Final report

Wambiana: Grazing strategies and tools to improve profitability and land condition

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Abstract

The Wambiana grazing trial was established near Charters Towers in 1997 to test and develop evidence-based management strategies to manage for rainfall variability. This fourth phase (2018-2022) of the project focussed on developing and demonstrating adaptive strategies and decision tools to help producers sustainably manage for climate variability.

Trial conditions were challenging with extended drought years. Pasture condition declined to very low levels under heavy stocking, but in contrast to previous years, also declined to varying extents in the other strategies. Importantly, the results show that simply stocking at long-term carrying capacity (LTCC) inevitably leads to land condition decline, unless stocking rates are adjusted downwards in lower rainfall years.

The key recommendation is thus to stock at close to LTCC in better seasons, but promptly reduce stocking rates with approaching drought. This long-term strategy allows producers to maintain viability in dry years, minimise land degradation and maximise the potential for post drought recovery. Results indicate that for a 20,000 ha property, adopting such a strategy would give an extra $3 million over 24 years in accumulated gross margin compared to heavy stocking.

The long term trial data was also used to develop tools to predict paddock forage quality, further improve tools to estimate forage availability, and increase the ability of the GRASP model to simulate the performance of different management strategies.

A major extension effort was conducted at the Wambiana site with ongoing input from the Grazier Advisory Committee. Two large field days were held (total area managed 1.41 million ha), there were site visits by a total of 657 visitors and additional presentations elsewhere e.g. at NGD sites to an additional audience of 328.

Four on property sites in different catchments demonstrated the principles of good management to a large number of producers and identified a range of ways to implement these principles on property. These included improving reproductive efficiency, developing trigger points and action plans to manage drought and strategic use of improved pastures.

An independent survey showed that the project is delivering relevant, practical information and support for industry with a very high percentage of producers implementing practice improvements. Producers rated the project as very relevant with strong (100 %) support for its continuation.

Executive summary

The Wambiana grazing trial was established near Charters Towers in 1997 to test and develop evidence-based management strategies to manage for rainfall variability. This fourth project phase (2018-2022) continued testing these strategies with the addition of recommendations from the 2016 project review. The renewed focus has been to develop adaptive, flexible grazing management strategies to improve profitability and land condition, collaboration with other agencies to further develop tools to assist producers in managing climate variability, and to increase adoption by a range of extension activities including demonstrating the benefits of improved management at four on-property demonstration sites. The long term results from the trial have been consolidated with producer experience and improved decision tools to develop strategies and recommendations to manage sustainably and profitably in our highly variable environment.

Seasonal conditions were challenging throughout the project with ongoing below average rainfall and the enduring legacy of the extreme 2014/15 drought year. Over the 24 years of the trial, average annual live weight gain (LWG) was highest (116 kg/hd) in moderately stocked strategies, like the moderate stocking rate (MSR) and Rotational spell (R/Spell), but lowest (100 kg/hd) in the heavy stocking rate (HSR). Individual LWG in the two Flexible stocking (Flex) strategies varied based on stocking rate but was similar (115 kg/hd) to the fixed stocking MSR and R/Spell. Carcass weight, fat thickness and price per kg were also far higher in these strategies than in the HSR.

Conversely, average annual LWG/ha was higher (19 kg/ha) in the HSR than in the other strategies (14 to 16 kg/ha). However, this was only achieved with expensive drought feeding in seven of the 24 years of the trial, compared to only one in 24 years for other strategies. Due to higher costs and lower product value, average annual gross margin (GM) in the HSR ($7/ha) was thus only half that in the other strategies ($13/ha). For a 20,000 ha property this equated to a forgone income of $3 million over 24 years in accumulated gross margin. The heavy stocking rates initially applied in the HSR (4-5 ha/AE) were also unsustainable in the moderate to longer term with drastic reductions in stocking rates required in eleven of the 24 years of the trial.

While there was little difference in average LWG and average GM/ha between fixed stocking at Long Term Carrying Capacity (LTCC) and flexible stocking, progressively matching stock numbers to forage supply avoided the need to destock, as happened in the MSR and R/Spell in 2017/18. The flexible strategies hence had a GM of $9.50/ha compared to a net loss of -$17/ha in the latter strategies. Further, despite another poor wet season in 2021/2022, the flexible strategies will remain stocked for the upcoming 2022/23 season in sharp contrast to the R/Spell, MSR and HSR which will all be destocked due to low forage availability.

Pasture composition continued to decline in the HSR with the frequency of the key 3P (palatable, perennial and productive) species *Bothriochloa ewartiana* falling from 27 % in 1998 to only 3% in 2021. Surprisingly, the frequency of *B. ewartiana* also declined to varying extents in other strategies from 20-27 % in 1998 to between 11-18 % in 2021. The decline in condition in 'better' managed treatments is concerning and appears due to a complex of three factors including, the length and severity of the current drought period, the marked increase in woody plant cover, particularly *Carissa ovata*, and in strategies where stocking rates weren't reduced, grazing management.

The decline in pasture condition in the MSR and R/Spell contrasts sharply with previous results where these strategies maintained pasture condition. This result is particularly significant and shows that the widely promoted recommendation of stocking at LTCC will inevitably lead to a decline in land condition unless stocking rates are adjusted downwards in lower rainfall years. While land condition also declined in the two flexible strategies despite reduced stocking rates, their current higher TSDM and cover indicates faster recovery trajectories when wetter seasons return. These results, as well as our experiences in managing these strategies, highlight the obvious need to adjust stocking rates as seasons change even if stocked at LTCC.

While stocking rates are undoubtedly the primary determinant of land condition, the results also emphasise the need for wet season spelling, as shown by the relatively better condition of those strategies with wet season spelling. Results from the associated small plot spelling trial also show the additional benefits of spelling in aiding recovery but only when combined with moderate stocking rates. Based on these results and the long term trial data, the key recommendation for sustainable and profitable management is to apply flexible stocking rates around LTCC combined with wet season spelling.

The project also collaborated with the Department of Environment and Science (DES) on developing and improving decision tools to assist management decisions in managing seasonable variability. First, long term trial diet quality data was used to develop a remote sensing based tool to predict and forecast paddock forage quality. This proof of concept work showed that it is possible to predict and forecast forage quality up to three months ahead from the end of the wet season with reasonable accuracy. Ultimately, this could be developed into an operational, real time system for managers.

A simple tool was also developed using remote sensing metrics NDVI and fractional green cover (FrGreen) to classify paddock forage quality relative to animal maintenance requirements. Testing of the tool against the trial's long term diet quality data indicated that both NDVI and FrGreen were of moderate to high accuracy in classifying forage quality into broad classes relative to maintenance. Accuracy varied slightly between year types being highest for dry and lowest for wet years. Accuracy was also greater for animals with higher maintenance requirements i.e. cows vs. steers.

The long term Wambiana pasture, soils and animal data also continued to be used as the foundation for a number of other modelling and/or remote sensing tools. For example, the Department of Environment and Science's 'prototype forage biomass tool' estimates paddock level pasture mass for a number of sites based on cover: pasture mass relationships from the trial. The new DAF 'Bob Shepherd's 'Ready Reckoner' stocking rate calculator is directly based on predictions of pasture biomass derived from GRASP parameterised and calibrated with Wambiana data. The trial data similarly continues to be used to help parameterise the FORAGE on-line tool for estimating long term carrying capacity and pasture biomass.

Collaborative work with the Drought and Climate Adaptation Program (DCAP) also tested the ability of GRASP to simulate long term pasture change in the heavy and moderate stocking strategies. While GRASP successfully simulated the first 16 years of change, it was unable to capture the extent of degradation during the recent drought and the subsequent lack of recovery. The work nevertheless revealed several unrepresented processes in GRASP in particular, the impact of the woody shrub *Carissa ovata* and the exotic grass *B. pertusa* on pasture production. The study also provided parameterisation for improving GRASP's ability to model grazing lands and will contribute directly to current GRASP applications predicting carrying capacity and pasture biomass.

Two walk-over-weigh units (WOW) collected valuable daily LWG data with no disturbance to animals. However, the objective of developing a tool to predict LWG was unachievable due to issues matching the temporal scale of different data sources, the relatively short term WOW data and the complexity of predicting daily LWG in spatially diverse paddocks. The WOW units nevertheless provided high resolution data on how stocking rate, land condition and season drive LWG. In particular, graphic evidence was provided on how poor land condition reduces the capacity of the pasture to respond to out of season rainfall and drive LWG. While a valuable research tool, the WOWs had a number of technical and operational issues that reduced performance; as such they cannot be regarded as low input, off-the-shelf technology.

A major extension effort was also conducted throughout this project. As before, the trial's Grazier Advisory Committee provided vital producer input to ensure industry relevance. There were also 30 site visits by a total of 629 visitors between January 2018 and April 2022, with additional presentations on the trial outcomes to an additional 328 people over this same period. Two large field days were held with attendees managing a combined total of 1.41 million ha. The first was in October 2019. Feedback from this field day was very positive with 75 % of producers intending to apply the information learnt on property.

The second field day in 2021 was also rated as 'extremely useful' with producers being highly likely to make a management change within the next 12 months based on what they had learnt. Importantly, there was very strong support for the trial continuation, albeit with some modifications e.g. testing 'regenerative' grazing options. . Possibly the most significant outcome, however, was the self-volunteering and subsequent establishing of the 'Bunuro' on-property demonstration site near Torrens Creek.

The closely linked ReefPlan funded Northern Grazing Demonstration (NGD) project demonstrated the 'Wambiana management principles' on four properties in different catchments in Queensland. The project was too short to show land condition change but was an important extension and learning hub for producers and agency staff. One of many key learnings was the need to actively manage stocking rates as conditions deteriorate in dry years, including the use of trigger points and an action plan, as was demonstrated at the 'Ametdale' site in April 2018. As the Leichardt Creek managers noted '….*this place used to run around 3200 head to supply 1000 weaners a year. Since cutting that number back to around 2400 we still wean around 800 a year, getting more calves from the cows we have. Overall, those animals leaving the place are better. So, our overall kg/ha has increased……largely due to having a mindset of producing grass for cattle to eat*.'

Different ways of implementing sustainable management at the property level were also developed with producers. Amongst others, these included first, improving reproductive efficiency as a way of reducing breeder numbers but still maintaining production. And second, establishing areas of sown pastures to reduce stocking rates or allow spelling of native pasture paddocks. For agency staff, the challenges of accurately estimating pasture yields in large, diverse paddocks was an important learning, as was the varying utility of different fodder budgeting tools. Importantly, many producers preferred relatively simple methods like the DAF 'Shepherd Ready reckoner' to adjust stocking rates in preference to more complicated tools like 'Stocktake' and 'FORAGE'. Overall, the NGD demonstrated the principles of good management to a large number of producers and identified a range of ways to implement these principles on property.

The value of the WGT to industry was demonstrated via an independent survey of knowledge, attitudes, skills and aspirations (KASA) of trial participants. A very high percentage (73 %) reported an attitudinal change with the WGT providing the evidence needed to change management. Sixty three percent (63 %) learnt new skills with 70% aspiring to make a management change regarding wet season spelling and adjusting stocking rates to seasonal conditions.

Overall, the KASA survey showed that the WGT is delivering relevant and practical information, with one producer noting '*the long term research gives strength behind the data…its consistency increases the certainty that graziers will get the same result'*. The WGT also provides support for industry with a very high percentage of producers implementing practice improvements, improving their knowledge, and management skills for example, around forage budgeting and spelling. The value of the WGT to improving the uptake of feedbase research and development cannot be underestimated, with producers noting '…now *we make decisions before our backs are to the wall and look for other options to reduce stocking rates'*. *Seeing* the paddock treatment differences in particular had a profound effect on producers *'learning what to do and what not to do'* and having the opportunity to treatment outcomes with peers and technical staff. Consequently graziers rated the WGT as being of high to very high relevance with strong (100 %) support for its continuation.

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We also thank the Wambiana Grazier Advisory Committee for their commitment and involvement in the trial. Aside from their interest and guidance a number of them were also on hand to direct and help with burning and firefighting on a number of occasions. Most importantly, they shared openly and honestly their many years of experience and knowledge of the land and property management.

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Peter O'Reagain and John Bushell
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Abbreviations

3P Grass	Productive, perennial and palatable grasses
2P Grass	Grasses with two of the three characteristics of 3P species
AE	Animal equivalent
AGM	Accumulated gross margin
BOM	Bureau of Meteorology
CP	Crude protein
DCAP	Drought and Climate Adaptation Program
DEHP	Department of Environment and Heritage Protection
DES	Department of Environment and Science
EOD	End of Dry season (November)
EOW	End of Wet season (May)
Flex	Flexible stocking strategy
Flex+S	Flexible stocking with wet season spelling strategy
FrGreen	Fractional green cover (%)
GAC	Grazier advisory committee
GM	Gross margin
GLM	Grazing Land Management
GRASP	GRASs Production pasture growth model
ha	Hectare
hd	Head
HSR	Heavy stocking rate strategy
IVD	*In vitro* digestibility
KASA	Knowledge, attitudes, skills and aspirations
LTCC	Long term carrying capacity
LWG	Live Weight Gain
MSR	Moderate stocking rate strategy
M8U	Molasses and urea (8%)
N	Nitrogen
NDVI	Normalised Difference Vegetation Index
NGD	Northern Grazing Demonstration project
NLIS	National Livestock Identification Scheme
R/Spell	Rotational spelling strategy
SOI	Southern Oscillation Index – Variable strategy
spp	Species
SR	Stocking rate
TSDM	Total standing dry matter
VAR	Variable Stocking strategy
WOW	Walk over weighing
WS	Wet Season
WGT	Wambiana grazing trial
YLD	Yield
yr	Year

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1. Background

Beef businesses in northern Australia are under intense pressure to both increase profitability to ensure business sustainability (McLean *et al.*, 2014, McLean *et al.*, 2020) and improve land condition to meet community expectations e.g., (Queensland, 2017). This is a major challenge in a complex, dynamic environment with highly variable rainfall, highlighted by the fact that 64% of Queensland is currently (January 2022) drought declared or has just come out of protracted drought. Large areas of pasture are also in poor (C) condition with much reduced carrying capacity due to the failure to match stock numbers to available forage and carrying capacity (Shaw *et al.*, 2022). This directly reduces productivity and profitability: Mclean et al (2014) specifically recommend that enterprises improve climate risk management and match stocking rates to carrying capacity to increase profitability (pg. 69). Similarly, based on the recent Cashcow survey of herd performance in northern Australia (McGowan *et al.*, 2014), the first management action to increase herd productivity was to 'Manage the feedbase' and 'budget available feed to optimise cattle production'.

The Wambiana Grazing Trial (WGT) was established in 1997 to test and develop grazing strategies to help producers manage sustainably and profitably in a variable climate. Importantly, the strategies had to be tested at a scale relevant to the beef industry (O'Reagain and Bushell, 1999); O'Reagain *et al.*2011). The results have been widely extended via numerous field days, presentations and training packages like MLA's Edge GLM program. Results have also been extended in space and time via modelling e.g. (Scanlan *et al.*, 2011) and trial data has also been critical in calibrating remotely sensed based products and modelling which underpins decision tools like AussieGrass, FORAGE and Vegmachine e.g., Bastin *et al.*, 2012, Scarth, 2010b, Scarth *et al.*, 2010, Schmidt *et al.*, 2016, Scarth, 2010a, Scarth *et al.*, 2020, Bastin *et al.*, 2016.

A key finding of the first twenty years of the WGT trial i.e. up to around 2018 (O'Reagain, *et al.* 2018), was that moderate stocking at long-term carrying capacity was a profitable and sustainable strategy for managing rainfall variability. Surprisingly, varying stocking rates based on available pasture (with or without the use of SOI seasonal climate forecasts) was no more profitable than constant moderate stocking. Moreover, excessive stocking rates immediately before and going into the 2002-07 drought, resulted in significantly poorer pasture condition in the two 'variable' strategies (O'Reagain and Bushell, 2008). Nevertheless, through subsequent trial learnings and producer advice (i.e., adaptive management), these two 'variable' strategies evolved into, 'flexible stocking' strategies (+/- wet season spelling) with much improved stocking rate decision rules. Since their implementation in 2011, and in particular during the current drought, these two adaptively managed 'flexible' strategies (+/- spelling) have performed exceptionally well (O'Reagain *et al.*, 2018).

These recent results, along with enterprise level modelling, suggest that flexible strategies could give markedly better productivity and land condition outcomes in the longer term than constant moderate stocking. However, these WGT results are relatively short term (5 years) and the outcomes inconclusive. Beef producers, scientists and extension offices at the MLA funded WGT 'futuring' workshop in June 2016 accordingly concluded that further testing of these strategies was needed and strongly supported continuation of the trial (O'Reagain *et al.*2018).

Further productivity and sustainability gains could also be made using advanced decision support tools to respond proactively to changing seasonal conditions. For example, tools to remotely measure pasture yield and quality at the paddock scale would be invaluable in stocking rate adjustments and/or marketing decisions (Bastin *et al.* 2016). Similarly, recent development of walk-over-weighing technology allows real-time collection of cattle weights which, coupled with other tools, has significant potential to assist managers to respond far more rapidly and efficiently to changing seasonal and/or market conditions (Leigo *et al.*, 2016). However, while the number of technology products available to beef businesses is continually growing e.g. 'FORAGE', developing these tools requires appropriate long term data, as well as ongoing cycles of testing, validation and re-parametrisation at the research and commercial paddock scale. Critically, practical management systems that integrate these tools with other signals, like seasonal climate forecasts, need to be developed in partnership with industry to ensure adoption.

Significant productivity gains could also be achieved by regenerating the large areas of poorer (C) condition land present on many properties and thus increasing carrying capacity. However, in large paddocks such regeneration is really only economic using improved grazing management and wet season spelling. Unfortunately, while many key long lived perennials like Mitchell grass (*Astrebla* spp.) and desert bluegrass (*Bothriochloa ewartiana*) may produce seed, they seldom recruit successfully into adulthood (Orr and O'Reagain 2011), a life history characteristic of many, longer lived perennial grasses (O'Connor, 1991). The response to wet season spelling is thus often extremely slow, as found in the short-term spelling trial embedded in the WGT (Jones *et al*., 2016). It is imperative that such trials be continued to develop evidence-based spelling guidelines to help find ways to accelerate regeneration of C condition land and thus improve productivity.

Significant improvements in profitability and land condition are thus theoretically possible using adaptive grazing strategies, advanced decision support tools and regenerating land condition. Improved adoption of these technologies and more sustainable grazing management could also be increased by combining on-property demonstration with case studies and new and existing beef and reef water quality extension programs.

This project will benefit beef producers by:

1. Testing and developing flexible, adaptive grazing management guidelines to help producers manage climate variability and improve profitability and land condition,
2. Using satellite monitoring, walk over weighing and paddock data to develop decision support tools to assist producers making stocking rate and marketing decisions,
3. Establishing on-property demonstration sites to show what can be achieved with good grazing management,
4. Improving adoption by working closely with producers and extension programs funded by MLA and Reef Water Quality initiatives.

This project builds on MLA's investment in the long-term Wambiana Grazing Trial and collaborates with producers and other agencies to deliver improved management guidelines and practical decision support tools to increase the profitability and sustainability for beef businesses in northern Australia.

2. Objectives

1. Complete a full monitoring and evaluation plan to evaluate KASA (knowledge, attitude, skills and aspirations) of producers involved.
2. Have four demonstration sites each of which will have their own producer group. Producers will be involved in the management of these sites and will advise on the creation of adaptive grazing management guidelines.
3. Conduct field days at each of the sites, to build awareness of developed grazing management strategies. These will link directly to the Grazing BMP program training courses and one-on-one extension —delivered by QDAF - to extend findings and build awareness.
4. Test whether adaptive, flexible stocking gives superior profitability and land condition outcomes relative to fixed, moderate stocking.
5. Have further developed advanced decision support tools to assist beef producers increase profitability and sustainability through better management of the feedbase.
6. Have rigorously tested the ability of different wet season spelling strategies to regenerate poor (C) condition land.
7. Have demonstrated the potential improvements in land condition and profitability achievable through improved grazing management strategies at a range of sites.
8. Develop a set of grazing management guidelines based on the above.
9. Develop four case study reports — one for each of the demonstration sites — for submission. Note this must be compiled into one single report with a completed executive summary section.

The extent to which these objectives have been met is shown below in **Table 1**.

Table 1 Extent to which current project B.ERM.0108 objectives have been achieved.

