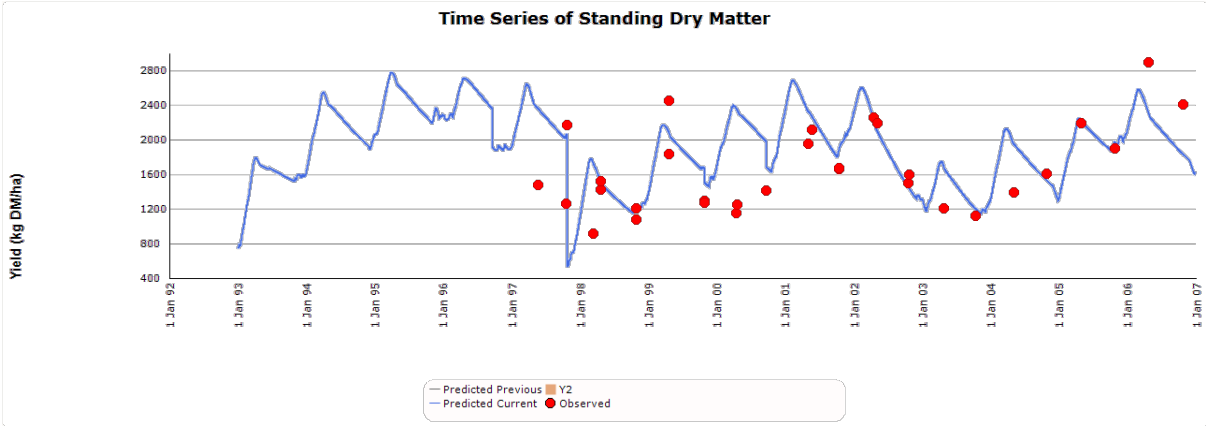


Figure 14-152: Simulated TSDM in Wedgetail paddock, Mt Sanford (blue line) and TSDM observations (red dots)

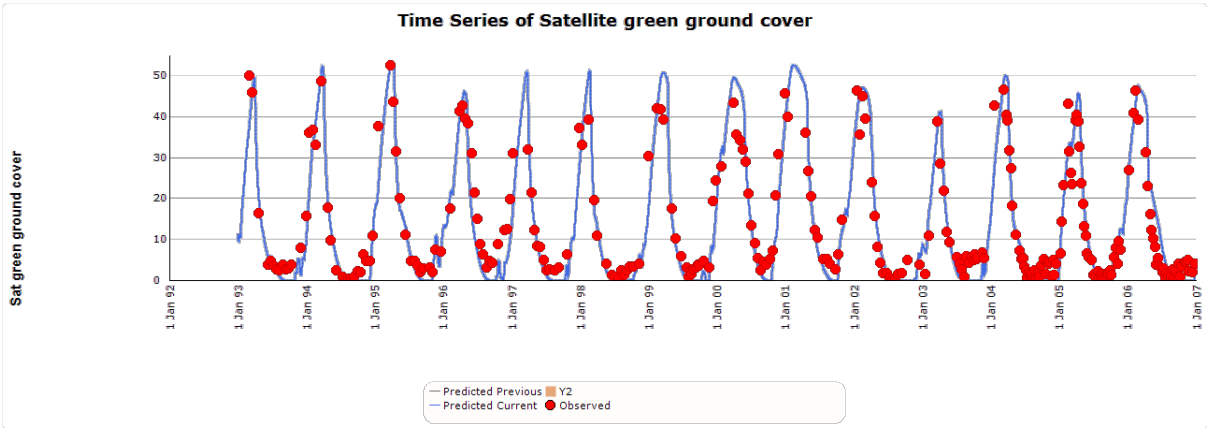


Figure 14-153: Simulated green cover in Wedgetail paddock, Mt Sanford, (blue line) and satellite derived green ground cover observations (red dots)

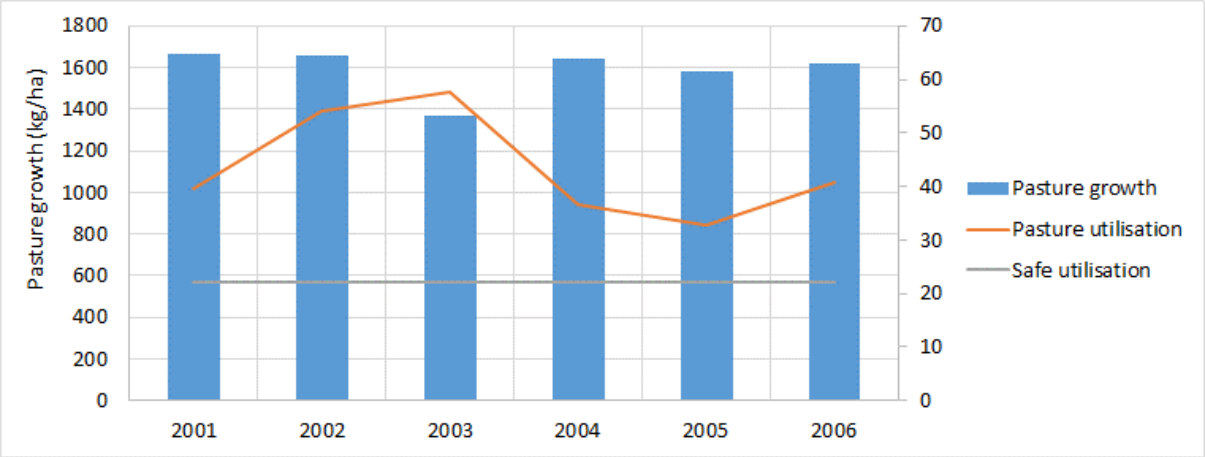


Figure 14-154: Simulated pasture growth and utilisation at Budgie, Mt Sanford

Pigeon Hole

The Pigeon Hole Project (Hunt *et al.* 2013) was situated 300km southwest of Katherine, on an open grassland on a basalt derived cracking vertosol with pastures dominated by *Sorghum timorense*, *Aristida latifolia*, and *Chrysopogon fallax*. The research site covering 300km^2 included 12 paddocks including a 3-paddock wet season spelling complex and a multi paddock cell grazing system which were each modelled as one modelling unit. There was a range of target utilisation rates between 15 and 40%, but most other paddocks/treatments had 20% utilisation targets. Stocking rates were variable through time to achieve target utilisation rates. Botanal data including yield, grass basal area, ground cover and species composition was collected twice yearly at the end of the growing season and the end of the dry season, across all years and sites. TSDM and green cover were simulated with a high degree of accuracy (Figure 14-159 - Figure 14-194). There was a very high confidence in modelling assumptions (90%).

Rainfall during the Pigeon Hole Project was at or above median (Figure 14-156). Pasture growth was very high in 2004 and 2006, and close to average in 2005 and 2007. Despite above average total rainfall in 2003, the start of the wet season was very late in February 2003 and most of the rain fell within a short 2-week period in February which led to a lot of runoff and gullying across the site. Extensive fires in November 2002, also contributed to low growth. To simulate the observed low TSDM and green cover, grass basal area was reduced for 2003. Most paddocks were dominated by annual Sorghum which grew a great deal of bulk in wet years but did not carry over after the

following wet season. To simulate this, wet season detachment was set quite high at 0.006g/g/day, which is consistent with north Queensland parameterisation of land types.

Across all paddocks and years pasture utilisation ranged from 6 to 58% (Figure 14-159 - Figure 14-195), providing a good range to detect utilisation effects on breeder performance.

The median long-term pasture growth simulated for each paddock using the final paddock calibrated model declined with increasing average simulated pasture utilisation (of the five years between 2003 and 2007) (P=0.01, Pearson's r -0.67, r^2=0.45, Figure 14-155). An ungrazed paddock provided potential pasture growth (Figure 14-157 - Figure 14-158). The regression predicted that median long-term simulated pasture growth (kg/ha) = 2505.5-13.63* utilisation. At 36% utilisation median simulated long-term growth declined by about 500kg/ha or by 20% of potential growth with no grazing. Although there was quite a range in median pasture growth at around safe utilisation levels between 2088 and 2465 kg/ha, above 25% utilisation long-term simulated growth was less than 2100 kg/ha.

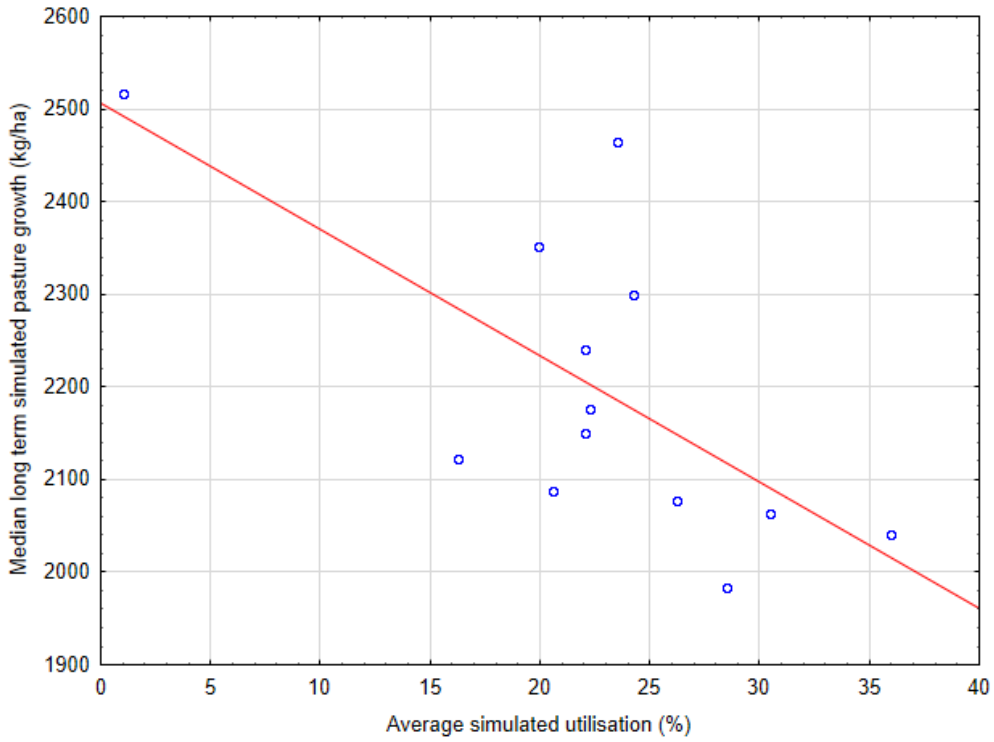


Figure 14-155: Median pasture growth vs. average simulated pasture utilisation at Pigeon Hole

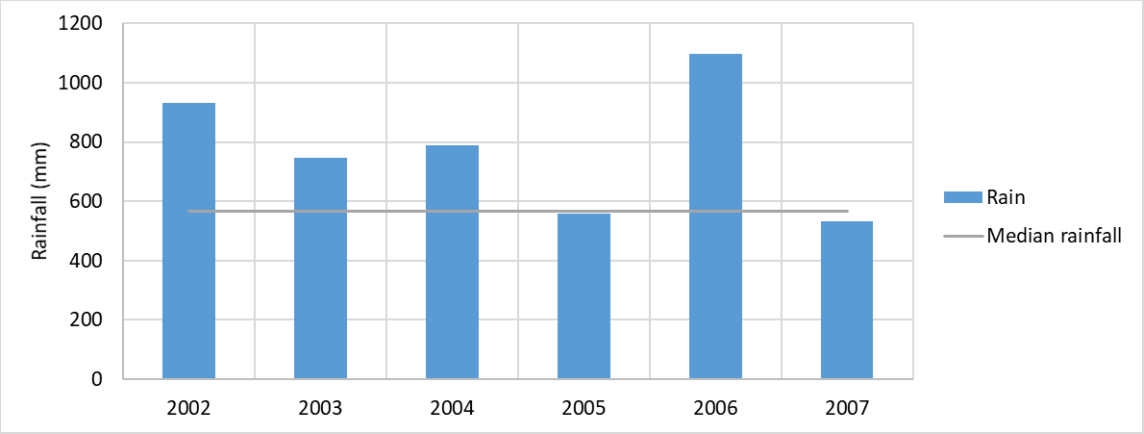


Figure 14-156: Rainfall at Pigeon Hole

400 ha Biodiversity exclosure

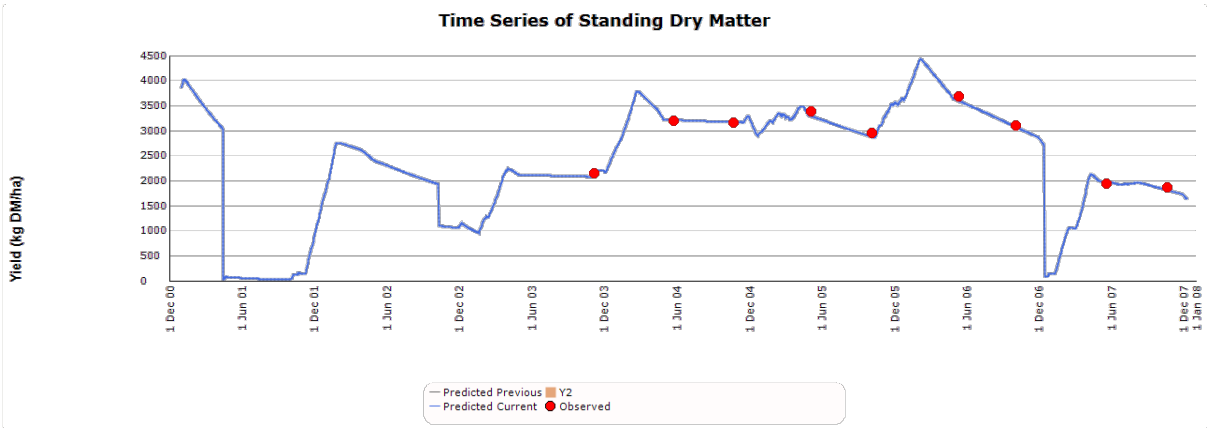


Figure 14-157: Simulated TSDM in the 400 ha Biodiversity exclosure, Pigeon Hole (blue line) and TSDM observations (red dots)

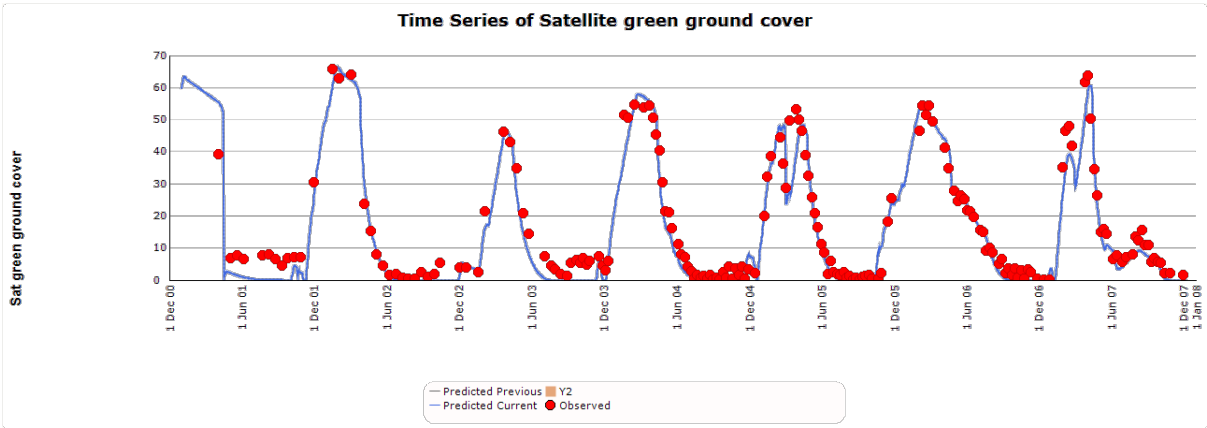


Figure 14-158: Simulated green ground cover in the 400 ha Biodiversity exclosure, Pigeon Hole (blue line) and TSDM observations (red dots)

Barra Paddock

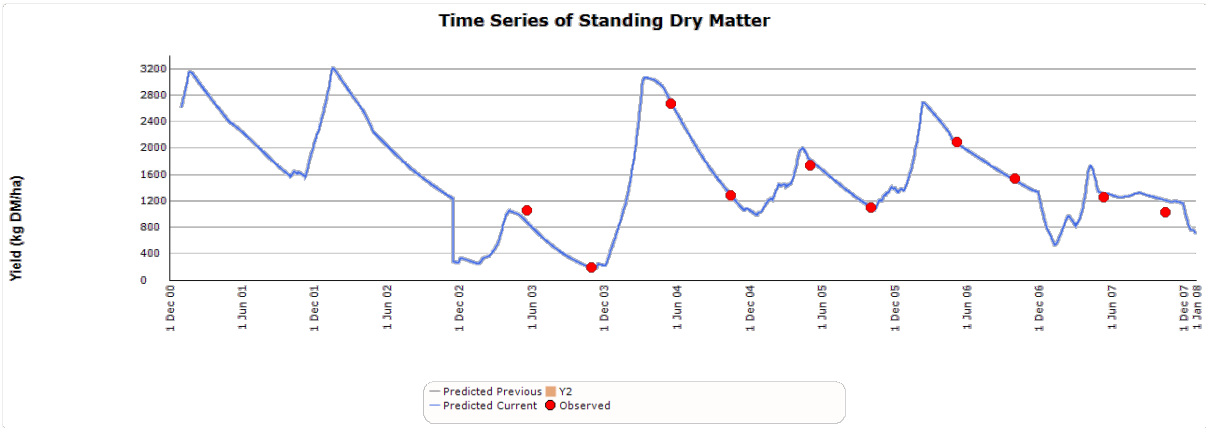


Figure 14-159: Simulated TSDM in Barra Paddock, Pigeon Hole (blue line) and TSDM observations (red dots)

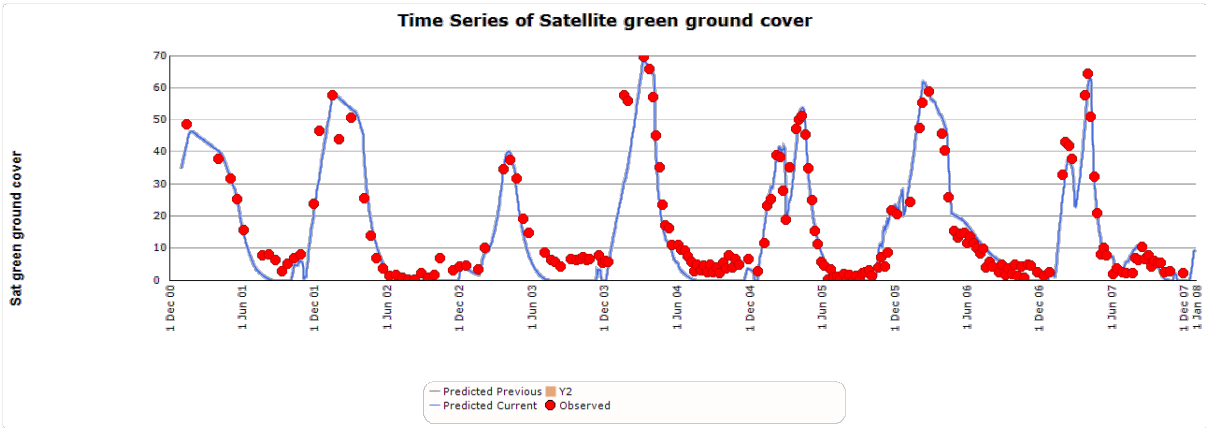


Figure 14-160: Simulated green cover in Barra Paddock, Pigeon Hole, (blue line) and satellite derived green ground cover observations (red dots)

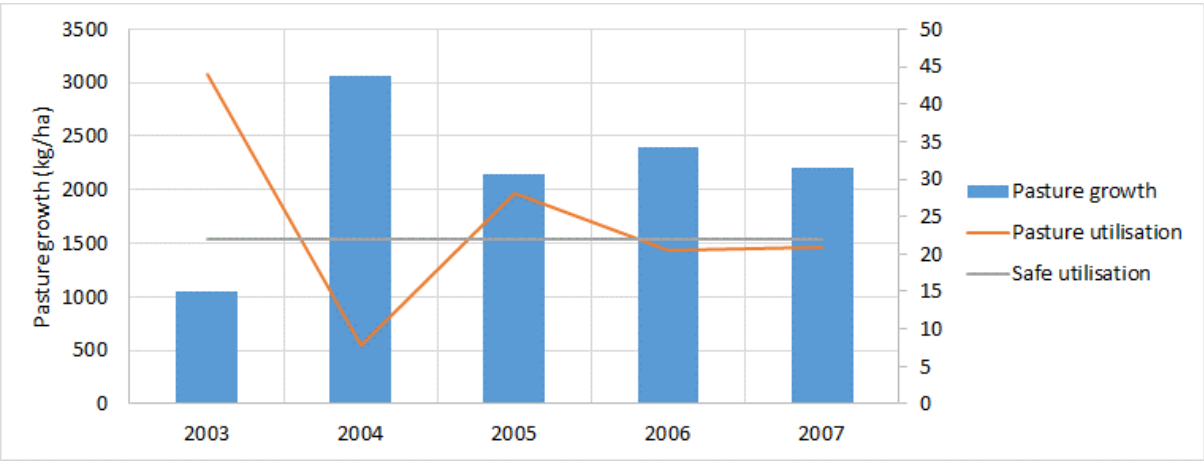


Figure 14-161: Simulated pasture growth and utilisation at Barra Paddock, Pigeon Hole

Bauhinia Paddock - 25% Target Utilisation

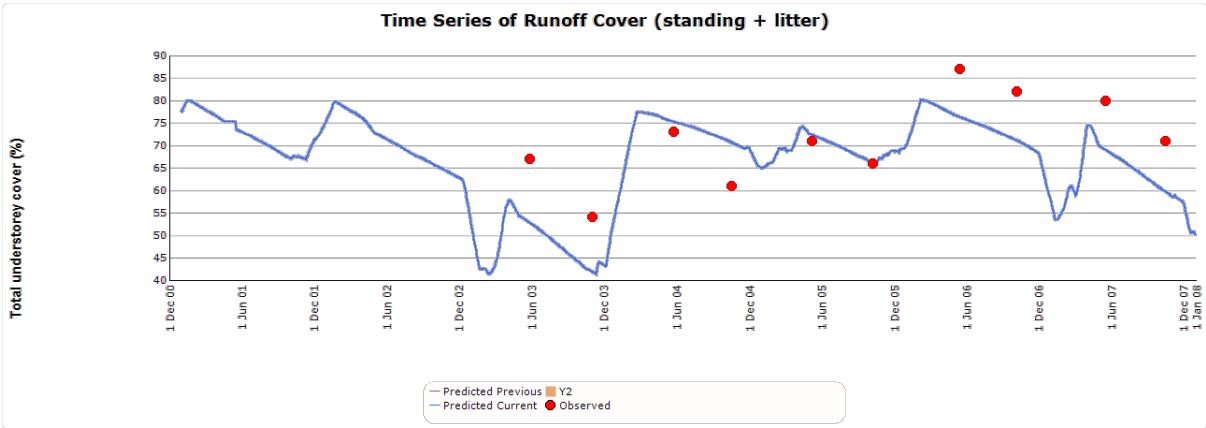


Figure 14-162: Simulated TSDM in Bauhinia Paddock, Pigeon Hole (blue line) and TSDM observations (red dots)

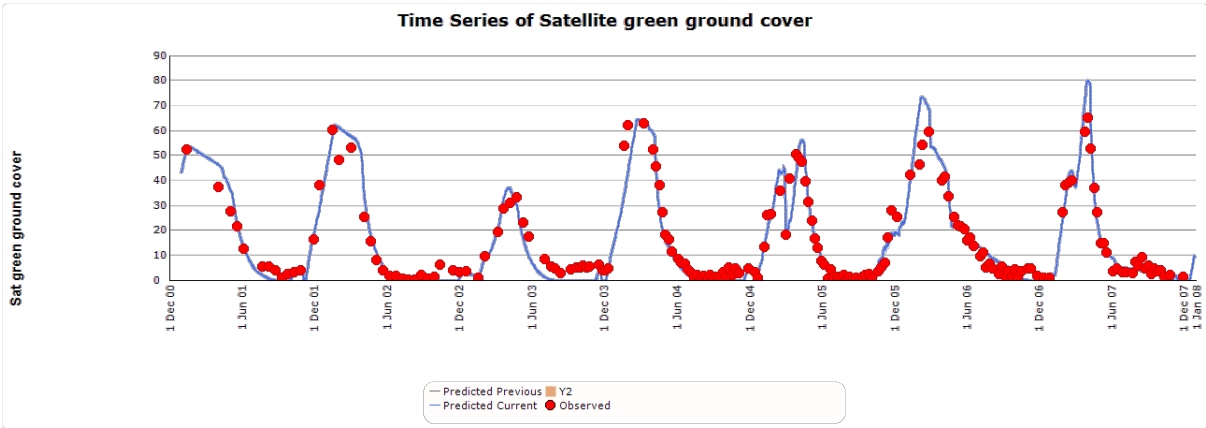


Figure 14-163: Simulated green cover in Bauhinia Paddock, Pigeon Hole, (blue line) and satellite derived green ground cover observations (red dots)

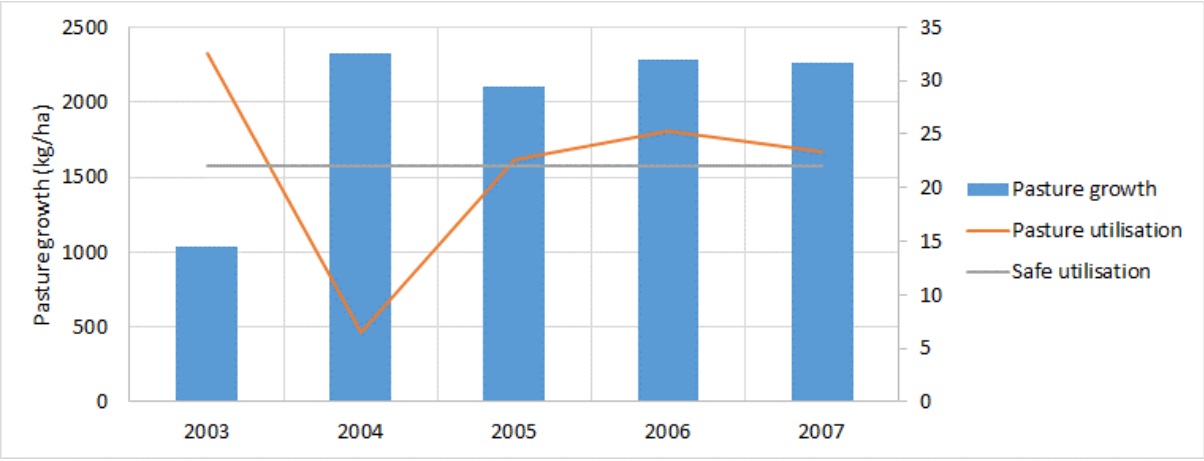


Figure 14-164: Simulated pasture growth and utilisation at Bauhinia Paddock, Pigeon Hole

Brolga Paddock – 15% Target Utilisation

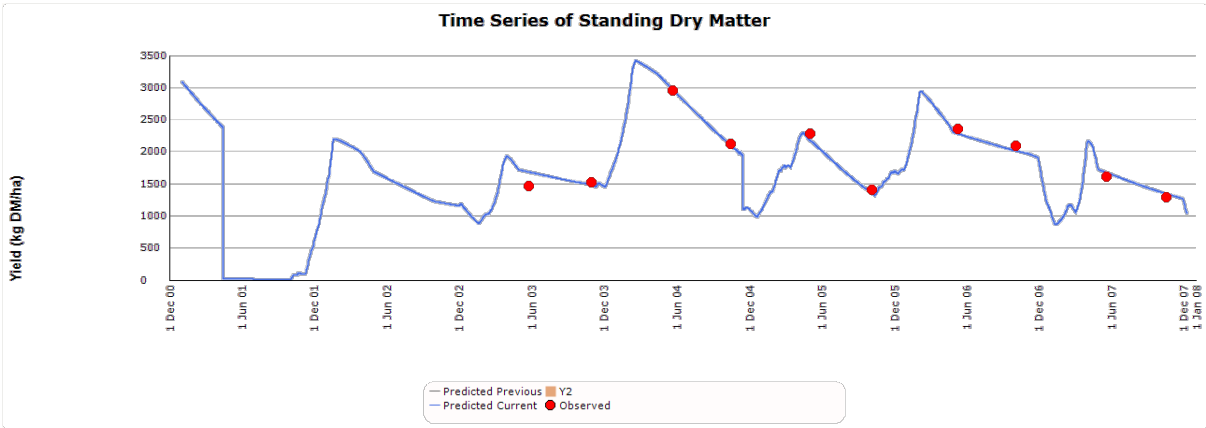


Figure 14-165: Simulated TSDM in Brolga Paddock, Pigeon Hole (blue line) and TSDM observations (red dots)

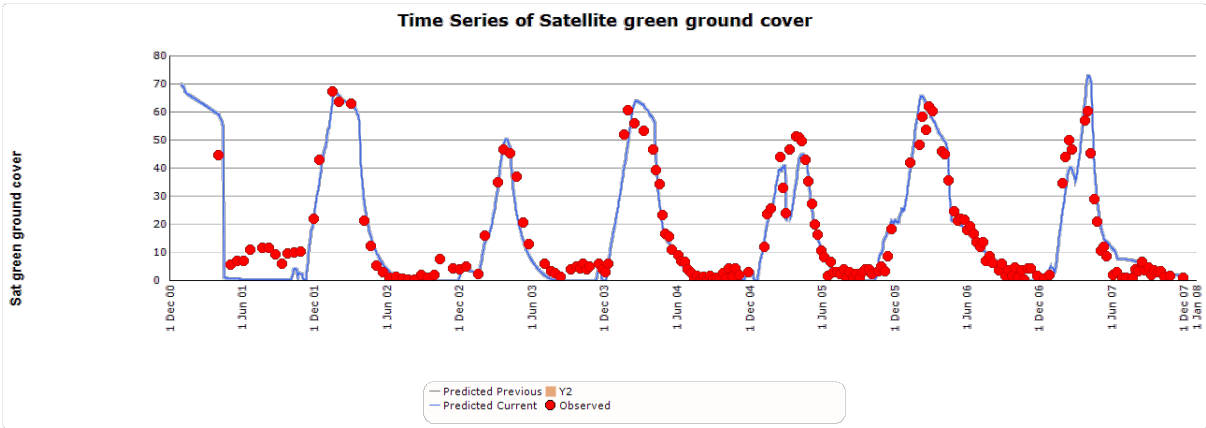


Figure 14-166: Simulated green cover in Brolga Paddock, Pigeon Hole, (blue line) and satellite derived green ground cover observations (red dots)

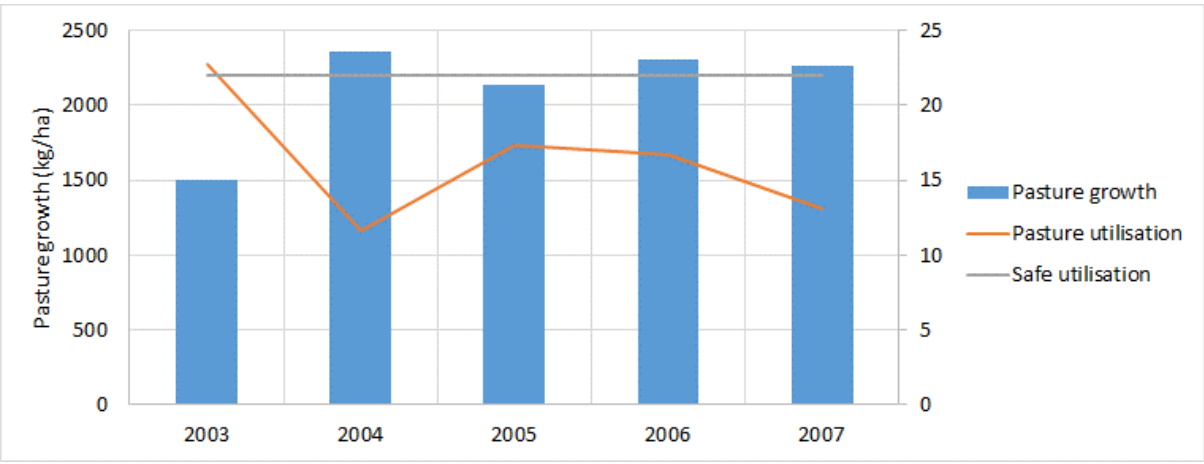


Figure 14-167: Simulated pasture growth and utilisation at Brolga Paddock, Pigeon Hole

Bullock – Wet Season Spelling

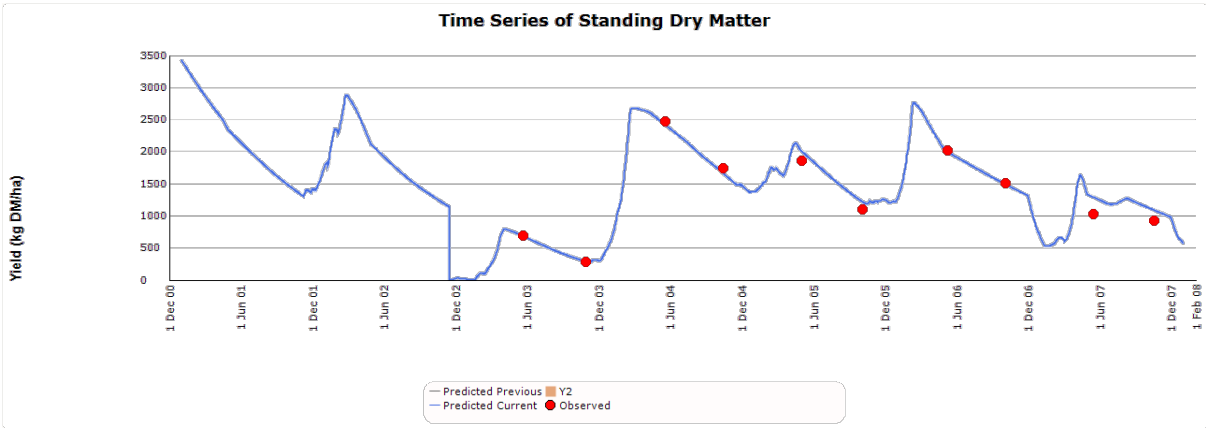


Figure 14-168: Simulated TSDM in the West Season Spelling paddocks, Pigeon Hole (blue line) and TSDM observations (red dots)

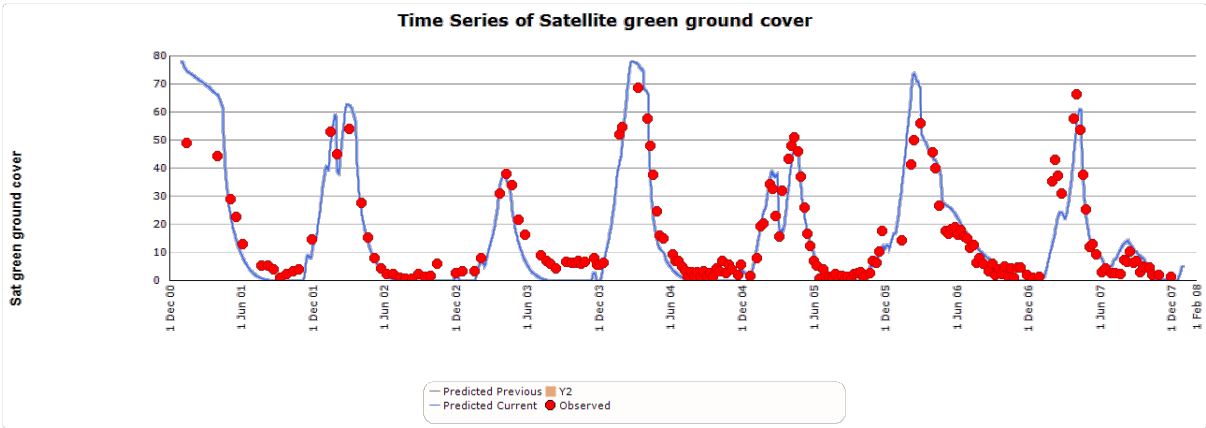


Figure 14-169: Simulated green cover in Wet Season Spelling paddocks, Pigeon Hole, (blue line) and satellite derived green ground cover observations (red dots)

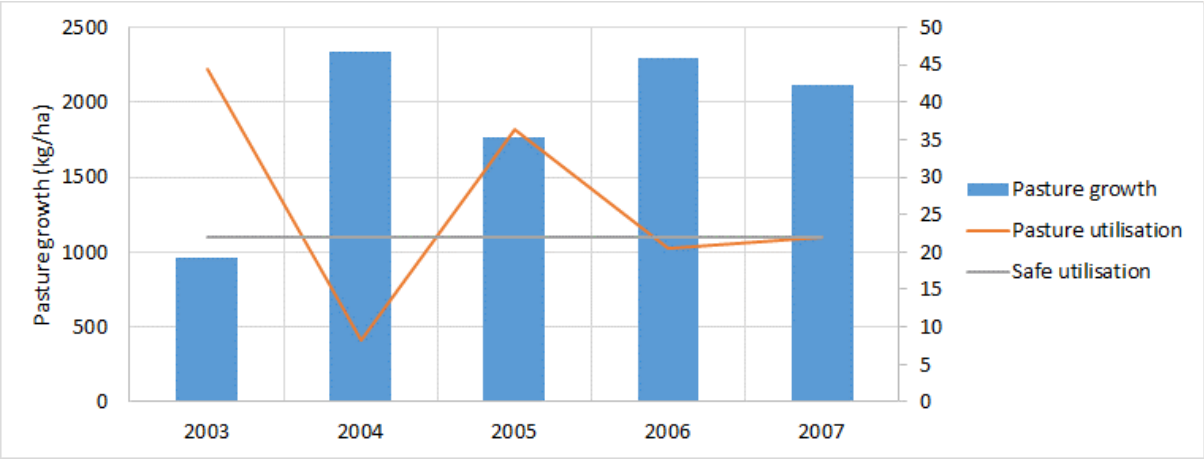


Figure 14-170: Simulated pasture growth and utilisation at the Wet Season Spelling paddocks, Pigeon Hole

Cell Grazing

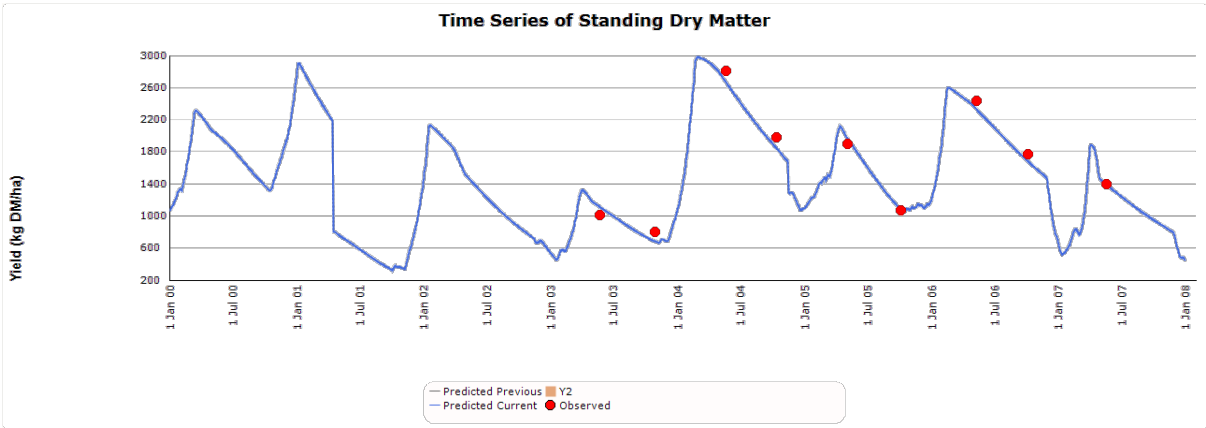


Figure 14-171: Simulated TSDM in Cell Grazing paddocks, Pigeon Hole (blue line) and TSDM observations (red dots)

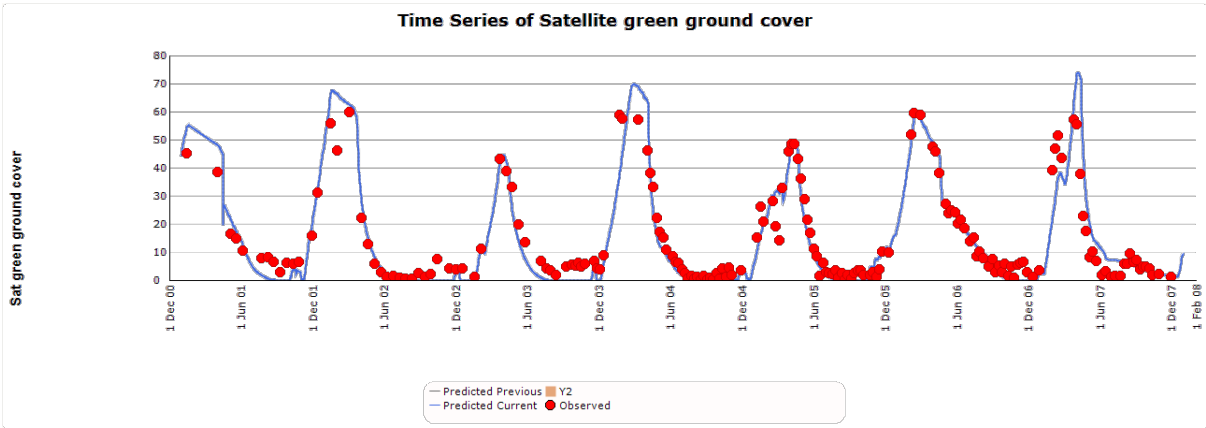


Figure 14-172: Simulated green cover in Cell Grazing paddocks, Pigeon Hole, (blue line) and satellite derived green ground cover observations (red dots)

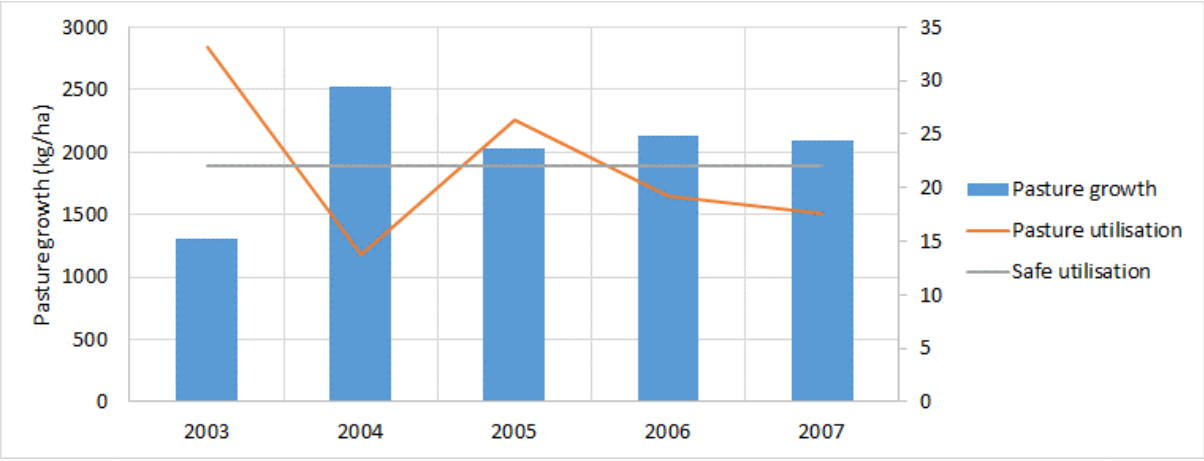


Figure 14-173: Simulated pasture growth and utilisation at the Cell Grazing paddocks, Pigeon Hole

Dead Cat – 40 % Target Utilisation

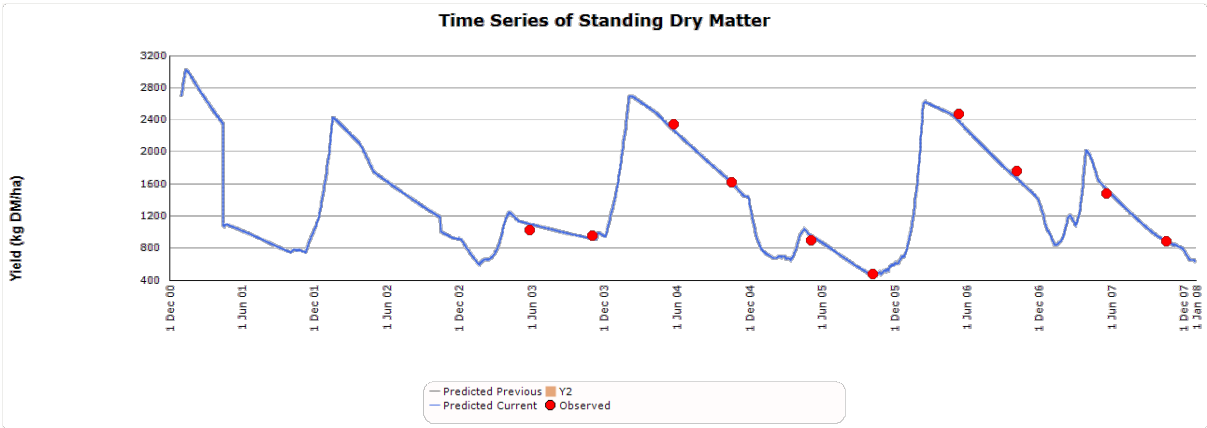


Figure 14-174: Simulated TSDM in Dead Cat Paddock, Pigeon Hole (blue line) and TSDM observations (red dots)

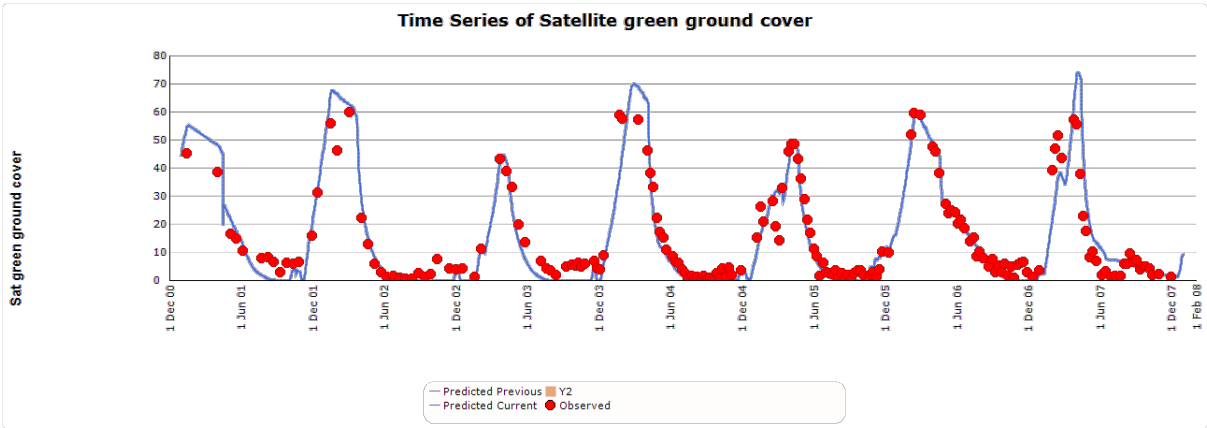


Figure 14-175: Simulated green cover in Dead Cat Paddock, Pigeon Hole, (blue line) and satellite derived green ground cover observations (red dots)

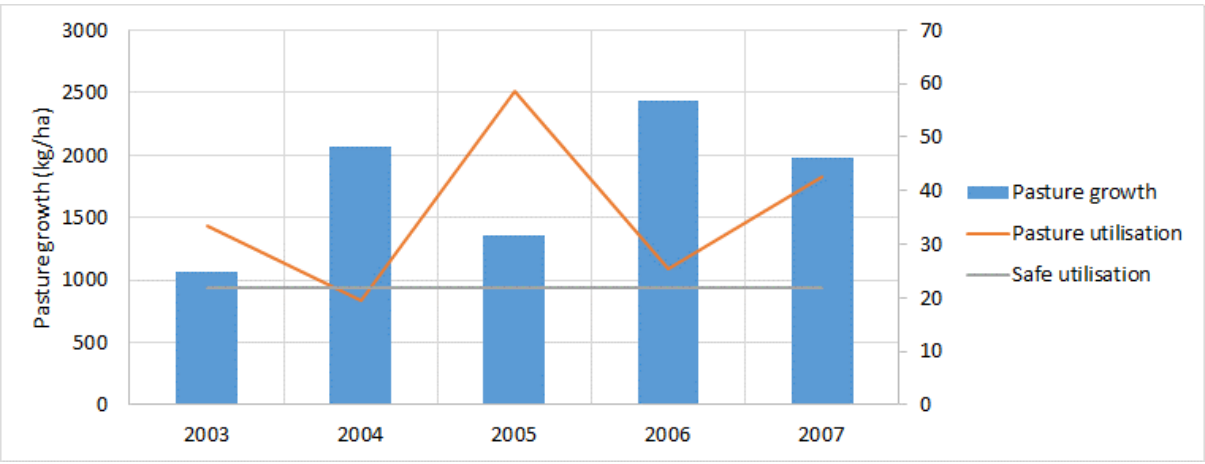


Figure 14-176: Simulated pasture growth and utilisation at Dead Cat Paddock, Pigeon Hole

Number 13 Paddock – Set Spelling

Number 13 paddock was nominally set stocked, but the stocking rate varied year to year as much as the set utilisation paddocks (Figure 14-177) and pasture utilisation was higher than the targeted 20% most years (Figure 14-180).

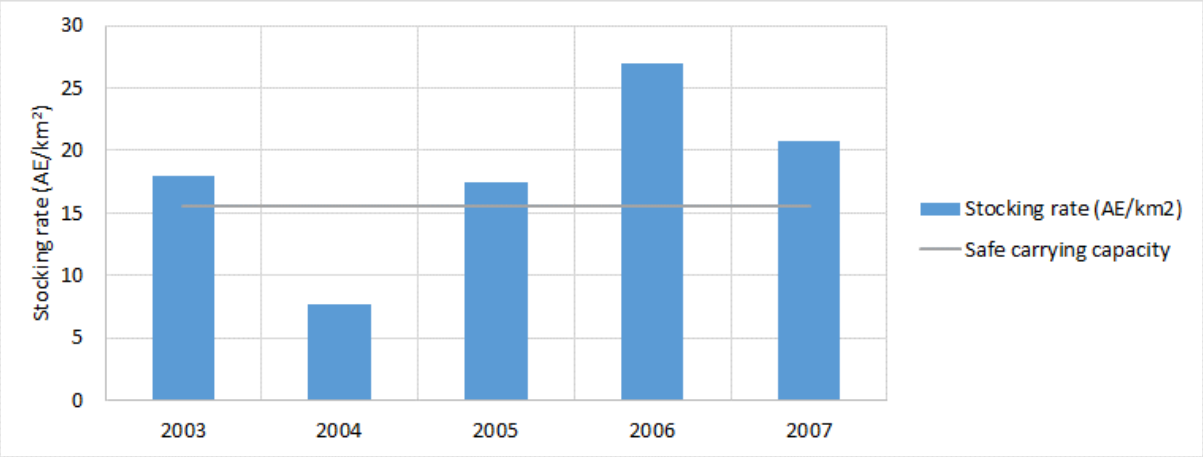


Figure 14-177: Stocking rate vs safe carrying capacity in Number 13 Paddock, Pigeon Hole

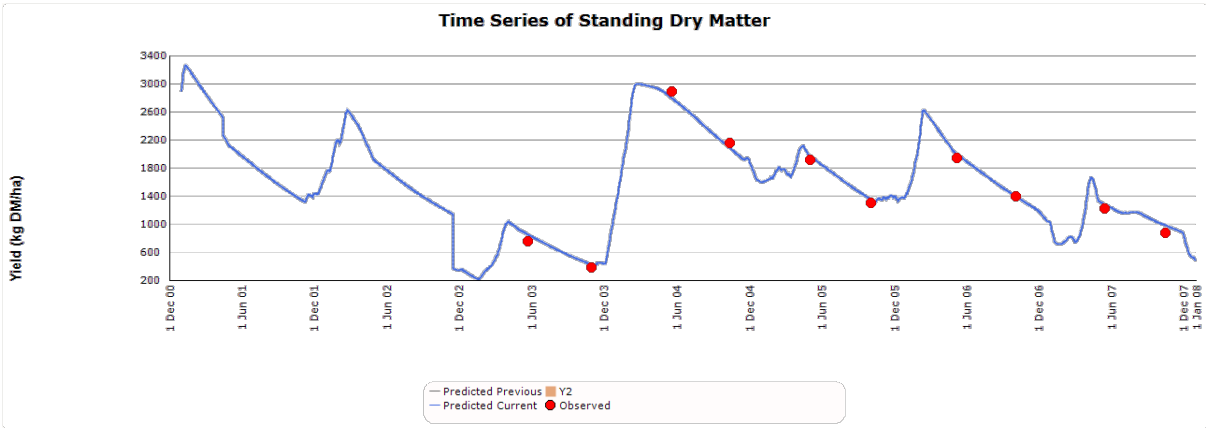


Figure 14-178: Simulated TSDM in Number 13 Paddock, Pigeon Hole (blue line) and TSDM observations (red dots)

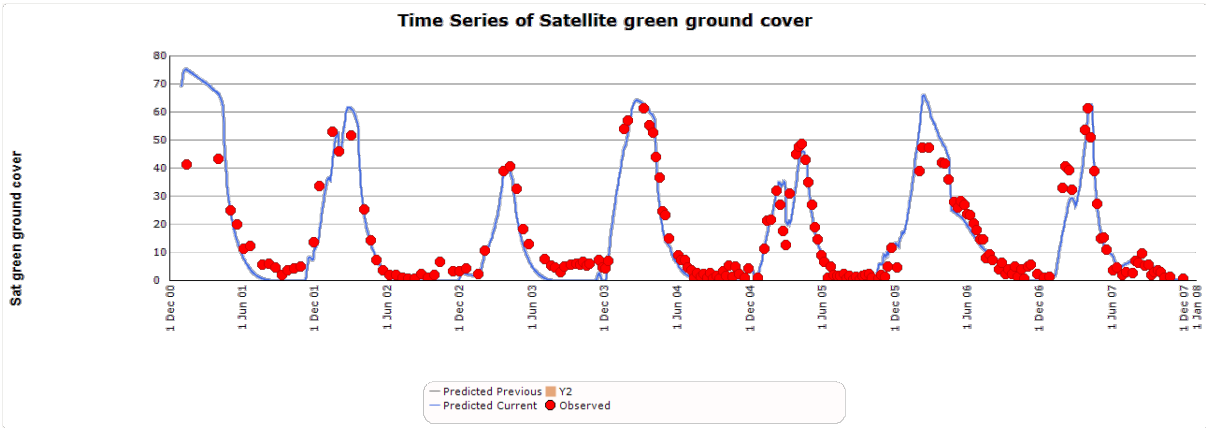


Figure 14-179: Simulated green cover in Number 13 Paddock, Pigeon Hole, (blue line) and satellite derived green ground cover observations (red dots)

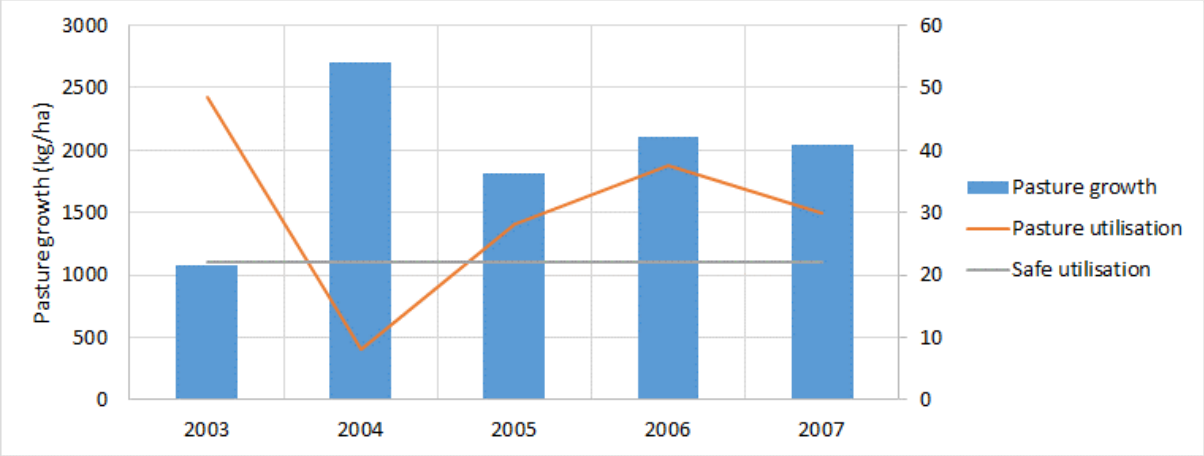


Figure 14-180: Simulated pasture growth and utilisation at Number 13 Paddock, Pigeon Hole

North Stevens Creek Paddock

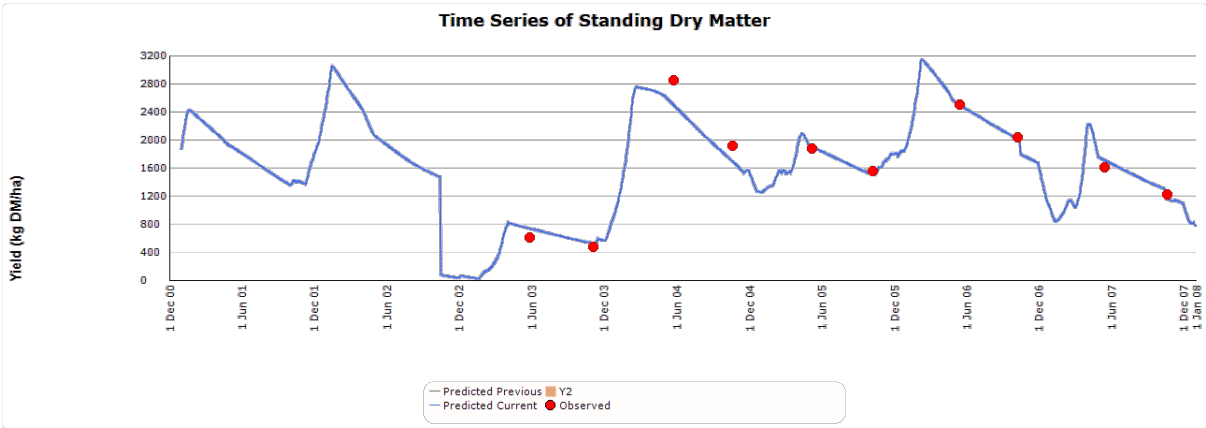


Figure 14-181: Simulated TSDM in North Stevens Creek Paddock, Pigeon Hole (blue line) and TSDM observations (red dots)

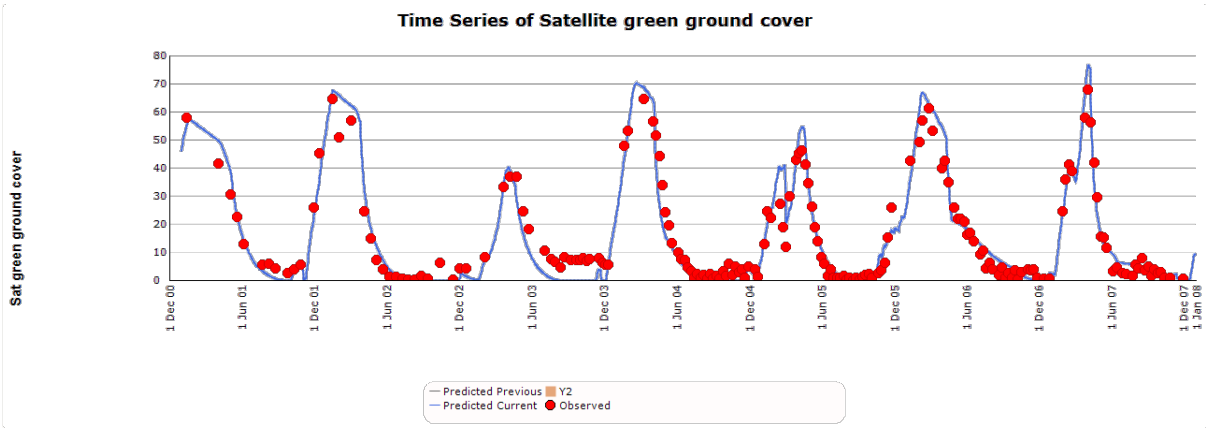


Figure 14-182: Simulated green cover in North Stevens Creek Paddock, Pigeon Hole, (blue line) and satellite derived green ground cover observations (red dots)

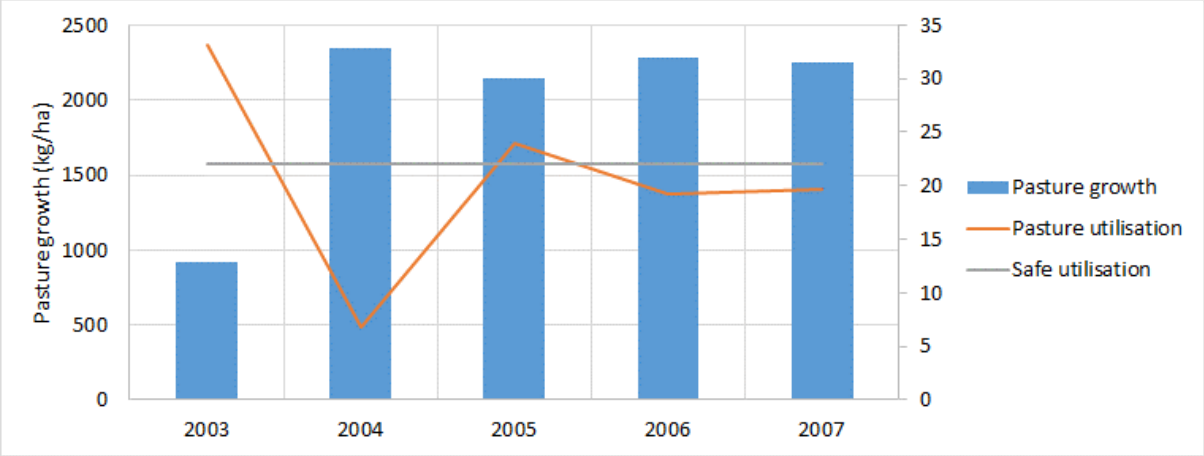


Figure 14-183: Simulated pasture growth and utilisation at North Stevens Creek Paddock, Pigeon Hole

Racecourse Paddock

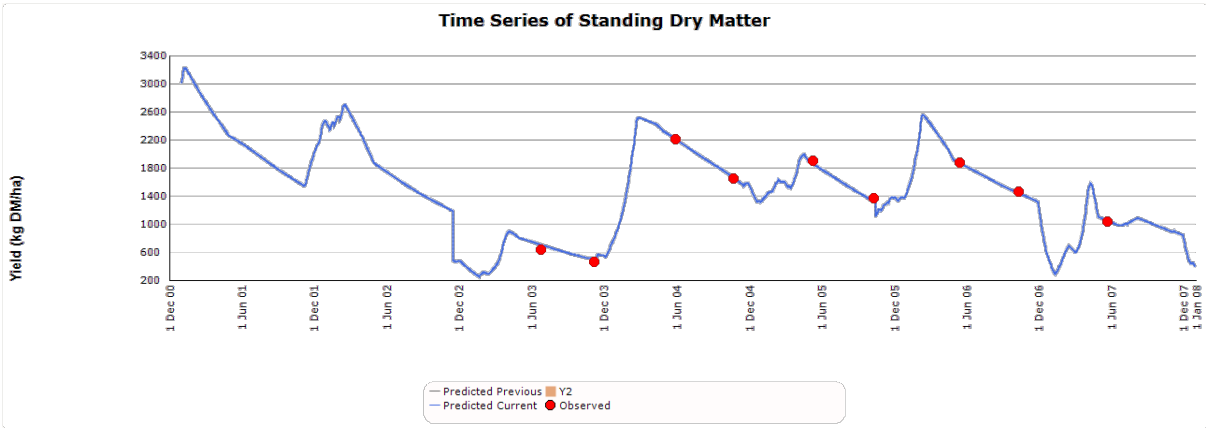


Figure 14-184: Simulated TSDM in Racecourse Paddock, Pigeon Hole (blue line) and TSDM observations (red dots)