Objective	Achievement criteria	Result	Progress	Outcome
1.Complete full monitoring and evaluation plan to evaluate KASA	KASA report delivered	1. KASA survey of 30 graziers done by GR Consulting in December 2021; report completed January 2022.	✓	Achieved; report presented in chapter 22
2.Have four on property sites to demonstrate 'Wambiana' principles.	Establish four on property demonstration sites	2. Four on property demonstration sites established in Burdekin, Herbert, Fitzroy and Bowen-Broken catchments in Northern Grazing Demonstration (NGD) project.	✓	Project completed; case studies attached – see Appendix 8 & chapter 14; Ametdale site to continue.
3. Conduct field days at each of the sites, link to Grazing BMP - on-one extension by QDAF	Field days at all sites and link to one on one extension	3. Field days (14) were conducted at all sites; linked to grazing BMP (when still available) & other extension projects. Also large field days at the Wambiana site in 2019 and 2021.	✓	Achieved; see chapter 14
4. Test whether adaptive, flexible stocking gives superior outcomes to fixed, moderate stocking.	Test strategies at WGT	4. Tested at WGT under challenging drought conditions; animal production and economic outcomes similar, but advantages of flexibility clearly shown in ongoing drought. Recovery likely to be far better under flexible strategies when seasons improve but ongoing monitoring required.	✓	Achieved; see chapters 3 to 8; final draft paper attached
5. Have further developed advanced decision support tools.	Predict and forecast forage quality from remote sensing	5.1 A tool to predict & forecast paddock forage quality was developed with DES using long term WGT diet quality data.	✓	5.1. Achieved; see section 10.1; paper published in *Ecological Indicators*.
	Estimate forage quality from remote sensing	5.2 The ability of NDVI and FrGreen to classify forage quality relative to maintenance requirements was developed and tested on long term WGT data. Both	✓	5.2 Achieved; see section 10.2

Objective	Achievement criteria	Result	Progress	Outcome
		indices very useful indicators; greatest accuracy in dry years.		
5. Have further developed advanced decision support tools (contd.)	Improved tool to predict paddock yields	5.3 Testing of protype tool based on long term WGT cover and yield data to estimate paddock yields from ground cover continued at demonstration sites and Spyglass. Feedback supplied to DES to improve Spyglass estimates.	✓	5.3. Achieved; see section 11.1
	Simple tool for graziers to estimate stocking rates.	5.4 ‘Shepherd’s stocking rate Ready Reckoner’ further tested with graziers in NGD and found to be very useful; modelled stocking rates partly based on Wambiana data.	✓	5.4 Achieved; see Appendix 10.2
	Improved GRASP model	5.5 Long term WGT data shared with DCAP project and DES; GRASP tested against trial data and upgraded to improve predictions of pasture response to management; improved model will be used to improve FORAGE estimates of LTCC.	✓	5.5. Achieved; paper published in ModSim 2021- see chapter 11.4.
	Test walk over weighing; use data to predict live weight gain (LWG)	5.6 Walk-over-weighing (WOWs) units run on 4 paddocks and good data on weekly LWG obtained; however application issues also identified. Using WOW and other data to predict daily LWG unsuccessful and a major technical challenge.	✓	5.6. Largely achieved- except for prediction of LWG- see chapter 12
6. Test ability of different wet season spelling strategies to regenerate C condition land.	Test different wet season spelling strategies.	6.1 Different wet season treatments applied at WGT in ‘spelling’ trial under below average rainfall conditions; data analysed. Spelling improved post drought recovery under moderate but not heavy stocking.	✓	6. Achieved but response to spelling constrained due to drought. Data has been analysed and a paper is undergoing journal peer review. See Appendix 14.

Objective	Achievement criteria	Result	Progress	Outcome
7. Demonstrated potential improvements in land condition and profitability	Demonstrated improvements in land condition and profitability at WGT and NGD sites.	7. Improved profitability convincingly shown at WGT but pasture condition has declined in all treatments due to drought. Some recovery in condition at 1 NGD demo site; no change at others due to short (3-4 year) period of project.	✓	7. Achieved as far as drought and dry seasonal conditions allowed; see chapters 6,7,8 and 14.
8. Develop grazing management guidelines based on the above.	Grazing management guidelines developed	8. Draft grazing management guidelines based on WGT data & learning from demonstration sites developed. Draft 'How to guides' also completed but graphics input needed.	✓	8. Achieved; see chapters 17 & 18; also Appendix 12
9. Develop four case study reports compiled into a single report & executive summary	Case studies and executive summary completed for 4 NGD sites	9. Case studies completed for all 4 NGD sites; executive summary also completed.	✓	9.Achieved; chapter 14.2; see Appendix 7
9.1 a. Summary of collected (not statistically analysed) 2021/22 seasonal data	Summary of collected data for 2020/21 season	9.1 a Animal and pasture data largely completed on schedule; some delays in pasture surveys due to record May rainfall.	✓	9.1a. Achieved/in progress. See chapter 21
9.1 b. Report on KASA survey	KASA survey completed	9.1b. A KASA survey completed, report included: WGT had had significant positive impact on graziers' knowledge, awareness and likelihood of adopting better practices.	✓	9.1 b. Achieved; KASA survey summary in chapter 22; full report in Appendix 11
9.1c Report on Planning Review actions.	Report on planning actions from field days etc	9.1.c. Formal consultation conducted with graziers, technical staff and advisors. Strong support for trial to continue; need to look at regeneration of C condition land & management of *Carissa.*	✓	9.2 c. Achieved and ongoing – see chapter 23

Objective	Achievement criteria	Result	Progress	Outcome
9.1 d. New and Confirmed Information product updates (lessons from *9.1 d. (contd.)* Wambiana booklet, Guidelines & Rules of thumb, explanations and associated draft Fact Sheets based on a "How do I…. ?" format	New & confirmed information products New & confirmed information products	9.1 d. '*Lessons from Wambiana'* booklet still in draft form, needs input & guidance from MLA comms. 9.1.d. Management guidelines completed for spelling, fire, adjusting stocking rates and setting LTCC. 9.1.d. 'Fact sheets' based on 'How do I..' completed but needs input from comms for graphic design.	× ✓ ✓	Partially achieved in draft form & needs MLA comms input as discussed previously. Achieved; see chapters 17 & 18 Achieved; see chapter 18 and Appendix 12
9.1 e. Summary report on wet season spelling strategies to regenerate poor (C) condition land	A report on wet season spelling strategies	9.1 e. Summary report on wet season spelling strategies completed - see Appendix 8	✓	9.1 e. Achieved; see Appendix 8
9.1 f. Following consultation with MLA, publish the 4 Satellite case studies."	Four published case studies from Northern Grazing Demonstration project	9.1. f. NGD case studies completed (Appendix 7) and could be published online on *FutureBeef* website; MLA comms input needed.	✓	9.1 f. Achieved; see Appendix 7 but MLA comms input needed.

Table 2 Additional details: Delivery against Objectives 1-3

Objective 1	Target	Actual	Comment
1 Awareness of project and issues	80 000 based on 20000 per annum over 4 years based on 1 article/yr for QCL, N. Muster, MLA Feedback , CQ Beef etc	54671	Based on 11 articles over 4 years & readership statistics in Table 26 - 28.
2. Active participation	780 people over 4 years includes WGT field days, NGD sites, GLM Edge, advisory committee meetings etc	633	• No Grazing BMP activities due to cancellation of program by AgForce. • Covid restrictions reduced other activities
3. Producers advocating for project	110 over 4 years including WGT advisory committee , NGD producer groups	108	Includes 'supporters' in KASA survey. • Covid restrictions prevented some meetings as did collaborator illness at 1 NGD site

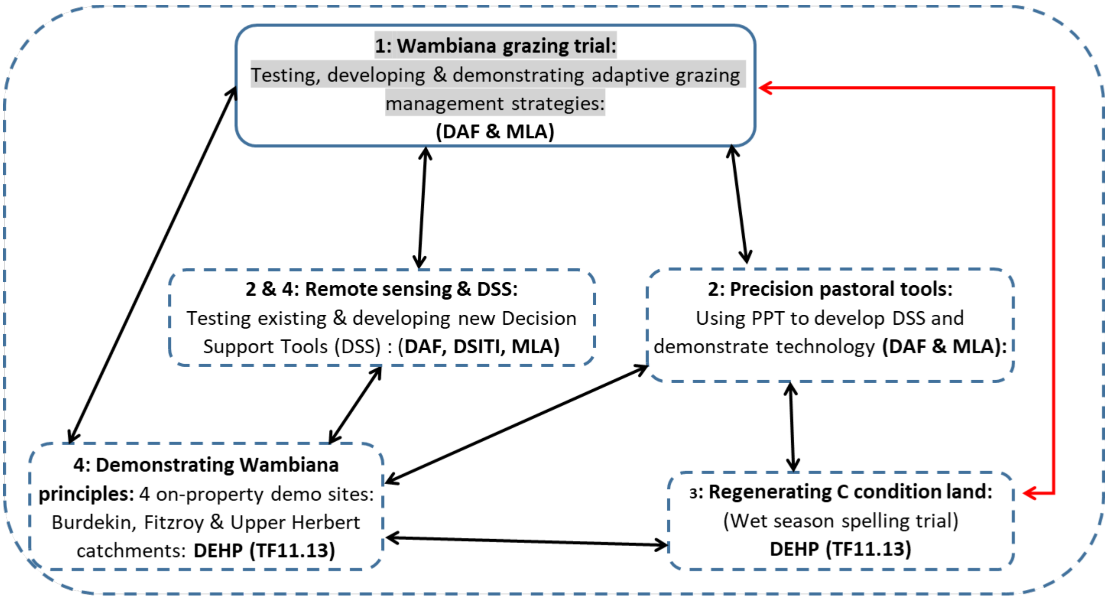
Table 3 Breakdown of activities and numbers (people) for Objectives 2 and 3 in Table 2 above

Activity	Target	Actual	Comment
Northern Grazing Demo sites	275	212	Includes NGD neighbour days and field days NB: Covid restrictions
MLA Edge Grazing Land Management	30	60	60 attendees; total of 33 properties
MLA Edge Grazing Fundamentals	-	178	178 attendees; total of 80 properties
Grazing BMPs	100	-	BMP program cancelled by AgForce
Wambiana field days	180	183	Total number of people attending
Wambiana trial- advocacy	40	108	WGT Advisory committee & NGD consultative committees

3. Project structure and methodology

The long-term Wambiana grazing trial (WGT) near Charters Towers was continued with the grazier advisory committee playing a key role in major management decisions for the site. Four on-property demonstration sites were also established as part of the sub-project (DEHP TF11.13) funded by the Department of Environment and Heritage Protection (Figure 1).

Figure 1 Schematic diagram of the linkages between the four components of the present project. (DSITI=Dept. Science Information Technology & Innovation (now DES); DEHP= Department of Environment & Heritage Protection; QDAF=Queensland Dept. Agriculture & Fisheries).



Four research questions were addressed at the WGT and the 4 demonstration sites.

3.1 Can productivity and land condition be improved using adaptively managed grazing strategies?

The performance of adaptive grazing management strategies (flexible stocking with wet season spelling and flexible stocking without spelling) was compared against three constant stocking strategies i.e. heavy stocking, moderate stocking and moderate stocking with spelling. Strategies were run in large (100 ha), spatially diverse, replicated paddocks at the WGT. Stocking rates in the 'flexible' strategies were managed adaptively with two priority- and two secondary- decision points annually. Stocking rate adjustments were based on available forage, days to break of season, seasonal climate forecasts like the Southern Oscillation Index (SOI) and SPOTA-1, land condition and animal performance. Wet season spelling was also managed flexibly with the total area spelled, and the frequency and length of spell based on seasonal conditions, pasture condition and grazing pressure on unspelled sections.

Paddocks were stocked with 6 to 35 Brahman steers of 1.5 and 2.5 years of age. Steers usually spent two years on the trial before being sent to the meatworks. Animal husbandry followed accepted industry practice. Diet quality was determined three weekly using faecal Near Infra-Red

Spectroscopy (Coates and Dixon, 2011, Coates and Dixon, 2007). Animal production data was collected on live weight gain, condition score, hip height and carcass characteristics. Annual gross margins were calculated for all strategies. Pasture yield and species composition were assessed twice per annum using the dry weight rank method (Tothill *et al.*, 1992). Frequency of all pasture species was also assessed annually on permanent monitoring sites stratified by soil type. Although not part of this proposal, runoff and soil loss will continued to be measured on the existing five 1 ha runoff catchments spread over the different treatments at the Wambiana trial site.

3.2 Can improved decision tools be developed to improve stocking rate and other decisions?

The usefulness of existing decision tools based on remote sensing and pasture modelling e.g. 'FORAGE' continued to be assessed at the WGT and was be extended to the four on-property demonstration sites (see 3.4 below). A tool based on newly developed satellite metrics e.g. Landsat based fractional green cover, and the long term pasture and diet quality data collected at the WGT was also further developed with the Department of Environment and Science (DES) Remote Sensing Centre. These tools were used to estimate paddock pasture yields e.g. Schmidt *et al.*(2016) as well as changes in pasture quality. These tools were further tested, calibrated and demonstrated at the on-property demonstration sites.

Two Precision Pastoral walk-over–weigh (WOW) units with auto-drafters were installed at the WGT to allow real-time measurement of steer weights in each of two adjacent treatments i.e. four paddocks in total. Liveweight change was related to diet quality and forage availability. This work directly builds on, but also significantly advances that of Leigo *et al.*(2016) in that it uses higher resolution imagery (Landsat or Sentinel vs MODIS), more advanced metrics (using more recent fractional cover algorithms) and measures diet quality directly (faecal NIRS) rather than green biomass

3.3 Can C condition land be economically regenerated using wet season spelling? [DEHP funded]

The replicated small plot trial to test the ability of different wet season spelling regimes to regenerate C condition land initiated at the WGT in 2012 (Jones *et al.*, 2016) was continued. This consists of forty 30 by 30 m plots with detailed data collected on plant basal area, population dynamics, landscape function and pasture production of both spelled and non-spelled control areas. This detailed work helps fill the critical knowledge gap on the dynamics and specific management requirements of key perennials like desert bluegrass (*Bothriochloa ewartiana*), and links directly to the larger, paddock scale WGT spelling treatments.

3.4 How can regional scaling of outcomes be achieved?

Selected WGT management principles along with existing and new decision support tools were extended and demonstrated on 4 properties in reef priority sub-catchments in the Burdekin, Fitzroy, Bowen-Broken and Upper Herbert catchments in the linked DEHP project TF11.13 'Demonstrating the productivity and sustainability benefits of improved grazing management'.

Demonstration sites consisted of a single, large paddock managed according to the selected principle e.g. match stocking rates to available forage, and some selected animal management intervention. Management was conducted by the property owner with input from a local grazier group and DAF staff.

Data was collected on pasture yield, composition and in some cases, animal performance in demonstration paddocks. Case studies of the 4 participating properties were developed. Decision tools: models and tools tested and developed in sections (2) and (4a) were extended to other regions in Queensland through existing DES Reef Water Quality and Climate Adaptation themed programs.

4. Wambiana trial experimental procedure

4.1 Introduction

The trial was established in 1997 on ‘Wambiana’, 70 km SW of Charters Towers, Queensland, Australia. Long term (111 year) mean annual precipitation is 640 mm (C.V. = 40%). The study area is an open *Eucalyptus* savanna in the *Aristida-Bothriochloa* pasture community (Tothill and Gillies, 1992) and is described in greater detail in O’Reagain *et al.* (2009). There are five grazing treatments each replicated twice in two blocks of five paddocks (93 to 117 ha).

4.2 Soils

There are three main soil-vegetation associations on the site (Figure 2). The Ironbark (*Eucalyptus melanophloia*) woodlands are on yellow, brown or red kandosols ((Isbell, 1996) which are relatively well drained but low fertility. The Reid River Box (*E. brownii*) woodlands are generally texture contrast in nature and include sodosols, chromosols, dermosols and sodosol-kandosol gradations. Soils are relatively shallow (30-40 cm), of moderate fertility relative to the Ironbark and overlie a dense clay subsoil. Lastly the Brigalow soils contain *Acacia harpophylla* and/or Box but may also be almost treeless in some areas. These heavy clays are relatively fertile and vary from vertosols to grey earths. In a few places gilgais are also strongly developed. The ten paddocks are laid out to contain similar proportions of these three soil types i.e. Ironbark (23%), Brigalow (22%) and Box (55%).

4.3 Grazing strategies

Five grazing strategies that are used by graziers in the district and/or are recommended to manage rainfall variability e.g. (Ash *et al.*, 2000) were selected. These were:

1. Moderate stocking rate (MSR) - continuously stocked at the estimated long term carrying capacity (LTCC) of the site to achieve an average of 20-25 % utilisation of expected pasture growth. The MSR was initially stocked at about 10 ha/animal equivalent (AE= 450 kg steer) but in June 2001 this was increased to 8 ha/AE.
2. Heavy stocking rate (HSR) - continuously stocked at about twice the LTCC to achieve an average of 40-50 % utilisation of expected pasture growth. The HSR was initially stocked at 5 ha/AE but this was increased to 4 ha/AE from June 2001 onwards. The stocking rate was reduced to about 6 ha/AE between May 2006 and May 2009 due to low rainfall and the extreme scarcity of forage in this treatment.
3. Variable stocking (VAR) - stock numbers adjusted annually in May at the end of the wet season (May) according to available pasture (range: 3-10 ha/AE).
4. Southern Oscillation Index – Variable stocking (SOI)- stock numbers adjusted annually at the end of the dry season (November) according to available pasture and the SOI based seasonal forecast for the coming wet season (range: 3-10 ha/AE).
5. Rotational wet season spelling (R/Spell) – paddocks divided into three equal subsections with one subsection spelled each year for the full wet season. The R/Spell was initially stocked at 6.5 ha/AE but in 2003 this was reduced to 8 ha/AE. This occurred due to the ill effects of a planned fire in one subsection and the subsequent drought in 2001 (see below).

Following the technical review of the trial in November 2009 and consultation with the Wambiana grazier advisory committee (GAC), some treatments were adapted as indicated (Table 4).

Table 4 Comparison of the Wambiana Phase 1 and Phase 2 grazing strategies (HSR=Heavy stocking rate, MSR=moderate stocking rate, R/Spell=rotational spelling, SOI=southern oscillation index-Variable stocking, WS=wet season spelling, VAR=Variable stocking).

Phase 1 Strategy (1998-2010)	Phase 2 Strategy (2011-2022)
HSR (4 ha/AE)	HSR (4 ha/AE)
MSR (8 ha/AE)	MSR (8 ha/AE)
R/Spell (3 sub paddocks-8 ha/AE)	R/Spelling (6 sub paddocks-8 ha/AE)
VAR (3-12 ha/AE)	'Flexible' + WS spelling (6 sub paddocks- 4-12 ha/AE)
SOI-Variable (3-12 ha/AE)	'Flexible'- no spell (4-12 ha/AE)

These changes reflected key learnings from Phase 1 regarding 'Variable' stocking as well as outputs from the Northern Grazing Systems project (Scanlan and McIvor, 2010). These Flexible strategies differed from simple Variable stocking in the following ways:

- Four potential stocking rate adjustment points through the year compared to only a single adjustment point in the Variable (end of wet season) or SOI-Variable (late dry season) strategies.
- The primary adjustment point is in May at the end of the wet season where stocking rates can be adjusted up or down.
- Three secondary adjustment points (mid-dry, late dry and early wet season) where conditions are assessed but stocking rates can only be maintained or reduced, i.e. no increases allowed.
- Stocking rates adjusted on the basis of available forage, expected time to the next wet season and climate forecasts for the approaching wet.
- Upper limits set to stocking rate – usually no more than 50% above long term carrying capacity.
- Upper limits set on the rate of any stocking rates increases – maximum of 25 % increase per year (more if existing stocking rates are extremely low).

Note that to minimise carryover effects from previous treatments both the Flexible (Flex) and Flexible plus spelling (Flex+S) were each allocated to one paddock from the previous Variable and SOI-Variable strategies.

For the R/Spell and the Flex+S, the philosophy for having six instead of just three sub-paddocks for spelling was to allow greater flexibility in the total area spelled and the length of spell applied in different seasons as outlined below.