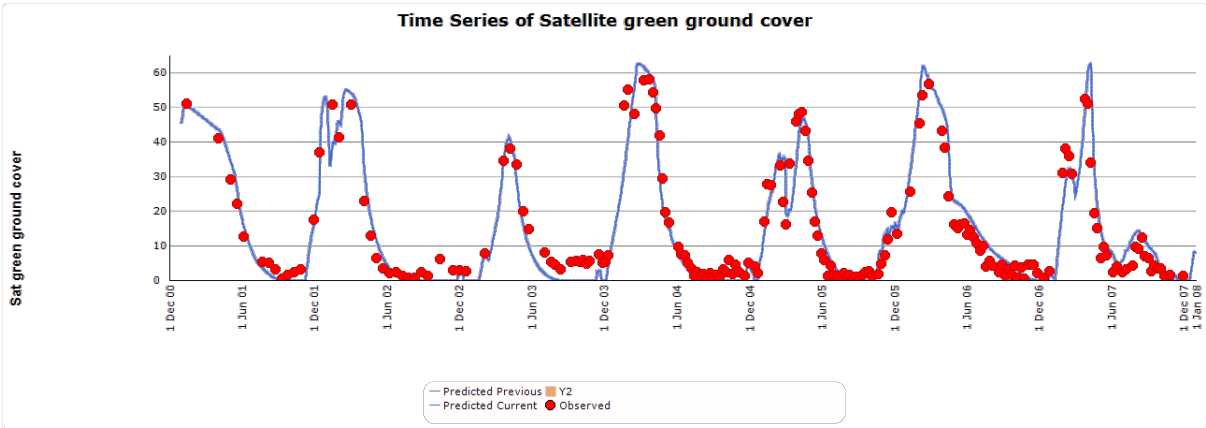


Figure 14-185: Simulated green cover in Racecourse Paddock, Pigeon Hole, (blue line) and satellite derived green ground cover observations (red dots)

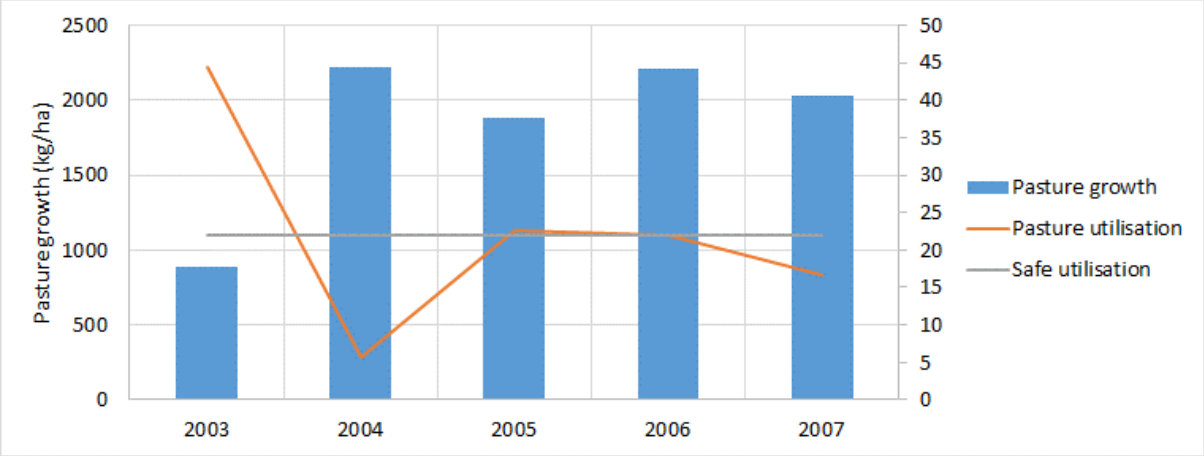


Figure 14-186: Simulated pasture growth and utilisation at Racecourse Paddock, Pigeon Hole

Sandstone Paddock – 20% Target Utilisation

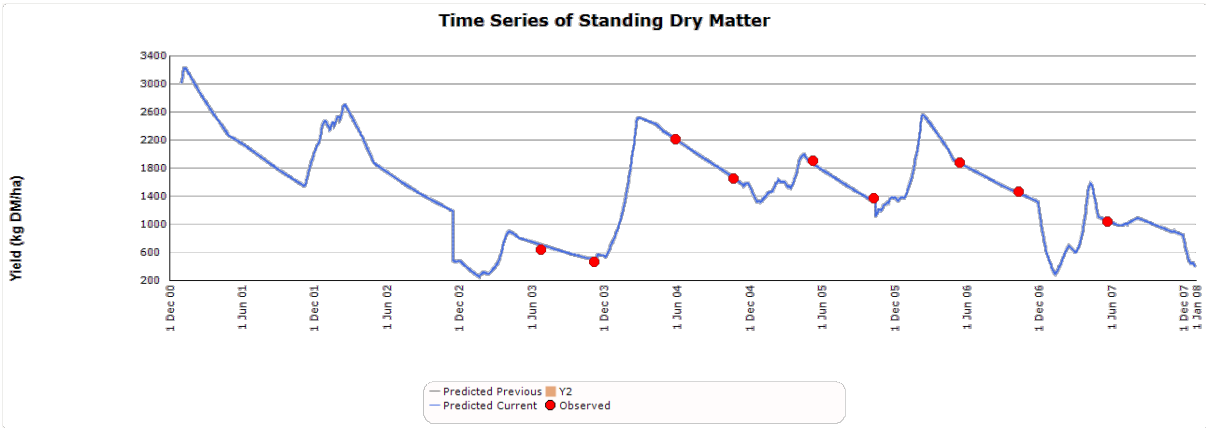


Figure 14-187: Simulated TSDM in Sandstone Paddock, Pigeon Hole (blue line) and TSDM observations (red dots)

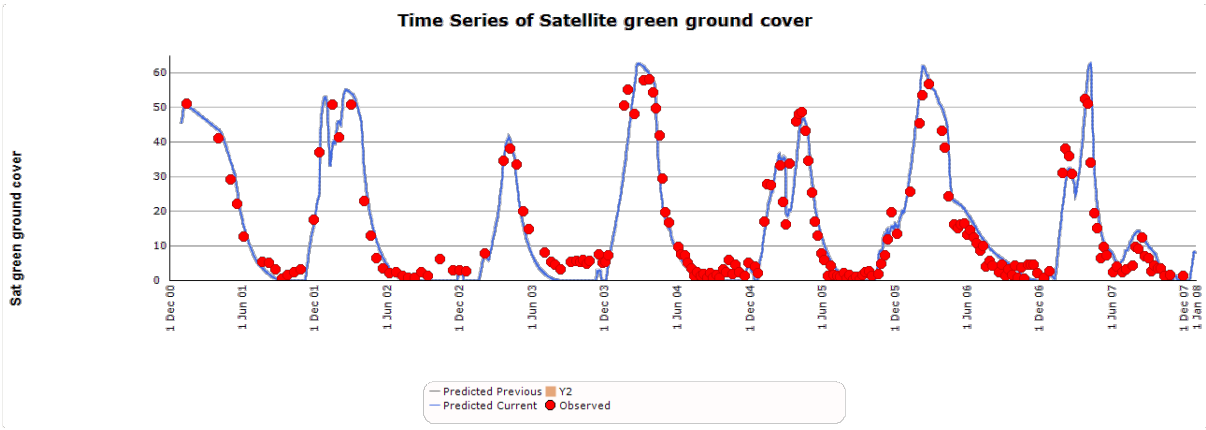


Figure 14-188: Simulated green cover in Sandstone Paddock, Pigeon Hole, (blue line) and satellite derived green ground cover observations (red dots)

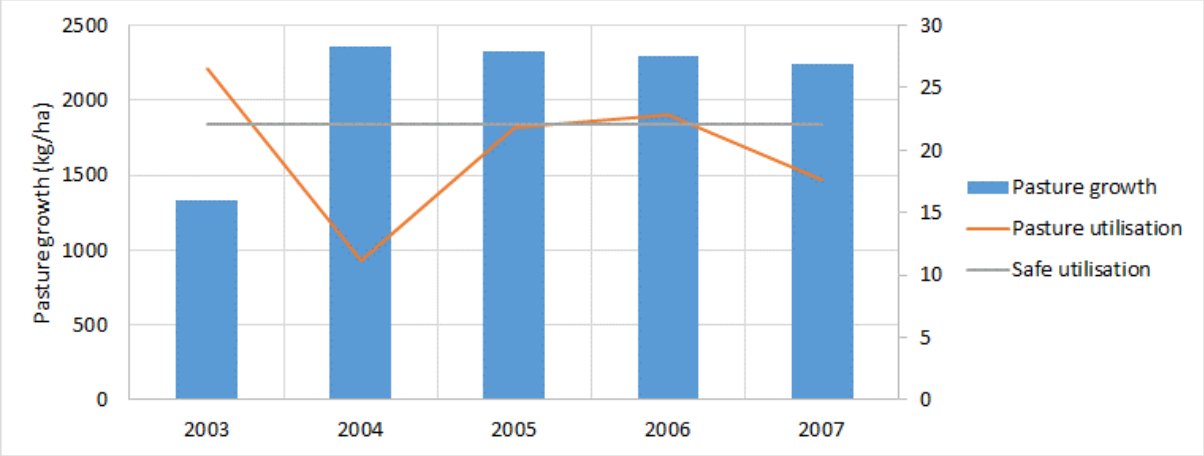


Figure 14-189: Simulated pasture growth and utilisation at Sandstone Paddock, Pigeon Hole

South Stevens Creek Paddock

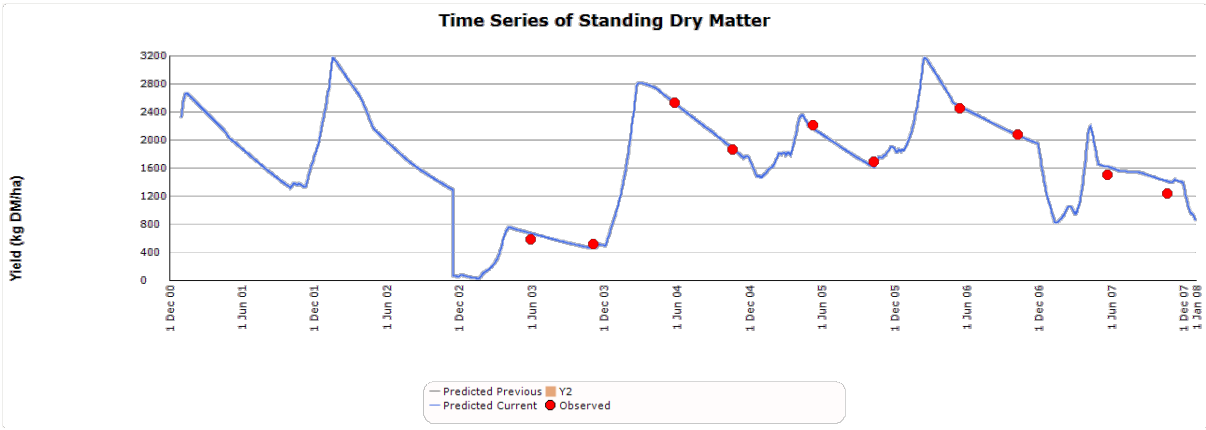


Figure 14-190: Simulated TSDM in South Stevens Creek Paddock, Pigeon Hole (blue line) and TSDM observations (red dots)

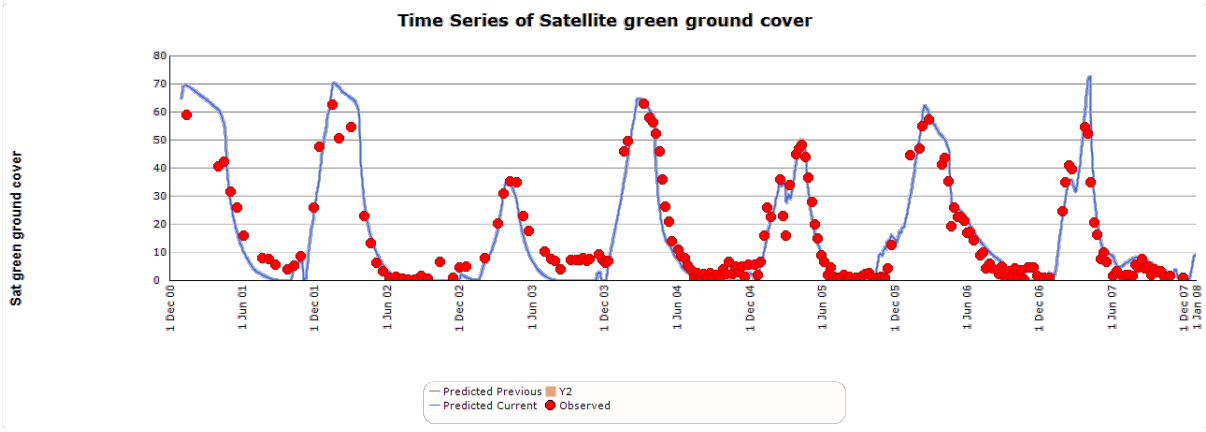


Figure 14-191: Simulated green cover in South Stevens Creek Paddock, Pigeon Hole, (blue line) and satellite derived green ground cover observations (red dots)

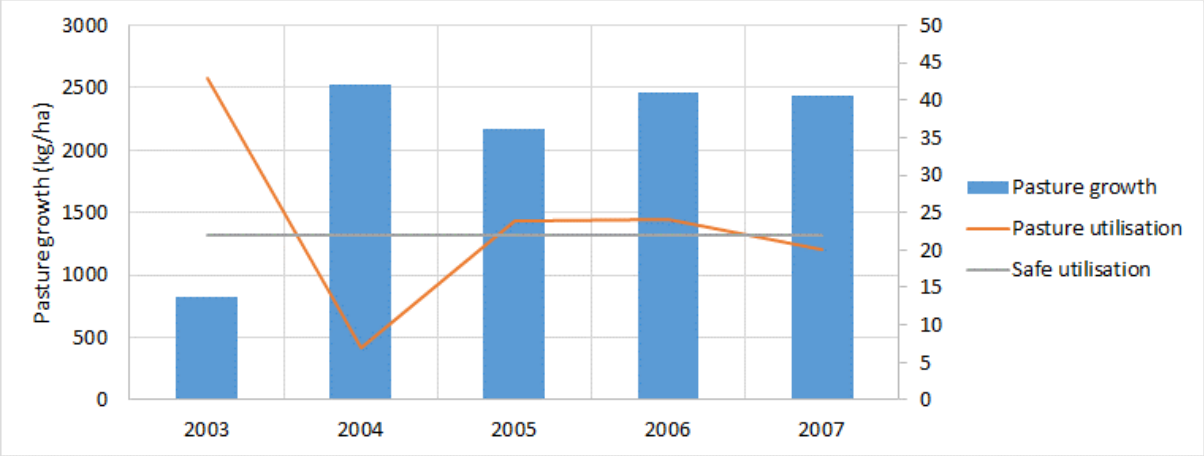


Figure 14-192: Simulated pasture growth and utilisation at South Stevens Creek Paddock, Pigeon Hole

Villiers Paddock – 30% Target Utilisation

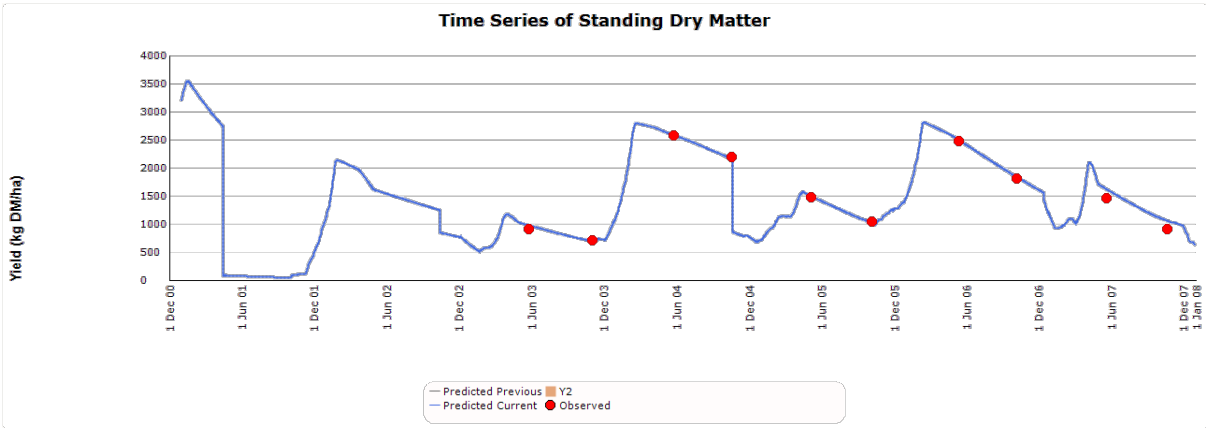


Figure 14-193: Simulated TSDM in Villiers Paddock, Pigeon Hole (blue line) and TSDM observations (red dots)

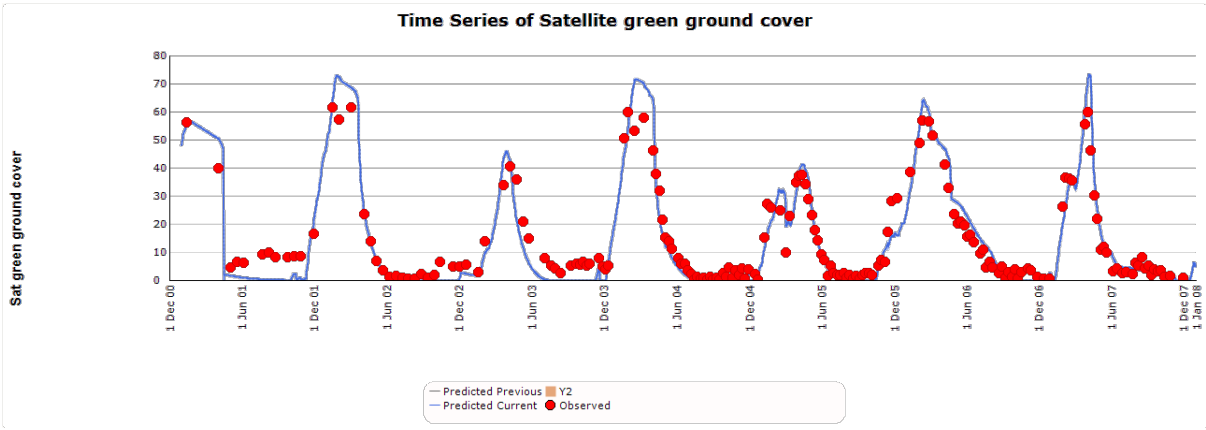


Figure 14-194: Simulated green cover in Villiers Paddock, Pigeon Hole, (blue line) and satellite derived green ground cover observations (red dots)

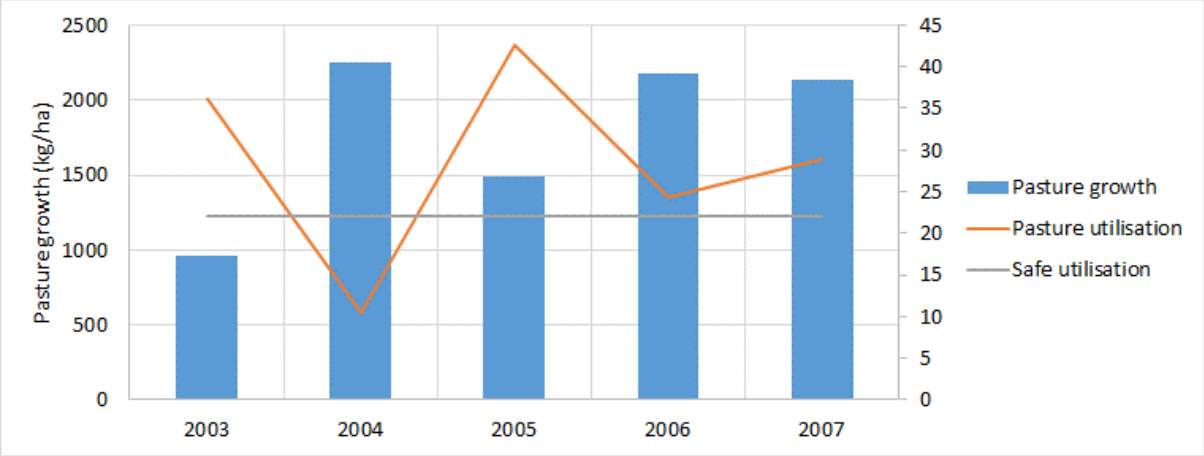


Figure 14-195: Simulated pasture growth and utilisation at Villiers Paddock, Pigeon Hole

14.4 Terms and factors screened for association with the four measures of cow reproductive performance

Parameter	Definition
dataset_id	Unique identifier for each dataset record
Dominant land type	Specific dominant land cover type at location
Broad land type	Broad ecological or vegetation classification
Region	General region or study area
station	Name or identifier of the station
paddock	Name or identifier of the paddock
stationpaddock	Combined station and paddock identifier
anim_eid	Animal electronic ID (e.g., RFID or NLIS tag)
anim_vid	Visual ID tag of the animal
ydrop	Year the animal was born (year drop)
age	Animal age in years at time of observation
hh1	Hip height measurement 1
hh2	Hip height measurement 2
anim_breed	Breed of the animal
anim_class	Class of the animal (e.g., cow, heifer, steer)
year_obs	Year of observation
prev_dateproc_wd	Previous Wet/Dry muster processing date
prev_bcs_wd	Previous body condition score (Wet/Dry muster)
prev_lact_wd	Previous lactation status (Wet/Dry muster)
prev_corrwt_wd	Previous corrected weight (Wet/Dry muster)
prev_dateproc_pt	Previous Pregnancy Test muster processing date
prev_bcs_pt	Previous body condition score (Pregnancy Test muster)
prev_lact_pt	Previous lactation status (Pregnancy Test muster)
prev_corrwt_pt	Previous corrected weight (Pregnancy Test muster)
dateproc_wd	Current Wet/Dry muster processing date
mobid_wd	Wet/Dry muster mob identifier
bcs_wd	Body condition score (Wet/Dry muster)
pd_wd	Pregnancy diagnosis result (Wet/Dry muster)
lact_wd	Lactation status (Wet/Dry muster)
wt_wd	Weight (Wet/Dry muster)
corrwt_wd	Corrected weight (Wet/Dry muster)
calfdate_wd	Calving date (Wet/Dry muster)
fate_wd	Animal fate in Wet/Dry muster (e.g., retained, sold)
pdkfrom_wd	Paddock the animal came from (Wet/Dry muster)
pdkreturned_wd	Paddock the animal returned to (Wet/Dry muster)
dateproc_pt	Current Pregnancy Test muster processing date
mobid_pt	Pregnancy Test muster mob identifier
bcs_pt	Body condition score (Pregnancy Test muster)
pd_pt	Pregnancy diagnosis result (Pregnancy Test muster)
lact_pt	Lactation status (Pregnancy Test muster)
wt_pt	Weight (Pregnancy Test muster)

corrwt_pt	Corrected weight (Pregnancy Test muster)
calfdate_pt	Calving date (Pregnancy Test muster)
fate_pt	Animal fate in Pregnancy Test muster
pdkfrom_pt	Paddock the animal came from (Pregnancy Test muster)
pdkreturned_pt	Paddock the animal returned to (Pregnancy Test muster)
next_dateproc_wd	Next Wet/Dry muster processing date
next_bcs_wd	Next body condition score (Wet/Dry muster)
next_lact_wd	Next lactation status (Wet/Dry muster)
next_corrwt_wd	Next corrected weight (Wet/Dry muster)
next_dateproc_pt	Next Pregnancy Test muster processing date
next_bcs_pt	Next body condition score (Pregnancy Test muster)
next_lact_pt	Next lactation status (Pregnancy Test muster)
next_corrwt_pt	Next corrected weight (Pregnancy Test muster)
prev_lact_annual	Previous year lactation status
prev_preg_annual	Previous year pregnancy status
prev_calfmonth_annual	Previous year calving month
lact_annual	Current year lactation status
preg_annual	Current year pregnancy status
calfmonth_annual	Month of calving in the current year
p4m_annual	Pregnancy within 4 months while lactating
mort_calf_annual	Calf mortality in the year
mort_brdr_annual	Breeder mortality in the year
annual_adg	Annual average daily gain
wet_adg	Wet season average daily gain
dry_adg	Dry season average daily gain
fate_annual	Final fate for the year
prev_annual_adg	Previous year's average daily gain
prev_wet_adg	Previous wet season ADG
prev_dry_adg	Previous dry season ADG
next_lact_annual	Lactation status next year
next_preg_annual	Pregnancy next year
next_calfmonth_annual	Calving month in the next year
avg_thi_pre2m	Average THI (Temperature Humidity Index) 2 months prior
avg_thi_moc	Average THI at muster on capture
avg_thi_post3m	Average THI 3 months after
p72_thi_pre2m	72nd percentile THI pre-2 months
p72_thi_moc	72nd percentile THI during month of calving
p72_thi_post3m	72nd percentile THI post-3 months
p86_thi_pre2m	86th percentile THI pre-2 months
p86_thi_moc	86th percentile THI during month of calving
p86_thi_post3m	86th percentile THI post-3 months
p96_thi_pre2m	96th percentile THI pre-2 months
p96_thi_moc	96th percentile THI during month of calving
p96_thi_post3m	96th percentile THI post-3 months

avg_cci_pre2m	Average cloud cover index (CCI) pre-2 months
avg_cci_moc	Average CCI during month of calving
avg_cci_post3m	Average CCI post-3 months
p_exec30_cci_pre2m	Days with CCI >30 pre-2 months
p_exec30_cci_moc	Days with CCI >30 during month of calving
p_exec30_cci_post3m	Days with CCI >30 post-3 months
p_exec33_cci_pre2m	Days with CCI >33 pre-2 months
p_exec33_cci_moc	Days with CCI >33 during month of calving
p_exec33_cci_post3m	Days with CCI >33 post-3 months
p_exec36_cci_pre2m	Days with CCI >36 pre-2 months
p_exec36_cci_moc	Days with CCI >36 during month of calving
p_exec36_cci_post3m	Days with CCI >36 post-3 months
TSDM_pre2m	Total Standing Dry Matter pre-2 months (kg/ha)
TSDM.moc	Total Standing Dry Matter at month of calving (kg/ha)
TSDM_post3m	Total Standing Dry Matter post-3 months post calving (kg/ha)
GrnTSDM_pre2m	Green Total Standing Dry Matter 2 months pre calving (kg/ha)
GrnTSDM	Green Total Standing Dry Matter during month of calving (kg/ha)
GrnTSDM_post3m	Green Total Standing Dry Matter 3 months post-calving (kg/ha)
percNSward_pre2m	Percentage of nitrogen in the sward in paddock 2 months prior to calving
percNSward	Percentage of nitrogen in the TSDM
percNSward_post3m	Percentage of nitrogen in the TSDM in the 3 months post-calving
arndCalf_AvTSDM6Mth	Average Total Standing Dry Matter in the 6 months (± 3 mths) around calving
arndCalf_AvGrnTSDM6Mth	Average Green TSDM in the 6 months (± 3 mths) around calving
arndCalf_AvPropGrn6Mth	Average proportion of green pasture in the 6 months (± 3 mths) around calving
arndCalf_SumGrowth6Mth	Sum of pasture growth in the 6 months (± 3 mths) around calving
arndCalf_Av%TSDMUtil6Mth	Average percentage utilisation of TSDM in the 6 months (± 3 mths) around calving
arndCalf_Av%N_TSDM6Mth	Average percentage nitrogen in TSDM in the 6 months (± 3 mths) around calving
arndCalf_Av%N_Growth6Mth	Average percentage non-green growth in the 6 months (± 3 mths) around calving
Paddock area (km2)	Size of the paddock in square kilometres
Watered area (%) All area within	All area within 3km and half area between 3-5km from water
	Percentage of paddock within effective watering distance
% paddock within 3km	Percentage of paddock area within 3km of water source
% paddock within 5km	Percentage of paddock area within 5km of water source
Maximum DTW (km)	Maximum Distance to Water (km)
Number of permanent waters	Count of permanent water sources in paddock
Number of non-permanent waters	Count of non-permanent water sources in paddock
Median rainfall (mm)	Median rainfall amount during study period (mm)
Rainfall CV (%)	Coefficient of variation of rainfall (%)
Average rainfall during study (m	Average rainfall across study duration (mm)

Median long-term modelled pasture growth (kg/ha	Median modeled pasture growth (kg/ha)
Safe utilisation lower (%)	Lower bound of safe pasture utilisation percentage
Safe utilisation mid (%)	Mid-range estimate of safe pasture utilisation
Safe utilisation upper (%)	Upper bound of safe pasture utilisation percentage
Confidence in utilisation model	Confidence rating for utilisation models
Modellers	Names or initials of model developers
AE/ permanent water (AE/water)	Animal equivalents per permanent water source
AE/ permanent and non permanent	Animal equivalents per all water sources
Long-term safe carrying capacity	Sustainable animal equivalents per square km
Grazing strategy	Description of grazing management approach
Spelling / no spelling	Data spelling verification status
Date	Date of data record entry or observation
Rain	Recorded rainfall amount (mm)
TBA	Tree basal area
FPC	Fractional pasture cover (%)
Grass_Grwth	Grass growth measurement (kg/ha)
TSDM	Total Standing Dry Matter
AvGrnTSDM	Average Green Total Standing Dry Matter
AvDeadTSDM	Average Dead Total Standing Dry Matter
AE/km2	Animal equivalents per km^2
AccGrowth	Accumulated annual pasture growth (between October 1 and September 30)
Utilisation	Annual pasture utilisation
%NSward	Percentage of nitrogen in the sward / TSDM
%NGrowth	Percentage of nitrogen in new growth
Burn	Burn treatment indicator
BurnDate (MMDD)	Date of burn (month and day)
Burn%	Percentage of area burned
Relative utilisation	Relative pasture utilisation index
RUE (pasture growth / mm rain)	Rain Use Efficiency (pasture growth per mm rain)
Modelling Confidence	Confidence rating of model output
Supplement	Supplement feed offered
Supplement_Timing	Timing of supplement feeding
SupplementType	Type of supplement used
SupplementMethod	Method of supplement application
Mating	Mating status or program details
AvAvailSoilP0-5cm	Average available soil phosphorus 0-5 cm depth
MedianAvailSoilP0-5cm	Median available soil phosphorus 0-5 cm
MinAvailSoilP0-5cm	Minimum available soil phosphorus 0-5 cm
MaxAvailSoilP0-5cm	Maximum available soil phosphorus 0-5 cm
season_SumGrowth_Jan-Mar	Total pasture growth Jan-Mar
season_SumGrowth_Apr-Jun	Total pasture growth Apr-Jun

season_SumGrowth_Jul-Sept	Total pasture growth Jul-Sept
season_SumGrowth_Oct-Dec	Total pasture growth Oct-Dec
season_AvTSDM_Jan-Mar	Average TSDM Jan-Mar
season_AvTSDM_Apr-Jun	Average TSDM Apr-Jun
season_AvTSDM_Jul-Sept	Average TSDM Jul-Sept
season_AvTSDM_Oct-Dec	Average TSDM Oct-Dec
season_AvGrnTSDM_Jan-Mar	Average green TSDM Jan-Mar
season_AvGrnTSDM_Apr-Jun	Average green TSDM Apr-Jun
season_AvGrnTSDM_Jul-Sept	Average green TSDM Jul-Sept
season_AvGrnTSDM_Oct-Dec	Average green TSDM Oct-Dec
season_AvProp_Grn_Jan-Mar	Average proportion green pasture Jan-Mar
season_AvProp_Grn_Apr-Jun	Average proportion green pasture Apr-Jun
season_AvProp_Grn_Jul-Sept	Average proportion green pasture Jul-Sept
season_AvProp_Grn_Oct-Dec	Average proportion green pasture Oct-Dec
season_Av%NSward_Jan-Mar	Average percentage NSward Jan-Mar
season_Av%NSward_Apr-Jun	Average percentage NSward Apr-Jun
season_Av%NSward_Jul-Sept	Average percentage NSward Jul-Sept
season_Av%NSward_Oct-Dec	Average percentage NSward Oct-Dec
season_Av%NGrowth_Jan-Mar	Average percentage new growth Jan-Mar
season_Av%NGrowth_Apr-Jun	Average percentage new growth Apr-Jun
season_Av%NGrowth_Jul-Sept	Average percentage new growth Jul-Sept
season_Av%NGrowth_Oct-Dec	Average percentage new growth Oct-Dec
season_%TSDM_Util_Jan-Mar	Percentage TSDM utilisation Jan-Mar
season_%TSDM_Util_Apr-Jun	Percentage TSDM utilisation Apr-Jun
season_%TSDM_Util_Jul-Sept	Percentage TSDM utilisation Jul-Sept
season_%TSDM_Util_Oct-Dec	Percentage TSDM utilisation Oct-Dec

14.5 Research vs. commercial breeder herd performance in Southern NT

There was a wide disparity in breeder performance between the commercial stations and Old Man Plains (OMP) research station in the Southern NT region (Figure 14-196 - Figure 14-202). The variation in breeder herd performance between research and commercial herds for the Southern NT region was explored for the August 2025 Alice Springs BeefUp presentation and slides from that presentation are shown below.

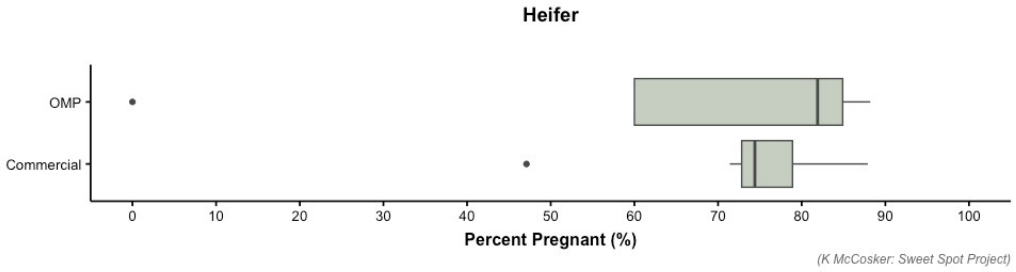
It should be noted, however, that these summary statistics are based on very small sample sizes within categories and are therefore likely to exhibit increased variability. No statistical analyses were performed and caution is advised when interpreting or comparing these differences.

The difference in breeder herd performance between commercial and research herds in Southern NT could be due to many management and environmental factors. Differences are unlikely to be related to rainfall, as it was higher on average during the station datasets (Table 4-10). But it could be due to the higher pasture growth (Table 4-10), possibly reflecting different land types and or better land condition on OMP, lower stocking rates (Table 4-9) and pasture utilisation (Table 4-11) and smaller paddock sizes on Old Man Plains (Table 4-8, Figure 4-10).

Annual pregnancy

Performance of heifers

There was a wider range of annual pregnancy rates for heifers on OMP than on commercial stations in the Southern NT (Figure 14-196).

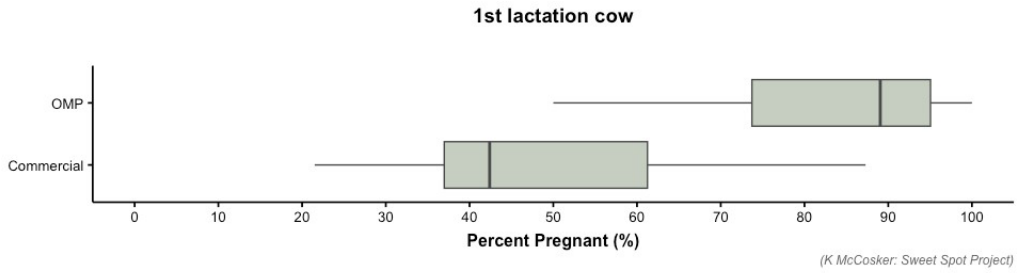


	No. of mobs	Minimum	Lower quartile	Median	Upper quartile	Maximum
OMP	4	0	60	82	85	88
Commercial	8	47	73	74	79	88

Figure 14-196: Boxplot and descriptive summary showing the distribution of annual pregnancy rates for heifer mobs in Southern NT for research and commercial station herds. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Performance of 1st lactation cows

1st lactation cows on commercial stations had lower annual pregnancy rates than on OMP (median less than half, Figure 14-197).

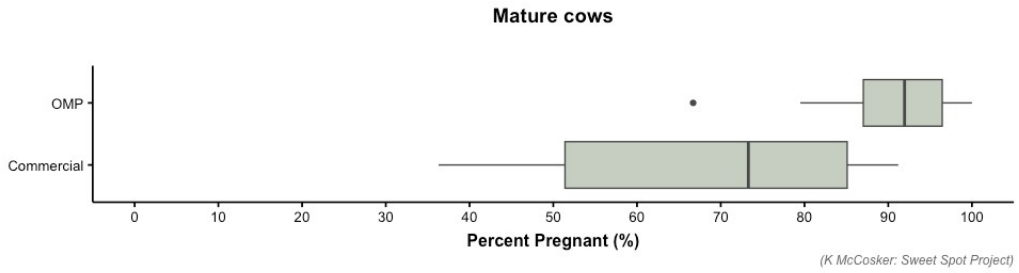


	No. of mobs	Minimum	Lower quartile	Median	Upper quartile	Maximum
OMP	14	50	74	89	95	100
Commercial	6	22	37	42	61	87

Figure 14-197: Boxplot and descriptive summary showing the distribution of annual pregnancy rates for mature cow mobs in Southern NT for research and commercial station herds. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Performance of mature cows

The annual pregnancy rates of mature cows were more similar between research and commercial station herds than for first lactation cows (Figure 14-198), but there was still a 20% difference in median annual pregnancy rates between the two groups.



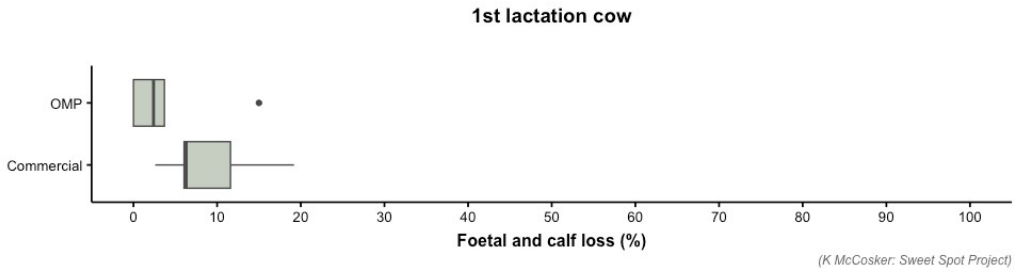
	No. of mobs	Minimum	Lower quartile	Median	Upper quartile	Maximum
OMP	32	67	87	92	96	100
Commercial	13	36	51	73	85	91

Figure 14-198: Boxplot and descriptive summary showing the distribution of annual pregnancy rates for mature cow mobs in Southern NT for research and commercial station herds. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Foetal and calf loss

Performance of 1st lactation cows

Median calf loss between pregnancy test and weaning for 1st lactation cows was three times higher on commercial stations than on OMP research mobs (Figure 14-199).

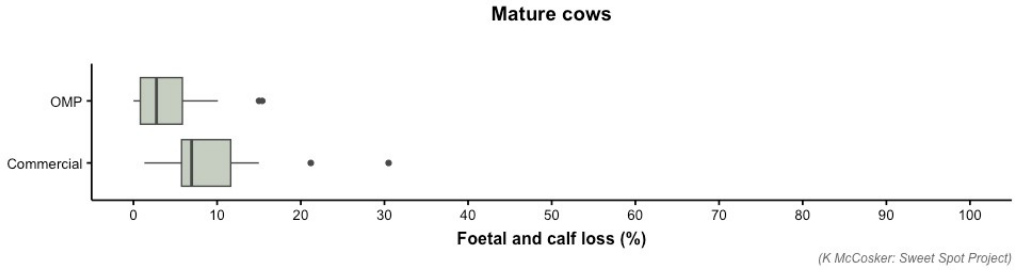


	No of mobs	Minimum	Lower quartile	Median	Upper quartile	Maximum
OMP	5	0	0	2	4	15
Commercial	8	3	6	6	12	19

Figure 14-199: Boxplot and descriptive summary showing the distribution of foetal and calf loss for 1st lactation cow mobs in Southern NT for research and commercial station herds. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Performance of mature cows

Median foetal and calf loss amongst mature cows on commercial stations was more than double that on the research station (Figure 14-200).



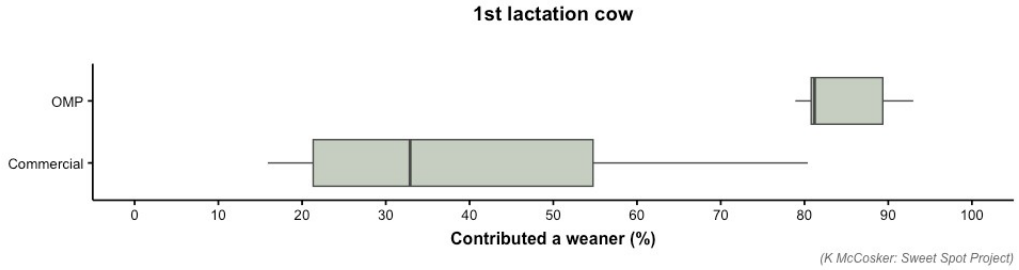
	No of mobs	Minimum	Lower quartile	Median	Upper quartile	Maximum
OMP	16	0	1	3	6	15
Commercial	12	1	6	7	12	31

Figure 14-200: Boxplot and descriptive summary showing the distribution of foetal and calf loss for mature cow mobs in Southern NT for research and commercial station herds. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Weaned a calf

Performance of 1st lactation cows

The weaning rates of 1st lactation cows were more variable and lower for station mobs (median less than half that on OMP, Figure 14-201).

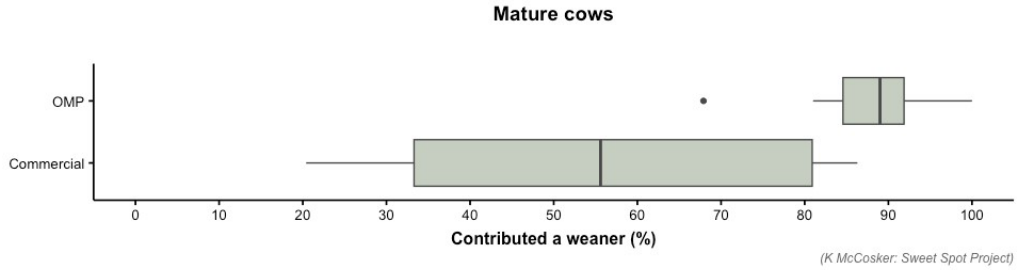


	No of mobs	Minimum	Lower quartile	Median	Upper quartile	Maximum
OMP	7	79	81	81	89	93
Commercial	6	16	21	33	55	80

Figure 14-201: Boxplot and descriptive summary showing the distribution of weaning rates for 1st lactation cow mobs in Southern NT for research and commercial station herds. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

Performance of mature cows

The weaning rates of mature cow mobs were more variable and the median was 33% lower on commercial stations than on OMP research station (Figure 14-202).



	No of mobs	Minimum	Lower quartile	Median	Upper quartile	Maximum
OMP	16	68	85	89	92	100
Commercial	9	20	33	56	81	86

Figure 14-202: Boxplot and descriptive summary showing the distribution of weaning rates for mature cow mobs in Southern NT for research and commercial station herds. The central line within each box represents the median, the box spans the interquartile range (IQR), whiskers extend to values within 1.5 × IQR, and points indicate outliers

14.6 Description of the breeder herd dataset to aid interpretation of analyses

Bos indicus content

Bos indicus content level varied substantially across regions for individuals and management groups (Table 14-3, Figure 14-203, Table 14-4, Figure 14-204). Across all reproductive measures, clear regional patterns existed in relation to *Bos indicus* content. Northern NT was dominated almost entirely by high *Bos indicus* herds (>75%), with over 90% of individuals and mobs in this category, reflecting a very different breed composition to the other regions. Central NT was generally balanced with cattle across each category. In contrast, much lower *Bos indicus* content was observed in the Southern NT, where more than 70% of individuals and mobs contained less than 50% *Bos indicus*. By comparison, North East Queensland herds were dominated by medium *Bos indicus* content, with 74–79% of individuals and 50–89% of mobs in the 50–75% category, and the remainder made up of higher-content groups (>75%).

Table 14-3 Regional counts and percentages of individual cattle by *Bos indicus* content across the entire dataset

Reproductive measure	*Bos indicus* content	<50%		50-75%		>75%	
	Region	Count	Percent	Count	Percent	Count	Percent
Annual pregnancy	North East Qld			11,647	79	3,092	21
	Southern NT	11,913	69.8	5,147	30.2		
	Central NT	9,365	55.9	4,161	24.8	3,225	19.3
	Northern NT			1,614	5.4	28,437	94.6
Pregnant within 4 months	North East Qld			3,842	79.3	1,001	20.7
	Southern NT	4,568	80.1	1,135	19.9		
	Central NT	4,759	67.6	1,266	18	1,017	14.4
	Northern NT			496	4.5	10,450	95.5
Weaning rate	North East Qld			5,997	74	2,106	26
	Southern NT	8,915	85.8	1,480	14.2		
	Central NT	5,856	60.3	2,102	21.6	1,752	18
	Northern NT			1,152	5.5	19,669	94.5
Foetal and Calf loss	North East Qld			4,257	77.1	1,262	22.9
	Southern NT	4,763	80.5	1,155	19.5		
	Central NT	4,856	63.5	1,710	22.4	1,078	14.1
	Northern NT			515	4.5	10,956	95.5

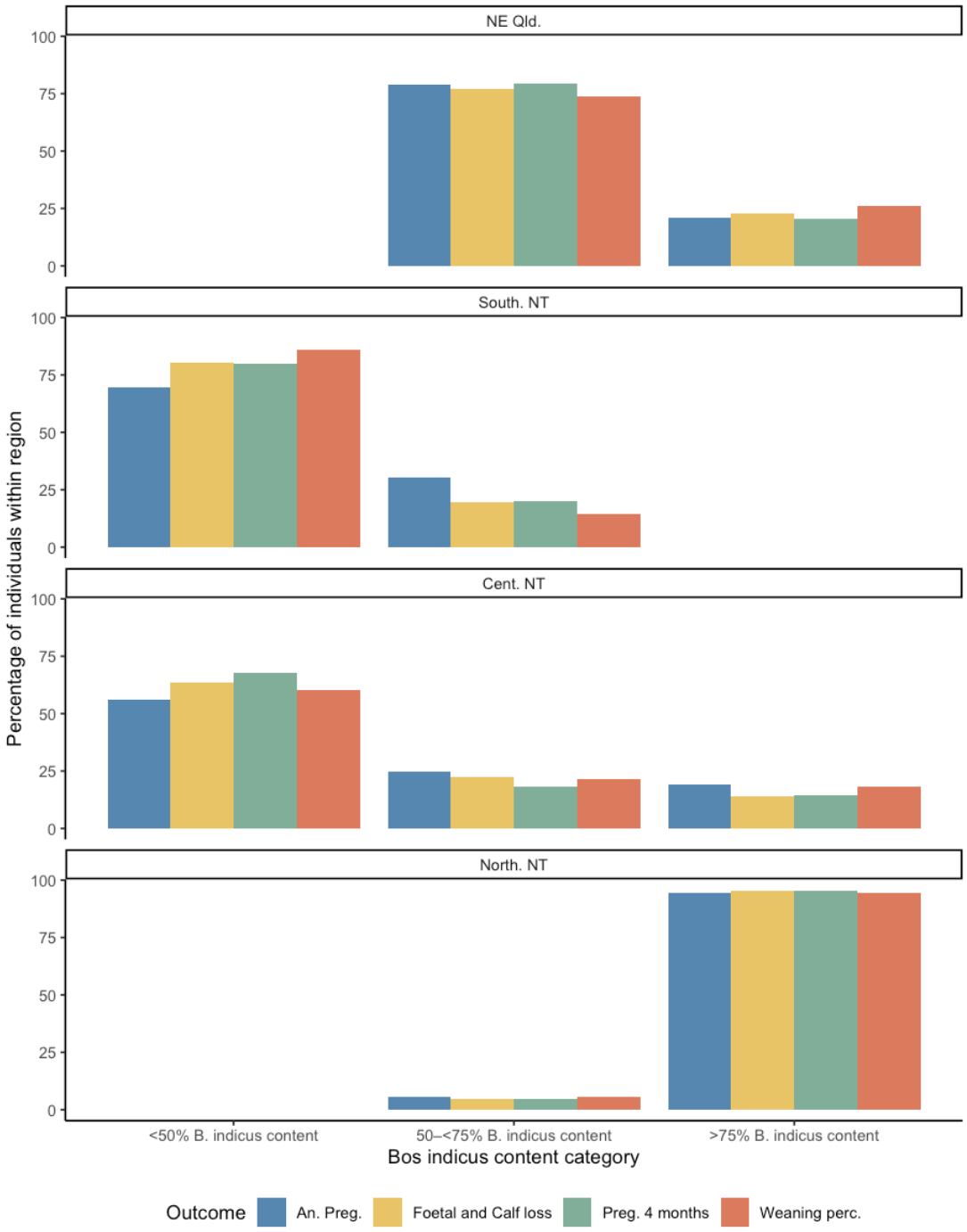


Figure 14-203: Distribution of available reproductive performance across *Bos indicus* content groups within region. Bars represent the percentage of records within region that contained non-missing data for annual pregnancy rate, pregnant within 4 months, weaning rate, and calf loss

Table 14-4: Regional counts and percentages of mobs by *Bos indicus* content across the entire dataset

Reproductive measure	*Bos indicus* content	<50%		50-75%		>75%	
	Region	Count	Percent	Count	Percent	Count	Percent
Annual pregnancy	North East Qld			48	88.9	6	11.1
	Southern NT	19	27.5	50	72.5		
	Central NT	34	69.4	6	12.2	9	18.4
	Northern NT			16	8.8	165	91.2
Pregnant within 4 months	North East Qld			48	88.9	6	11.1
	Southern NT	19	27.5	50	72.5		
	Central NT	34	69.4	6	12.2	9	18.4
	Northern NT			16	8.8	165	91.2
Weaning rate	North East Qld			1	50	1	50
	Southern NT	1	50	1	50		
	Central NT	1	33.3	1	33.3	1	33.3
	Northern NT			1	50	1	50
Foetal and Calf loss	North East Qld			48	88.9	6	11.1
	Southern NT	19	27.5	50	72.5		
	Central NT	34	69.4	6	12.2	9	18.4
	Northern NT			16	8.8	165	91.2

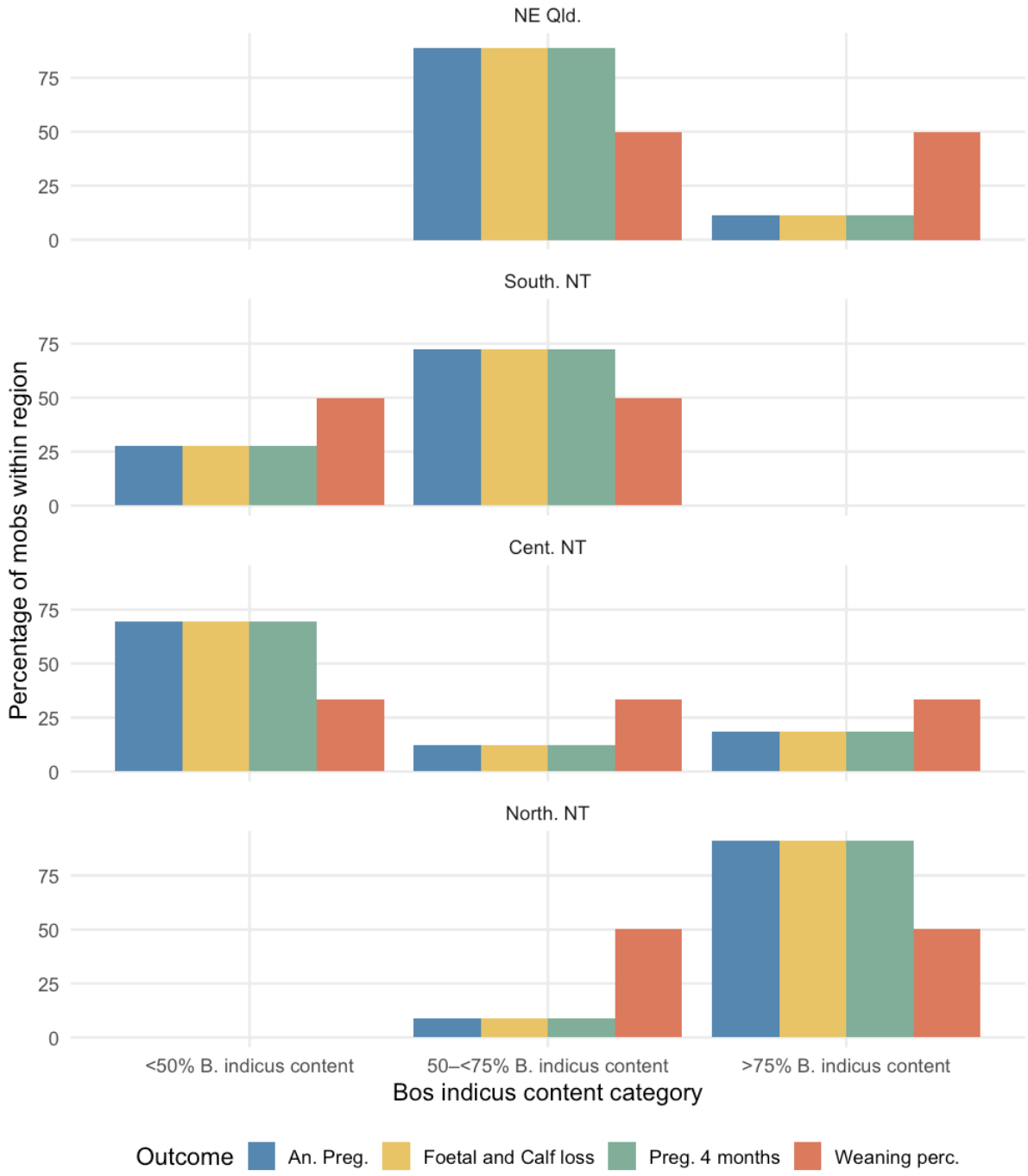


Figure 14-204: Distribution of available reproductive performance across *Bos indicus* content groups within region. Bars represent the percentage of mobs within region that contained non-missing data for annual pregnancy rate, pregnant within 4 months, weaning rate, and calf loss

Relative utilisation category

The distribution of individual cattle and management groups within the different relative utilisation classes for the different *Bos indicus* contents is shown in Table 14-5, Figure 14-205, Table 14-6 and Figure 14-206. Across all reproductive measures, there are clear differences in the distribution of pasture utilisation by *Bos indicus* content. Individuals and herds with <50% *Bos indicus* showed a bimodal pattern, with peaks observed at 0.8-1 utilisation and ≥2.3 utilisation. In contrast, ~30% data relating to individuals and herds with 50–75% Bos indicus was concentrated in the 0.5–0.8 utilisation

category, 20% at 1.07–1.38 utilisation and the remaining categories equally represented. The distribution of data for individuals and herds with >75% *Bos indicus* content appears somewhat representative of a normal distribution centred around the middle three relative utilisation categories: 0.81–1.06, 1.07–1.38, and 1.4–1.69. Approximately 60% of the data fell within these moderate to moderately high utilisation classes.

Table 14-5 Breed content counts and percentages of individuals by relative utilisation category across the entire dataset

Reproductive measure	*Bos indicus* content	<50%		50-75%		>75%	
	Relative utilisation	Count	Percent	Count	Percent	Count	Percent
Annual Pregnancy	≤0.5	2,731	12.8	2,034	9	3,194	9.2
	0.5–0.8	2,998	14.1	7,482	33.2	4,910	14.1
	0.81–1.06	4,176	19.6	3,216	14.2	6,071	17.5
	1.07–1.38	2,582	12.1	5,015	22.2	7,156	20.6
	1.4–1.69	1,519	7.1	1,544	6.8	7,723	22.2
	1.7–2.2	2,652	12.5	2,216	9.8	3,469	10
	≥2.3	4,620	21.7	1,062	4.7	2,231	6.4
Pregnant within 4 months	≤0.5	1,263	13.5	855	12.7	1,726	13.8
	0.5–0.8	1,490	16	2,022	30	1,925	15.4
	0.81–1.06	2,090	22.4	821	12.2	2,026	16.2
	1.07–1.38	1,240	13.3	1,414	21	2,720	21.8
	1.4–1.69	1,047	11.2	411	6.1	1,998	16
	1.7–2.2	1,319	14.1	761	11.3	1,092	8.8
	≥2.3	878	9.4	455	6.8	981	7.9
Weaning rate	≤0.5	1,569	10.6	952	8.9	2,521	10.7
	0.5–0.8	1,782	12.1	3,314	30.9	3,381	14.4
	0.81–1.06	2,697	18.3	1,441	13.4	3,860	16.4
	1.07–1.38	1,869	12.7	2,040	19	5,254	22.3
	1.4–1.69	1,200	8.1	759	7.1	4,545	19.3
	1.7–2.2	2,142	14.5	1,385	12.9	2,290	9.7
	≥2.3	3,512	23.8	840	7.8	1,676	7.1
Foetal and Calf loss	≤0.5	1,227	12.8	863	11.3	1,749	13.2
	0.5–0.8	1,553	16.1	2,560	33.5	1,934	14.5
	0.81–1.06	2,122	22.1	852	11.2	2,051	15.4
	1.07–1.38	1,256	13.1	1,433	18.8	2,971	22.3
	1.4–1.69	1,027	10.7	497	6.5	2,501	18.8
	1.7–2.2	1,389	14.4	955	12.5	1,102	8.3
	≥2.3	1,045	10.9	477	6.2	988	7.4

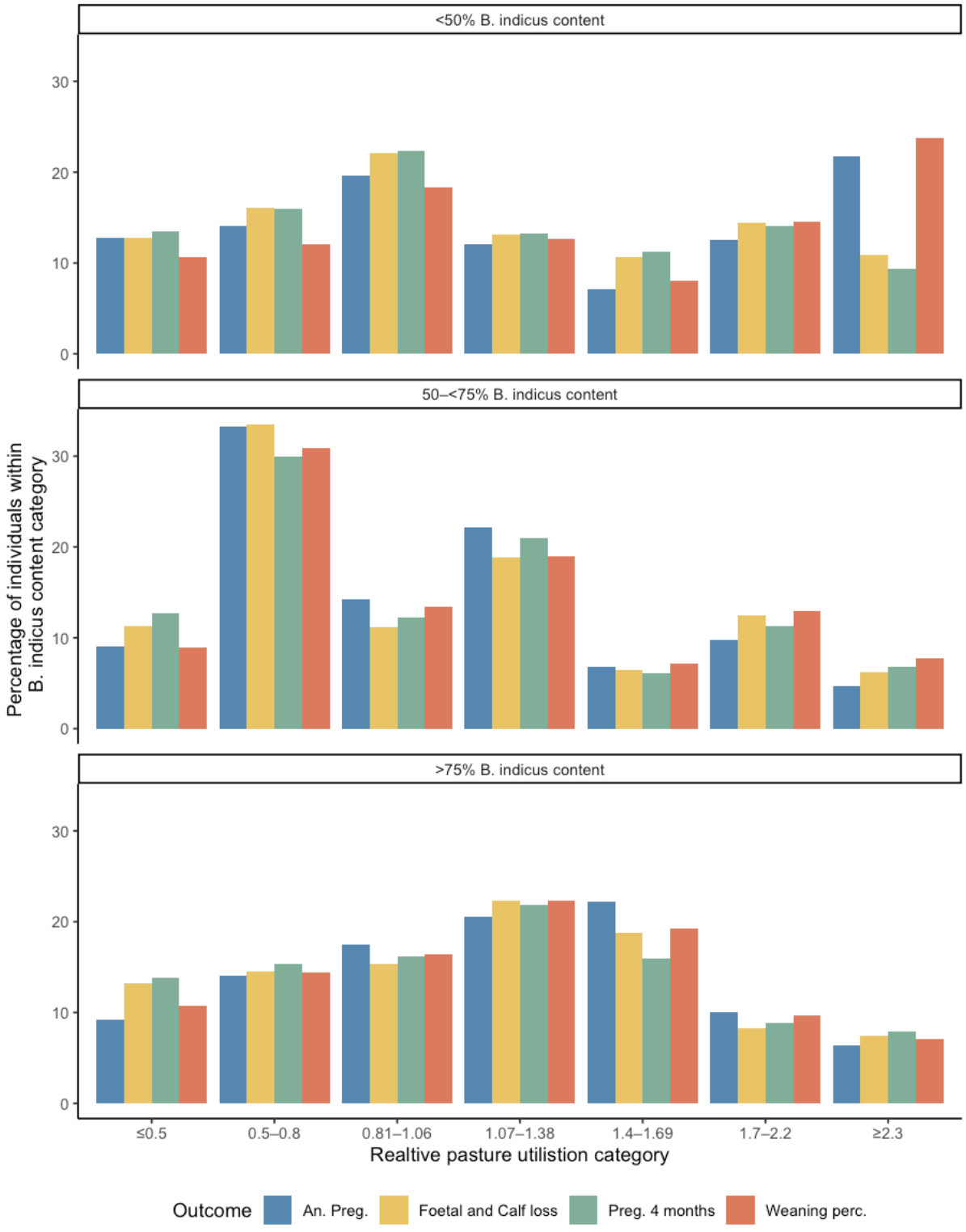


Figure 14-205: Distribution of available reproductive performance data across relative utilisation classes within breed content groups. Bars represent the percentage of records within each *Bos indicus* content category (<50%, 50–<75%, and >75%) that contained non-missing data for annual pregnancy rate, pregnancy to 4 months, weaning rate, and calf loss

Table 14-6 Regional counts and percentages of mobs by *Bos indicus* content across the entire dataset

Reproductive measure	*Bos indicus* content	<50%		50-75%		>75%	
	Relative utilisation	Count	Percent	Count	Percent	Count	Percent
Annual Pregnancy	≤0.5	13	24.5	12	10	19	10.6
	0.5–0.8	10	18.9	31	25.8	43	23.9
	0.81–1.06	10	18.9	17	14.2	37	20.6
	1.07–1.38	4	7.5	26	21.7	29	16.1
	1.4–1.69	3	5.7	8	6.7	17	9.4
	1.7–2.2	6	11.3	16	13.3	22	12.2
	≥2.3	7	13.2	10	8.3	13	7.2
Pregnant within 4 months	≤0.5	13	24.5	12	10	19	10.6
	0.5–0.8	10	18.9	31	25.8	43	23.9
	0.81–1.06	10	18.9	17	14.2	37	20.6
	1.07–1.38	4	7.5	26	21.7	29	16.1
	1.4–1.69	3	5.7	8	6.7	17	9.4
	1.7–2.2	6	11.3	16	13.3	22	12.2
	≥2.3	7	13.2	10	8.3	13	7.2
Weaning rate	≤0.5	1	14.3	1	14.3	1	14.3
	0.5–0.8	1	14.3	1	14.3	1	14.3
	0.81–1.06	1	14.3	1	14.3	1	14.3
	1.07–1.38	1	14.3	1	14.3	1	14.3
	1.4–1.69	1	14.3	1	14.3	1	14.3
	1.7–2.2	1	14.3	1	14.3	1	14.3
	≥2.3	1	14.3	1	14.3	1	14.3
Foetal and Calf loss	≤0.5	13	24.5	12	10	19	10.6
	0.5–0.8	10	18.9	31	25.8	43	23.9
	0.81–1.06	10	18.9	17	14.2	37	20.6
	1.07–1.38	4	7.5	26	21.7	29	16.1
	1.4–1.69	3	5.7	8	6.7	17	9.4
	1.7–2.2	6	11.3	16	13.3	22	12.2
	≥2.3	7	13.2	10	8.3	13	7.2

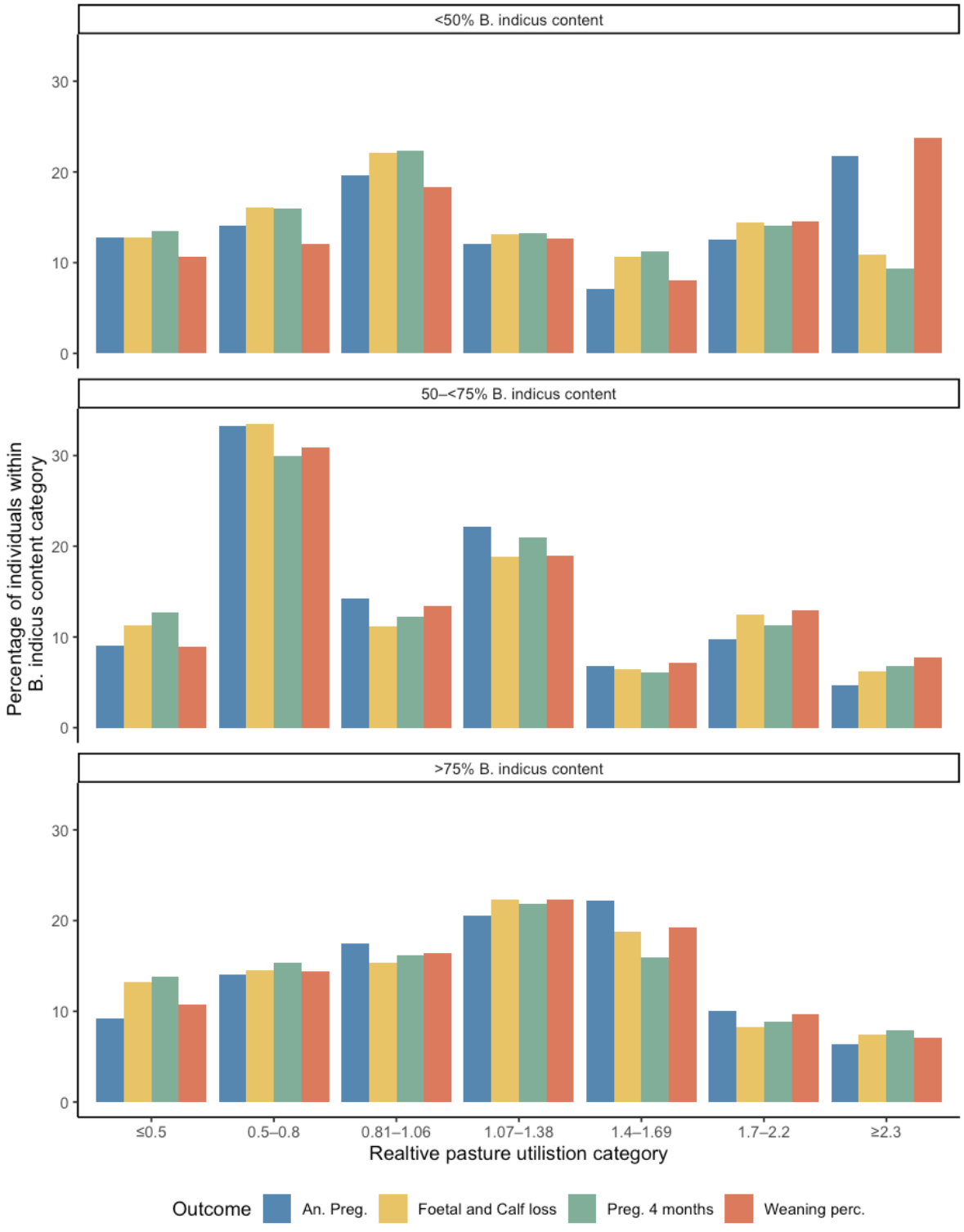


Figure 14-206: Distribution of available reproductive performance data across relative utilisation classes within breed content groups. Bars represent the percentage of mobs within each *Bos indicus* content category (<50%, 50–<75%, and >75%) that contained non-missing data for annual pregnancy rate, pregnancy to 4 months, weaning rate, and calf loss

Calving distribution

The distribution of calving showed substantial regional variation, with most births consistently occurring in November-December (Figure 14-207), in late spring to early summer. In Central NT, 47% of calves were born during this period, followed by 28% in September-October and 21% in January-February; very few births occurred from March to June. A similar pronounced peak was evident in North East Queensland, where 45% of calving took place in November-December. In contrast, Southern NT exhibited a broader calving season, with peaks in September-October (32%) and November-December (37%). Northern NT also showed a less concentrated pattern, with 29% of births in November-December and ~22% each in Sep–Oct and Jan–Feb, with a fewer calvings occurring in Jul–Aug (9%) and May–Jun (5%). These results indicate clear regional differences in time of calving.