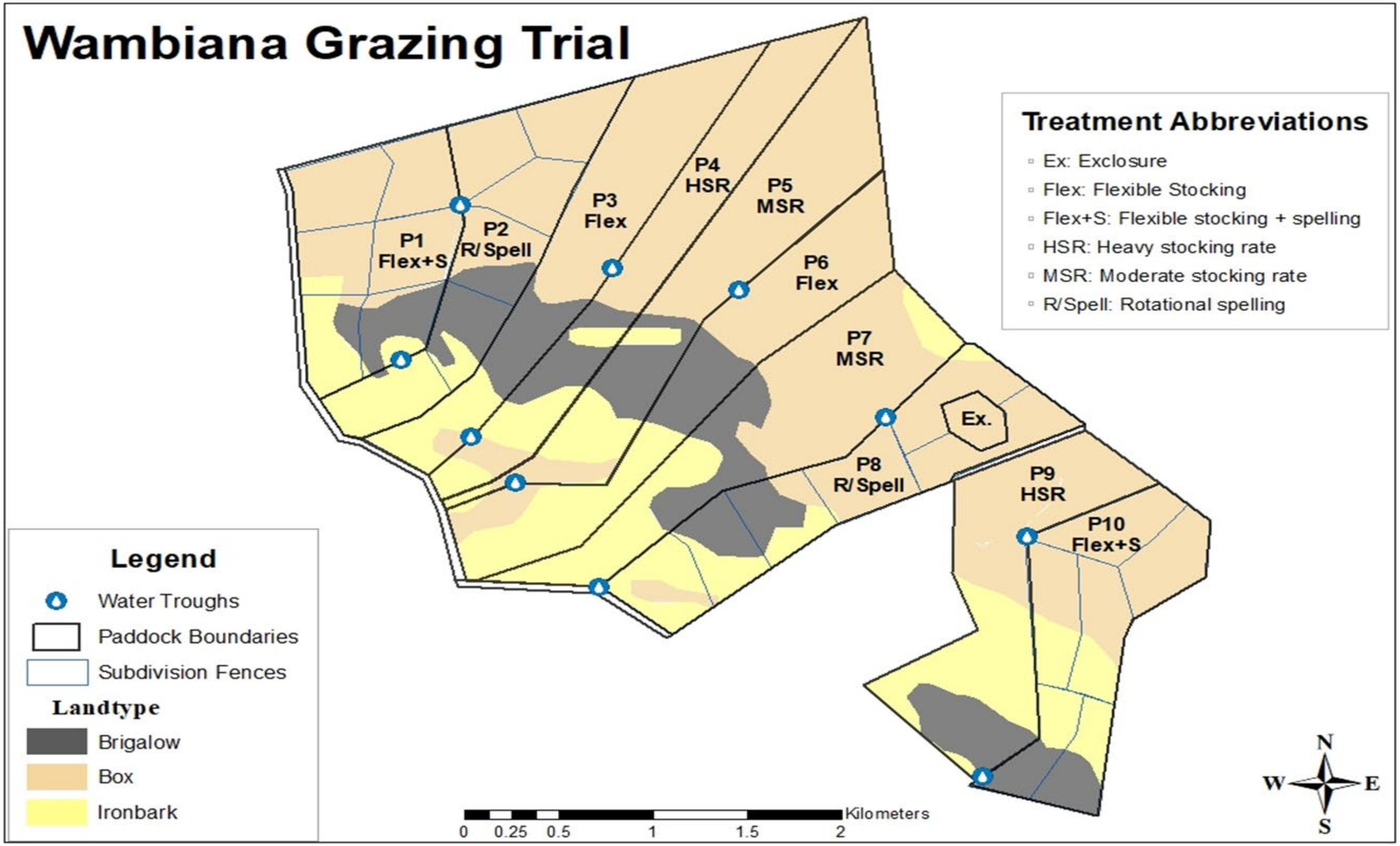


Figure 2: Map of Wambiana grazing trial showing main soil groupings and treatment paddocks for Phase 2 onwards (see text for details).

4.4 Management of grazing strategies

All grazing strategies were applied in an adaptive fashion in an attempt to make the results as relevant to the grazing industry as possible. In essence, strategies were applied more as philosophies than as rigid treatments as circumstances changed and unforeseen circumstances arose. Hence some strategies were adjusted, or management was changed temporally, when it became obvious that a manager following a particular management philosophy would do likewise. This was done in close consultation with a grazier advisory committee. For example, stocking rates in the heavy stocking rate (HSR) strategy were reduced by a third between 2005 and 2009 when conditions were so bad it was clear that even the heaviest stocker would reduce stocking rates to some extent to avoid the continual and exorbitant costs of drought feeding. Stocking rates in the HSR were similarly reduced in 2014/15 due to drought. We follow the injunction of (Belovsky *et al.,* 2004) and more recently, by (Teague and Barnes, 2017), that ecological experiments be realistic and not apply conditions that would not be experienced in reality.

The frequency, timing and total area spelled was also managed in an adaptive, flexible manner based on the need for spelling, the timing and spatial distribution of rainfall, pasture growth rates and grazing pressure in non-spelled areas. Consequently, sub-sections of the R/Spell and Flex+Spell were spelled for periods of three weeks (2014/15) to 25 weeks in a year depending upon conditions.

4.5 Fire management

The trial site was burnt 11–12 October 1999 and then spelled for three months before grazing recommenced on the 12 January 2000. The site was burnt again in late October 2011 to control woodland thickening and to reset the pasture for the imposition of the new treatments. To ensure sufficient fuel all animals were sent to the meatworks in June and the site ungrazed until the fire. During this period, the replacement steers were agisted at Spyglass Beef Research Facility, north of Charters Towers. The site was spelled post fire until 1 February 2012 when sufficient growth had occurred for grazing to resume.

Two other fires were also applied to subsections of the R/Spell prior to spelling in 2000 and 2001. Unfortunately, the 2001 fire was followed by the 2002-2007 drought. The adverse impacts of this fire combined with the drought on the R/Spell are described in more detail elsewhere (O'Reagain *et al.*, 2009).

4.6 Animal management

Paddocks were stocked with two and three year old Brahman steers from James Cook University's Fletcherview Research Station and managed following industry best practice. Cattle were initially unsupplemented. However in accord with updated guidelines, dry-season urea (32 % urea) and wet season phosphorous supplementation (11.3 % P, 4.20 % urea) were provided from May 2003 onwards (Appendix 2). Steers were inoculated for botulism C and D, and from May 2003 were also implanted with Compudose 400 (Elanco Animal Health, Australia) hormonal growth promotants (HGP).

Drought feeding, as molasses and 8% urea (M8U) or M8U with copra meal, was provided as required when forage was in extremely short supply e.g. <100 kg/ha. This occurred in one or both HSR paddocks in seven out of the 24 years of the trial (Appendix 2). Steers also had to be withdrawn and fed hay and M8U for various periods from one or both HSR paddocks in 2004/05, 2014/15, 2015/16, 2017/18 and 2020/21 to maintain animal welfare. In 2004/05 withdrawn steers were returned to the HSR following rain in January 2005. However, in 2014/15 most withdrawn HSR steers were sold early (25 March 2015) due to the failed wet season. In 2017/18 withdrawn steers from 1 replicate of the HSR were also sold early in January 2018; accordingly this replicate was stocked considerably lighter than its target rate (8 vs. 5 ha/AE). In 2020/21 conditions were so bad in one replicate of the HSR that in September 2020 half the animals were sold and the remainder put on drought feeding until it rained in January 2021.

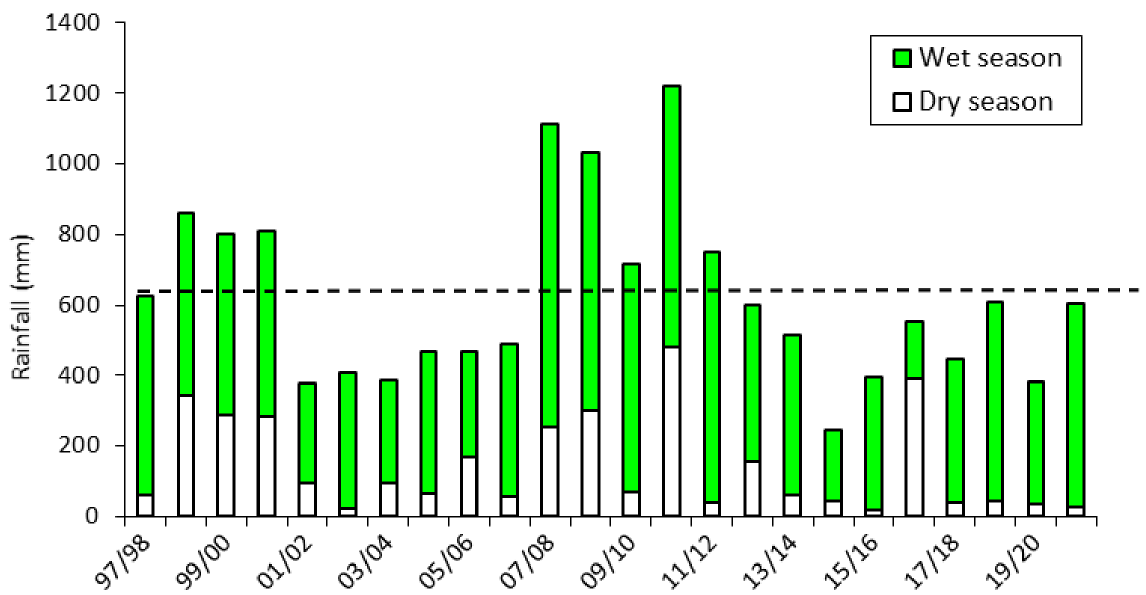
Drought feeding was only required in the remaining treatments in 2015/16 (see Appendix 2). This was a very dry year (397 mm) which followed the extreme drought of 2014/15 (246 mm). A few poor condition steers were also withdrawn for eight weeks from some of these treatments late in the 2015 dry season but were returned to their paddocks late in January 2016.

5. Wambiana trial seasonal conditions

5.1 Rainfall

Rainfall varied markedly (246-1223 mm) over the trial period with extended sequences of wet and dry years (Figure 3) with the first four years of good rainfall followed by six below average rainfall years (2001/02 - 2006/07). In contrast, the following years were extremely wet, with 2010/11 the wettest in 50 years. Thereafter, drought conditions returned, with below average rainfall from 2013/14 onwards. The 2014/15 season was particularly dry (246 mm) having the fourth lowest rainfall in 111 years. With the exception of 2016/17 (554 mm) rainfall in later years was also generally poorly distributed with short wet seasons and extended dry seasons, despite 2018/2019 and 2020/2021 being close to achieving median rainfall of 604 mm.

Figure **3 Annual rainfall (July to June) from 1997/98 to 2020/21 at the Wambiana trial. Dotted line = long term average**

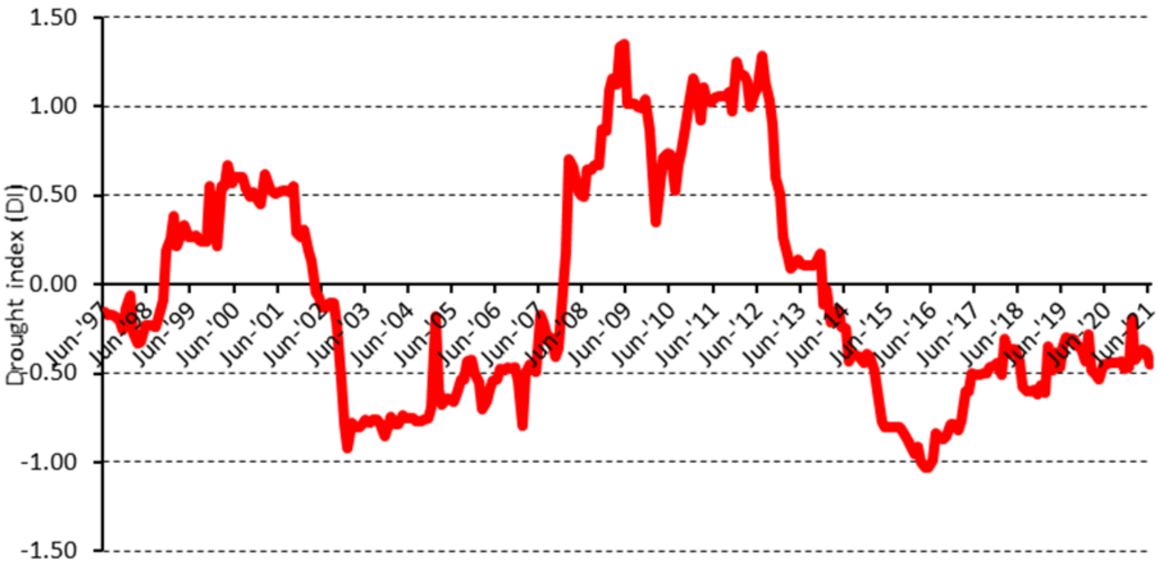


To illustrate the changing seasonal conditions and changes in moisture availability the two year Foley drought index (DI) was calculated as:

DI=∑ previous 24 months rainfall from month x - ∑ long term average rainfall for these 24 months/long term averages annual rainfall.

The Foley drought index (Foley, 1957) shows the two drought periods, and in particular highlights the ongoing rainfall deficit and below average rainfall over the last eight years (Figure 4).

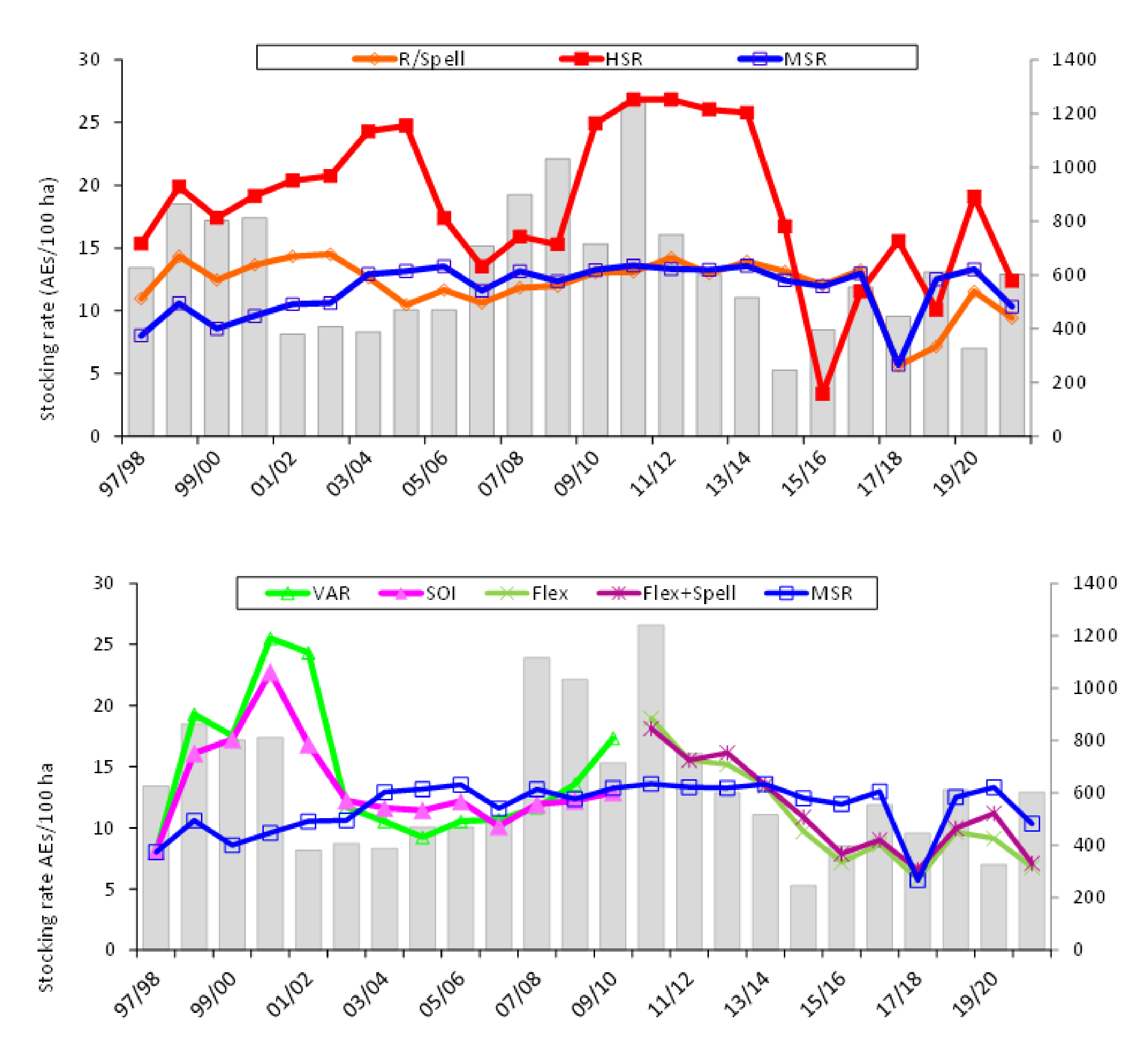
Figure 4 Two year moving Foley drought index for the trial period. Note the extended dry conditions continuing throughout the period of the current report.



5.2 Stocking rates

In the HSR, the initial high stocking rates had to be reduced by one-third between 2005 and 2009 (O'Reagain *et al.*, 2011). Although they were subsequently increased in the good years from 2009/10 onwards, they had to be slashed again in 2014/15 due to drought (**Figure 5**). It is significant that management intervention was required in the HSR much sooner in this drought than in the previous drought period (2002-2007). This indicates a major decline in resilience in this treatment due to reduced pasture vigour and the loss of a significant proportion of the perennial grass tussocks. Stocking rates in the HSR were reduced further at the start of the 2015/16 season to about 3.3 AEs/100 ha, i.e. markedly lower than the usual rate of 25 AEs/100 ha or 4 ha/AE. Since then, stocking rates have fluctuated at moderately higher levels but are still far below the nominal stocking rates for the HSR (Figure 5).

Figure 5 Rainfall and stocking rates of the different treatments over the trial period. Top: The MSR, HSR and R/Spell and (Bottom) the VAR and SOI (later the Flex and Flex+Spell) with the MSR shown for comparison. See text for treatment abbreviations



In contrast to the HSR, stocking rates in the MSR and R/Spell were relatively easily sustained through the first drought cycle without drought feeding or destocking being required (**Figure 5**). Stocking rates were initially also sustained into the second drought but by late 2015 drought feeding also had to be implemented for a few weeks (eight) with a few very poor condition animals also withdrawn even in these treatments.

While 2016/17 had good, well distributed rains, by late December 2017 the MSR and R/Spell paddocks had extremely low ground cover and yields (<200 kg/ha) due to ongoing drought effects and their fixed stocking rates. These paddocks were accordingly destocked from January – May 2018 (Figure 5) based on the philosophy that under similar circumstances a 'moderate stocker' would do the same to avoid degrading the resource.

In the VAR and SOI strategies, stocking rates were adjusted with pasture availability, with very high stocking rates in 2000/2001 leading to overgrazing in the following dry year (O'Reagain *et al.*, 2011). Stocking rates were cut sharply thereafter in both strategies and subsequently managed in a more risk averse fashion (**Figure 5**). This risk averse philosophy was applied even more strongly when these treatments transitioned into the Flex and Flex+S treatments in 2010. Thus in the good years from 2008 to 2013, stocking rates were slowly increased but never approached those applied in the first four wet years of the trial. Conversely, as conditions deteriorated in 2013/14 stocking rates were progressively cut and dropped well below those in the MSR and R/Spell. Accordingly, in 2015/16 and into 2016/17, stocking rates in the MSR and R/Spell were the heaviest on the trial.

More recently, stocking rates were cut in the Flex and Flex+Spell in December 2020 and again, in the Flex+Spell in December 2021, based on end-of-dry forage budget. This was despite predictions of above average rainfall for both of the approaching wet seasons.

The heavy stocking rate (HSR) initially performed well with the early good seasons (O'Reagain *et al.*2009), but stocking rates had to be sharply reduced in drought years (Figure 5). Drought feeding also had to be provided to the HSR in seven of the 24 years of the trial compared to only once (2015) in the other treatments (Table 5). As pasture condition deteriorated with time, resilience declined with management interventions in the HSR required far sooner in the second compared to the first dry phase.

5.3 Unexpected disturbances

There was a severe outbreak of armyworm *Leucania separata* through the district following a very big rainfall event in January 2003. While the armyworm damage was largely confined to the box landtypes, leaves were stripped from grass tussocks, especially *Chrysopogon fallax* leaving little grazing. This wet season defoliation obviously had an impact on subsequent pasture vigour, although this was possibly relatively minor compared to the drought that followed.

Two episodes of feral pig damage also occurred through the trial period. The first occurred in the wetter years of 1999-2000 with some relatively small patches, particularly on the box soils, severely impacted with small areas completely ploughed over.

The second episode occurred in the wet period from 2008-2012 with a large boom in feral pig populations across the district. Despite a vigorous baiting and trapping effort, severe damage occurred, with extensive areas on the trial rooted up and/or extensively turned over. Impacted areas took a surprisingly long time to recover and undoubtedly impacted pasture composition. Surveys of pig damage across the trial indicate that the pig impact was evenly distributed across all treatments.

6. Effect of grazing strategies on animal performance and profitability

This chapter presents the effects of different grazing strategies on animal production and profitability over the full 24 years of the Wambiana trial. The animal production results are presented in greater detail in the attached paper '*Long term effects of different stocking strategies on cattle production in a highly variable rainfall environment*' (Appendix 1).