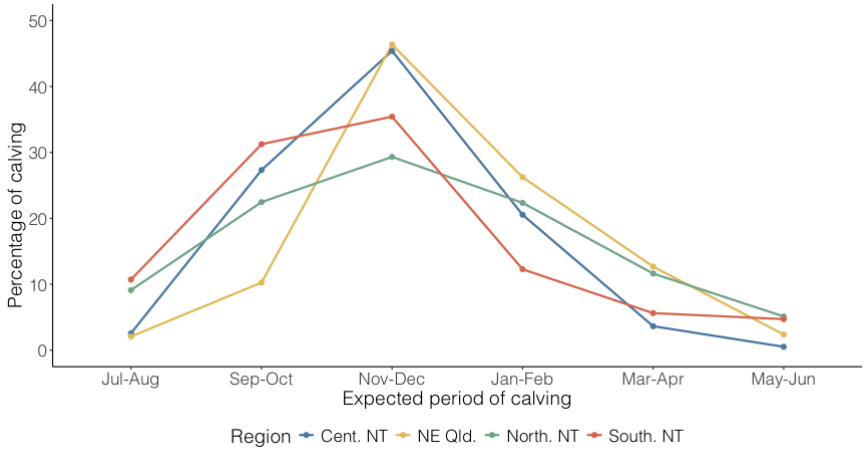


Figure 14-207. Percentage of expected calvings by calving period within region

14.7 Bioeconomic analyses extra tables

Table 14-7: Herd size and pasture-related average annual performance metrics for the simulated Barkly herds. Average of 44 years

Simulation name	Average annual AE	Average Stocking rate total station (AE/100 ha)	Average Stocking rate usable area (AE/100 ha)	Head Breeders with bulls	Average utilisation rate (%)	Median utilisation rate (%)	Pasture yield June 30 (kg/ha)	Land condition state	Percent perennial grasses
1 - 23651 AE	19811	3.0	4.3	13754	12.4	7.0	1448	2.1	82
2 - 25922 AE	21932	3.3	4.7	15380	13.6	7.8	1431	2.1	81
3 - 27210 AE	28193	4.2	6.1	20209	17.0	10.5	1376	2.1	81
4 - 28514 AE	32831	4.9	7.0	23779	19.6	13.0	1319	2.1	80
5 - 30746 AE	37274	5.6	8.0	27372	25.7	15.9	1098	2.7	72
6 - 31908 AE PB	40186	6.0	8.6	29973	25.6	17.5	1115	2.6	74
7 - 33482 AE PB	40433	6.1	8.7	30433	26.6	17.6	1093	2.7	73
8 - 34400 AE PB	44768	6.7	9.6	34306	30.5	22.5	967	3.2	64
9 - 35222 AE PB	45791	6.9	9.8	37241	34.6	25.9	806	4.0	50
10 - 35267 AE PB	50282	7.6	10.8	41746	36.0	29.3	772	4.1	49

Table 14-8: Reproduction-related average annual performance metrics for the simulated Barkly herds. Average of 44 years

Simulation name	Annual conception count	Conception rate	Annual calf Count	Calving rate	Annual weaner Count	Weaning rate	Min and Max weaning rate / range	Kgs weaners/ Year	Kgs weaners/ ha	Kg weaners/ Breeder head	Kg weaners/ breeder AE
1 - 23651 AE	13267	87%	9553	76%	9180	73%	59-82%	1964455	4.2	143	152
2 - 25922 AE	14834	87%	10678	76%	10259	73%	59-82%	2187983	4.7	142	152
3 - 27210 AE	19477	87%	13977	76%	13386	73%	57-82%	2838978	6.1	140	152
4 - 28514 AE	22965	88%	16463	76%	15730	73%	58-81%	3331778	7.2	140	160
5 - 30746 AE	26346	88%	19248	77%	18268	73%	49-82%	3807702	8.2	139	158
6 - 31908 AE PB	28766	86%	20669	75%	19636	71%	30-85%	4101251	8.8	137	156
7 - 33482 AE PB	29026	85%	21153	74%	20065	69%	5-97%	4185145	9.0	138	158
8 - 34400 AE PB	32247	82%	22995	71%	21871	66%	5-97%	4581153	9.8	134	154
9 - 35222 AE PB	34116	75%	23637	64%	22331	60%	0-98%	4685649	10.1	126	152
10 - 35267 AE PB	37161	74%	27027	65%	24221	57%	0-98%	4992995	10.7	120	150

Table 14-9: Production-related average annual performance metrics for the simulated Barkly herds. Average of 44 years

Simulation name	Kgs produced/ year	Kgs produced/ AE	Kgs produced/ Ha	Kgs sold/ Year	Kgs sold/ Ha	Kgs sold/ AE
1 - 23651 AE	2938424	148	6.3	3199045	6.9	161
2 - 25922 AE	3269203	149	7.0	3548707	7.6	162
3 - 27210 AE	4256687	151	9.1	4522631	9.7	160
4 - 28514 AE	4965816	151	10.7	5213787	11.2	159
5 - 30746 AE	5568261	149	12.0	5844720	12.6	157
6 - 31908 AE PB	6005549	149	12.9	6491122	13.9	162
7 - 33482 AE PB	5939201	147	12.8	6442822	13.8	159
8 - 34400 AE PB	6537938	146	14.0	7228292	15.5	161
9 - 35222 AE PB	6260301	137	13.4	7410013	15.9	162
10 - 35267 AE PB	6096045	121	13.1	6745581	14.5	134

Table 14-10: Financial-related average annual performance metrics for the simulated Barkly herds. Average of 44 years

Simulation name	Gross Profit	Gross profit per AE	Variable Costs	Variable costs/AE	Gross profit margin	Gross profit margin/AE	Profit	Profit/AE	Profit per kg produced	Profit / ha
1 - 23651 AE	$8,036,994	$406	-$1,780,289	-$90	$6,256,705	$316	$4,650,057	$235	$1.58	$10
2 - 25922 AE	$8,970,769	$409	-$1,938,870	-$88	$7,031,899	$321	$5,253,221	$240	$0.62	$11
3 - 27210 AE	$11,598,669	$411	-$2,391,853	-$85	$9,206,816	$327	$6,920,351	$245	$1.61	$15
4 - 28514 AE	$13,477,643	$411	-$2,720,054	-$83	$10,757,589	$328	$8,095,033	$247	$1.63	$17
5 - 30746 AE	$15,122,509	$406	-$3,052,834	-$82	$12,069,675	$324	$9,046,771	$243	$1.63	$19
6 - 31908 AE PB	$16,131,314	$401	-$3,295,495	-$82	$12,835,819	$319	$9,576,704	$238	$1.62	$21
7 - 33482 AE PB	$15,943,301	$394	-$3,300,494	-$82	$12,642,808	$313	$9,363,700	$232	$1.59	$20
8 - 34400 AE PB	$16,995,136	$380	-$3,610,837	-$81	$13,384,299	$299	$9,753,580	$218	$1.58	$21
9 - 35222 AE PB	$14,507,119	$317	-$3,593,511	-$78	$10,913,608	$238	$7,199,925	$157	$1.49	$15
10 - 35267 AE PB	$11,625,135	$231	-$3,789,360	-$75	$7,835,775	$156	$3,757,917	$75	$1.15	$8

Table 14-11: Herd size and pasture-related average annual performance metrics for the simulated Burdekin herds. Average of 42 years

Simulation name	Average annual AE	Average Stocking rate total station (AE/100 ha)	Head Breeders with bulls	Average utilisation rate (%)	Median utilisation rate (%)	Pasture Yield June 30 (kg/ha)	Land condition state	Percent perennial grasses
1 - 2349 AE	2148	8.7	1115	15.6	14.4	2076	1.4	89
2 - 2466 AE	2290	9.2	1196	17.0	16.1	2015	1.5	87
3 - 2670 AE	2309	9.3	1239	19.5	16.8	1859	2.0	83
4 - 2748 AE	2195	8.8	1243	21.1	16.5	1732	2.4	77
5 - 2917 AE	2005	8.1	1082	21.7	16.2	1690	2.7	73
6 - 3099 AE	1425	5.7	753	19.0	6.6	1723	2.9	70
7 - 2670 AE PB	2465	9.9	1316	20.7	18.6	1824	2.0	82
8 - 2801 AE PB	2336	9.4	1235	23.2	19.2	1611	2.8	70
9 - 2915 AE PB	2098	8.5	1116	32.0	26.8	1078	4.5	43
10 - 3099 AE PB	2005	8.1	1073	35.7	27.0	940	5.1	33
11 - 3269 AE PB	2102	8.5	1173	37.7	29.3	858	5.8	24
12 - 2786 AE HB	2226	9.0	1266	26.5	21.8	1325	3.7	56
13 - 2619 AE HB	2649	10.7	1412	22.8	20.1	1731	2.4	77
14 - 2896 AE	1930	7.8	1107	35.2	28.1	945	5.0	35
15 - 2874 AE	2180	8.8	1250	24.4	19.2	1533	3.0	67
16 - 2835 AE PB	2454	9.9	1302	35.2	28.6	1180	4.0	50
17 - 2610 AE HB	2457	9.9	1293	19.0	17.8	1933	1.7	85
18 - 2436 AE HB	2273	9.2	1186	16.5	15.6	2040	1.5	88
19 - 2925 AE	2052	8.3	1126	32.9	25.4	1060	4.4	43
20 - 2713 AE HB	2266	9.1	1268	23.9	19.3	1529	3.0	67
21 -2497 AE HB	2379	9.6	1339	20.4	17.5	1825	2.2	80
22 - 2670 AE SS	2375	9.6	1325	19.8	17.7	1826	2.1	81
23 - 2750 AE SS	2357	9.5	1455	24.7	20.5	1447	3.4	61
24 - 2917 AE SS	2274	9.2	1355	24.9	19.5	1424	3.5	59
25 - 3099 AE SS	1829	7.4	1094	23.5	12.7	1557	3.3	62
26 - 2917 AE SS PB	2141	8.6	1335	39.2	32.2	924	5.2	32
27 - 3099 AE SS PB	1908	7.7	1161	39.6	29.4	817	6.2	20

Table 14-12: Reproduction-related average annual performance metrics for the simulated Burdekin herds. Average of 42 years

Simulation name	Annual conception count	Conception rate	Annual calf Count	Calving rate	Annual weaner Count	Weaning rate	Weaning rate min – max / range	Kgs weaners/ Year	Kgs weaners/ha	Kg weaners/ Breeder head	
1 - 2349 AE	856	77%	813	73%	748	67%	48-83%	118,537	4.8	106	
2 - 2466 AE	918	77%	875	73%	802	67%	47-88%	126,570	5.1	106	
3 - 2670 AE	890	72%	848	68%	778	63%	43-84%	122,890	5.0	99	
4 - 2748 AE	823	66%	779	63%	714	57%	35-80%	112,761	4.6	91	
5 - 2917 AE	754	70%	712	66%	652	60%	5-79%	103,466	4.2	96	
6 - 3099 AE	512	68%	494	66%	462	61%	0-80%	73,223	3.0	97	
7 - 2670 AE PB	981	75%	929	71%	851	65%	47-84%	134,473	5.4	102	
8 - 2801 AE PB	944	76%	894	72%	819	66%	40-80%	128,933	5.2	104	
9 - 2915 AE PB	805	72%	770	69%	710	64%	4-79%	111,465	4.5	100	
10 - 3099 AE PB	771	72%	742	69%	686	64%	0-80%	107,059	4.3	100	
11 - 3269 AE PB	793	68%	776	66%	720	61%	0-82%	112,440	4.5	96	
12 - 2786 AE HB	758	60%	726	57%	666	53%	18-82%	104,986	4.2	83	
13 - 2619 AE HB	1079	76%	1020	72%	936	66%	48-81%	148,134	6.0	105	
14 - 2896 AE	687	62%	650	59%	607	55%	0-83%	95,253	3.8	86	
15 - 2874 AE	756	60%	709	57%	648	52%	0-83%	102,784	4.2	82	
16 - 2835 AE PB	941	72%	910	70%	844	65%	38-80%	132,192	5.3	101	
17 - 2610 AE HB	994	77%	942	73%	866	67%	50-79%	137352	5.5	106	
18 - 2436 AE HB	908	77%	867	73%	795	67%	49-81%	125771	5.1	106	
19 - 2925 AE	756	67%	726	64%	678	60%	1-79%	106,102	4.3	94	
20 - 2713 AE HB	800	63%	765	60%	705	56%	29-79%	111,276	4.5	88	
21 -2497 AE HB	836	62%	800	60%	738	55%	31-83%	117,010	4.7	87	
22 - 2670 AE SS	909	69%	867	65%	796	60%	42-84%	125,782	5.1	95	
23 - 2750 AE SS	904	62%	864	59%	791	54%	30-80%	124,656	5.0	86	
24 - 2917 AE SS	844	62%	810	60%	744	55%	21-79%	117,278	4.7	87	
25 - 3099 AE SS	629	57%	604	55%	560	51%	0-80%	88,309	3.6	81	
26 - 2917 AE SS PB	712	53%	699	52%	648	49%	0-79%	101,438	4.1	76	
27 - 3099 AE SS PB	694	60%	669	58%	619	53%	0-80%	96,703	3.9	83	

Table 14-13: Production-related average annual performance metrics for the simulated Burdekin herds. Average of 42 years

Simulation name	Kgs produced/ year	Kgs produced/ AE	Kgs produced/ Ha	Kgs sold/ Year	Kgs sold/ Ha	Kgs sold/ AE
1 - 2349 AE	252,181	117	10.2	247767	10.0	115
2 - 2466 AE	269,031	117	10.9	263886	10.7	115
3 - 2670 AE	262,325	114	10.6	255639	10.3	111
4 - 2748 AE	238,101	108	9.6	225731	9.1	103
5 - 2917 AE	216,012	108	8.7	211862	8.6	106
6 - 3099 AE	143,796	101	5.8	149338	6.0	105
7 - 2670 AE PB	283,636	115	11.5	276458	11.2	112
8 - 2801 AE PB	267,121	114	10.8	270993	10.9	116
9 - 2915 AE PB	227,650	109	9.2	241426	9.8	115
10 - 3099 AE PB	210,360	105	8.5	233049	9.4	116
11 - 3269 AE PB	211,915	101	8.6	238765	9.6	114
12 - 2786 AE HB	225,189	101	9.1	217368	8.8	98
13 - 2619 AE HB	304,618	115	12.3	294528	11.9	111
14 - 2896 AE	190,434	99	7.7	204347	8.3	106
15 - 2874 AE	215,742	99	8.7	196087	7.9	90
16 - 2835 AE PB	270,340	110	10.9	286529	11.6	117
17 - 2610 AE HB	284102	116	11.5	277086	11.2	113
18 - 2436 AE HB	265779	117	10.7	260624	10.5	115
19 - 2925 AE	215,974	105	8.7	233069	9.4	114
20 - 2713 AE HB	236,293	104	9.5	229292	9.3	101
21 -2497 AE HB	248,227	104	10.0	237017	10.0	100
22 - 2670 AE SS	264,137	111	10.7	256146	10.3	108
23 - 2750 AE SS	249,883	106	10.1	237664	9.6	101
24 - 2917 AE SS	237,822	105	9.6	232183	9.4	102
25 - 3099 AE SS	172,425	94	7.0	167232	6.8	91
26 - 2917 AE SS PB	197,253	92	8.0	206923	8.4	97
27 - 3099 AE SS PB	177,380	93	7.2	194834	7.9	102

Table 14-14: Financial-related average annual performance metrics for the simulated Burdekin herds. Average of 42 years

Simulation name	Gross Profit	Gross profit/AE	Gross profit/ha	Variable costs	Variable costs/AE	Variable costs/ha	Gross profit margin	Gross profit margin/AE	Gross profit margin/ha	Profit	Profit/AE	Profit/ha	Profit/kg produced
1 - 2349 AE	$697,355	$325	$28.18	-$237,206	-$110	-$9.58	$460,149	$214	$18.59	$152,348	$71	$6.16	$0.60
2 - 2466 AE	$748,539	$327	$30.24	-$252,696	-$110	-$10.21	$495,843	$217	$20.03	$188,042	$82	$7.60	$0.70
3 - 2670 AE	$724,786	$314	$29.28	-$251,293	-$109	-$10.15	$473,492	$205	$19.13	$165,691	$72	$6.69	$0.63
4 - 2748 AE	$671,838	$306	$27.14	-$237,312	-$108	-$9.59	$434,526	$198	$17.56	$126,725	$58	$5.12	$0.53
5 - 2917 AE	$587,103	$293	$23.72	-$221,017	-$110	-$8.93	$366,086	$183	$14.79	$58,285	$29	$2.35	$0.27
6 - 3099 AE	$343,556	$241	$13.88	-$162,785	-$114	-$6.58	$180,771	$127	$7.30	-$127,030	-$89	-$5.13	-$0.88
7 - 2670 AE PB	$794,821	$322	$32.11	-$267,374	-$108	-$10.80	$527,446	$214	$21.31	$219,645	$89	$8.87	$0.77
8 - 2801 AE PB	$726,628	$311	$29.36	-$259,553	-$111	-$10.49	$467,075	$200	$18.87	$159,274	$68	$6.44	$0.60
9 - 2915 AE PB	$583,845	$278	$23.59	-$237,038	-$113	-$9.58	$346,807	$165	$14.01	$39,006	$19	$1.58	$0.17
10 - 3099 AE PB	$505,430	$252	$20.42	-$235,744	-$118	-$9.53	$269,686	$135	$10.90	-$38,115	-$19	-$1.54	-$0.18
11 - 3269 AE PB	$493,108	$235	$19.92	-$245,061	-$117	-$9.90	$248,047	$118	$10.02	-$59,754	-$28	-$2.41	-$0.28
12 - 2786 AE HB	$601,102	$270	$24.29	-$236,066	-$106	-$9.54	$365,036	$164	$14.75	$57,235	$26	$2.31	$0.25
13 - 2619 AE HB	$862,384	$326	$34.84	-$285,783	-$108	-$11.55	$576,600	$218	$23.30	$268,799	$101	$10.86	$0.88
14 - 2896 AE	$449,792	$233	$18.17	-$225,781	-$117	-$9.12	$224,010	$116	$9.05	-$83,791	-$43	-$3.39	-$0.44
15 - 2874 AE	$589,485	$270	$23.82	-$229,669	-$105	-$9.28	$359,817	$165	$14.54	$52,016	$24	$2.10	$0.24
16 - 2835 AE PB	$688,387	$281	$27.81	-$269,915	-$110	-$10.91	$418,472	$171	$16.91	$110,671	$45	$4.47	$0.41
17 - 2610 AE HB	$797,354	$324	$32.22	-$268,677	-$109	-$10.86	$528,677	$215	$21.36	$220,876	$90	$8.92	$0.78
18 - 2436 AE HB	$739,410	$325	$29.88	-$250,344	-$110	-$10.11	$489,065	$215	$19.76	$181,264	$80	$7.32	$0.68
19 - 2925 AE	$521,334	$254	$21.06	-$235,228	-$115	-$9.50	$286,106	$139	$11.56	-$21,695	-$11	-$0.88	-$0.10
20 - 2713 AE HB	$637,664	$281	$25.76	-$241,788	-$107	-$9.77	$395,876	$175	$15.99	$88,075	$39	$3.56	$0.37
21 -2497 AE HB	$675,855	$284	$27.31	-$247,759	-$104	-$10.01	$428,096	$180	$17.30	$120,295	$51	$4.86	$0.48
22 - 2670 AE SS	$727,480	$306	$29.39	-$257,102	-$108	-$10.39	$470,378	$198	$19.01	$162,577	$68	$6.57	$0.62
23 - 2750 AE SS	$704,070	$299	$28.45	-$258,678	-$110	-$10.45	$445,391	$189	$18.00	$137,590	$58	$5.56	$0.55
24 - 2917 AE SS	$643,168	$283	$25.99	-$245,496	-$108	-$9.92	$397,672	$175	$16.07	$89,871	$40	$3.63	$0.38
25 - 3099 AE SS	$431,757	$236	$17.44	-$199,675	-$109	-$8.07	$232,082	$127	$9.38	-$75,719	-$41	-$3.06	-$0.44
26 - 2917 AE SS PB	$489,136	$228	$19.76	-$243,595	-$114	-$9.84	$245,541	$115	$9.92	-$62,260	-$29	-$2.52	-$0.32
27 - 3099 AE SS PB	$406,381	$213	$16.42	-$227,055	-$119	-$9.17	$179,326	$94	$7.25	-$128,475	-$67	-$5.19	-$0.72

14.8 Bioeconomic analyses relationships of variables with profit

14.8.1 Barkly

The following section explores how profit varied with different variables for the Barkly station simulations. All figures are ordered left to right from lowest to highest profitability.

Relationship between annual profit and the resource base

Average June 30 pasture yield tended to decline as profitability of herds increased (Figure 14-208). The two exceptions, the herds with highest initial sizes, had by far the lowest pasture yields. Average June 30 pasture yield was closely and positively associated with average annual percent perennial grass composition.

The four most profitable herds had intermediate values for June 30 pasture yield. The average annual percent perennial grass composition of herd 8 – 34400 AE PB, the most profitable herd, was 64%, similar to its 67% composition at the commencement of the simulation period. Hence, land condition was maintained with this herd. The three next most profitable herds had average annual percent perennial grass compositions of between 72 and 74%, and thus were associated with a slight improvement in land condition and hence pasture growth. Four herds (1 – 23651 AE, 2 -225922 AE, 3 – 27210 AE and 4 – 28514 AE) with lower initial sizes, with no purchasing of breeders and lower utilisation rates, were able to increase percent perennial grass composition to around 80%, and thus land condition improved from mid B to A. The herds which improved land condition from mid B to A were less profitable than those which maintained land in B condition.

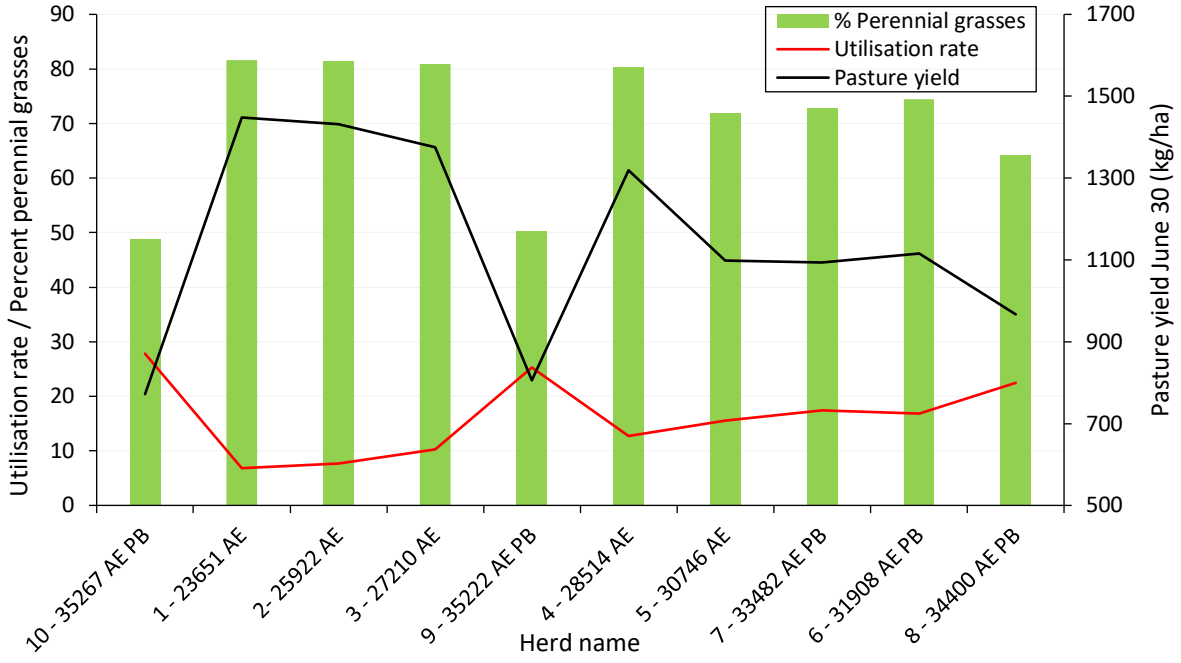


Figure 14-208: Average June 30 pasture yield of the 10 simulated Barkly herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 44 years

The most profitable of the 10 herds simulated was 8 – 34400 AE PB, although the average annual profitability of the top four herds varied by only 7% (Figure 14-209). Its median annual pasture utilisation rate was 22.4%, which was the 3rd highest of the 10 herds (Table 7-24). Above 34400 AE

there was a steep drop in land condition, associated with higher pasture utilisation and lower profits / AE.

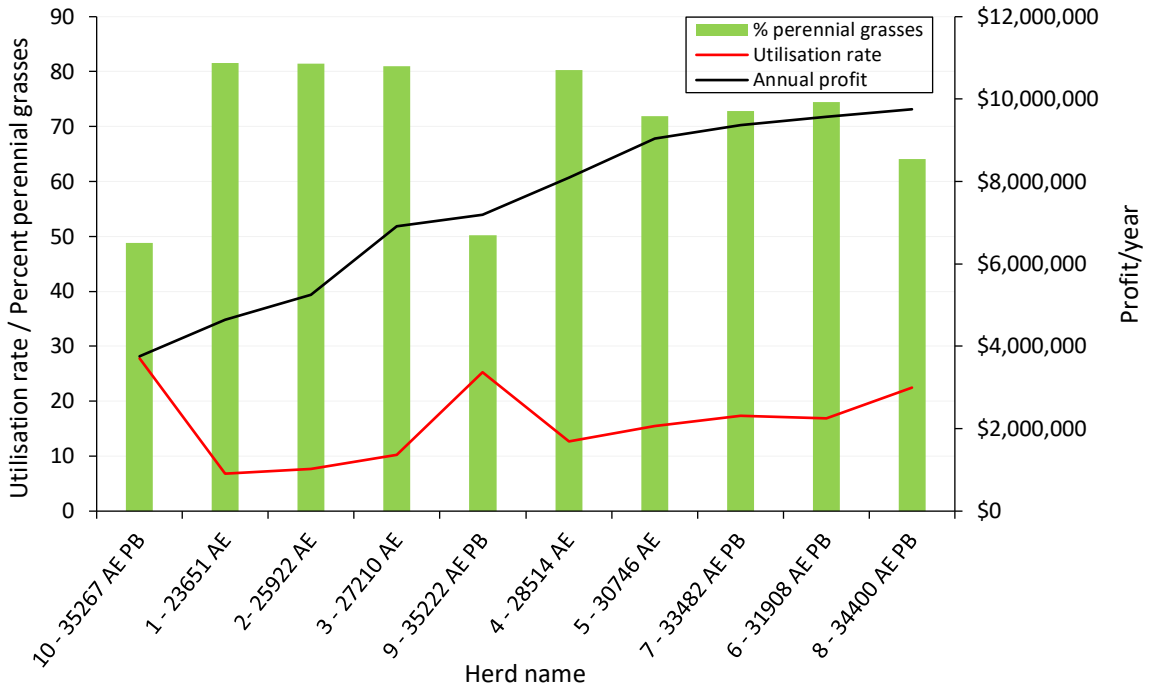


Figure 14-209: Average annual profitability of the 10 simulated Barkly herds, ordered from left to right in increasing profitability, and their associated median annual pasture utilisation rates and average annual percent perennial grass composition. Average of 44 years

Relationship between annual profit and breeder herd size and total AEs

In Figure 14-210 below, and in the figures that follow, the 10 herds along the x axis are ordered from left to right in increasing average annual profitability. Apart from herds 9 – 35222 AE PB and 10 – 35267 AE PB, average annual profit increased with breeder herd size from 13754 (1-23651 AE) to 34306 head (Herd 8 –AE 34400). While herds 9 – 35222 AE PB and 10 – 35267 AE PB had the largest breeder herds, these were maintained by purchasing large numbers of breeders when climatic conditions improved after drought. This kept utilisation high, preventing recovery following dry periods and drove down land condition, pasture growth and animal performance.

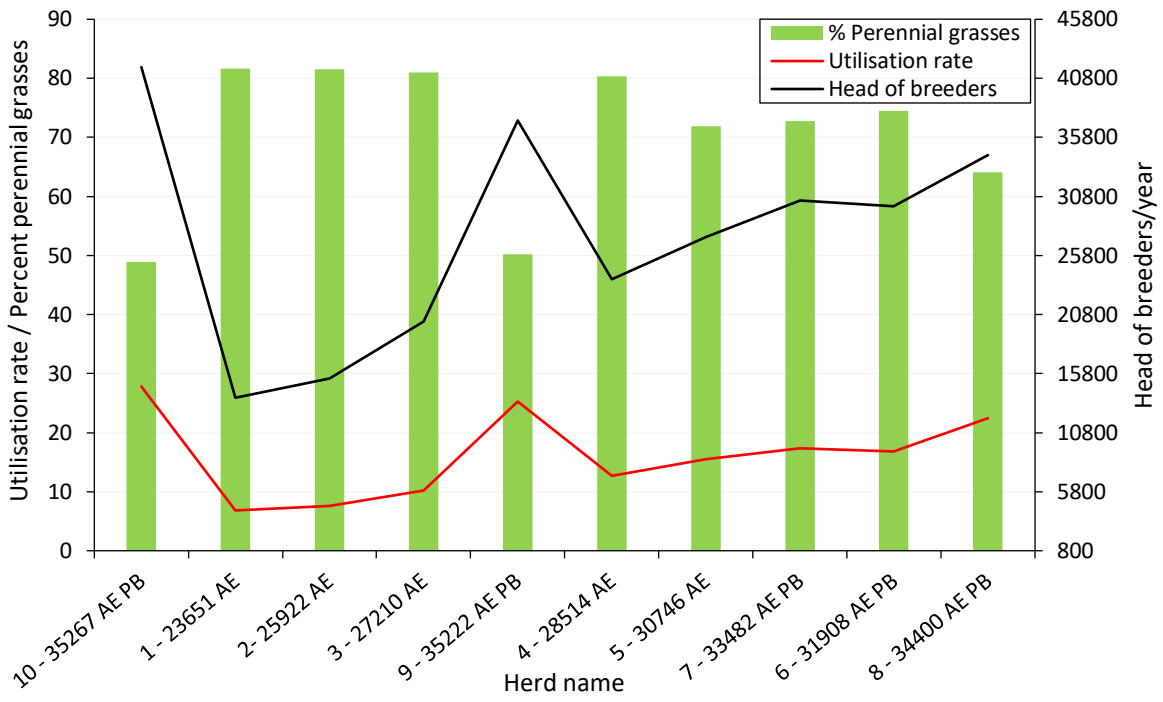


Figure 14-210: Average annual breeder herd size (head) of the 10 simulated Barkly herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass compositions. Average of 44 years

As with breeder herd size (head), both initial and average annual total herd size (AE) were similarly correlated with profitability. Again, the highest average annual herd sizes for 9 – 35222 AE PB and 10 – 35267 AE PB were maintained by purchasing large numbers of young female breeders, which drove declines in land condition, pasture growth and animal performance (Figure 14-211).

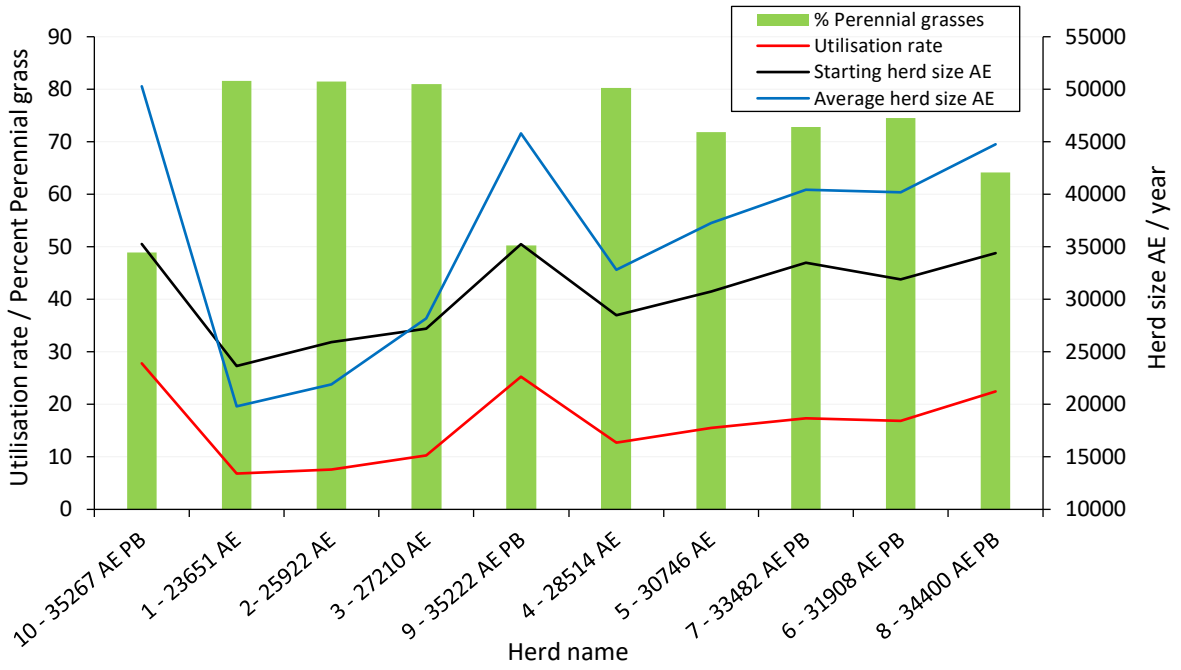


Figure 14-211: Average annual and initial adult equivalent (AE) herd size of the 10 simulated Barkly herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass compositions. Average of 44 years

Inter-annual variability in total herd size expressed as coefficient of variation was not well correlated with profitability (Figure 14-212). The three most profitable herds had intermediate coefficients of variation. Coefficients of variation for the three most profitable herds, ranging from 41 to 54%, were similar to the coefficient of variation of 44% for annual rainfall during the simulation period. Herds with lower and higher coefficients were less profitable. Again, the two herds with the highest coefficients of variation had the highest average annual pasture utilisation rates and lowest % perennial grasses.

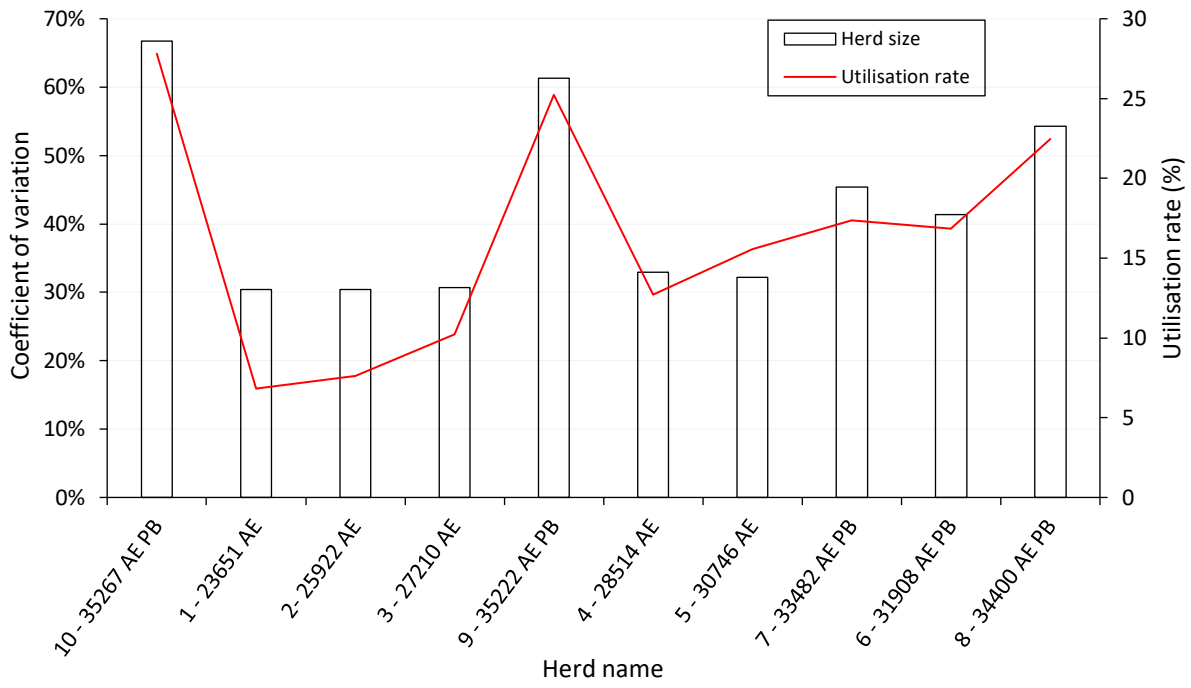


Figure 14-212: Coefficients of variation in annual herd size and median annual pasture utilisation rate for the 10 simulated Barkly herds, ordered from left to right in increasing annual profitability. Average of 44 years

Relationship between annual profit and reproductive rates

Reproductive rates, including conception, calving and weaning, were not correlated with average annual profit. As the trends were the same for conception, calving and weaning, only the results for weaning rates are presented (Figure 14-213). Weaning rates were poorly correlated with the profitability of herds. They were highest for herds with the lowest initial sizes, smallest for the two herds with highest initial sizes, and intermediate for the three most profitable herds.

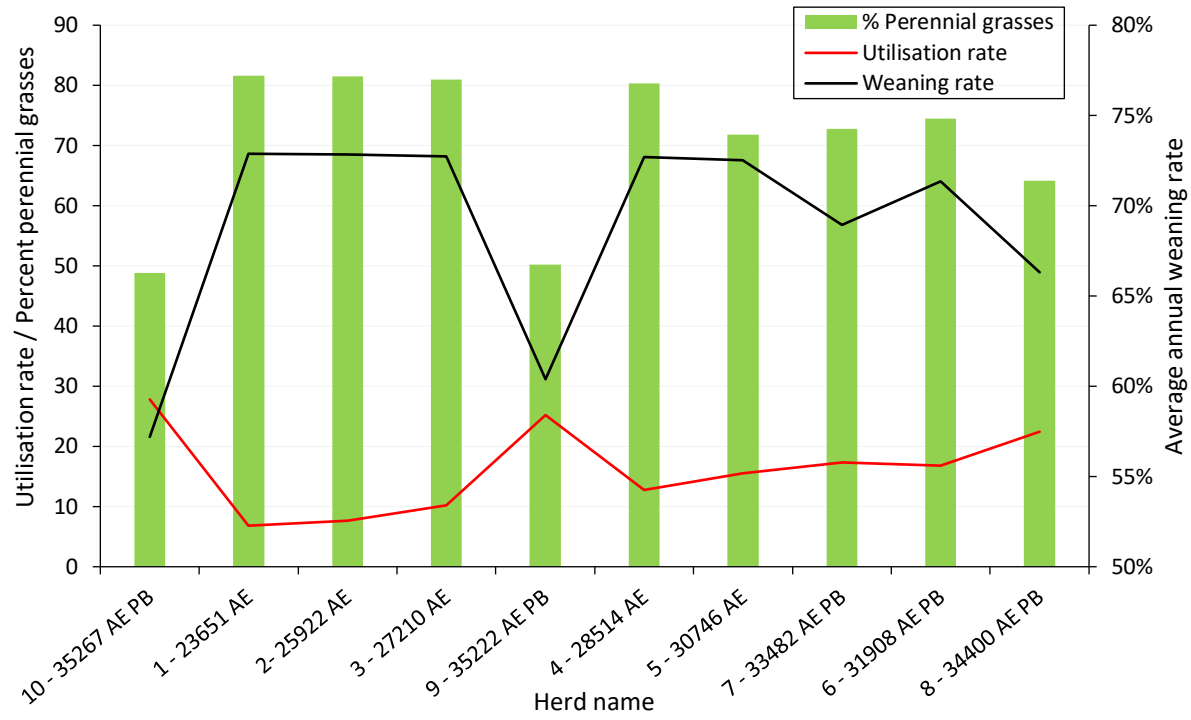


Figure 14-213: Average annual weaning rate of the 10 simulated Barkly herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 44 years

Relationship between annual profit and kg weaners produced/year

As with the sizes of breeder and total herds, the kg of weaners produced annually tended to increase with increasing profitability, with exceptions being the two herds which had the two highest initial sizes (Figure 14-214).

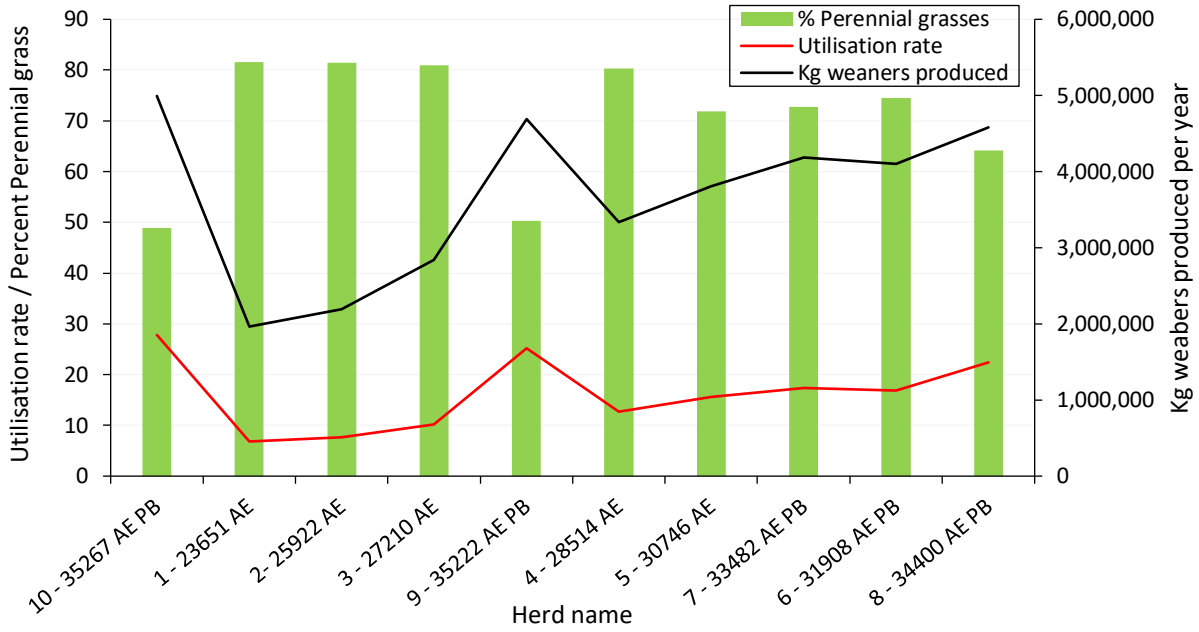


Figure 14-214: Average annual kg of weaners produced per year for the 10 simulated Barkly herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 44 years

Relationship between annual profit and kg beef produced/AE

The average annual kg of beef produced/AE was lowest for the two herds with the highest initial sizes, but varied little across the other eight herds (Figure 14-215).

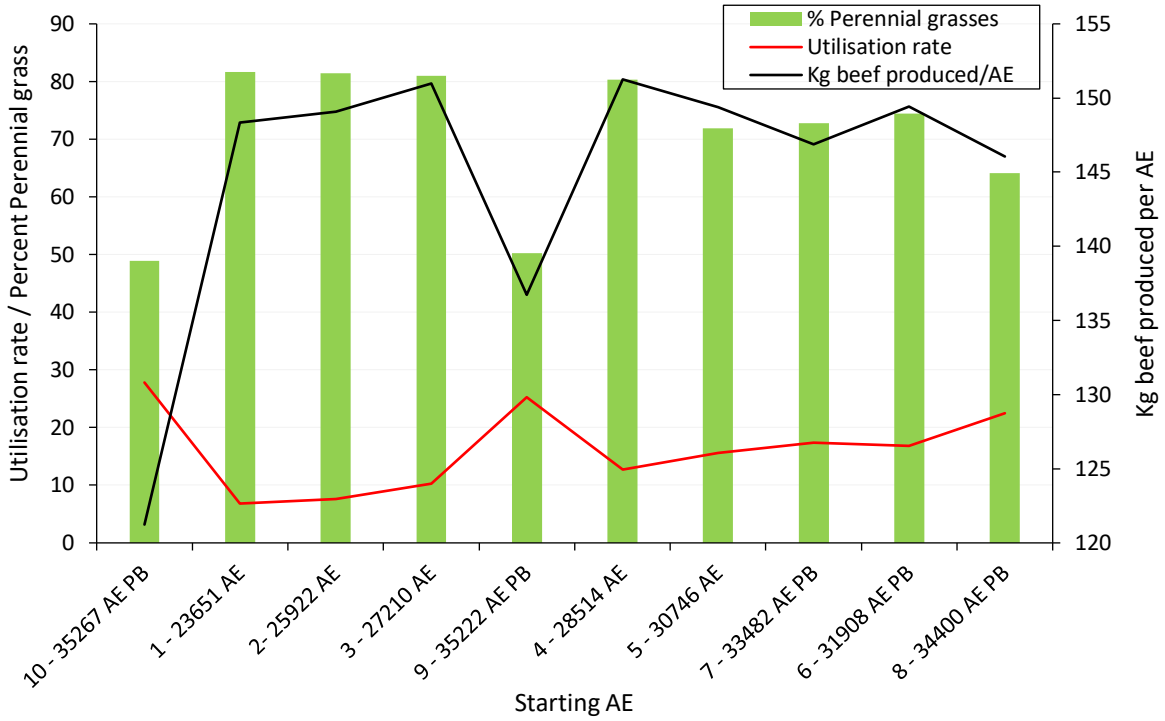


Figure 14-215: Average annual kgs of beef produced/AE for the 10 simulated Barkly herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 44 years

Relationship between annual profit and kg beef produced/year

A similar trend was observed for the average annual kgs of beef produced by the simulated herds, with this tending to increase with increasing profitability (Figure 14-218).

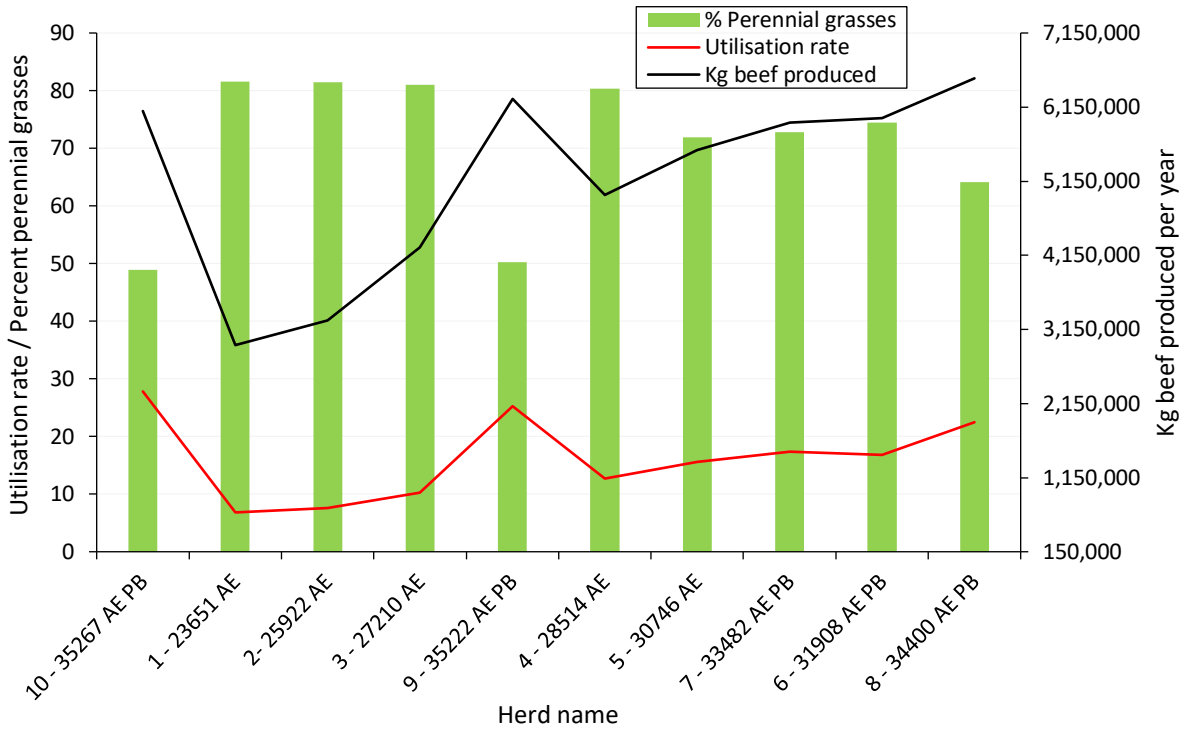


Figure 14-216: Average annual kgs of beef produced of the 10 simulated Barkly herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 44 years

Relationship between annual profit and gross profit

Annual profit equals gross profit minus both variable and overhead costs. Gross profit is the annual income from cattle sales minus costs of purchasing cattle plus the difference in the value of cattle present at the end and beginning of the financial year. As expected, average annual gross profit generally increased with increasing average annual profit (Figure 14-217). The two exceptions were the two herds with the highest initial herd sizes and utilisation rates.

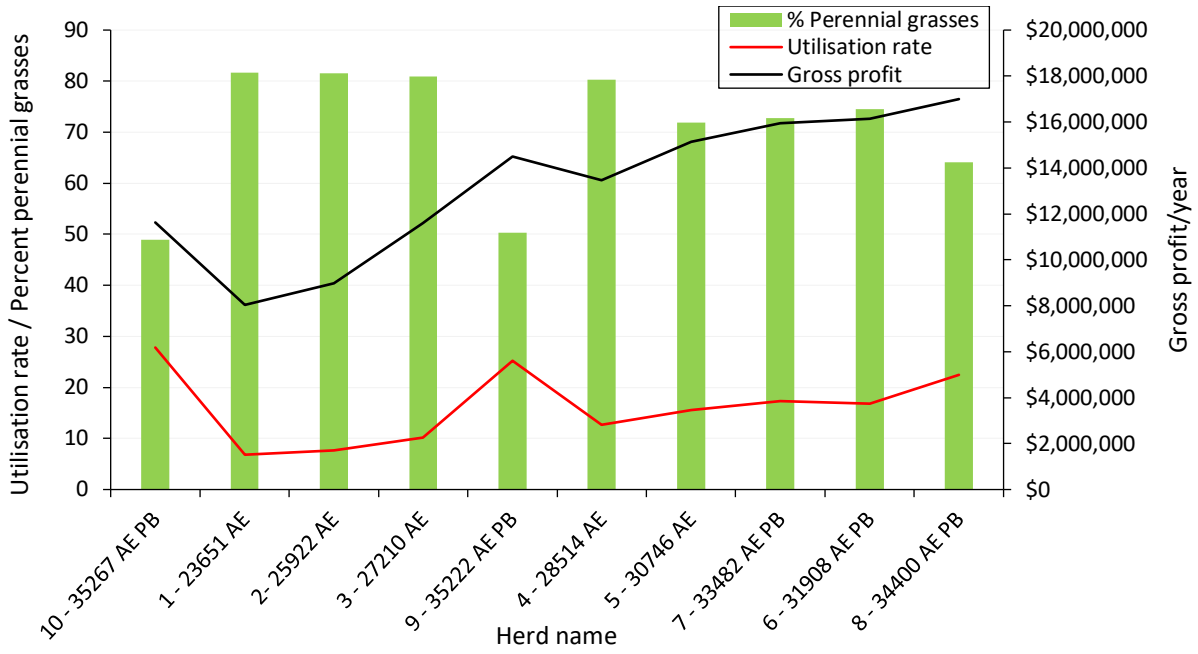


Figure 14-217: Average annual gross profit of the 10 simulated Barkly herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 44 years

Relationship between annual profit and total variable costs

Variable costs are the per-individual animal expenses incurred for activities such as mustering, weaning, castration, tags and husbandry treatments. As expected, total variable costs were highest for the herds with the highest average annual herd sizes (Figure 14-218), and the trend was the same as that for total herd size (Figure 14-211). Overall, apart from the two herds with highest initial sizes, total variable costs tended to increase with increasing average annual profit.

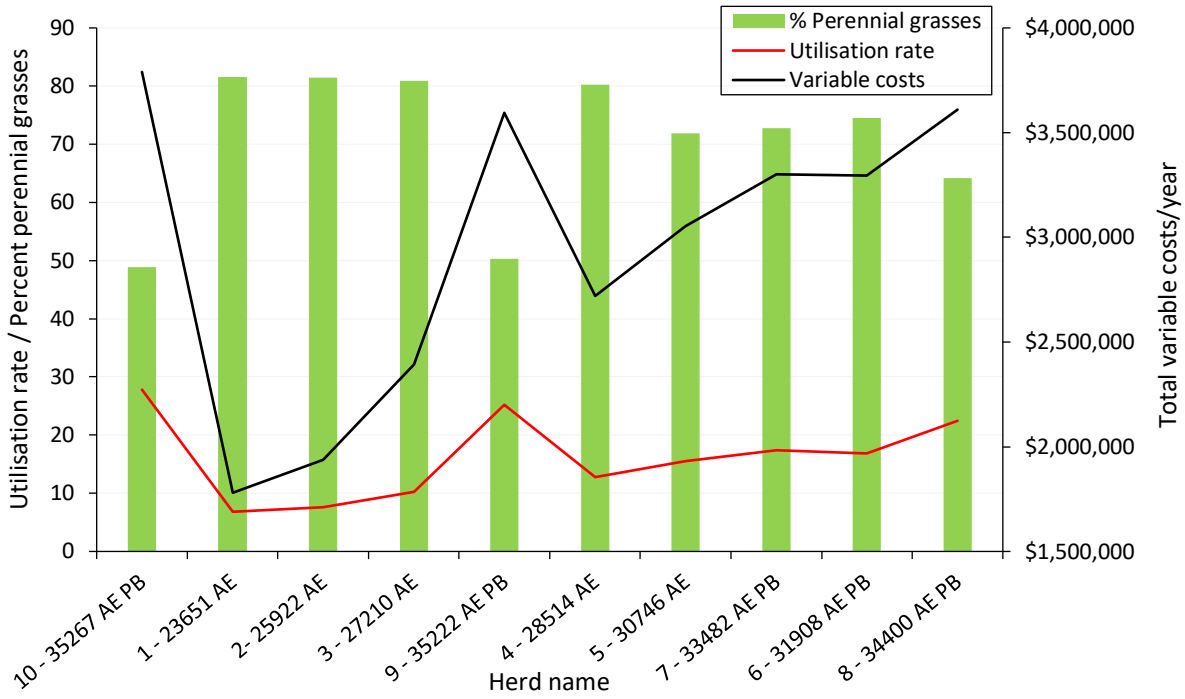


Figure 14-218: Average annual total variable costs of the 10 simulated Barkly herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 44 years

Relationship between annual profit and variable costs/AE

Variable costs/AE were lowest for the two herds with the highest initial sizes, highest utilisation rates and poorest land condition, and apart from these two herds, variable costs/AE tended to decline with increasing profitability of herds (Figure 14-219). Overall, variable costs/AE decreased with increasing herd size.

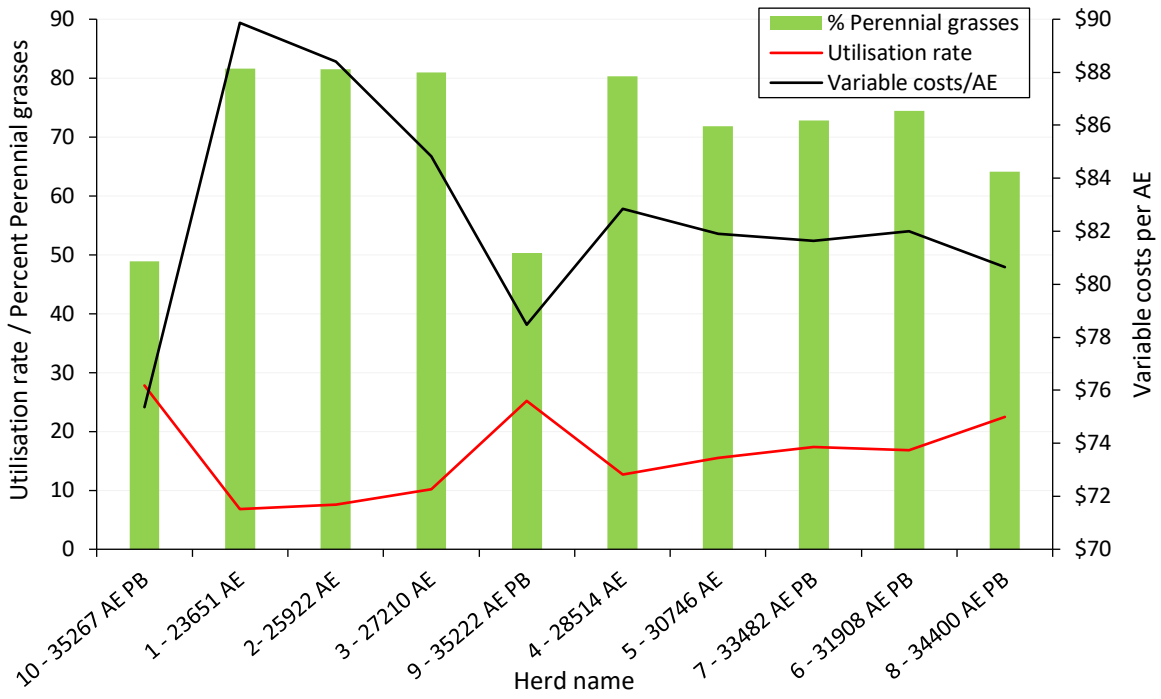


Figure 14-219: Average annual variable costs/AE of the 10 simulated Barkly herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 44 years

Relationship between annual profit and profit/AE

Average annual profit/AE was not correlated with average annual total profit (Figure 14-220). Profit/AE was similar for eight of the 10 simulated herds, and the two herds with the largest initial sizes had much lower land condition and profit/AE.

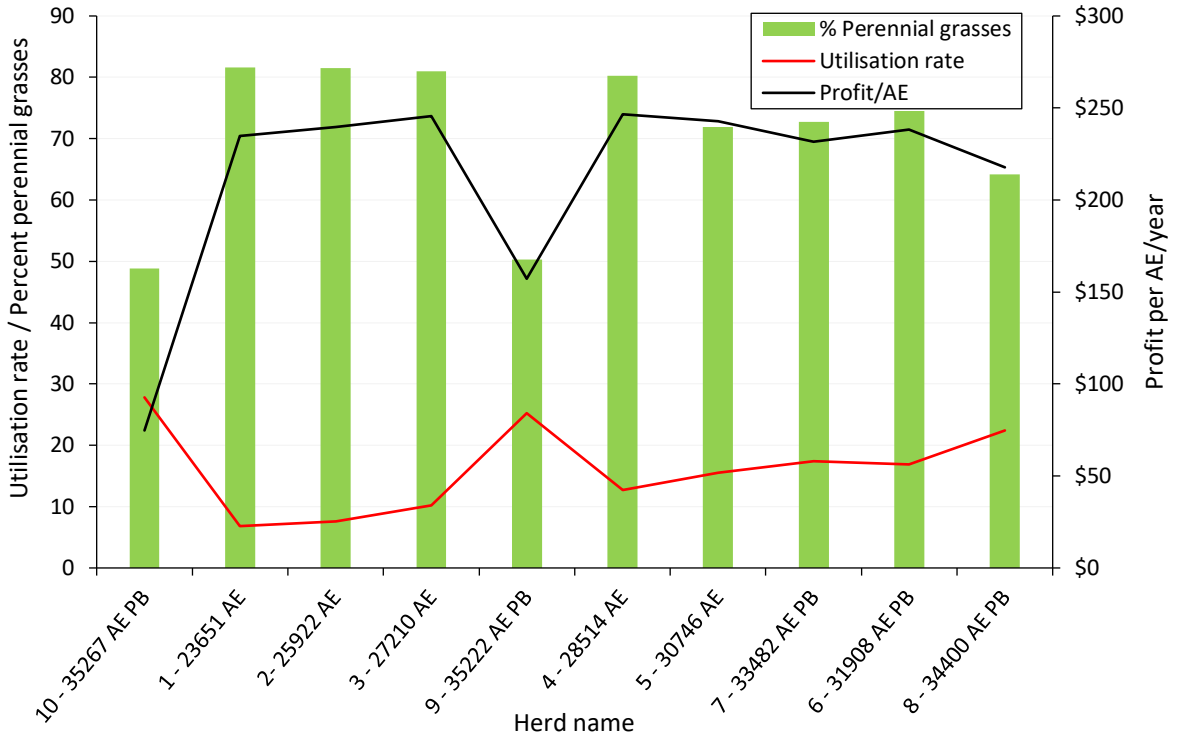


Figure 14-220: Average annual profit/AE of the 10 simulated Barkly herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 44 years

14.8.2 Burdekin

Relationship between annual profit and the resource base

Relationship between annual profit and pasture yield at June 30

While the nine most profitable herds had similar average June 30 pasture yields, pasture yield generally increased with increasing profitability (Figure 14-221). Due to parameter relationships used in CLEM, pasture yield was closely related with percent perennial grass composition and pasture utilisation rate.