6.1 Methodology

Experimental animals were 3/4 Brahman-cross steers from 1997/98 to 2003/04 inclusive. However, from 2004 onwards, steers were 7/8 Brahmans. Paddocks were usually stocked with 11-35 steers, depending upon treatment and year. Animal husbandry, supplementation and drought feeding followed standard industry practice and is described in more detail in section 4.6.

Between 1998 and 2000, all animals were about two years of age and were replaced annually in May. From 2000 onwards, paddocks contained two similar sized cohorts of two and three year old steers, with the older cohort being replaced by new, younger animals each year. This allowed a longer period for treatment effects to emerge and enabled older, heavier animals to be sent to the meatworks to allow assessment of carcass grades and values. Animals thus generally spent two years on the trial (O'Reagain *et al.* 2009) unless they needed to be sold early because of drought.

6.1.1 Animal measurements

Cattle were weighed, condition scored and their hip heights recorded after overnight fasting at the start and end of each grazing year (May) as well as at the nominal end of the dry season (December). Most steers were sent to the meatworks after two years on the trial i.e. there was no target weight. However, younger steers were also sometimes included if required for stocking rate reductions. Carcass data from meatworks feedback sheets was matched to individual steers via NLIS numbers. Where stocking rates had to be cut late in the dry season (e.g. under Flexible stocking) steers were sold via local cattle agents and priced as being in poor condition (see below).

6.1.2 Economic analysis

Economic analysis was performed as described by O'Reagain *et al.* 2011. Briefly, the beef produced per treatment i.e. total LWG per hectare per annum, was valued based on 2004 to 2010 price grids for the three main meatworks that serve the district. Based on trial data three 'typical' carcass types were selected: (1) good condition steer: price \$1.50/kg liveweight; (2) medium condition steer: price \$1.40/kg liveweight and (3) poor condition steer: \$1.30/kg liveweight. Meatworks feedback sheets for trial steers indicate an approximate premium of about \$0.20/kg for heavier animals in better condition.

Animals were valued at \$1.50/kg at the start of the grazing year (1 June) due to the premium that younger steers typically command. At the end of each grazing year (31 May), all animals in a treatment were valued as described above, based on average body condition or meatworks data if available. Cattle removed in the late-dry season, as happened in the SOI strategy in November 2001 or the R/Spell in late 2003, were valued at \$1.30/kg due to their poor condition.

Variable costs were the actual supplement, vaccination and HGP implant costs per strategy. The costs and amounts of supplement, drought feeding and agistment used in the different treatments are provided in Appendix 2. For comparative purposes, all costs were adjusted to January 2010 prices at Charters Towers. Supplement prices (GST and transport inclusive) were: molasses and urea ($0.26/kg), cottonseed meal ($0.76/kg), weaner supplement ($0.60/kg), dry season urea lick ($0.81/kg) and wet season lick ($1.21/kg). Where animals were withdrawn and fed hay as in 2004 or 2014, an agistment cost of $2.75/steer/week was used. Interest costs on livestock capital were based on the total value of livestock in a paddock at the start of the season using a real interest rate of 5%.

All costs and benefits were expressed in 2010 values. Treatments were compared using Gross Margins (GM). These were calculated for individual paddocks as:

GM= MassOut*value - variable costs - interest costs - MassIn*value

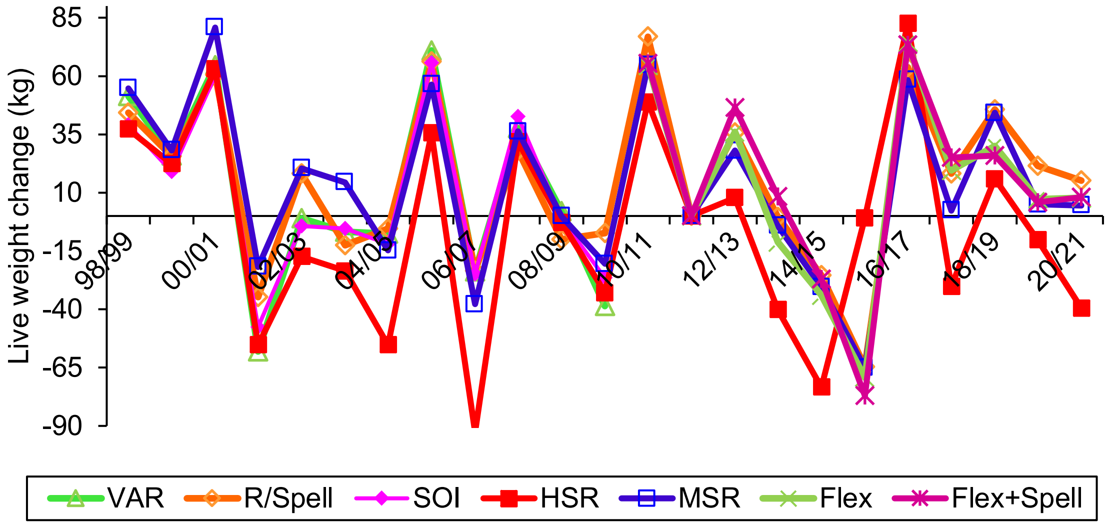
Where MassIn and Massout is the total mass of all animals in a paddock at the start and end of a grazing year respectively, value is price of beef in $/kg, variable costs are all supplement and inoculation costs and interest cost reflects interest on livestock capital calculated at 7.5%. Accumulated gross margin (AGM) was calculated as the sum of paddock gross margins for successive years.

6.2 Results

6.2.1 Dry season and total animal liveweight change

Substantial dry season (DS) weight loss occurred in all treatments in some years with loses of from -40 kg/hd in 2006/07 to as much as -69 kg/hd in 2015/16 (Figure 6). Conversely, in other years appreciable DS weight gain occurred with LWGs of as much as +71 kg/hd in 2005/6 and 2016/17. These differences were largely rainfall driven with weight gain in years with above average ‘dry season’ rainfall such as 2010/11. However, good LWGs also occurred in years with relatively low ‘dry season’ rainfall but where precipitation was well distributed throughout the year.

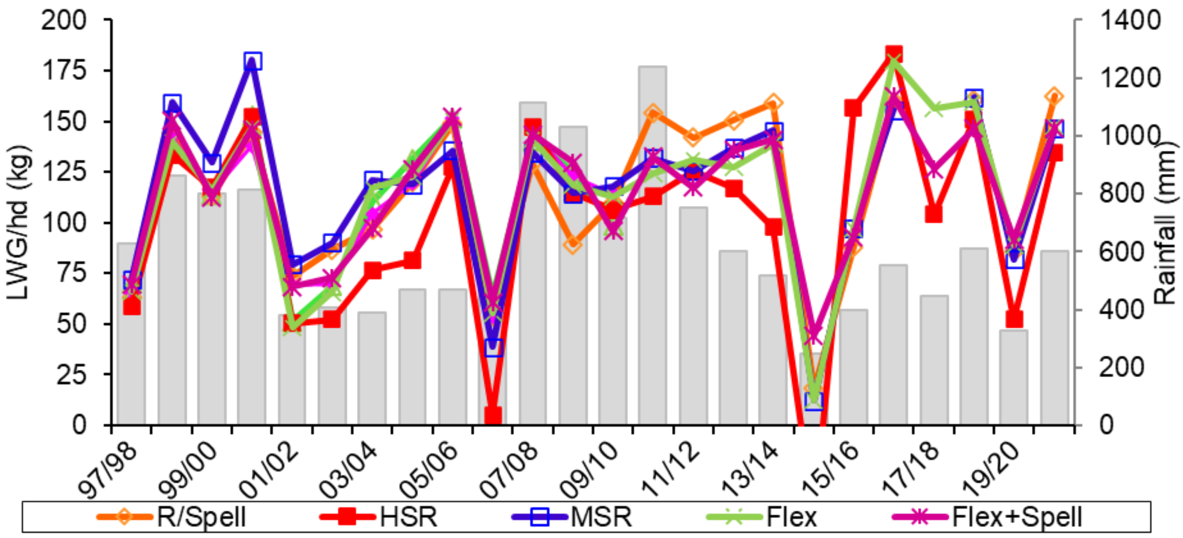
Figure **6 Dry season live weight change for steers at the Wambiana trial from 1997/98 to 2020/1.** (See text for treatment abbreviations).



Dry season LWG was generally highest in the MSR and/or the R/Spell (Figure 6). Dry season LWG in the Var/Flex strategies varied relative to other strategies, depending upon the stocking rate. However, dry season LWG was by far the poorest in the HSR in nearly all years. These differences were extreme in drought years; in 2006/07 for example, HSR steers lost 93 kg in weight i.e. 55 - 69 kg/hd more than the other strategies. Similarly, in the 2014/15 drought, HSR steers lost 39 kg more than the other strategies. While good dry season LWGs were recorded in the HSR in some years, this only occurred due to the extremely light stocking rates in the HSR imposed in such seasons due to drought.

Total annual LWG per animal also varied markedly between years with average LWGs varying from 43 kg to 168 kg/yr depending upon rainfall (Figure 7). In drought years like 2005/6 and 2014/15 however, animals barely maintained weight and, in the HSR, actually lost weight over the year. Treatment significantly affected total LWG, but this effect varied with year as shown by the significant ($p<0.001$) treatment by year interaction (Appendix 1). This is not unexpected given the variation in rainfall, the range of stocking rates applied in the Var/Flex strategies and the drought induced stocking rate changes in the HSR.

Figure 7 Average annual live weight gain per head (LWG/hd) versus rainfall for steers at the at the Wambiana trial from 1997/98 to 2020/21.



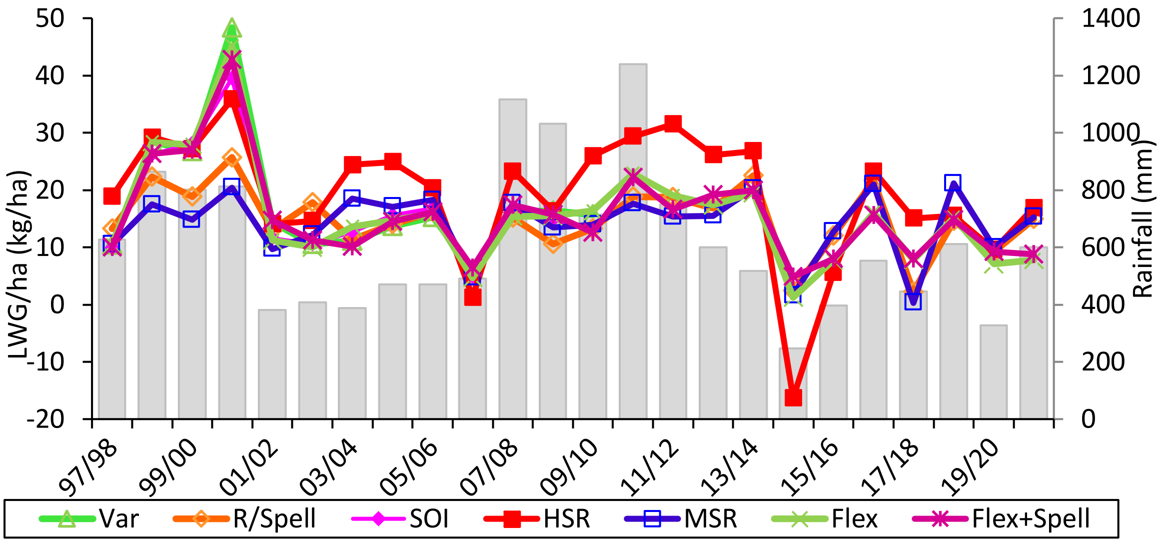
While the effect of treatment varied with year, average LWG over the 24 year trial period was highest in the MSR (117 kg/hd) and the R/Spell (116 kg/hd). Individual LWG in the Var/Flex strategies varied depending upon the stocking rate applied in any particular year but on average, was similar to the MSR and R/Spell (Table 5). Total LWG in the HSR was by far the worst, being the lowest of all treatments in fifteen out of twenty three years (NB: this excludes the 2015/16 season when the HSR was very lightly stocked due to drought). These differences in LWG were strongly amplified by drought, with for example the HSR steers losing an average of -54 kg over the 2014/15 season. Overall, average LWG in the HSR (100 kg/hd) was thus 12-21 kg lower than the average of other treatments in Phase 1, and from 18 to 27 kg lower per head than other treatments in Phase 2.

6.2.2 Liveweight gain per hectare

Total LWG/ha varied markedly with rainfall and ranged from 34 kg/ha (averaged over all treatments) in 2000/01 to as little as 5 kg/ha in 2006/07 and -1.2 kg/ha in 2014/15, both drought years (Figure 8). The effect of treatment was significant but again varied with year as shown by the strong year by treatment interaction (Appendix 1).

Overall, LWG/ha in the HSR was highest (or at least, joint highest) in 18 out of the 23 years in which valid comparisons can be made (Table 5). In particular, LWG/ha in the HSR was nearly always greater (17 out of 23 years) than in the moderately stocked MSR and R/Spell. LWG/ha in the Var/Flex strategies varied with stocking rate, with LWG/ha similar or even higher than the HSR in earlier good years (1998/99 to 2001/02) when the Var/Flex strategies were heavily stocked. In contrast, in later years when stocking rates in the Var/Flex strategies were lighter, LWG/ha was similar or even less than those in the MSR or R/Spell (Figure 8).

Figure 8 Average annual live weight gain per hectare (LWG/ha) versus rainfall for steers at the Wambiana trial from 1997/98 to 2020/21. Treatment abbreviations as before.



Average LWG/ha over the trial period was thus higher in the HSR (20 kg/ha) than in both the MSR (14 kg/ha) and the R/Spell (15 kg/ha). However, treatment differences varied markedly between years with LWG/ha in the HSR up to 12 to 16 kg/ha greater than other strategies in really good years like 2000/01 and 2009/10, but only two or three kg/ha greater in other years. In contrast, in drought years, LWG/ha in the HSR was generally lowest, with for example, a net loss (-16 kg/ha) in 2014/15. While LWG/ha were also very low in other treatments that year (range: 1-5 kg/ha), these were at least positive (Figure 8).

6.2.3 Carcass variables

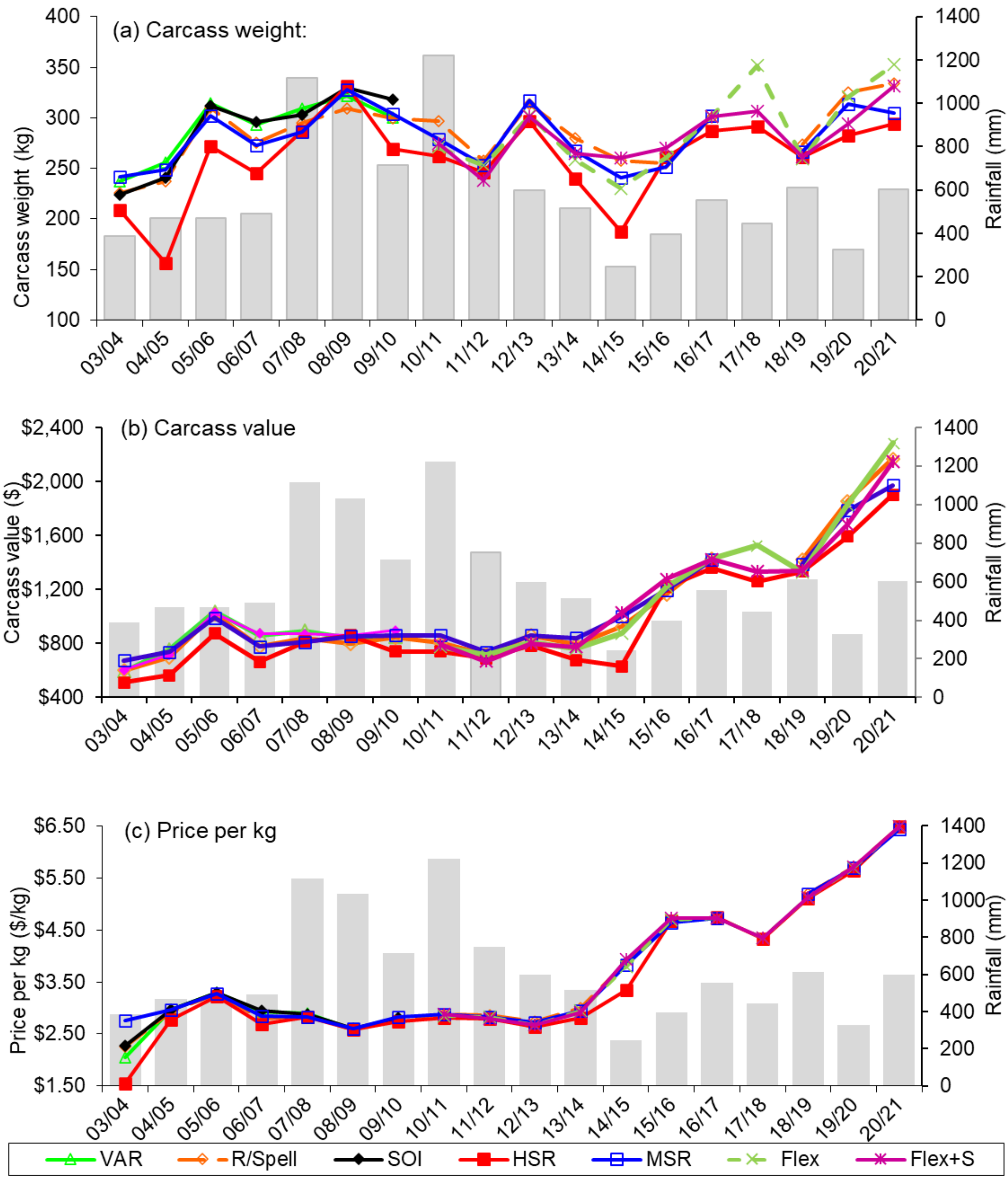
Carcass weight and price per kg also varied sharply between years due to rainfall (**Figure 9**) price per kg was also obviously driven by market factors, in particular the more than doubling of cattle prices between 2013 and 2021. Treatment affected all carcass variables but like live weight gain, this effect was strongly dependent upon year (Appendix 1). Overall carcass weight was markedly lower in the HSR than in the other strategies in most years. Fat depth was also lower in the HSR and consequently total carcass value also tended to be lowest in the HSR.

Although treatment differences were relatively minor in good seasons, these differences were far more marked in drier years, with carcass weights in the HSR from 70 kg to 100 kg lighter in drought years like 2003/04 and 2014/15. The only exceptions to this trend were when the HSR was relatively lightly stocked such as in 2016/17 and/or seasons were relatively good.

The average price/kg of HSR steers received was -$0.14/kg to -$0.18/kg lower than that in other treatments over all years. Overall, average carcass price in the HSR was thus $73 to $134 lower than in the other treatments. Again, these differences varied with seasonal conditions with the price/kg in the HSR up to $0.50/kg lower and carcass value up to $326 dollars less in drought years like 2014/15, but these differences were far less marked in good rainfall years like 2008/09 (Appendix 1).

While the carcass characteristics were nearly always better in the other strategies than in the HSR, no one treatment consistently performed the best. For example, carcass weights and values tended to be highest in the Var/Flex strategies in drier periods like 2004/05 to 2007/08, when these strategies were lightly stocked. Conversely, carcass weights were heavier in the R/Spell and MSR in wetter periods like 2010/11 and 2012/13, when the Var/Flex strategies were relatively heavily stocked (Figure 9).

Figure 9 Carcass characteristics in terms of (a) carcass weight (b) carcass value and (c) price per kg versus rainfall for meatworks steers at the Wambiana trial from 2003/04 to 2020/21.



6.2.4 Economic analysis

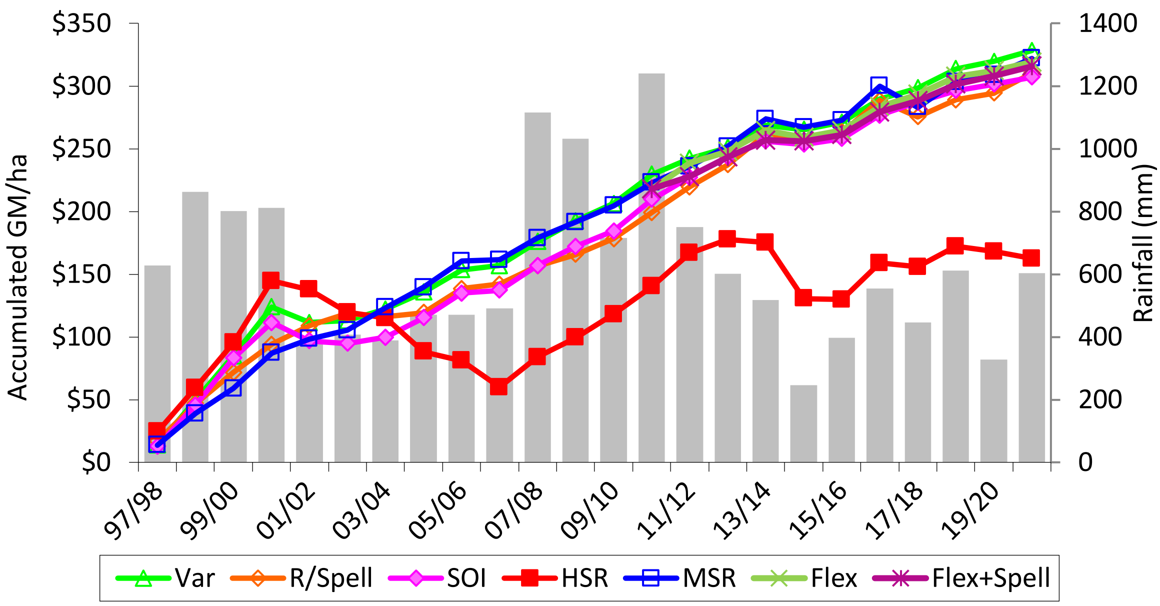
Although LWG/ha was on average highest in the HSR, due to the lower product value, greater interest costs on livestock capital and costs of drought feeding, average gross margin per ha was half that in the other strategies (Table 5). Income variability was also far higher with the HSR having a negative gross margin in eleven out of 24 years compared to only two or three out of twenty four years in the other strategies.

Table 5 Average annual liveweight gain (LWG) per head (hd), LWG per hectare (ha), gross margin (GM/ha) and the number of years (yrs) drought feeding was needed and years with a negative (-tive) income over 24 years at the Wambiana trial. Interest on livestock capital calculated at 5%.

Treatment	LWG/hd (kg)	LWG/ha (kg/ha)	Yrs drought feed	GM/ha ($/ha)	Yrs with -tive income
Flex	115	15	1	$13	3
Flex+Spell	115	16	1	$13	3
HSR	100	19	7	$7	11
MSR	117	14	1	$13	2
R/Spell	116	15	1	$13	2

The accumulated gross margins (AGM) calculated over the twenty-four years of the trial show that while the HSR initially performed very well, the onset of the first drought in 2002 resulted in a steady decline on AGM over six consecutive years (Figure 10). Despite subsequent recovery in the next wet cycle, AGM declined again or remained constant through the second drought. Importantly, AGM would have declined further if stocking rates in the HSR had not been kept relatively low in the more, recent drier years.

Figure 10 Change in accumulated gross margin over the 24 years of the trial from 1997/98 to 2020/21. Interest on livestock capital calculated at 5%.



In contrast, in the variable strategies the sharp reduction in stocking rates in 2001/02 avoided the costs of drought feeding. This reduction and the subsequent more risk-averse approach adopted, allowed AGM to steadily increase over the following years in the Flex/Var strategies.

While AGMs in the MSR and R/Spell initially lagged behind the HSR strategies due to their lower stocking rates, after seven years they equalled and thereafter surpassed the HSR with the gap widening further in the second drought. Accordingly, by the end of the trial period the AGM in the HSR was only half ($162/ha) that in the other strategies (approx. $310/ha). For a 20,000 ha property, this equates to an approximately $3 million advantage for the other strategies relative to heavy stocking.

6.3 Discussion

These results build on those from the first 20 years of the trial (O'Reagain *et al.*, 2011, O'Reagain *et al.*, 2018, Neilly *et al.*, 2017) but importantly, provide new insights in that they include a much wider range of rainfall years, in particular the recent ongoing drought, allowing greater time for treatment effects on land condition and animal production to emerge.

Rainfall was the dominant driver of animal performance with LWG varying markedly over the 24 years of the trial. Nevertheless, treatment also had a strong effect with LWG driven strongly by stocking rate within rainfall years. Thus in nearly all years, individual LWG was highest in moderately stocked strategies like the MSR and R/Spell but lowest under heavy stocking. Individual animal performance in the VAR/Flex strategies varied relative to these latter strategies based on the stocking rate applied in particular years but was similar to the fixed MSR and R/Spell.

While LWG/hd in the HSR in some years was as good as in more lightly stocked treatments, this only occurred in years with well distributed rainfall when stocking rates in the HSR had been reduced in response to recent drought. Here, HSR cattle had a relatively constant supply of short, high quality green grass giving exceptional weight gains. The effect of heavy stocking rates on individual LWG was most evident in drier years when LWG/hd was far below that in the more moderately stocked strategies.

Consequently after two years HSR steers were often 30 to 60 kg lighter (depending upon the season) than their more moderately stocked peers. This resulted in markedly lighter carcasses and less fat cover which in turn, adversely affected grading, reducing price/kg and overall carcass price. Conversely, carcass price was generally highest under more moderate stocking rates because of the greater carcass weight, fat coverage and better meatworks grades. In commercial operations, these differences could be even greater; with meatworks price grids strongly geared for weight-for-age, cattle with slower growth rates would take up to a year or two longer to reach target weight, adversely impacting price/kg even further.

The superior LWGs under more moderate stocking rates directly reflects not only greater forage availability but in particular, higher diet quality (unpublished data). This was obvious even in the early years when despite more than adequate forage under heavy stocking, dietary quality and LWG/hd were still lower than in the MSR. While the observed differences in diet quality appeared relatively minor, these small differences can profoundly affect liveweight gain in these tropical savannas where forage quality is a major limitation to animal production.

As expected, LWG/ha was generally higher under heavy stocking and lowest under light or moderate stocking rates. Again, total production in the VAR/Flex strategies varied with the stocking rate applied in any year. These results confirm and extend earlier data (O'Reagain *et al.*2009) and are consistent with previous studies e.g. (Burrows *et al.*, 2010) that also showed maximum production per ha at heavier stocking rates.

Critically, the higher average LWG/ha in the HSR was only achieved via subsidization with drought feeding in seven of the 24 years of the trial (Appendix 2). A significant number of animals also had to be withdrawn from the HSR for welfare reasons in some years. Major stocking rate reductions were also required for extended periods in the HSR (Figure 5)

In contrast, aside from a relatively short period in 2014/15, an extreme (decile 1) drought year, drought feeding was not required in the other strategies. This was because stocking rates were close to carrying capacity in the MSR and R/Spell while stock numbers were adjusted proactively in the VAR/Flex strategies as seasonal conditions declined. A small number of steers also had to be withdrawn from these strategies for a few weeks in the 2014/15 same season but were returned to their paddocks within a few weeks.

Note that while the R/Spell and MSR were destocked for the 2017/18 wet season this was a pro-active action to avoid overgrazing. In contrast, when stocking rate reductions or destocking was needed in the HSR this a reactive action taken to avoid animal welfare issues.

The most obvious difference in LWG in the present study was the contrast between the HSR and the other strategies. However, there were also differences in the performance of the latter four strategies with their relative performance varying over time as conditions changed.

First, although overall average individual LWG was very similar in the R/Spell and MSR marked differences existed in their relative performance between the two phases of the trial. Thus in Phase 1, individual LWG in the R/Spell was slightly poorer than the MSR. This is surprising, as wet season spelling would be expected to improve pasture condition and hence animal production. However this discrepancy may be attributed to first, the slightly heavier stocking rate employed for the first six years in the R/Spell (6.5 ha/AE) compared to the MSR (8 ha/AE). And second, the combined effects of an ill-timed fire in part of the R/Spell in 2001 and the subsequent drought (Chapter 4.3).

In Phase 2 this trend was somewhat reversed, with individual LWG generally higher in the R/Spell relative to the MSR. This is noteworthy because despite the same stocking rate, spelling inevitably results in a higher wet season stocking rate (approx. 5.5 ha/AE) in the R/Spell than in the MSR where the whole paddock is open to grazing. The higher LWG in the R/Spell thus suggests that spelling has improved pasture condition somewhat, possibly buffering the effects of the increased wet season stocking rates on animal production and sustaining LWGs well into the dry season.

The performance of the Var/Flex stocking strategies relative to the set stocked MSR and R/Spell varied depending on season and the stocking rate applied in the former strategies. Individual LWG was thus relatively good in years like 2014/15 when these strategies were very lightly stocked but conversely, relatively poor in a year like 2000/01 when these strategies were very heavily stocked.

These differences in LWG in turn directly affected profitability and potential economic performance. While total LWG/ha was greatest in the HSR, this came at the cost of expensive drought feeding in seven of the 24 years, reduced product value due to lower carcass prices and increased cost of interest invested in livestock capital. In contrast, lighter stocked strategies or those where stocking rates had been adjusted downwards in dry years largely avoided these costs and also earned a higher product value due to better carcass prices. Consequently, gross margins in the HSR were far more variable and ultimately only half those in the remaining four strategies.

It is important to note that these economic analyses are very sensitive to the price differential for animals in better condition and in particular, interest rates (O'Reagain *et al.*2011). While incorporating a cost for interest on livestock capital is the norm in any economic analysis, it is debatable whether the 'cost' of money invested in cattle is factored into decision making by managers.

6.4 Summary

1. Animal performance in the dry season varied with extreme weight loss in some years and weight gains of up to 71 kg/hd in years with better rainfall. Treatment had a strong effect with dry season performance poorest in the HSR treatment.
2. Total LWG per head per year also varied between years from 43 to 168 kg/hd per annum depending upon rainfall and its distribution. In drought years HSR steers lost weight over the full twelve months.
3. Treatment had a significant effect on LWG/hd but the effect varied between years. Over the 24 years of the trial, average LWG per head was highest in the MSR (117 kg/hd) and R/Spell (116 kg/hd) but lowest in the HSR (100 kg/hd). LWG in the Variable/Flexible stocking strategies varied depending upon stocking rate but was similar to the MSR and R/Spell.
4. The average price/kg of HSR steers was -$0.14/kg to -$0.18/kg lower, and average carcass price thus $73 to $134 lower than in the other treatments.
5. Total LWG/ha also varied between years from as much as 34 kg/ha in good years to less than 5 kg/ha in drought years. Overall LWG/ha was higher in the HSR (20 kg/ha) than in the MSR or R/Spell (14-15 kg/ha). LWG/ha in the VAR/Flex strategies again varied with the stocking rate but was similar to the MSR and R/Spell.
6. The higher LWG/ha in the HSR was only achieved with drought feeding in 7 out of the 24 years of the trial; compared to only 1 year of drought feeding in the other treatments.
7. Due to greater drought feeding and livestock interest costs and lower product value, average gross margin per ha in the HSR ($7/ha) was only half that ($13/ha) in the other strategies.
8. Consequently after 24 years, the accumulated gross margin in the HSR was only half that ($162/ha) in other strategies ($310/ha).

7. Effects of different grazing strategies on pasture change

In this section data is presented on how pasture species composition, yield and frequency changed in response to the different management strategies and rainfall over the 24 years of the trial. Data is also presented showing the change in cover of woody species, in particular the native shrub *Carissa ovata*.

7.1 Methodology

7.1.1 Pasture measurements

The frequency of all grasses, sedges and forbs was measured annually from the mid to late wet season in 100 quadrats (0.25m^2) collected across five transects each 100 m long on 1 ha monitoring sites. Sites were stratified across all soil types with two to three monitoring sites on each soil type per paddock, giving a total of 65 sites. Data was collected using the BOTANAL methodology (Tothill *et al.*, 1992) with all grasses, sedges and forbs identified to the species level. The density of 3P grasses (palatable, productive, perennial grasses) was also assessed based on the average number of 3P tussocks in quadrats.

Paddock pasture yields and ground cover (not presented) were estimated at the end of the wet season (May) using the Botanal methodology (Tothill *et al.*1992) along transects that ran the length of each paddock and bisected all soil types. Species yield data was grouped into functional groups i.e. 3P grasses, 2P grasses (perennial, productive and/or palatable), annual grasses, 'other' (other grasses, sedges, forbs, legumes) and unpalatable wire grasses (*Aristida* and *Eriachne* species). Pasture yields and cover were also assessed annually at the end of the dry season but this data is not presented.

7.1.2 Woody plant cover

The change in woody vegetation cover across the trial site from 1990 to 2020 was assessed with remotely sensed Landsat images using the 'persistent green % cover' index supplied by the Department of Science. (G. Fraser *pers. comm*). *Carissa ovata* cover was also assessed using the line intercept method at eight different times over the trial period on a subset of the long term monitoring sites on the site.

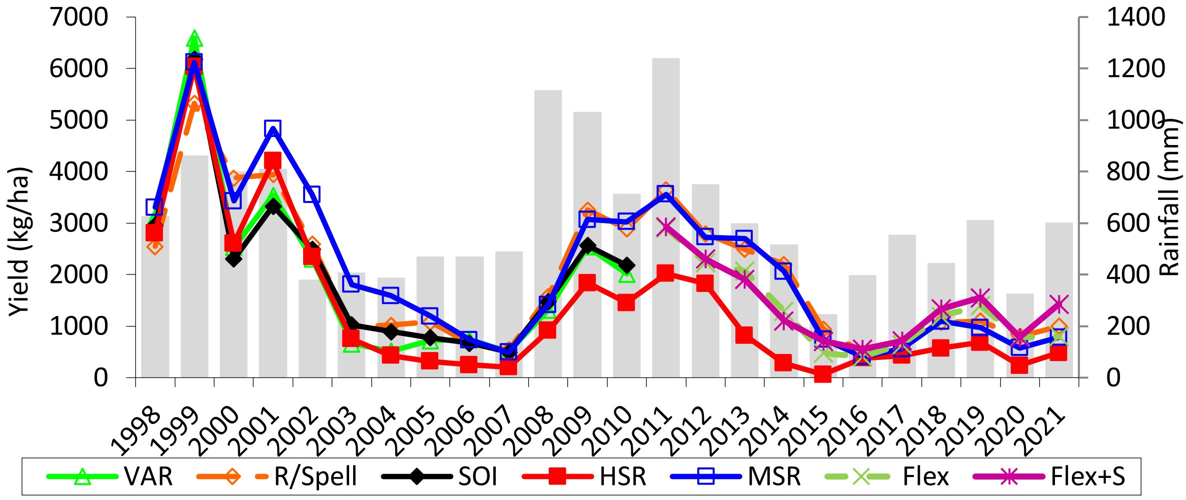
7.2 Results

7.2.1. Pasture yield and composition

End-of-wet season pasture total standing dry matter (TSDM) varied markedly between years, falling from 5000-6000 kg/ha in early wetter years to less than 500 kg/ha in the first drought from 2001 to 2006 (Figure 11). Thereafter, pasture TSDM recovered substantially with the sequence of very good years but never recovered to the levels observed in earlier years. From 2012 onwards, pasture TSDM fell steadily as rainfall declined and, by May 2015, had fallen to only 50 kg/ha in the HSR. Despite some increase in later years, particularly in lighter stocked Flexible treatments, by May 2021 TSDM had declined to 400-1500 kg/ha across all treatments.

It is notable that while TSDM in the Flexible treatments was lower than the MSR and R/Spell during the 2008-2013 wet phase, from May 2017 onwards TSDMD was greater in the Flex+Spell and, to a lesser extent the Flexible strategy. This reflects in part, the reduction in stocking rates in the Flexible strategies post 2017 (Figure 5). The marginally higher TSDM in the Flex+Spell relative to the Flex also suggests that spelling was having a beneficial effect on pasture production.

Figure 11 End of wet season pasture yield versus rainfall from 1997/98 to 2020/21 for treatments at the Wambiana trial.

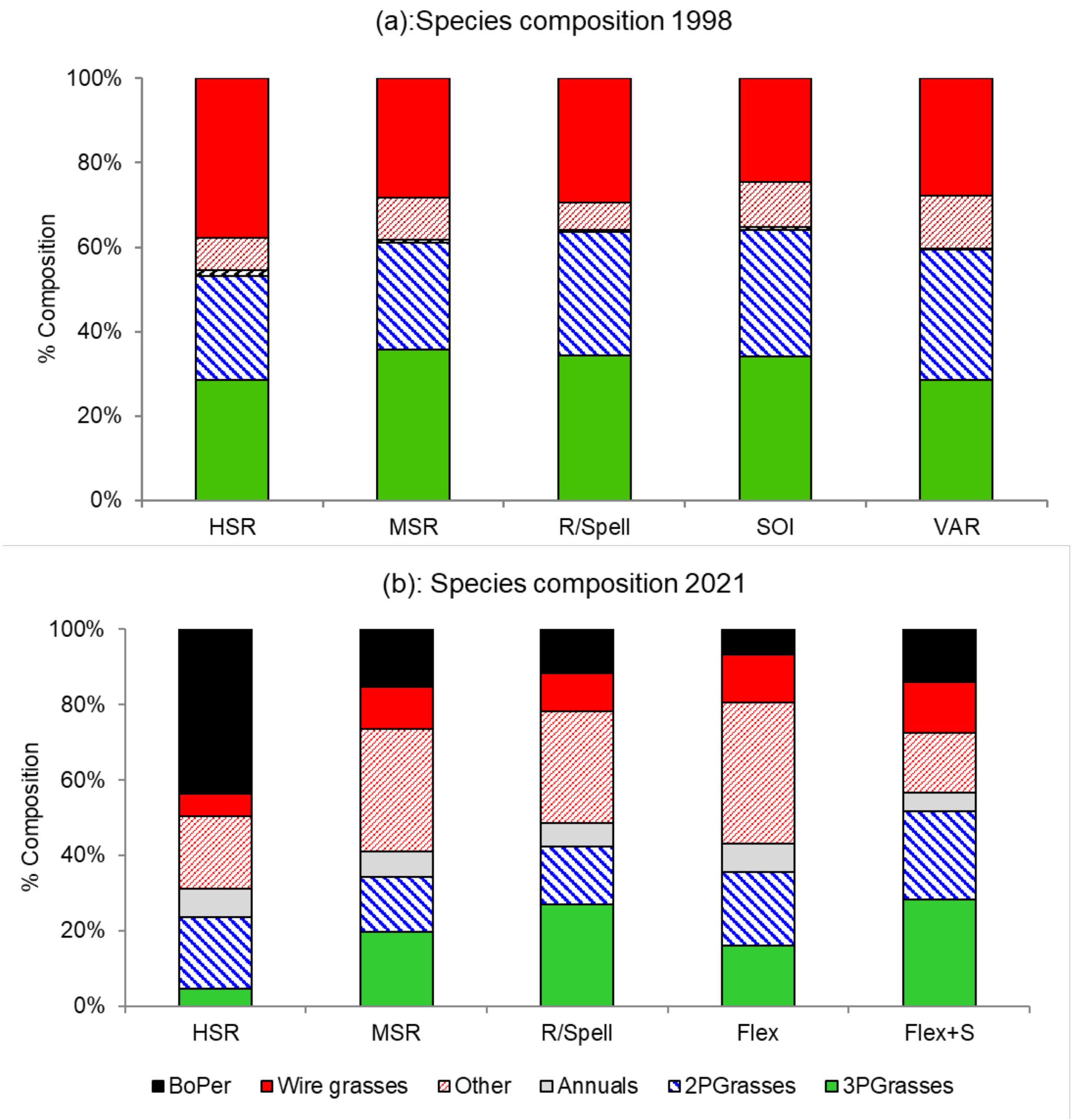


Pasture composition declined across all treatments between 1998 and 2021 with the largest decline by far occurring in the HSR (Figure 12). Thus by 2021, 3P species in the HSR comprised only 5% of pasture yield despite forming more than 30% of yield when the trial began in 1998. While the 3P % yield in 2021 was far higher in other treatments (range: 16-27 %) it had also declined from levels of 30% of yield in 1998.). The most dramatic change however occurred was the spread and expansion of *B. pertusa*. Although *B. pertusa* was virtually absent in 1998, by 2021 it comprised over 44 % of yield in the HSR. While the contribution of *B. pertusa* in 2021 was far lower in the other strategies (range: 7-16%) the increase is still noteworthy considering its initial absence.

The annual grass % yield also increased markedly in the HSR over time; although all this was not obvious in 2021 results, in previous years e.g. 2020, the % contribution of annual grasses had been far higher in the HSR (30%) compared to only approximately 10 % in other strategies (data not shown).

Viewed in isolation, changes in the % contribution to yield can be misleading given their relative nature i.e. an apparent change in the % of one species group may simply reflect a decline in the total contribution to yield of another group and vice versa. That aside, these changes show a major decline in pasture condition in the HSR with a major decline in proportion of 3P species but big increases in the *B. pertusa* and annual species. Importantly, pasture composition has also declined in the other treatments but the proportion of 3P species is still more than two to three times greater than that in the HSR. (Figure 12).