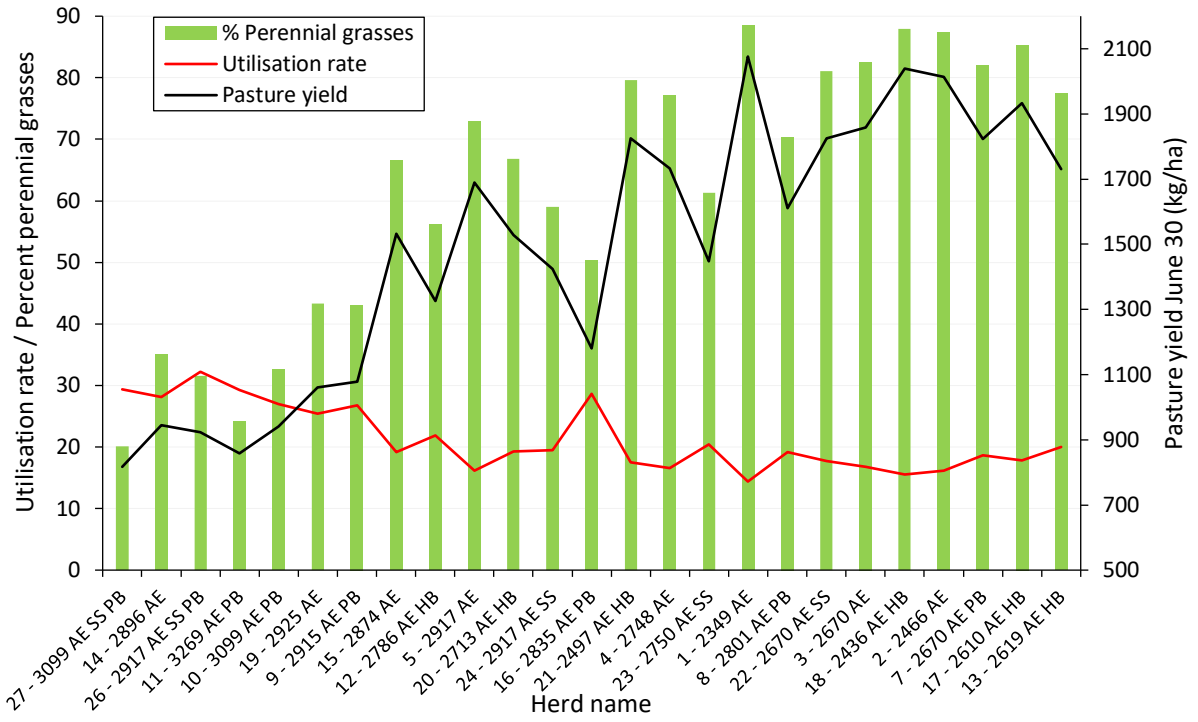


Figure 14-221: Average June 30 pasture yield for the 25 simulated Burdekin herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 42 years

The very close relationship between average June 30 pasture yield and percent perennial grass composition is shown in Figure 14-222. The highest average June 30 pasture yield of 2076 kg/ha occurred when percent perennial grass composition was 89%, while the lowest, of only 817 kg/ha, occurred when perennial grass composition was 20%.

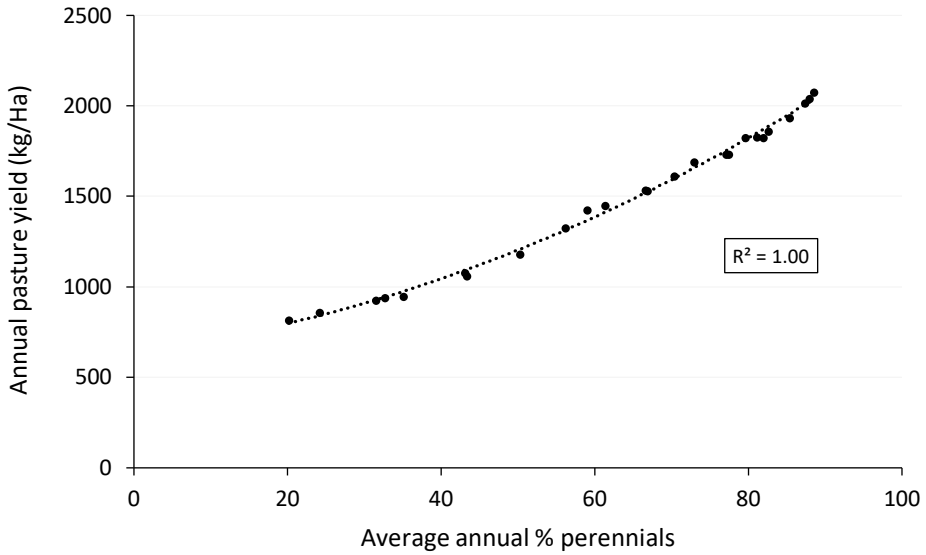


Figure 14-222: Relationship between average June 30 pasture yield and percent perennial grass composition for 25 of the 27 simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

The relationship between median pasture utilisation rate and average June 30 pasture yield is more clearly demonstrated in Figure 14-223. Average June 30 pasture yield was 817 kg/ha for the simulation with the highest average annual utilisation rate of 32%. This was only 39% of the average annual pasture yield of 2076 kg/ha for the simulation with a median annual utilisation rate of 14%.

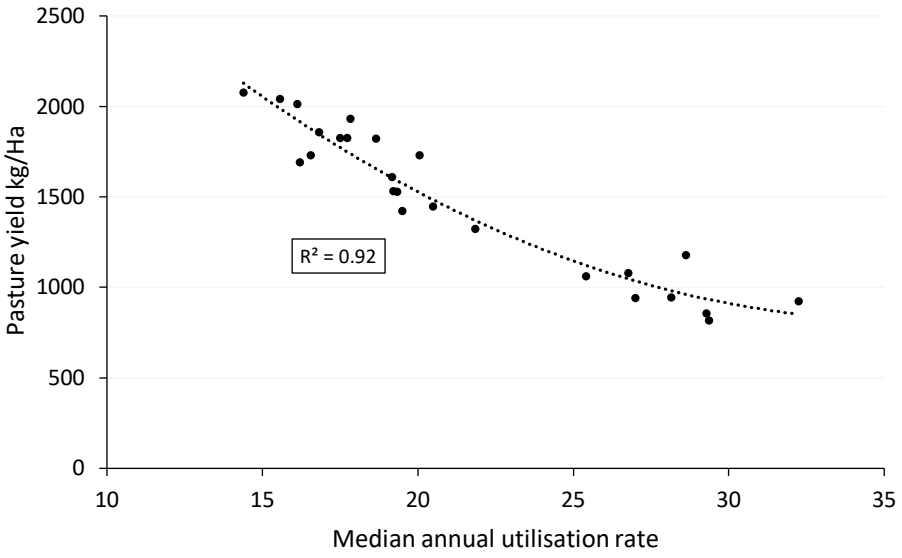


Figure 14-223: Relationship between average June 30 pasture yield and median annual pasture utilisation rate for 25 of the 27 simulated Burdekin herds (fitted line is a 2nd order polynomial). Average of 42 years

Relationship between annual profit and breeder herd size and total AEs

In Figure 14-224 below, and in other figures that follow, the 25 herds along the x axis are ordered from left to right in increasing average annual profitability. Average annual profit was poorly correlated with average annual size (head) of the breeder herd, and the size of breeder herds was

poorly correlated with both pasture utilisation rate and percent perennial grass composition. Simulated herds which purchased breeders (e.g. 16 – 2835 AE PB), sold steers in preference to breeders during droughts (e.g. 23 – 2750 AE SS) or held breeder numbers as constant as possible over the simulation period (e.g. 13 – 2619 AE HB), generally had the largest average annual breeder herd size. In comparison, simulated herds which sold all or large proportions of empty breeders during droughts (e.g. 5 – 2917 AE) had smaller average annual breeder herd sizes.

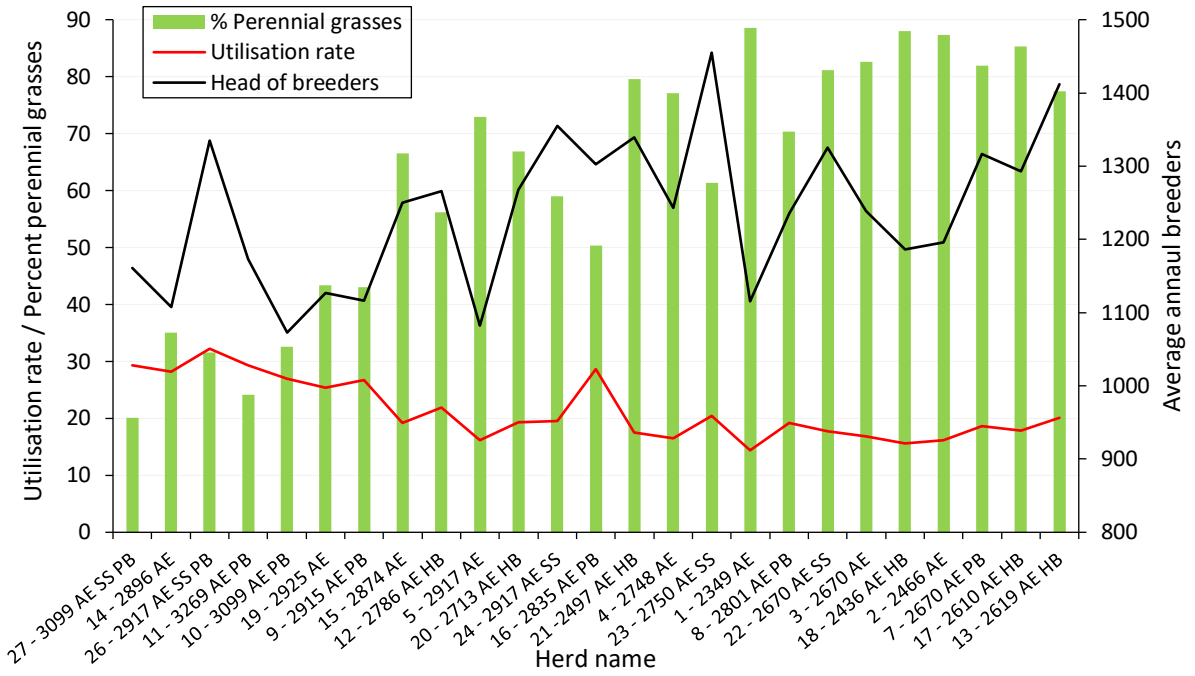


Figure 14-224: Average annual breeder herd size (head) of the 25 simulated Burdekin herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 42 years

Initial total herd size, at the beginning of the simulation period, tended to be inversely related to profitability (Figure 14-225). In contrast to this, annual profit tended to increase with increasing average annual herd size, which is indicative of the size of herds which could be maintained over the entire simulation period. For example, the average annual herd size of the three most profitable herds were higher than those of all other herds. Only herd 16 – 2835 AE PB had a similar herd size, due largely to having purchased 160 breeders annually for five consecutive years (total of 800) after the 1990s drought. Also, as annual profit increased, the difference between starting and average herd size tended to decrease. Only herd 13 - 2619 AE HB had an average herd size which was slightly larger than its starting herd size.

While there was an overall trend of increasing profitability with increasing average annual herd size, there were many herds which had similar average herd sizes but differed considerably in annual average profitability. Twelve herds, from 20 – 2713 AE HB to 2 – 2466 AE (Figure 14-225), had similar herd sizes, ranging from 2148 to 2454 AE, but annual profit ranged from $88,075 to $188,042. Hence, while average annual herd size had an important influence on annual profit, it was only one factor responsible for differences in average annual profit.

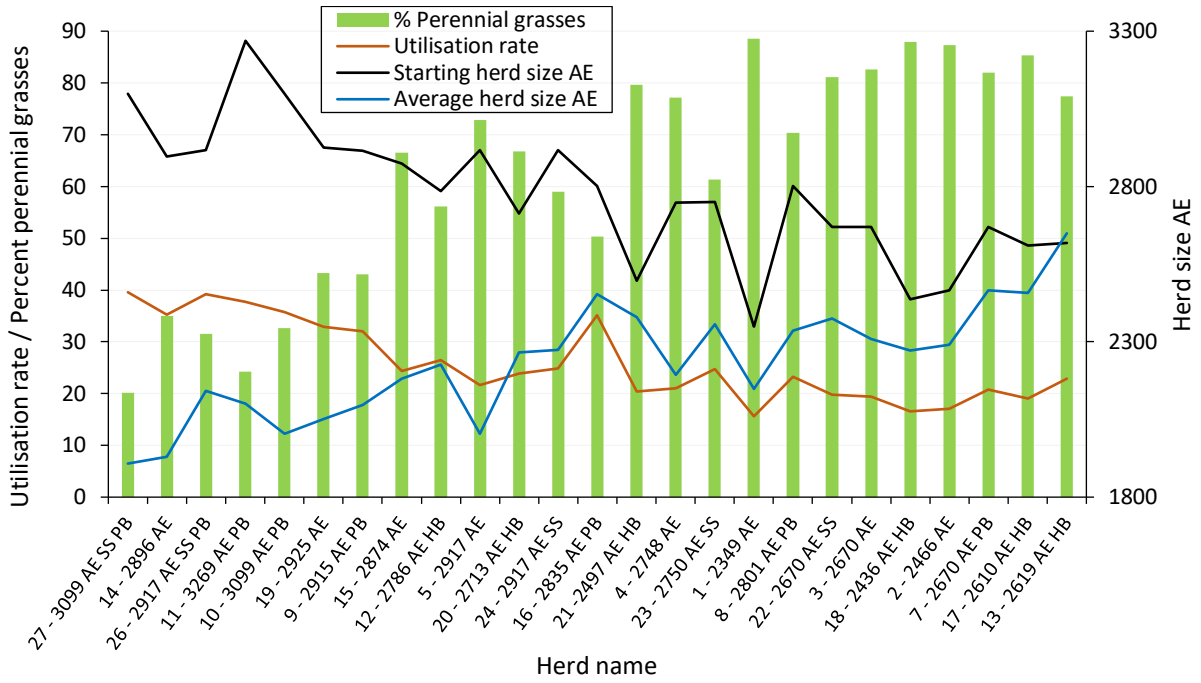


Figure 14-225: Average annual herd size and starting herd size of the 25 simulated Burdekin herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 42 years

Not only did the most profitable herds tend to have the highest average annual herd size, they also had amongst the lowest annual variability in herd size (Figure 14-226). The more profitable herds had a combination of high average annual herd size and low inter-annual variability (standard deviation of herd size). However, examination of the means and standard deviations of the simulated herds identified two main groups. First, the herds 27 – 3099 AE SS PB to 5 – 2917 AE had the lowest average annual herd sizes and the highest standard deviations. The second group of herds, from 20 – 2713 AE HB to 13 – 2619 AE HB, were characterised by higher average herd size and lower standard deviations.

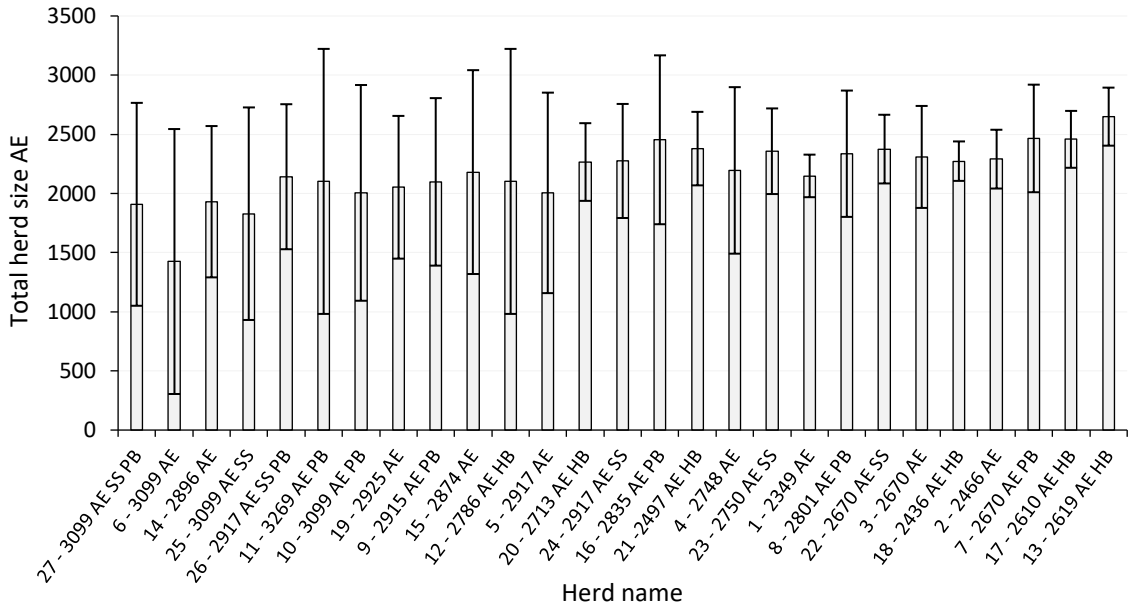


Figure 14-226: Mean annual herd size and one standard deviation either side of the mean for the 27 simulated Burdekin herds, ordered from left to right in increasing annual profitability. Average of 42 years

As a consequence of lower average and higher standard deviations in herd size, the first group of herds (27 – 3099 AE SS PB to 5 – 2917 AE) had coefficients of variation which were almost all higher than those for the second and more profitable group of herds (Figure 14-227). The coefficients of variation in herd size for the most profitable herds were only 7 to 18%, which were considerably lower than the coefficient of variation for annual rainfall during the simulation period of 41%. The simulated herds with the lowest coefficients of variation in herd size had median annual utilisation rates of between 14 and 20%.

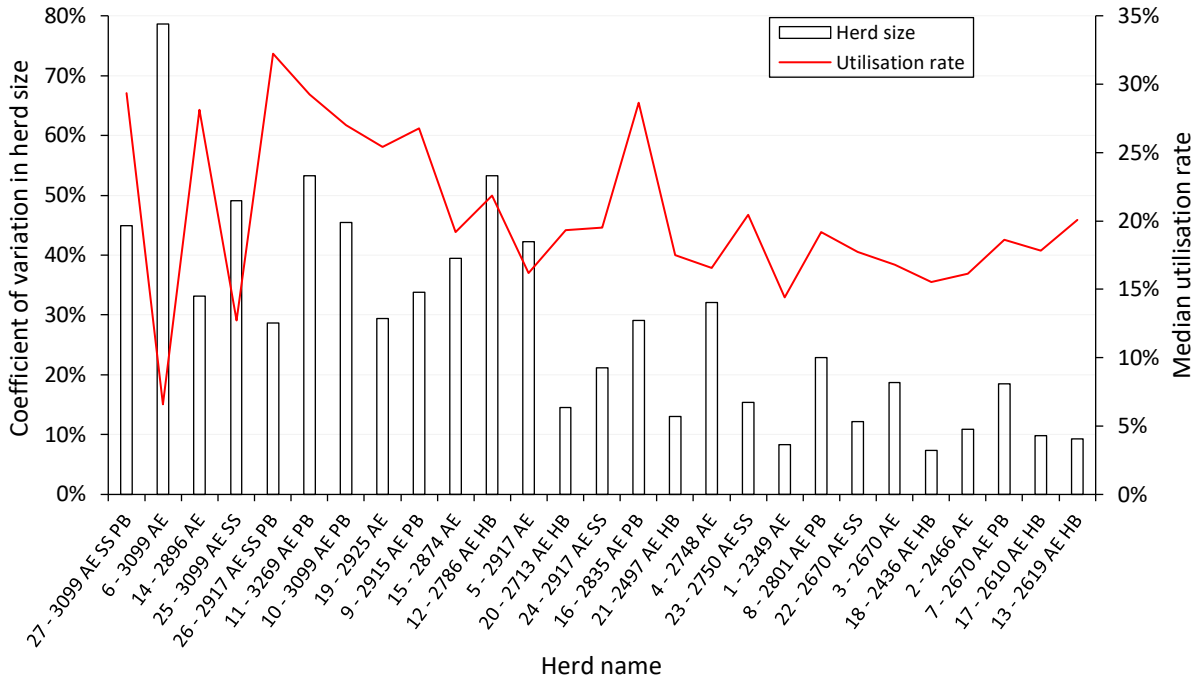


Figure 14-227: Coefficient of variation in annual herd size and median annual pasture utilisation rate for the 27 simulated Burdekin herds, ordered from left to right in increasing annual profitability. Average of 42 years

Relationship between annual profit and reproductive rates

Reproductive rates of conception, calving and weaning were also poorly correlated with average annual profit. For example, while herd 13 - 2619 AE HB had the highest annual profit, this was not due to having the highest average annual weaning rate (Figure 14-228). While the weaning rate of this herd was amongst the highest of all 25 herds, it was similar to those of several other herds.

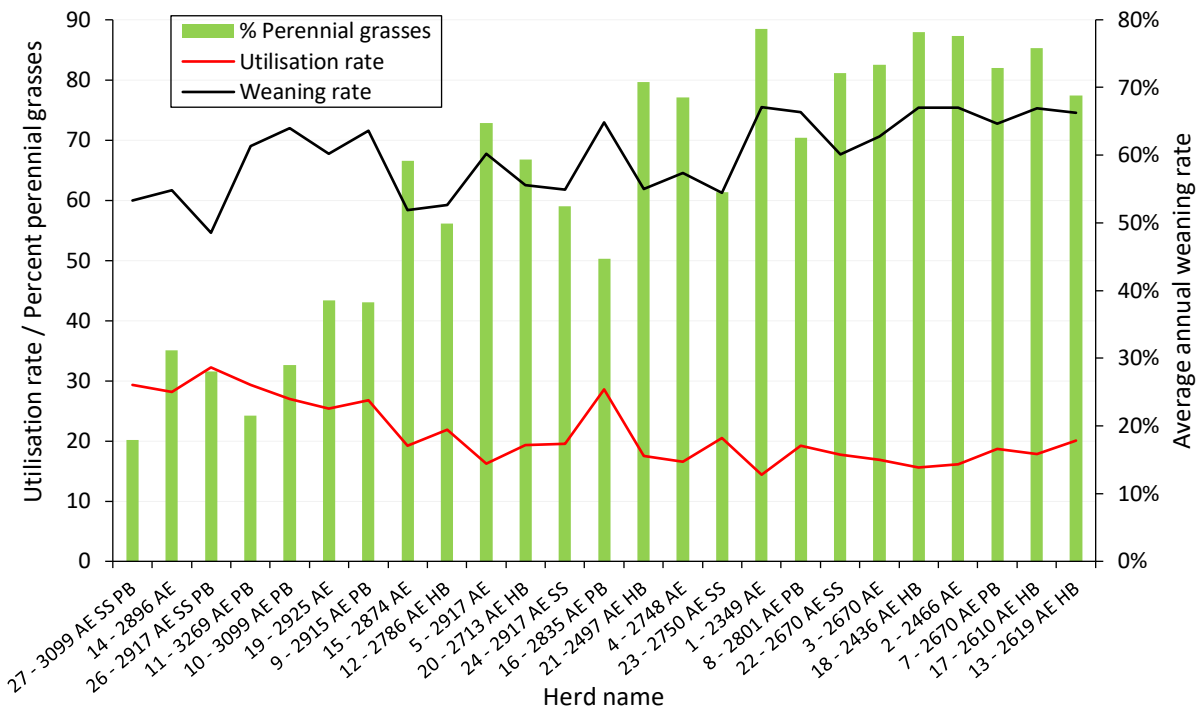


Figure 14-228: Average annual weaning rates of the 25 simulated Burdekin herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 42 years

Relationship between annual profit and kg weaners produced/year

While the weaning rates of the three most profitable herds were similar to those of several other herds, because of their larger herd sizes, they produced the most kg of weaners annually (Figure 14-229). However, for the 10 simulated herds between 16 – 3825 AE PB and 2- 2466 AE, the kg of weaners produced annually did not increase with increasing average annual profit. These herds had similar but lower herd sizes, and they differed greatly in their total variable costs.

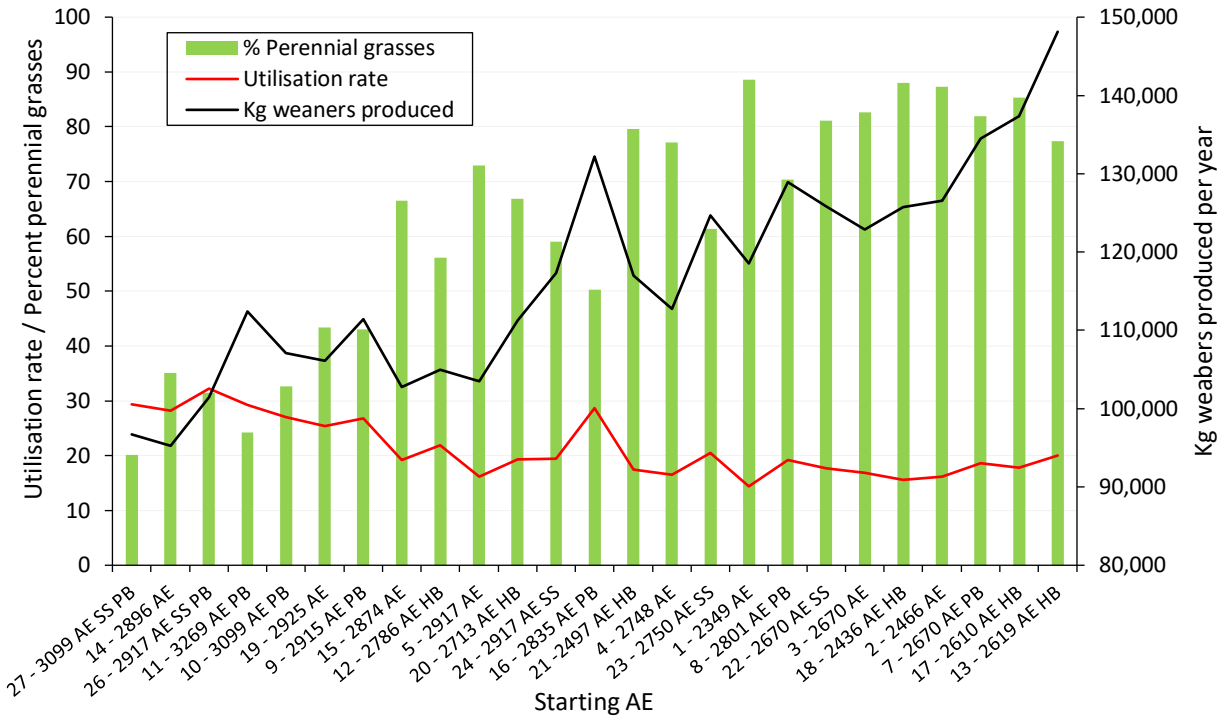


Figure 14-229: Average annual kg of weaners produced annually of the 25 simulated Burdekin herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 42 years

Relationship between annual profit and kg beef produced/AE

The kg of beef produced annually/AE (Figure 14-230) was more variable and less correlated with annual profitability than was total kg of beef produced annually. However, the nine most profitable herds had the highest kg of beef produced/AE.

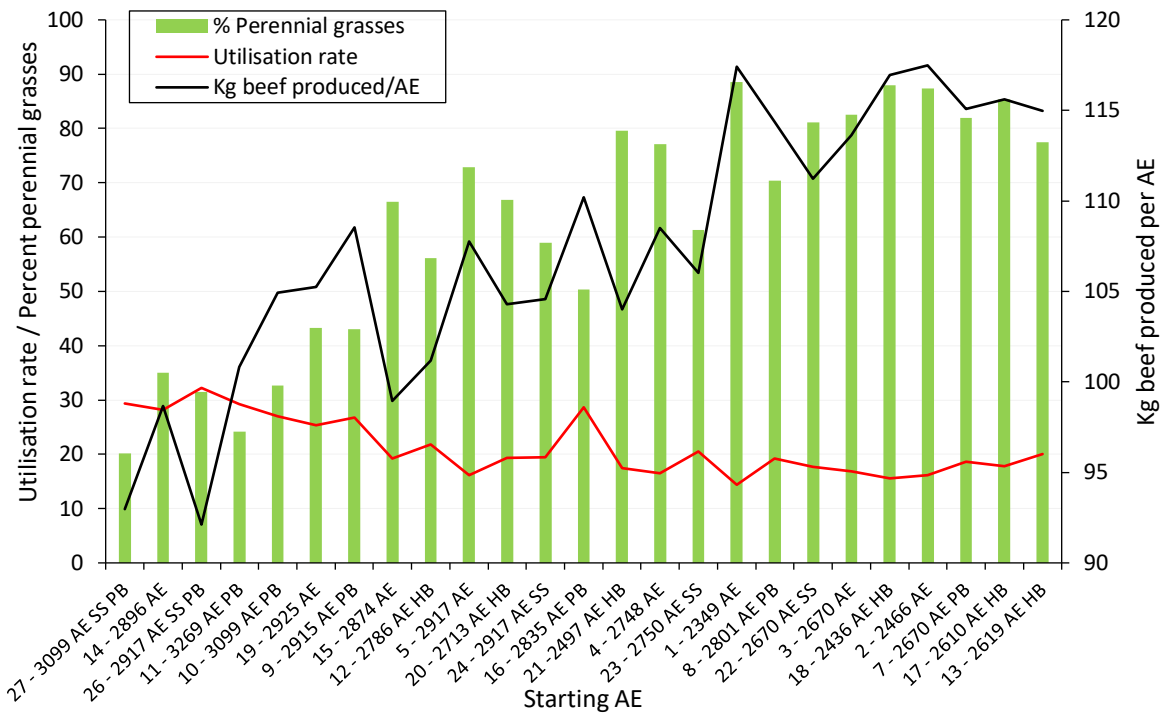


Figure 14-230: Average annual kgs of beef produced/AE of the 25 simulated Burdekin herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 42 years

Relationship between annual profit and kg beef produced/year

A similar trend was observed for the average annual kgs of beef produced/year by simulated herds. While the three most profitable herds produced the most kg of beef per year, many other herds with different average annual profits produced similar amounts of beef (Figure 14-231). However, again, there was a general trend for the kg of beef produced annually to increase with increasing perennial grass composition.

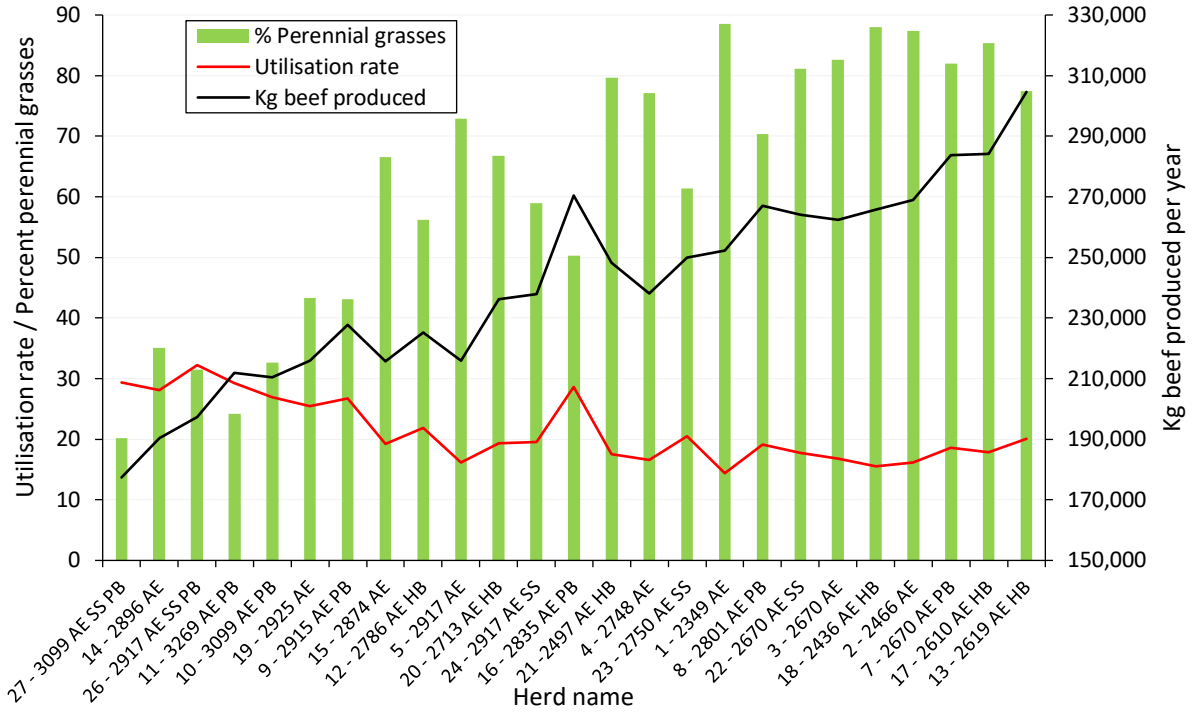


Figure 14-231: Average annual kgs of beef produced of the 25 simulated Burdekin herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 42 years

Relationship between annual profit and gross profit

Annual profit equals gross profit minus both variable and overhead costs. Gross profit is the annual income from cattle sales minus costs of purchasing cattle plus the difference in the value of cattle present at the end and beginning of the financial year. Herd 13 - 2619 AE HB, which had the highest annual profit, also had the highest average annual gross profit (Figure 14-232). The trend again was for gross profit to increase with increasing perennial grass composition, with the rate of increase similar to those for profit/yr and profit/AE. Average annual gross profit of the Barkly herds was not as closely correlated with profit as was the Burdekin herds. The two largest Barkly herds had high gross profit, but due to very high variable costs, they had relatively low overall profit.