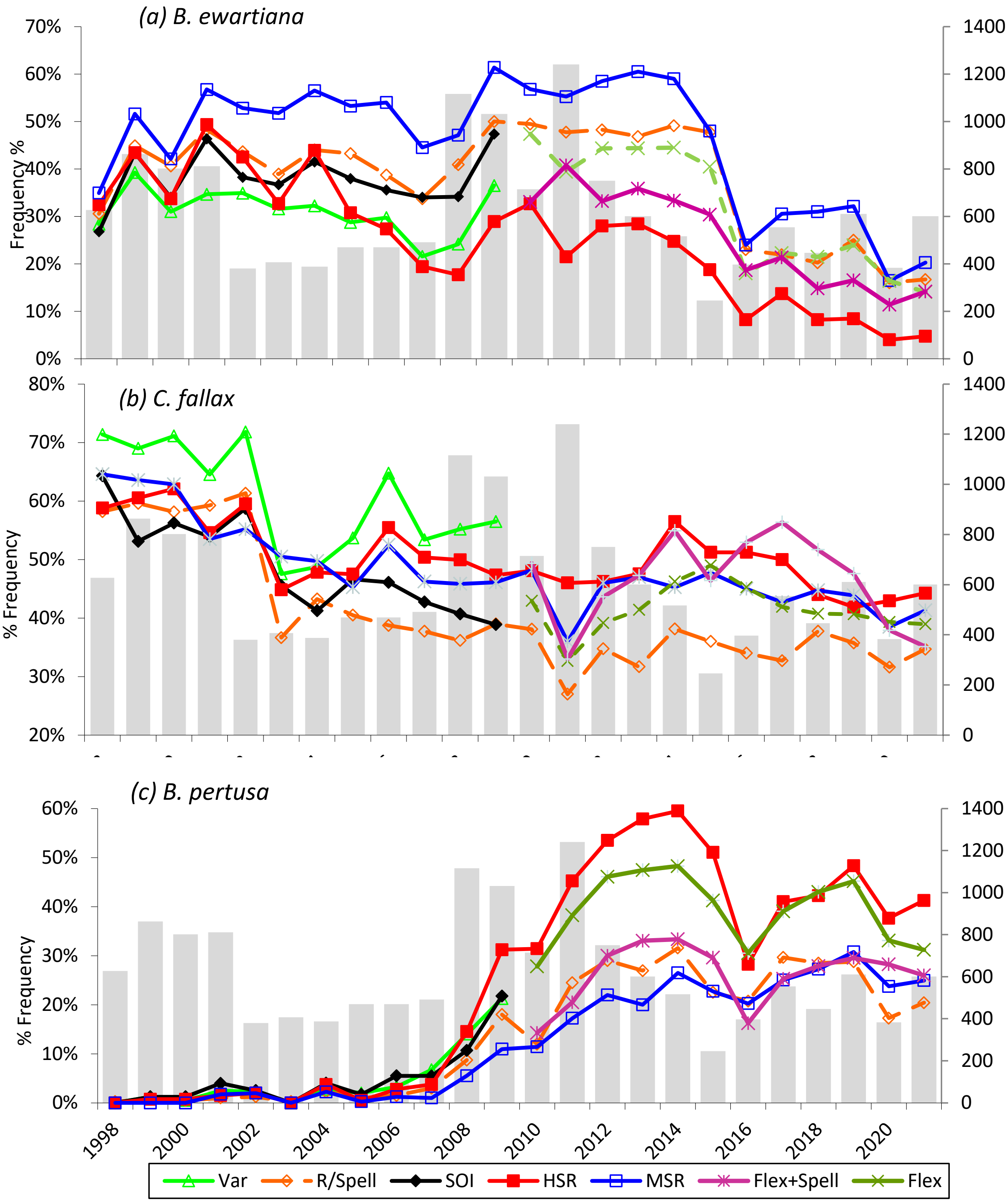
Figure 12 Percentage species composition of end of wet yields (May) in 1998 (top) and 24 years later in 2021 (bottom).



7.2.2 Changes in species frequency

The change in frequency of four selected indicator species measured on permanent monitoring sites on the box, clay and ironbark soils are shown in Figure 13. For the box and ironbark soils these are *B. ewartiana,* a long lived productive 3P species and a key indicator of good land condition, *Chrysopogon fallax* a long lived, grazing resilient, but less productive 2P species, *Heteropogon contortus* a desirable 3P grass and *B. pertusa* an invasive, exotic grass regarded as an indicator of heavy grazing pressure. The changes in frequency of two introduced leguminous *Stylosanthes* species are also shown separately. For the clay soils, only the frequency of the main indicator species *B. ewartiana* is shown.

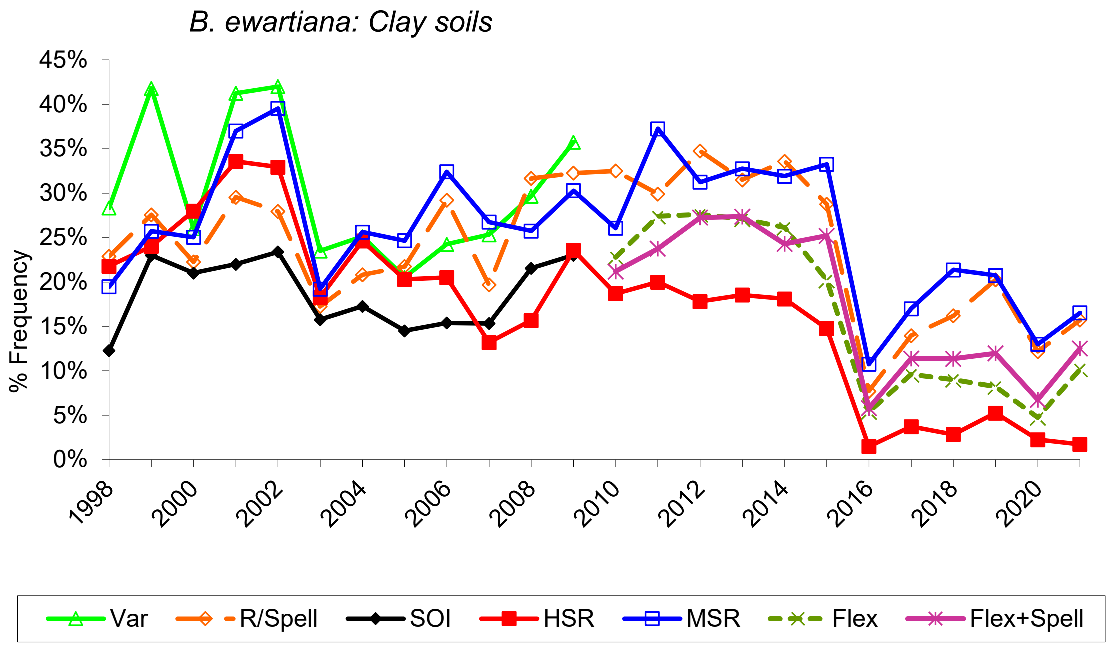
Figure 13 Change in species frequency of (a) *B. ewartiana*, (b) *C. fallax* and (c) *B. pertusa* versus rainfall on box soils from 1998 to 2021 at the Wambiana trial.



The results clearly show that the key indicator species *B. ewartiana* has declined significantly in all treatments on both box and clay soils. There are nevertheless marked treatment differences in the pattern of this decline. In the HSR, *B. ewartiana* on the box soils initially persisted through the early wet years but thereafter declined steadily to a frequency of only 5 % in 2021. In contrast, *B. ewartiana* persisted at relatively high levels in the MSR and R/Spell for the first 17 years of the trial but then declined dramatically due to the severe drought in 2015/2016. In the Flexible strategies, *B. ewartiana* declined slightly in the early years due to the very heavy stocking rates applied, but thereafter increased in response to a reduction in stocking rates and good rainfall post 2007. Nevertheless, the later drought also caused a significant decline in *B. ewartiana* in both Flexible strategies. Despite these drought effects, in 2021 the frequency of *B. ewartiana* was still markedly higher in the MSR, R/Spell and Flexible strategies than in the HSR.

On the clay soils an initial, a decline in *B. ewartiana* occurred across all treatments with the onset of the first drought in 2003 (Figure 14). Thereafter, *B. ewartiana* stayed relatively constant, or even increased slightly in the MSR and R/Spell, before declining sharply in all treatments following the low rainfall in 2014/15 and the subsequent onset of drought. As before, the greatest decline occurred in the HSR where *B. ewartiana* has now almost disappeared. While there is some evidence of recovery in the R/Spell and MSR, *B. ewartiana* appears to be remaining at relatively low levels in the two Flex treatments. This is surprising given the lower stocking rates in the two Flex treatments in recent years but is probably due in part to the encroachment of *A. harpophylla* juvenile trees on some of the monitoring sites in these treatments.

Figure 14 Change in species frequency of *B. ewartiana* on the clay soils from 1998 to 2021 at the Wambiana trial.



C. fallax has also declined on the box soils (Figure 13) across all treatments with the initial major decline occurring in 2002 through the first drought cycle. Thereafter, its frequency remained relatively steady with a relatively slight decline in more recent years. The markedly lower *C. fallax* frequency in the R/Spell is surprising but probably a side effect of the 2001 burning of the ironbark sections of these paddocks: with the burnt sections being spelled for the next three wet seasons due to their poor recovery (O'Reagain and Bushell, 2011). Consequently, the box sections were grazed at a relatively heavy stocking rate through the following drought years with animals confined to two thirds of the paddock over the wet season.

The decline in *C. fallax* was far more marked on the ironbark soils with an initial decline in the first drought followed by a much greater decline following the extremely dry 2014/15 season (). Interestingly, *C. fallax* in the HSR was markedly lower than in the other treatment in the first drought cycle but conversely, higher in the second drought. The large fall in *C. fallax* in the R/Spell in 2003 probably reflects the lag effects of the 2001 fire in the ironbark and the subsequent drought.

On the ironbark soil type, *H. contortus* also increased in wet years but seemed to decline much later in drought cycles than either B. *ewartiana* or C. *fallax* (Figure 15). However, these trends mask the fact that H. *contortus* is relatively drought susceptible with close to 100 % mortality of adult plants observed 2002/03 and 2014/15. In contrast to other perennials, it recruits very readily with large scale seedling establishment and recruitment occurring even within drought years.

Two of the most dramatic changes however were first, the rapid expansion of *B. pertusa,* particularly on the box soil type, but also in the ironbark (Figure 15) and clay soils (not shown) . For the first 10 years, *B. pertusa* was absent from most monitoring sites with frequencies of 2% or less recorded. However, following the 2002-2007 drought which created bare patches and then, very good rainfall in June 2007 (218 mm) and later July 2008 (136 mm) which allowed seeding, the grass spread rapidly. A similar trend was reported for *B. pertusa* and other exotic grasses in the smaller scale Ecograze study conducted in the Charters Towers region from 1992 to 2001 (Ash *et al.*, 2011).

Treatment effects were most pronounced on the ironbark with *B. pertusa* frequency by far the highest in the HSR compared to relatively low levels in the other treatments (Figure 15). In contrast, while *B. pertusa* frequency also increased the most in the HSR on the box soil type, it also increased significantly in the other treatments, particularly the Flex treatment. This partially reflects the heavy grazing pressure in this treatment in early years. However, the large variation in *B. pertusa* frequency between monitoring sites within the Flex strategy, possibly also simply reflects variation in the availability of seed.

The second major change was the increase, in the introduced legume *Stylosanthes* (Figure 16), particularly *S. hamata* (verano). This increase largely occurred on the ironbark soils with Stylo largely absent from the clay soils and remaining at low levels (<10 % frequency) on the box soils. Stylo has never been sown across the trial area but small quantities were present at the start of the trial. However, in the last six or seven years Stylo was observed rapidly increasing in surrounding laneways and off-trial paddocks. Stylo seed was then obviously spread across trial paddocks by cattle dung, macropods and possibly wind, with plants establishing on bare patches post drought. The increase in verano was by far the greatest in the MSR but large increases in frequency were also recorded in other treatments including the HSR. Seca stylo (*S. scabra*) also increased to some extent over the experimental period. Here the greatest increase occurred under moderate stocking rates, initially in the MSR, and later the R/Spell and Flex strategies. There was virtually no seca in either the HSR undoubtedly due to heavy grazing pressure. The very low levels of seca in the Flex+S are surprising (Figure 16) but possibly reflects the limited availability of nearby, off-trial seed sources. While stylo has a positive effect on cattle production, it can easily become dominant leading to the loss of better grasses through overgrazing (Partridge *et al.*, 1996).

Figure 15 Change in species frequency of (a) *B. pertusa* (b) *C. fallax*, and (c) *H. contortus* versus rainfall on ironbark soils from 1998 to 2021 at the Wambiana trial.

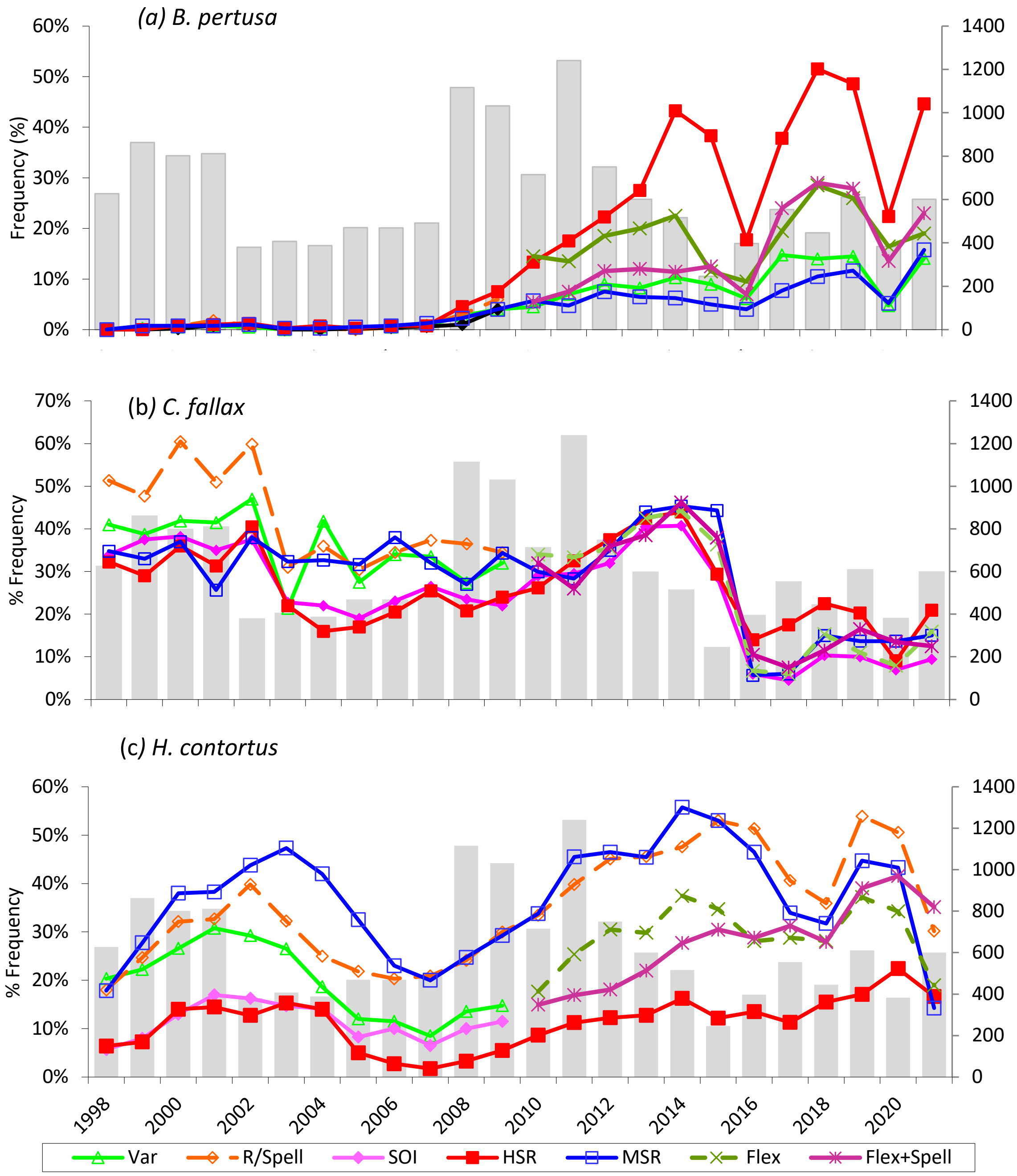
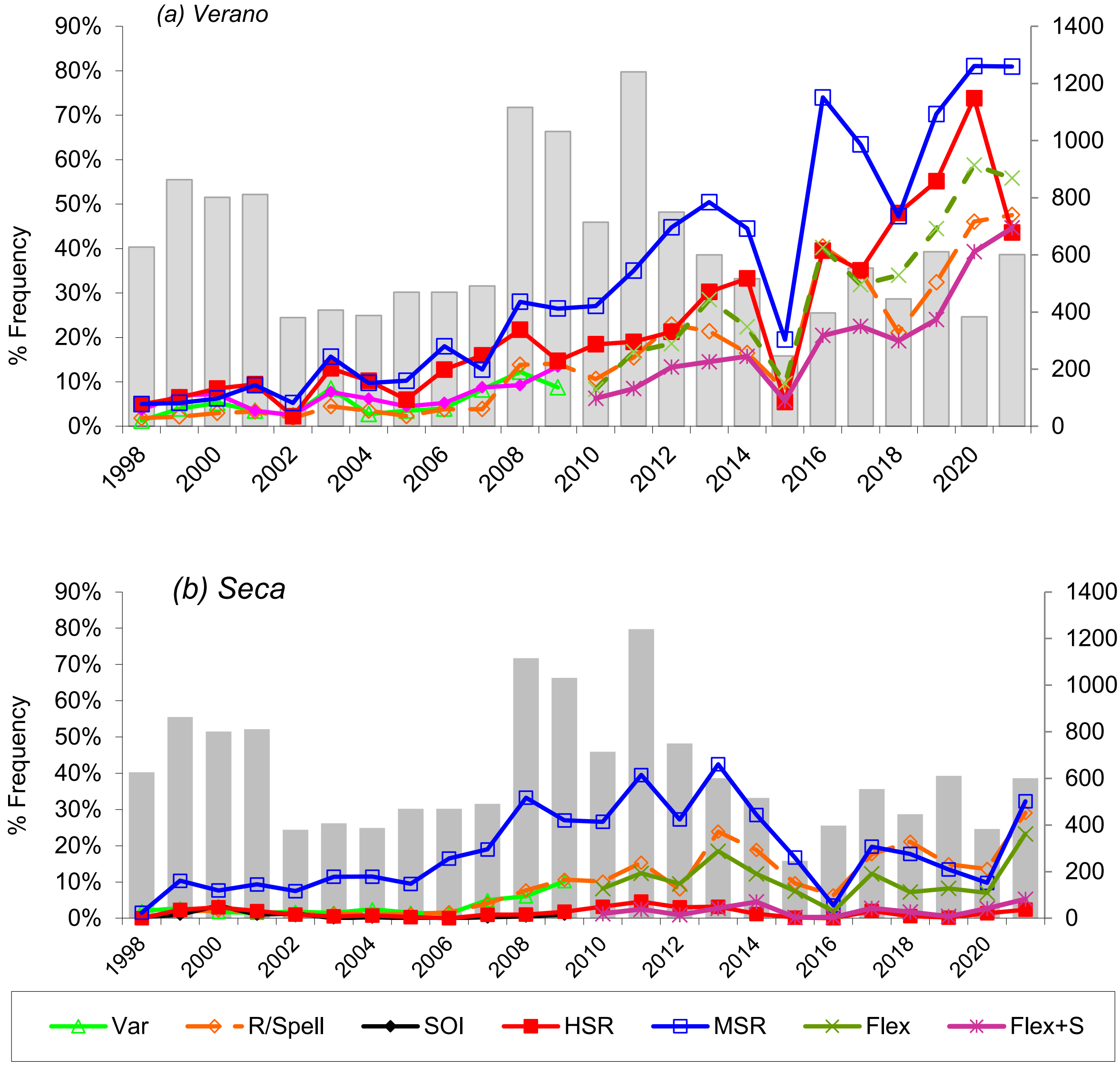


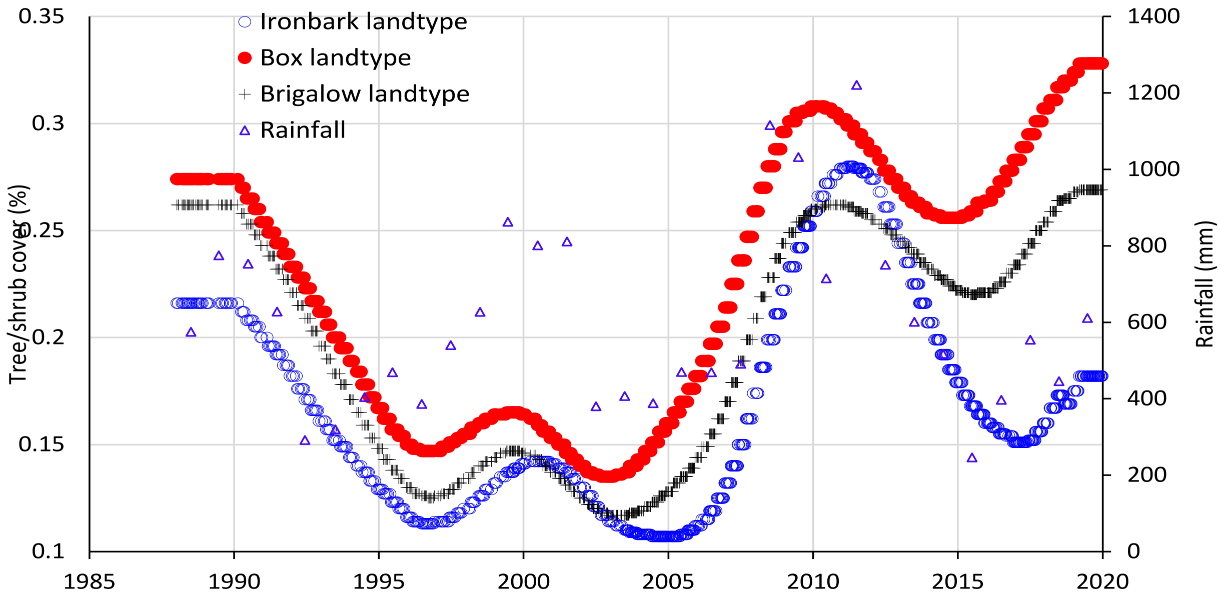
Figure 16 Change in the frequency of verano (top) and seca stylos (bottom) on ironbark soils versus rainfall from 1998 to 2021 at the Wambiana trial.



7.2.3 Woody plant cover

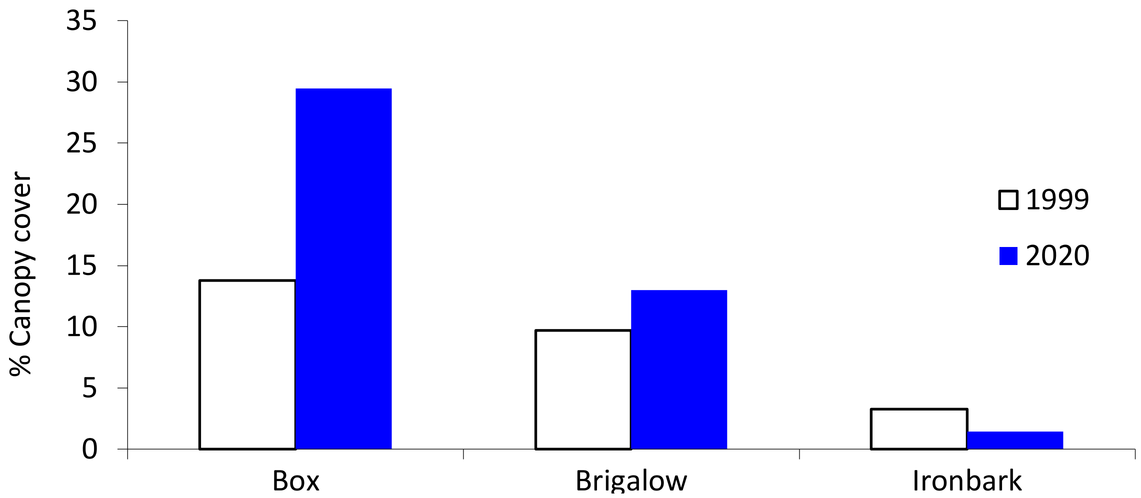
Remotely sensed persistent green cover shows woody cover declining on the site in the early 1990's presumably in response to the severe drought in early 1990s (Figure 17). However, woody cover started increasing before the start of the trial in late 1997 and aside from a small decline in the early 2000s drought, by 2010 had more than doubled on the box and brigalow landtypes. While woody cover declined further in the more recent 2013/14 drought, it has since recovered to its 2010 levels in these landtypes.

Figure 17 Change in remotely sensed tree and shrub cover (persistent green cover) versus rainfall at the trial site from 1985 to 2020. Data supplied by Grant Fraser, DES.



On the ironbark landtype, cover also increased dramatically post 2005, but fell sharply following the death of a significant number of large mature ironbark (*E. melanophloia*) trees with the severe drought in 2014/15. There was also nearly 100 % mortality of the cohort of juveniles that had emerged in the preceding wet phase (data not shown). Interestingly, paddock observations indicated that virtually no brigalow or box trees died in this later drought.

Figure 18 *Carissa* canopy cover on the box, brigalow and ironbark landtypes in 1999 and 2020.



These trends are supported by paddock data which show that despite fires in 1999 and 2011, *C. ovata* cover increased dramatically in the box and to a lesser extent, in the brigalow landtypes over the course of the trial (Figure 18). In contrast, the original very low *Carissa* cover on the ironbark declined even further in the 2014/15 drought. These results and paddock observations suggest that the majority of increase in persistent green cover on the box landtype is probably due to *Carissa* and, to a lesser extent, tree canopy growth, rather than increased tree density.

However on the brigalow landtype, there has been a significant increase in the number and size of *A. harpophylla* suckers in some (not all) areas. This indicates both tree thickening and increased *Carissa* cover on this land type (Figure 19; Figure 20).

Figure 19 Significant thickening of *A. harpophylla* on a heavy clay site over 20 years between 2001 and 2021. NB: This is the same site and is not a mistake.

Figure 20 Thickening of *A. harpophylla* and *Carissa* on a heavy clay site over 20 years between 2001 and 2021.

7.3 Discussion

Pasture condition has declined to a greater or lesser extent in all treatments as shown by the marked decline in 3P grasses and pasture production. This change is due to a combination of rainfall and grazing strategy, in particular stocking rates, the flexibility or otherwise of stocking rates and to a lesser extent wet season spelling. The increase in tree and shrub cover undoubtedly played an indirect, but difficult to quantify, role in this transition. Quantifying this effect is out of scope for the present study but should be investigated in the planned next phase of this project.

The extreme drought of 2014/15 was a major system shock as shown by the death of many large trees on the ironbark soils. The drought resulted in widespread mortality of 3P species with a large proportion of *B. ewartiana* plants dying (Chapter 9). Mortality of other perennial grasses was also very high including that of *Dichanthium sericeum* (Queensland bluegrass) and *Eriachne mucronata* ('never fail'), an extremely tough, long lived perennial. The effects of drought were also treatment dependent with heavy stocking rates amplifying the drought effect. For example, 60 % of *B. ewartiana* tussocks died on the MSR vs. 93 % in the HSR (see Chapter 9)

Treatment had a profound effect on pasture condition with the density and % yield of 3P species by far the lowest in the HSR. Although pasture condition was initially maintained in the early wetter years, condition declined rapidly through the first drought phase. Despite the subsequent wet period from 2008 to 2012, there was little recovery. Condition then declined sharply with the 2014/15 drought, with the decline steadily continuing through the ongoing drought conditions, despite much reduced stocking rates.

In contrast, the MSR and R/Spell largely maintained pasture composition, at least superficially, through the first 16 years of the trial. However, there were early indicators of decline as shown by first, patch grazing, particularly in the MSR, leading to overgrazing in some areas and second, the reduced yields in the second vs the first wet period. Pasture condition in the R/Spell, and in particular the MSR, declined sharply in the 2014/15 drought through significant mortality of 3P species. While much of this was drought induced, the relatively heavy fixed stocking rates (Figure 5) undoubtedly accelerated the decline.

The benefits of spelling observed in the present trial were not as strong as might be expected considering the significant improvements in pasture condition resulting from wet season spelling reported in the Ecograze study (Ash *et al.*2011). The present apparently subdued response may be attributed to a number of factors. First, the fertility and potential of the soils of the trial site are inherently lower than those used in the Ecograze study. Second, the slightly higher stocking rates (6.5 ha/AE) initially (1998-2003) applied to the R/Spell probably adversely impacted pasture condition. These initial higher stocking rates were imposed based on the Ecograze study which suggested that spelling could buffer slightly higher stocking rates. Third, the legacy effects of the ill-timed fire in October 2001 and the subsequent drought severely affected pasture condition in the R/Spell. As described previously (O'Reagain *et al.*2008), the burnt section needed to be spelled for three consecutive wet seasons which in turn placed considerable pressure on the rest of these paddocks over a sequence of extremely dry years. Lastly, the increase in *C. ovata* cover also probably dampened the response both via competition and indirectly, by increasing grazing pressure through reduced pasture production.

Pasture condition also declined in the two Var/Flex strategies, in part because of the heavy stocking rates imposed during the first few years of these treatments (Figure 5). The impact of this overgrazing persisted for at least 10 years despite much reduced stocking rates in subsequent years. Despite the very low stocking rates run in the Flex and Flex+S strategies through the recent ongoing drought, pasture condition is only slightly better than in the MSR or R/Spell treatments. The lack of a difference is surprising, but possibly reflects a combination of the ongoing legacy of the early overstocking and more importantly, the continuing impacts of the drought.

The decline in land condition has probably affected carrying capacity to some extent in all treatments. This is particularly so in the HSR where the initial heavy stocking rates cannot be maintained except for short periods in very wet years. Drought resilience has also declined with intervention in the form of drought feeding being required far sooner in the 2014/15 drought compared to the first drought.

While the sharp decline in land condition in the HSR is expected, the decline in land condition in all the remaining treatments is surprising. However, given the severity of the 2014/15 drought and the subsequent years of below average rainfall, these results do at least show that applying the basic principles of good management at least partly ameliorated the effects of the drought relative to heavy stocking.

Aside from rainfall and stocking rate, another important factor has been the growth and expansion of woody species. The reasons for this increase are unclear but possibly include reduced competition from the grass layer through overgrazing, the legacy effect of a low fire frequency pre-trial and the increased competitive ability of the C3 woody component due to increased atmospheric CO_2 levels (Bond and Midgley, 2000). *Carissa* in particular, was also well established on the site at the start of the trial and was noticeably thicker than on at least one adjacent property. According to the Wambiana property owners (J. Lyons *pers.comm*), the trial site had last been burnt some 30 years previously. This undoubtedly accounts for its high cover relative to Trafalgar, the neighbouring property, where fire was used far more frequently (R. Landsberg, *pers. comm*.).

The increase in *Carissa* cover on the box soils from about 15 to 30 % would directly have reduced the area available for pasture growth while also increasing competition with the grass layer. These in turn would have increased grazing pressure on remaining plants further accelerating overgrazing. On the clay soils, brigalow saplings also encroached into some grassy areas, resulting in the elimination of pasture in small patches through competition and shading.

Carissa is a widespread, relatively underreported problem in central and north Queensland. While no recent data is available, the 1999 Dalrymple shire soil survey reported that *Carissa* was the most important weed in the shire with 47 % of sites affected (Rogers *et al.*, 1999). The problem is far worse on tertiary sedimentary landscapes like those on the trial site, with a 1990 survey recording that 73 % of these sites were affected with *Carissa* comprising from 1 to 99% of ground cover (De Corte *et al.*, 1991).

Finally, the fact that pasture condition has declined in even the 'best' treatments is cause for concern and a sobering outcome (Figure 21). While the recent drought undoubtedly caused significant damage through marked mortality of perennial grasses, recovery with the later, slightly better seasons has been extremely slow. Similar observations have been made on properties throughout north Queensland with this lack of recovery being a major concern for industry.

Figure 21 Change in pasture condition at selected monitoring sites as indicated below.

(a) Heavy stocking rate: 2000 vs Heavy stocking rate 2020

(b) Moderate stocking rate: 2000 vs Moderate stocking rate 2020

(c) Variable stocking rate: 2002 vs Flexible + Spell 2021

7.4 Summary

1. Pasture TSDM changed dramatically over the 24 years of the trial from more than 5000 kg/ha in the early wet years to less than 1000 kg/ha in the first drought. While there was some recovery in the second wet phase, yields then fell sharply and have remained low through the second, extended drought since 2013.
2. Pasture composition also changed dramatically over the course of the trial with a general decline in 3P species like *B. ewartiana* and an increase in *B. pertusa* and other shorter lived, less productive 2P species.
3. The greatest decline in pasture condition occurred in the HSR with 3P species falling from 30 % of the yield in 1998 to only 5% of yield in 2021. The % 3Ps in other treatments also declined, largely due to drought, but by 2021 the % 3P grasses was still noticeably higher (16-27%) than in the HSR.
4. Although the exotic grass *B. pertusa* was virtually absent in 1998, it increased rapidly following the first drought and by 2021 it comprised 44 % of yield in the HSR. However, it only comprised 7-16% of yield in the other strategies.
5. The frequency of the key species *B. ewartiana* declined in all treatments over time. However, the rate and extent of this decline was fastest and greatest in the HSR: hence by 2021 the frequency of *B. ewartiana* in the HSR was only 3% compared to 12-18 % in other strategies. Conversely, the frequency of *B. pertusa* increased most in the HSR and least in other treatments.
6. The exotic legume *Stylosanthes* has also increased on the Ironbark soils, particularly *S. hamata* (verano) with the greatest increase in the MSR and HSR treatments. Seca Stylo (*S. scabra*) has also increased to a lesser extent, largely in lighter stocked strategies. This should improve LWGs but could lead to stylo dominance.
7. Woody plant cover, in particular the native shrub *Carissa* has increased significantly on the box and brigalow soils between 1998 and 2021. Tree cover also increased on the ironbark but declined sharply due tree death in the recent drought.
8. After 24 years land condition has declined significantly in all treatments as shown by the marked decline in 3P species, pasture TSDM and increased woody plant cover. However, the greatest decline by far has been in the HSR. It remains to be seen to what extent recovery occurs in the different strategies when favourable conditions return.

8 Comparison of flexible vs fixed stocking

This section addresses the specific question: can productivity and land condition be improved relative to constant stocking at LTCC by using adaptively managed, flexible stocking strategies? Accordingly, the focus here is on comparing the performance in particular of fixed moderate stocking (MSR), with the two Var/Flex stocking strategies i.e. the VAR and SOI strategies in Phase 1 (1998-2009) and the Flex and Flex+Spell (2010-2021) strategies in Phase 2.

8.1 Animal production and gross margins

Taken over the full 24 years of the trial, LWG per head in drought years was generally higher in the Var/Flex strategies due to the reduced stocking rates compared to the MSR. This occurred in both the first and second drought cycles (Figure 7). With lower stocking rates, the LWG/ha was also generally lower in the variable/flexible strategies by, for example, 2-7 kg/ha in the 2019/20 and 2020/21 seasons.

Relative gross margins (GM) varied in these dry years being lower in some years in the Var/Flex strategies than in the MSR. In other years like 2006/07 to 2008/09 gross margins were greater due to the higher (mainly interest) costs and lower product value of the relatively heavily stocked MSR (Figure 5).

In contrast, in wet years when stocking rates in the Var/Flex flexible strategies were increased above those in MSR, the reverse tended to occur with relatively lower LWG/hd, but higher LWG/ha and gross margins in the variable/flexible strategies. Averaged over all years, animal production and gross margins were thus very similar in the MSR and the Var/Flex strategies (Table 4).

However, comparing the strategies over the full 24 years of the trial is misleading. First, the good rainfall and pasture condition at the start of the trial resulted in very heavy stocking rates being applied in the Var/Flex strategies which resulted in high LWG/ha in these treatments. Second, the VAR and SOI strategies were undoubtedly overstocked in these early years which adversely impacted pasture condition. Aside from these initial high stocking rates, they were also managed in a far less adaptive' manner in Phase 1 than in Phase 2. For example, only 1 stocking rate adjustment point per year in Phase 1 versus four potential adjustment points in Phase 2 (see section 4.2).

A better option would be to compare performance over the most recent dry years (2013/14 - 2020/21). Taken over these last eight years, average LWG/hd was lower in MSR (110 vs 117 kg), with average total LWG/ha slightly higher in the MSR. Nevertheless, average GM/ha was the same in both the MSR and the two flexible strategies (Table 4). This alone is noteworthy in that it shows that the same GM/ha could be obtained despite running a significantly lower stocking rate through the drought in the two flexible strategies. This in turn is likely to drive significantly faster pasture recovery when better seasons return.

Table 6 Average annual live weight gain per head (LWG/hd), live weight gain per hectare (LWG/ha) and gross margin per hectare (GM/ha) for the MSR versus the average of the two flexible strategies (Flex and Flex+Spell) over the length of the trial (left) and the last eight dry years (right).

	Average: All years		Average: Last 8 dry years	
	MSR	Flexible	MSR	Flexible
LWG/hd (kg)	117.1	115.0	109.7	117.4
LWG/ha (kg)	14.1	15.6	11.7	9.5
GM/ha ($)	13.0	13.5	9.0	9.0

These averages, however, also mask an important difference which is only apparent when individual years are considered: in five of these eight years GM/ha was as good or better in the MSR than in flexible strategies. Nevertheless, the critical difference occurred in 2017/18 where due to fixed stocking rates the MSR (and R/Spell) had to be destocked for the wet season. Consequently, gross margins were negative in the MSR (-$17/ha) and far lower than in the Flexible strategies (+$9.50/ha). At a property level, the loss with the MSR is very significant. For example for a 20 000 ha property this equates to a net loss of $340 000 in one year.

8.2 Pasture production and condition

Pasture TSDM, species composition and the frequency of two key grass species are shown in Table 7. After 24 years, pasture yield and composition are by far the worst in the HSR. However, differences between the other strategies are relatively small. Nevertheless, in May 2021 TSDM in the Flex+Spell (1430 kg/ha) was double that in the MSR (785 kg/ha). Interestingly, pasture TSDM in the Flex is markedly lower than in the Flex+S and the R/Spell, possibly highlighting the beneficial effects of spelling. However, differences in 3P% yield in 2021 and the absolute change in 3P% yield since the start of the trial are minor in these four strategies and as such should be treated with caution given the caveats associated with proportional species composition data mentioned in section 7.2.1.

Table 7 Key pasture variables and indicators in 2021 after 24 years of applying different strategies at the Wambiana trial. 3P = perennial, palatable, productive grasses. Changes in % 3P yield and *B. ewartiana* frequency from 1998 to 2021 are absolute % change. See text for details.

	HSR	MSR	R/Spell	Flex	Flex+Spell
	End of wet season paddock yields May 2021				
Pasture yield (kg/ha)	484	785	1000	809	1430
Ground cover %	57%	64%	72%	73%	74%
3P yield (%)	5%	20%	27%	16%	28%
3P yield % change: 1998-2021	-24%	-16%	-7%	-15%	-3%
B. pertusa yield (%)	44%	15%	12%	7%	14%
	Frequency 2021				
B. ewartiana %[1]	3%	18%	16%	12%	13%
B. ewartiana % change 1998 - 2021[1]	-28%	-15%	-14%	-14%	-13%
B. pertusa (%)[2]	39%	25%	21%	24%	25%
3P density (plants/m^2)[1]	0.4	2.1	2.4	1.3	3.6

[1] box soils only, [2] all soils

Similarly, while the frequency and density of 3P species is by far the lowest in the HSR the differences between the remaining strategies are relatively small in comparison (Table 5). A noticeable exception is the higher density of 3P plants in the Flex+Spell (3.6 plants/m^2) compared to the MSR (2.1 plants/m^2). The low density of 3Ps in the Flex is hard to explain given the low stocking rates over the last 8 years but may simply be due to paddock differences between this treatment and the Flex+Spell strategies.

The lack of clear differences between the MSR and the Flexible strategies is surprising given the lower stocking rates in the recent drought in the Flexible strategies. This may partly reflect the legacy of the early heavy stocking rates applied in the VAR and SOI which undoubtedly resulted in severe overgrazing. This immediately preceded the first drought phase, leading to a substantial and long lasting decline in pasture condition.

The lack of clear differences between current adaptively managed Flexible strategies and the MSR may also reflect the ongoing effects of the present drought and the lack of opportunities for recruitment of 3P species (section 9). The drought also reduced the total amount of the paddock spelled and the length of spelling in the Flex+Spell which would obviously have reduced the potential benefits of the spelling in these years.

8.3 Discussion

While differences between the treatments appear relatively small, the fact that average GM/ha was the same in both the MSR and the two flexible strategies over the last eight dry years is significant (Table 4). This alone it shows that the same GM/ha could be obtained despite running a significantly lower stocking rate through the drought in the two flexible strategies. This in turn is likely to drive significantly faster pasture recovery when better seasons return.

Other experiences through the trial also clearly highlighted the benefits of adaptively managed, flexible stocking with these strategies resulting in greater pasture availability and less overgrazing in the later drought years than in the fixed stocking strategies (*pers. obs*.). The relative benefits of flexible stocking on pasture condition would probably have been far greater if the MSR and R/Spell had not been destocked for the 2017/18 wet season thus avoiding severe damage to these treatments.