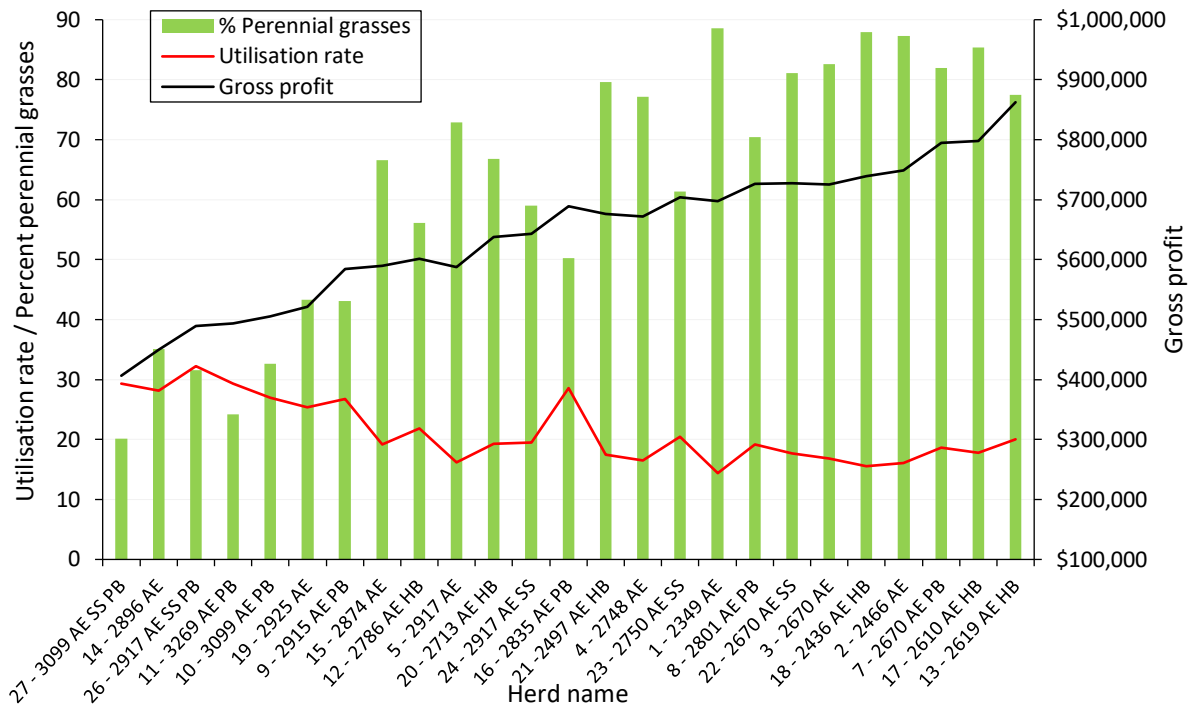


Figure 14-232: Average annual gross profit of the 25 simulated Burdekin herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 42 years

Relationship between annual profit and total variable costs

Total variable costs were poorly correlated with average annual profit (Figure 14-233). Even so, the three most profitable herds which had the highest average annual herd sizes also predictably had amongst the highest total variable costs. Several of the smaller and medium sized herds with high median utilisation rates also had high variable costs due to the high costs of M8U drought feeding. In comparison, total variable costs of the Barkly herds were more closely related to total herd size, as no drought feeding was employed.

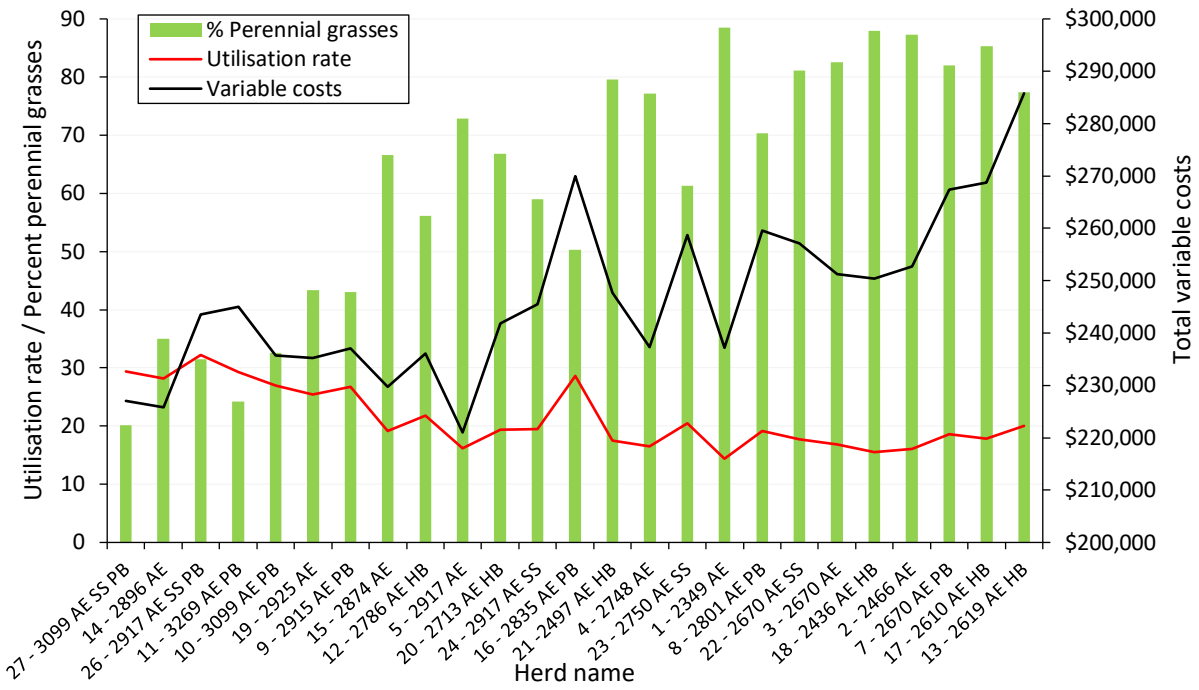


Figure 14-233: Average annual total variable costs of the 25 simulated Burdekin herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 42 years

Relationship between annual profit and variable costs/AE

While the seven least profitable herds had the highest variable costs/AE, the remaining herds, which had very different average annual profits, differed little in their variable costs/AE (Figure 14-234). Again, this was due to the high costs of drought feeding for herds with pasture utilisation rates that were higher than those of the most profitable herds.

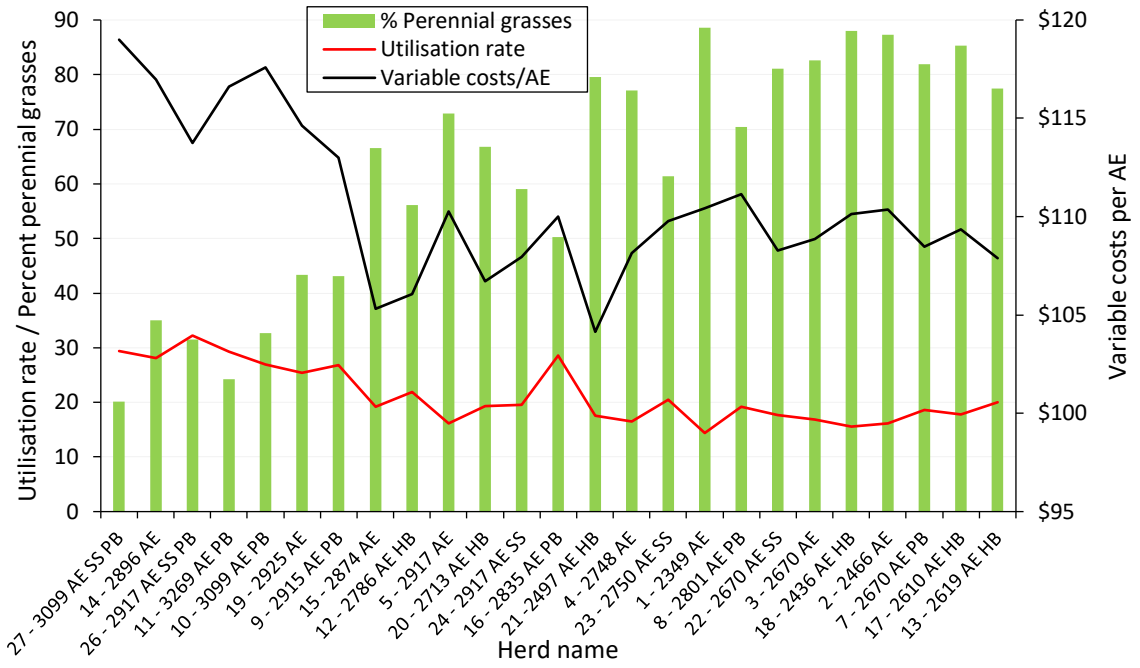


Figure 14-234: Average annual variable costs/AE of the 25 simulated Burdekin herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 42 years

Relationship between annual profit and profit/AE

The most profitable of the 27 herds simulated was 13 - 2619 AE HB (Figure 14-235). The median annual pasture utilisation rate of 20.1% for this herd was amongst the lowest of all 25 herds, and this herd had amongst the highest average annual percent perennial grass composition. Overall, there was a trend for average annual profit to increase with increasing percent perennial grass composition and decreasing utilisation rate. Even so, some less profitable herds, such as 18 – 2436 AE and 2 – 2466 AE, had lower utilisation rates and higher perennial grass composition than 13 - 2619 AE HB. While the profitability of the 12 most profitable herds (21 – 2497 AE HB to 13 - 2619 AE HB) steadily increased, they differed little in percent perennial grass composition and pasture utilisation rate.

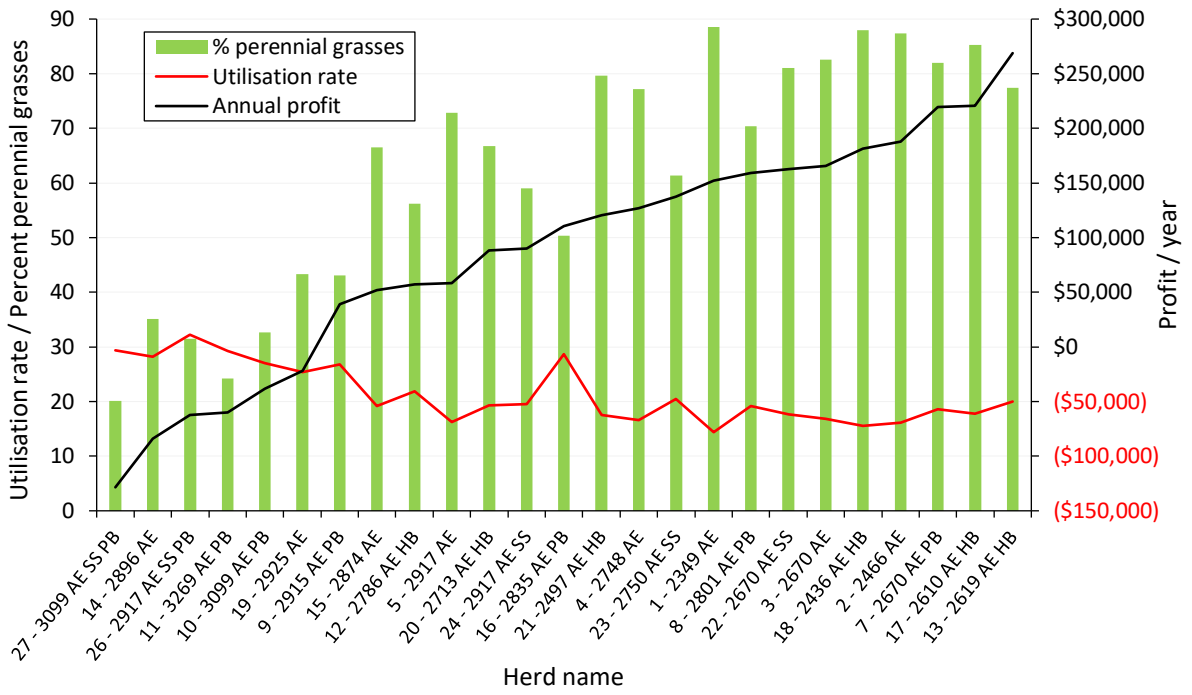


Figure 14-235: Average annual profitability of the 25 simulated Burdekin herds, ordered from left to right in increasing profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 42 years

Herd 13 - 2619 AE HB, which had the highest average annual profitability, also had the highest profit/AE (Figure 14-236). Generally, profit/AE tended to increase with increasing total profitability and with percent perennial grass composition. As can be seen from comparison of Figure 14-235 above and Figure 14-236 below, the trend for average annual profit was very similar to that for average annual profit/AE. This was different to the relationship reported above for Barkly herds, where the two largest herds had the lowest profits/AE and the other herds had very similar profits/AE.

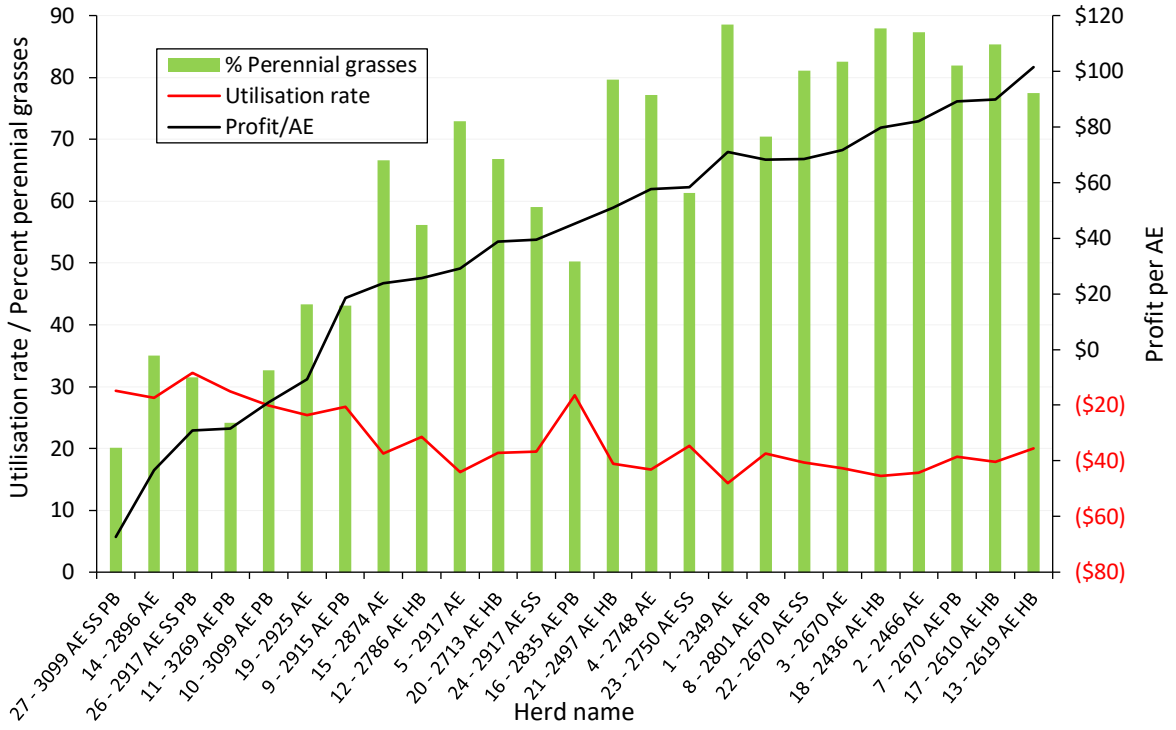


Figure 14-236: Average annual profit/AE of the 25 simulated Burdekin herds, ordered from left to right in increasing average annual profitability, and their associated median annual pasture utilisation rates and percent perennial grass composition. Average of 42 years

14.9 Transcript of Kidman Springs Sweet Spot in Action panel

At the Kidman Springs Beefup in August 2024 three producers from the surrounding Victoria River District were invited to share their experiences with us in managing stocking rates to enhance breeder performance. After twenty-five years of mostly above average rainfall stocking rates were tracking well above long-term safe stocking rates in the region, because the recent carrying capacity had been higher due to a multidecadal wetter period. A period of five years of average to below average rainfall in the region between 2018 to 2022 caught the industry unprepared, as there was no experience of 'average rainfall' in the current station managers. Any below median rainfall year had been followed by an above average rainfall year since the mid-1990s. The combination of higher stocking rates and lower pasture growth in this drier period led to high pasture utilisation rates, leading to very low weaning rates and stress on the resource base.

Kidman BeefUp 2024 – Sweet Spot Panel Session

Dan Chapman AACo, Mike Bailey Newry Station and Steve Petty CAIT, facilitated by Robyn Cowley

Transcript

00:00:00 (Robyn)

…and tell their story and then we'll open in up to everyone to ask questions. And I might prompt If I think they've got more gems they haven't shared with us.

But yeah, that's how we'll start. So we're going to start with Dan.

00:00:23 (Dan)

I'll just talk more broadly about AACo as a business and some of our stocking rate decisions that we have made in the last 10-15 years.

So historically we've relied on on-ground assessments and it has been largely rainfall driven, and as a business-, as we progress [and] we've worked with companies like CIBOLabs and we work more closely with the NT DPI, we've been really able to dial in some of our utilisation rates and really work to a Paddock scale to help drive land condition improvement and animal performance as well.

So, yeah, I'm pretty keen to share some of the stuff around how we've got to where we are today.

So, from the-, I've got some numbers written down here which is probably valuable for people to understand. From the height of our stocking rate, particularly **in the VRD, we've seen a 44% reduction in our overall herd between the three properties we have in the Vic River district**.

So, this is likely, I guess, historically the numbers were as a direct result of two to three decades of unseasonably or historically high rainfall. So at Delamere station, for example, our 120-year rainfall is 120mm lower than our 30-year rainfall average, so we had some expectations around paddock performance and production. And when the rainfall started to return to a more normal level, we probably didn't have a level of flexibility to quickly move stock off those properties.

So as a direct result of that, we really looked into removing the old and non-performing sort of animals as you would expect and really facilitated driving that good, accurate, stocking rate by utilising a bunch of satellite methods.

So we utilised Cibolabs, and Digital Earth Australia - has got really good water observations from space layer so we really get to understand the ephemeral water layer, because we-, one thing we

noticed, Robyn I spoke about this at length, the forage budget data didn't always line up with the long-term carrying capacity data when you relate it back to the relevant rainfall decile that we were seeing. And once you started to interrogate some of that data and looked at the ephemeral water and where that was within landscape, that probably accounted for roughly about 20% disparity that we were seeing.

I guess now it's an annual part of our programme that we undertake each year when we do undertake forage budgeting with long-term carrying capacities and assess the rainfall decile data. Thanks to the CliMate team who were kind enough to help us learn to interrogate that data thoroughly.

00:04:30 (Robyn)

So where are you at in the story, how were your animals performing, what were signals to you that adjustments might lead to better outcomes?

(Dan)

Yes. So we got to have a good look at some of the historical data and this is speaking to an all time low for us, **we were about 45% branding and now our 4 year average is sitting at 77%.** So that's from the point of intervention which was 2019.

And on top of that phenomenal **land conditioning improvement too, which is obviously-, over the long-term will actually help us to lift that stocking rate as well,** without compromising animal performance.

00:05:14 (Robyn)

So how quickly did you see these changes happen, in animals and in land condition?

00:05:17 (Dan)

So this was probably one of the frustrating parts for us, is that it did require a lot of data around that decision making to get to these stocking rate decisions. And then we had a poor wet season. So the last two to three wet seasons have been phenomenal for us in terms of seeing land condition improvement and it was really when we did start to see those back to back above average wet seasons, coupled with good spelling plans, that we that we really saw that land condition lift and the production improvements off the back of that.

00:05:50 (Robyn)

So how else can that affect all this, you made these massive adjustments to stock numbers, how does that affect other things like running costs?

00:06:01 (Dan)

Yeah. So what probably what it did, is it, it probably **really helped boost morale** within a lot of the camps, that’s one of the immediate things we did notice.

We weren’t sort of waiting for rainfall come October, November. We did have that good buffer and **our pastures were left in a rain ready state, so when we did get rainfall we were able to get good pasture growth** off the back of that.

Probably in addition to that Robyn, it was **probably supplementation costs were down slightly** as **crude protein and dry matter digestibility were maintained slightly higher for a longer period in the year**, which we backed up by a fair bit of faecal NIRS data to support that.

That was another thing, I was able to pick up some historical data and in a fairly equivalent wet season in the same paddock. I found some data from 2014 and some from 2022 and I think it's around-, in the same time of year it was a 1.5% percent lift in crude protein and 1.7% higher dry matter digestibility.

So the pasture they're on at this time of year is significantly better than it was at a higher stocking rate - this coming year is significantly better than that.

00:07:20 (Robyn)

You've got fewer animals so they haven't grazed out those high-quality components as quickly.

00:07:25 (Dan)

Yeah, that's exactly right. I think we have a better leaf to stem ratio as well which significantly contributed to that and that ability to be more selective with the diet.

00:07:42 (Robyn)

How else did these changes affect other things in relation to station management, for example, and opportunities?

00:07:47 (Dan)

That's a great question. So one thing that we have always historically suffered with in the VRD is that uncontrolled wild fire, and when you do have that higher stocking rate, you probably don't have that ability to actively burn and then rest and recover specific paddocks.

Well we've actually been able to get some really good mitigation measures in place for early season burning, and if we have had unplanned wildfires, we can then spell those paddocks in the back end of the year so we don't impact that perennial pasture base.

And just **more proactive spelling plans, we can identify areas where we really want to see that land condition up lift and help facilitate that**.

We've, we've also done some interesting things where we've got monocultures of say, black speargrass, we've had higher stocking rates in there for shorter periods of time to get good even utilisation, and the following year seen a pretty significant uplift in the diet quality too.

00:08:47 (Robyn)

So, what about other opportunities. Like if you have reduced your stock numbers and your individual animals are performing better, is that an opportunity for being involved in the herd management methodology and being credited for reducing emissions?

00:09:07 (Dan)

Yeah, that is a really good point Robyn.

We are a part of the-, **we do have a beef cattle herd management project established** at the moment and we do ern ACCus (Australian carbon credit units) off the back of that practise change that occurs as a result of that.

The other thing that's currently on our radar is around the biodiversity markets and natural capital more broadly, and looking at the improvement we can see over time on our assets and potential opportunities in that space too.

00:09:41 (Robyn)

So what advice do you have for others who are being-, you know, heading down this road?

00:09:48 (Dan)

I think the biggest thing is probably talking to the relevant industry experts and getting advice from a range of different people, and looking at how that's going to work on your individual property because everywhere is different and, what you said earlier, Robyn, the NT government doesn't have specific experience everywhere, but in my experience they've been very helpful with working with producers to try and help come up with solutions to specific questions and problems.

And utilising spatial tools has really changed the game when you're talking about such an extensive environment, like you really can only see what you can see on the ground.

00:10:26 (Robyn)

So this is an open question, do you have any other thoughts or things that you think I should've asked or that you wanted to add?

00:10:44 (Dan)

No.

00:10:45 (Robyn)

Ok, so we're going to go over to Mike now. And he's there not 'where the rubber hits the road' but 'where the cows hit the paddock', and we look forward to hearing your perspectives on that.

00:10:57 (Mike)

Just from Newry (2467km^2), so what we're trying to do is when we-, CAIT, the company we work for, we bought Newry in 2020 and from there we had to sort of stand on our own two feet with our production and cost reduction and what we could produce off the place.

The **main issues we found there is we had low calving percentage, or weaning percentages**, **and we had low turn off weights**. And for us to stand on our own two feet we had to improve both.

So where we started, you know, we were running 20,000 to 21,000 head [8.5 hd/km^2 across entire station] total when I arrived there.

We were sort of branding around 50 - 56% so to stand on our own two feet we started destocking.

So we came down to about 17,000, somewhere between 16500 and 17500, [20 % reduction to 6.9 hd/km^2] depending at what time of the year, and we did that and **we put more water sources in** at Newry; so dams, bores, and then off them water sources, we implemented more water points.

And by doing that, we were able to **spread the cattle out and utilise country that was untouched** - not so much untouched, but **made more available**. So yeah, not bush country I don't think though just country and paddocks that were outside grazing radiuses.

We tried focussing on **making our grazing radius 3km and then not increasing numbers in the paddocks**. So while doing that we spread the stock out and ultimately lowered the stocking rate in the grazing radiuses, not over the whole property.

And what we found by doing that, **we increased our turn off weight in our heifers, our transfer weight in our steers, and we increased our weaning percentage from the sort of low/mid 50s up to last year, we did 70 [%]**. We're just shy on that this year, we're looking to do a bit better than that.

So yeah, and that's worked really well. And then with our **turn off weights in our heifers, we've gone some sort of high two-hundreds to sort of mid three-hundreds in turn off weight**, which ultimately at the end of the day has **helped us lower our cost of production**, although at the moment is doesn't look like it because we are putting infrastructure in and that all goes towards it.

So it's taken about three to four, four years, so it's taken that to start-, we're starting to see **big improvements now with the weaning percentage and the turn off weights** which is really reflecting on the input-, the money that we put into the station.

So there's that and other things, you know, such as phosphorus and all that stuff.

So I guess where it's really helping us on the other end, by doing this is **we've got more pasture for our cows to eat**, to do a job on their progeny and what we're finding too is **our supplement costs have come down**. So that's a big thing that's helped us, **also bringing that cost of production down** and we can really target the cattle that we want to look after at certain times of the year.

Yeah, I guess that's more or less what we've done. Steve's probably got that in a bit more detail.

00:14:35 (Robyn)

That was really good, thanks. Before I throw to Steve I guess I'd like to ask you, like, how did you find that, I guess, before and now, stress levels etcetera, like you know, what are the other not necessarily painful consequences, but other things that have happened as a result of these changes?

00:15:02 (Mike)

Yeah, I think, you know, what Dan was saying, a big staff morale [change]. Like, we've gone from in 2022 I think, 2023, 2022 we had that really dry season and not much of a wet and, you know, we cruised through that, firstly because the first thing we did was increase the water points and-, through more sources. So you know, **we weren't stressing about water points** and then staff **weren't seeing the deaths or mortality**, so we've lowered that as well through the implementation of water development.

But you know, all the staff are a lot happier, you know. We're a lot more streamlined and we want to keep improving and seeing how far we can take it, and as the country recovers from being so stocked, you know. We're not really sure where it's going to stop and, you know, as Dan said, then-, and-, **potentially in years to come we'll be able to increase that carrying capacity because of the-, because we've let the land recover** after so many years of really getting the most out of it.

00:16:17 (Robyn)

Did you have any other thoughts before we throw to Steve? You will have other opportunities to speak if you want to later.

00:16:20 (Steve)

Good stuff.

So we took over the properties in 2019-2020 and we had a pretty good place, thanks to the people who were there before. So we've got Auvergne, Newry and Argyle.

The issue we found is we needed to drive productivity up and so the obvious place to start is you put phosphorus in, you put early weaning in you put all your management strategies in and we launched into all the typical things that you do to drive business productivity, and the big issue we kept having is that we could bring breeder condition up, but at the end of the year, the breeders at this time onwards would just drop in a big hole.

And some of the work Christie [Pearson] did showed that the-, we had breeders losing 100kg in about four months time.

And so things weren't that good. We looked at the level of stocking - so Newry for a start is 246,000 hectares, we're running 21,000 AEs. So if you quickly do the maths it's about 8.5AE per km^2.

Now that, you look at some of the data that Robyn put up, that's not over the top stocking rate. But if you then look at Newry where the cattle actually graze, they're grazing the areas near the water points, there's a big chunk of Newry that's not much use for cattle. I reckon **we were more about 17 AE per square km [of 3km watered area]**. So we were up there stocking rate wise. And that's on a three and a six km grazing radius, so.

Cost of production back then was about $1.90 per kg of gain, so it was-, I think the benchmark in this area-, that's not good enough really.

And Mike went through a whole heap of changes, and he's got the cost of production down to around that $1.60, $1.55 - $1.60, so the business is really sort of kicking some goals.

But **less cows, producing more calves**, and then transferring them down to Argyle. It's just a really nice story.

We have Auvergne next door and it's-, just from what we're working on, the changes that are there with Auvergne now, and sort of using Newry and the work that Mike's done as a basis of that, but I just thought I'd give you a bit of background on Auvergne.

So it's about 414,000 hectares roughly and it's been running about 33,000 - 35,000 AE. So again that's 8.4 AE per square km, and again that that's nothing to be concerned about. If you look at the developed (watered) area at Auvergne, it's about 14 AE per square km.

But if you then sort of say that you hit a dry year and most of our waters come off the river, we cut that up to probably about 30 AE's per square km and we just nail the country, and so if you look there at what we've done there at Auvergne, it's probably not quite to the level that Mike's sort of done it, but it's, yeah, twice a year weaning, phosphorous supplementation, so it's about 9.5 grams of P/head/day. So that's about what's that? 2 kilos of P per year - Tim will be here so he'll do the maths.

But yeah, wet/dry drafting, dry season supplementation, vibrio, botulism, right bulls with EBV's, you name it, we've put that in place.

Now, that herd is producing about 50 to 60% branding percentage. It's just not good enough. It's disgraceful in this year and if you look at the property at the end of the year, you go for drive there in a month's time, if you threw a match over your shoulder that place would go off like a bonfire.

So **the issue is not the fact that we are overstocked, we are overstocked per number of cattle per waterpoint, and if we actually work it back, we're running about 400 head per waterpoint on average. And so and that's too much for that country**.

So we're currently looking at sort of following where Newry is at, Auvergne's probably a year or two behind Newry, where Mike's at. We just started a big sell down of breeders and it's a painful exercise in the current market.

We've got a target in mind as to where we want the stocking levels to be there at Auvergne, but we've taken the cost of production-, so Auvergne is a pretty efficient business. As most of you guys know, in bigger businesses it's too easy to have a good cost of production. In fact, you don't have to try too hard at all, but, so currently Auvergne's at $1.22 cost per kg and that cost doesn't include capital investment and it doesn't include interest rates and things like that, so it's more on farm cost of production.

So Auvergne is a reasonably efficient business, but going back to the point Robyn made, is the sweet spot. So there's a sweet spot from a stocking rate perspective and the graph Robyn showed, the lighter you're stocked the better your productivity, we all know that.

It's hard to understand where those spots are. The more challenging one is where do you set your optimum economic position? So if we put in more water points, which is what we're doing at Auvergne, you're cutting the stocking rate back. **For every extra water we're not increasing numbers, but spreading a lot more cattle out**.

I can't off the top of my head remember the number of waters Mike put in (on Newry), but we put a lot of water in. Auvergne, we put about 25 waters in so far, but that includes the ones that we've got going that weren't going before and will be going again to try **to drive the average stocking rate down**.

But how far do we need to go?

We're not sure, but if we also have a lag of some flogged country around water points that we need to deal with, we need to move cattle from existing water points to the new water points.

It's not simple, it's not a simple operation. It takes up a fair bit of thought, and probably the take home message for us is that, we can spend a lot of time talking about productivity and you know have we got the EBV tested bulls, are we vaccinating with this, you know, we wet/dry draft and we draft X many ways and we supplement our dry cows and we do all that sort of stuff; **but the most basic thing that we should all know is what really is having the biggest impact in our herd. And that's stocking rate.**

Stocking rate's driving the big changes in in productivity, we put all the stuff in, including the big investment of phosphorus and we've got moderate results, so we're hoping Auvergne's going to follow the path of Newry.

And the other point Mike made, which is quite evident, is we don't have a company that's going to throw lots of money at us. We are on our own in terms of our investment. So we have to make every trick a winner and we have to be very careful in terms of what we do.

00:25:42 (ROBYN)

That sounds, wow, thanks everyone for sharing all those experiences that you've had, was there anything else you wanted to add, Steve? Any thoughts? You don't have to, otherwise I was just going to open it up to the audience.

00:25:58 (Steve)

No, probably only that our **target is trying to get down to around that 300 head per water point**.

It's easier said than done, when you've got some waters flogged, some not, some good country, some bad country. Yes, it's a complex equation with so many moving parts, it's no wonder it takes most people a long time to sort it out.