This need to destock was avoided in Flexible strategies by the progressive destocking implemented for seven consecutive years from 2010/11 onwards. Thus as seasons declined stocking rates were reduced from 5.5. ha/AE in 2010/11 to about 16 ha/AE in 2017/18. As a result, destocking was not required in the flexible strategies in 2017/18, thus maintaining a positive GM/ha and avoiding a net loss of -$17/ha.

Despite the present lack of differences in pasture composition, recovery of the Flexible strategies and in particular, the Flex+Spell, is expected to be faster than in the MSR once the seasons improve for the following reasons. First, the lower grazing pressure imposed through the drought in the Flexible strategies is likely to have inflicted less damage on surviving tussocks. Second, the wet season spell in the Flex+Spell is expected to have been of benefit to the pasture, allowing at least a short period of uninterrupted growth to some areas and presumably, accumulation of reserves. Finally, the greater pasture TSDM in the Flex and in particular the Flex+Spell, resulted in slightly greater ground cover levels which will aid infiltration rates and reduce runoff over coming wet seasons. These effects are likely to become even more marked given the extreme rainfall deficit and heat conditions experienced through most of the 2021/22 growing season which would further increase the pressure on plants in paddocks where stocking rates hadn’t been reduced.

8.4 Summary

1. Viewed over the full 24 years of the trial, there was little if any difference in individual LWG, total LWG per ha or gross margins between fixed stocking at LTCC and Variable/Flexible stocking.
2. Similarly, when taken over the last eight below-average rainfall years when these differences might be expected to be most marked there was little difference in average LWG/hd, total LWG/ha or gross margin.
3. However the simple fact that the same GM/ha could be obtained despite running a significantly lower stocking rate through the drought in the two flexible strategies is significant and is likely to drive faster recovery post drought.
4. The clear advantages of flexible stocking were also clearly shown by the fact that progressively adjusting stocking rates both between and within seasons in the flexible strategies avoided the need to destock as happened in the MSR and R/Spell in 2017/18. This in turn avoided the potential loss of -$17/ha that year incurred in both of the latter strategies.
5. After 24 years pasture TSDM is also markedly higher in the Flex+S, and to a lesser extent, the Flex, than in the MSR. However, as of yet any differences between species composition between these strategies are small.
6. Nevertheless, paddock observations in both Flexible strategies, and in particular the higher TSDM and the greater density of 3P plants in the Flex+S, suggest that these strategies will have a faster recovery trajectory when the wet years return than the MSR or R/Spell.

9. Test the ability of different wet season spelling strategies to regenerate poor (C) condition land.

Prepared by Paul Jones, DAF Emerald and Peter O'Reagain, DAF Charters Towers

9.1 Introduction

This chapter reports on the wet season spelling project at Wambiana led by Paul Jones (DAF, Emerald). The project was funded by MLA (B.NBP. 0555) for the period 2011 to 2016, and thereafter by the Northern Grazing Demonstration project. A draft paper on this work entitled '*Demography of perennial grass under varying resting and grazing regimes in central Queensland*' is attached in Appendix 14 while a technical note on recovering C condition land is presented in Appendix 9.

9.2 Methods

9.2.1. Project design and treatments

The project design, site description and methods are provided in detail in Appendix 14. In brief, the trial was conducted on the box landtype on the Wambiana grazing trial. A series of 30 m by 30 m plots were established in 2011 within two separate areas in one of the HSR paddocks (Paddock 4). One of these areas was adjacent to the fence separating this paddock and a MSR paddock (Paddock 5). This area was then incorporated into the MSR paddock by shifting the boundary fence. A range of identical wet season spelling strategies were then imposed on by fencing some plots within these two areas. Spelling was implemented by opening or closing fences at strategic times to allow cattle grazing. Control, unspelled plots were also established. This created a series of spelled and unspelled plots on C condition land with the background grazing being either heavy (Paddock 4) or moderate stocking (Paddock 5). This design provided insights into the interactions between the spelling regime and overall stocking rate (moderate vs heavy stocking) on pastures previously subjected to 14 years of heavy grazing pressure. Plots to be spelled were closed up when roughly 50 mm of rain had fallen in two days. Early wet season spelling periods were for six weeks following the date of closure. Full wet season spells were from the date of closure until the usual end of the wet season in April.

The five treatments in each paddock were:

- Continuous grazing i.e. no spelling
- Early wet season annual spelling
- Full wet season annual spelling
- Early wet season biennial spelling
- Full wet season biennial spelling

9.2.2. Measurements

Twelve permanent 0.25 m^2 quadrats were established in each plot and recorded in detail to follow changes in plant population dynamics and associated soil and pasture condition changes. The fixed quadrats were stratified based on the presence or absence of *B. ewartiana* i.e. in all plots the 12 quadrats contained an equal range of *B. ewartiana* densities from low to high. Measurements were made of perennial grass basal area and demography by successively plotting the area of each perennial plant in each quadrat on gridded graph paper over time. Other measurements are listed in Jones *et al.* (2016).

9.2.3 Statistical analysis

The pasture parameters at each sampling date were analysed by analysis of variance using a randomised block design. Initial values of any quadrat parameter being analysed (before treatments were applied) were used as covariates in a covariate analysis. Analyses were performed using GENSTAT (release 18.1, VSN International, Hemel Hempstead, UK). For conciseness, the detailed statistical outcomes are not presented in this report (see Appendix 14) for more detail)

9.3 Results

9.3.1 Seasonal conditions

Three years of well above average rainfall and good growing conditions preceded the establishment of the spelling trial in 2012 (Figure **3**). All plots were burnt when the Wambiana trial site was burnt in October 2011 as described earlier. The whole site was then then spelled for three months post fire until cattle were reintroduced in February 2012 (see section 4.5).

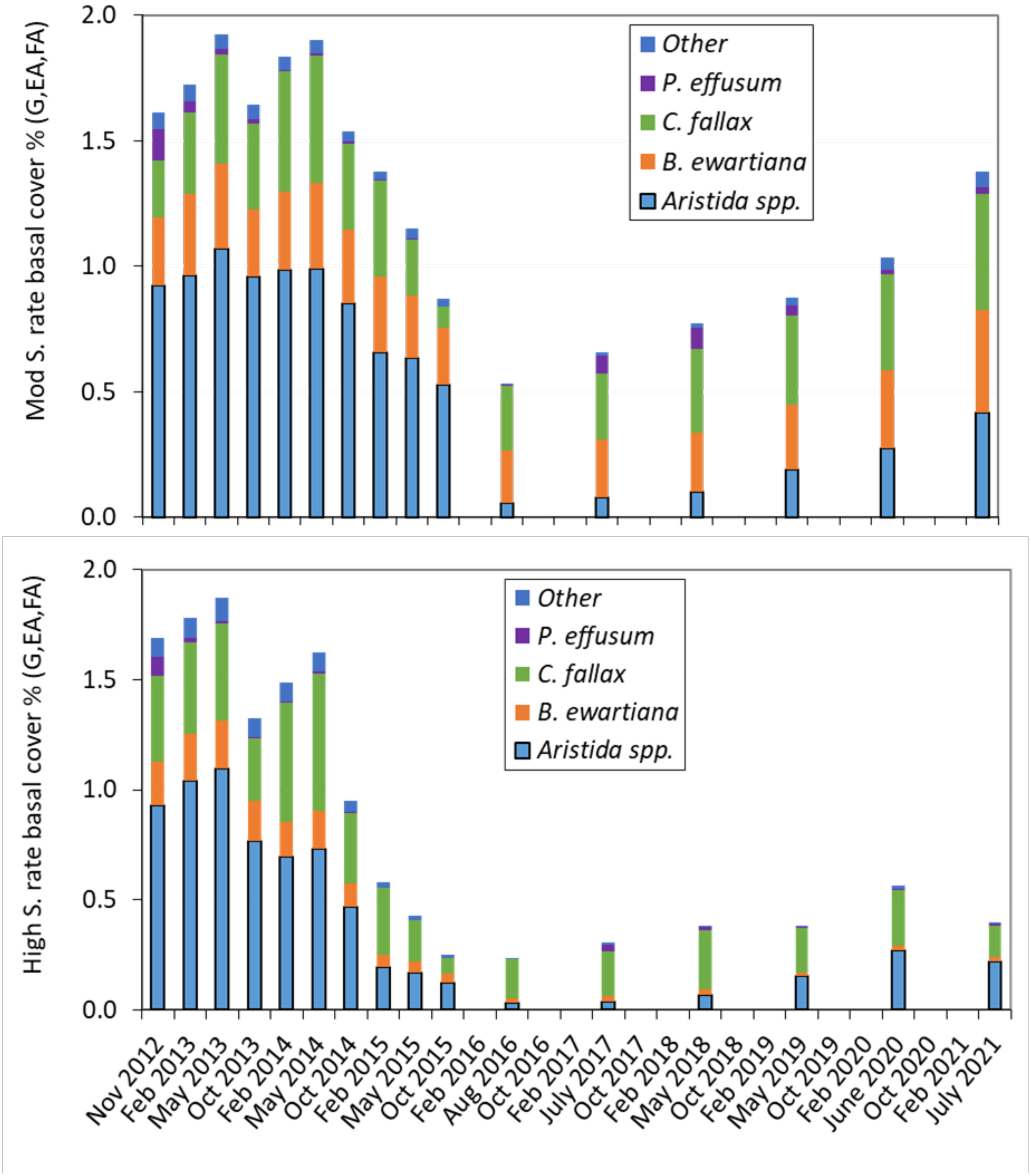
The first year of this trial (2012/13) had average rainfall (601 mm) and growing conditions. Thereafter, conditions deteriorated markedly, with 2014/15 the fourth driest year (246 mm) in 112 years. While 481 mm fell between November 2018 to April 2019, and conditions have improved to 2021, pasture growth has been very poor due to the adverse effects of the preceding drought years on plant mortality and pasture vigour. These well below average growing conditions continued with a further deterioration in conditions in the 2021/22 season due to much reduced wet season rainfall and extreme summer temperatures.

9.3.2 Wet season spelling results

The basal covers measured in this study (<2 %) appear low but are within the range of basal covers commonly reported for these semi-arid areas (e.g. O'Reagain *et al.,* 2008; Ash *et al.*, 2011). Analysis of the data showed that the effect of spelling on the grasses studied was relatively minor compared to the overriding effect of season and stocking rate (Appendix 14). For present purposes, data was thus generally averaged over the spelling treatments and the results presented as means for the heavy and moderate stocking rates respectively.

The effect of stocking rate and seasonal conditions on the basal cover of a number of key species is shown in (Figure 22). While the extreme drought decreased basal cover under both moderate and heavy stocking, its impact was evident some two years earlier under heavy compared to moderate stocking. Moreover, the recovery in basal cover in 2018 when conditions improved was also substantially lower under heavy than under moderate stocking.

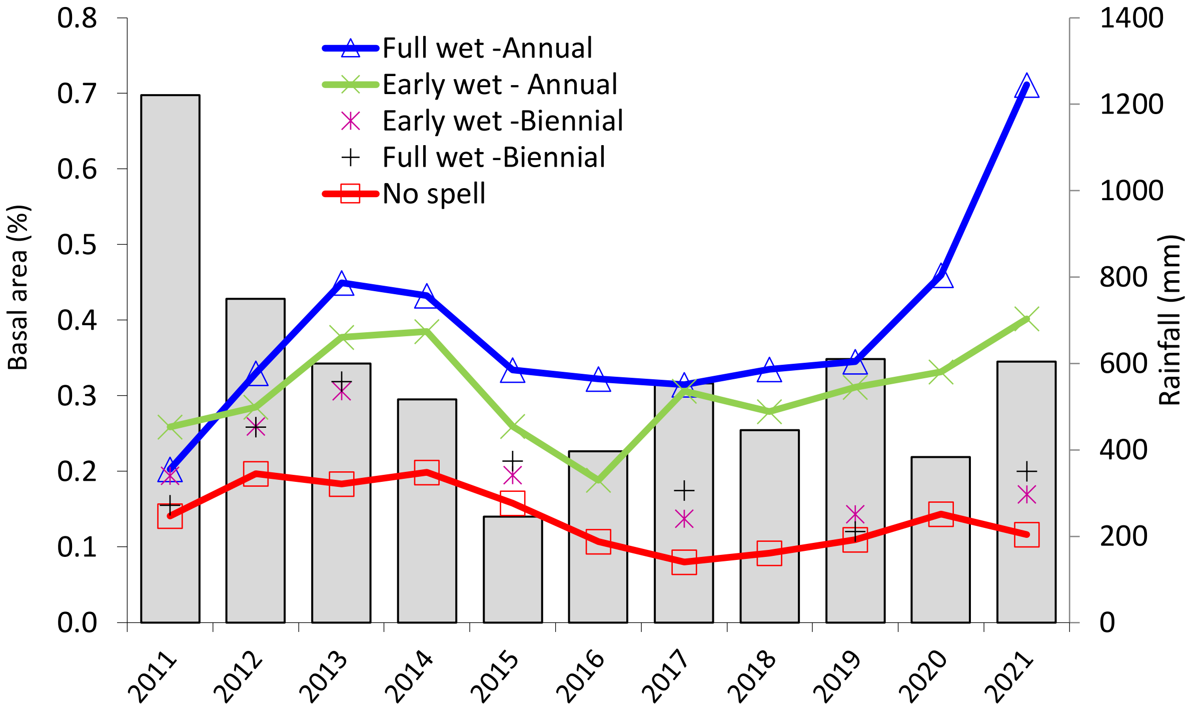
Figure 22 The change in perennial grass basal cover through the recent drought under (top) moderate stocking, and (bottom) heavy stocking rates. Note the data for each date is averaged across all spelling treatments



At the beginning of the spelling trial in November 2012, basal cover was mainly comprised of *Aristida* spp., which are generally considered as 'increaser' species of little forage value. Equal proportions of the more desirable species *C. fallax* and *B. ewartiana* were also present under both moderate and heavy stocking rates. However, by May 2018 *C. fallax* had become the dominant component of basal cover under both heavy and moderate stocking, indicating its resilience to heavy stocking rates. In contrast, *B. ewartiana* and Aristida spp. had almost disappeared under heavy stocking. Under moderate stocking, *B. ewartiana* largely maintained its basal cover despite the drought. The weaker perennial grasses *Digitaria* spp and *P. effusum* declined sharply with drought as did *H. contortus*, which has yet to show any recovery. Data collected in July 2021 indicated that basal cover was continuing to increase under moderate stocking but was still at a very low level under heavy stocking.

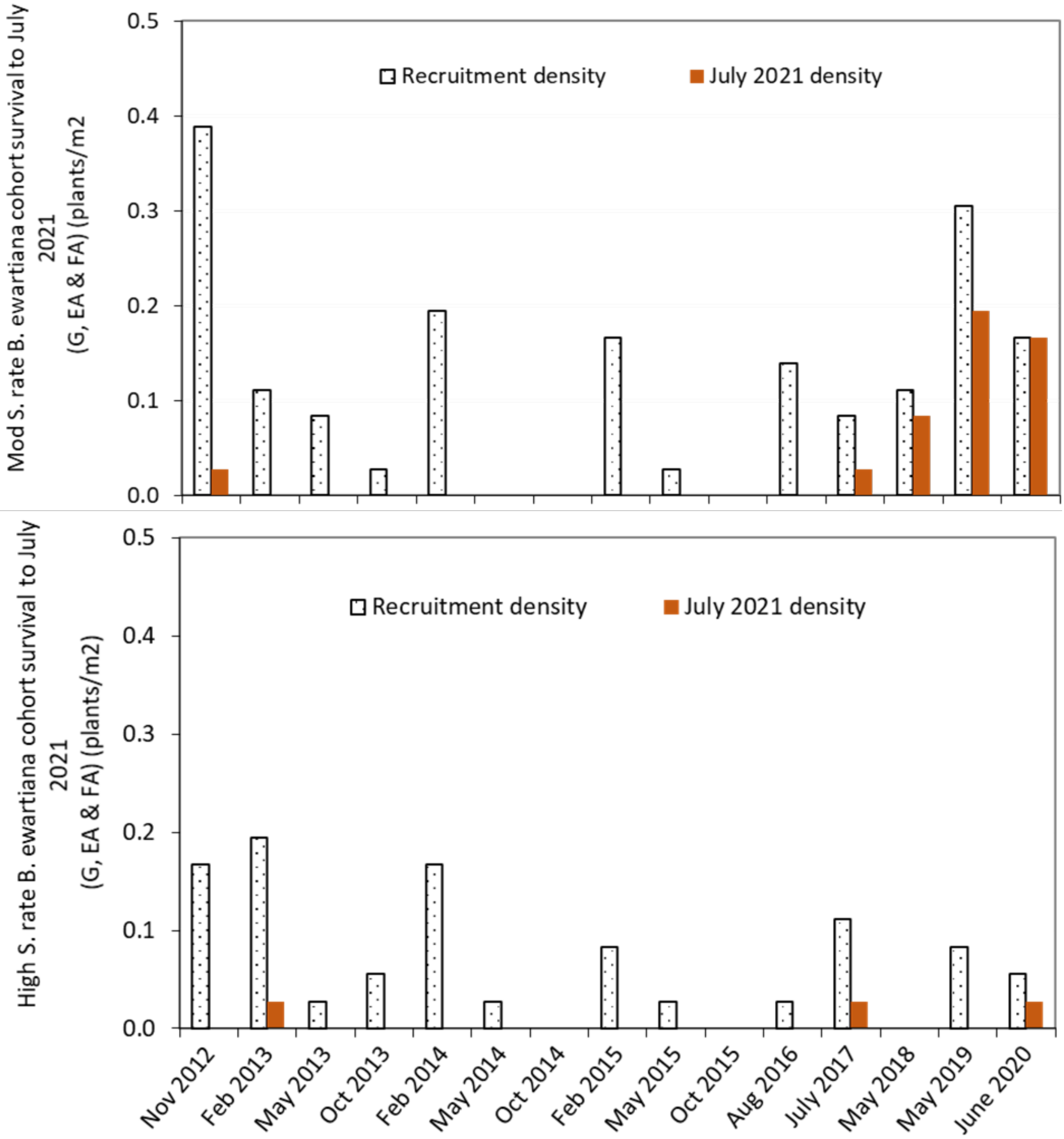
Spelling resulted in a small but non-significant increase in basal cover of *B. ewartiana* and *Aristida* spp. relative to non-spelling, but only under moderate stocking. The increase in *B. ewartiana* basal cover was greatest with full wet season, annual spelling with biennial spelling seemingly of little benefit (Figure 23). This trend of increasing cover coincided with the marginally improved seasonal conditions since 2019. Overall, pasture parameters were thus more affected by seasonal conditions and stocking rate than by the spelling treatment imposed.

Figure 23. The response of *B. ewartiana* basal cover to different spelling regimes compared to no spelling under moderate stocking. There were no significant differences between any of the spelling treatments and the control (no-spelling).



Despite the generally unfavourable conditions, a small number of *B. ewartiana* seedlings recruited nearly every year. However, as of July 2021 the survival rate of these plants was relatively low. Nevertheless, the survival rate of *B. ewartiana* seedlings under moderate stocking increased as seasonal conditions marginally improved, at least to July 2021 (Figure 24). Whether these recruits survive the low rainfall and extreme temperatures of the 2021/22 'wet' season remains to be seen.

Figure 24 Annual recruitment density of *B. ewartiana* between 2012 and 2021 (speckled bars) with the subsequent survival of each year cohort to 2021 (orange bars) under (top) moderate stocking, and (bottom) heavy stocking rates. Note the data for each point is averaged across the spelling treatments.



9.4 Discussion

The responses of the different grass species in the present study to the drought and stocking rate can be partly explained by the life histories and growth strategies of the species involved. *C. fallax* is a long-lived perennial grass with an estimated lifespan of more than 30 years (Orr and O'Reagain, 2011). It has underground stems or rhizomes that protect its basal meristems from grazing which explains its apparent resilience to drought and heavy stocking rates. This suggests that *C. fallax* may have a competitive advantage over *B. ewartiana* under heavy stocking and will probably become the dominant perennial grass in this treatment.

B. ewartiana is also a long-lived species (Orr and O'Reagain, 2011) but lacks below-ground rhizomes and has growing points on the base and stems making it susceptible to heavy, close grazing. Despite the drought, it has largely maintained basal cover under the moderate stocking rate due to a greater survival of original plants, greater recruitment and lower plant mortality compared to the heavy stocking rate treatment.

In comparison, *Digitaria* spp., *H. contortus, P. effusum* and Aristida spp have had big population fluxes in line with the highly variable rainfall. These species are relatively short-lived perennials but produce more viable seed and have far bigger seedbanks than *B. ewartiana.* Their populations can hence recover relatively quickly from seed post drought. *H. contortus* in particular can have big population fluctuations from year to year with almost 100 % mortality of adult plants in a drought year, followed by mass seedling recruitment the next (O'Reagain *et al.,* 2008). In contrast, *B. ewartiana* is far more stable with relatively little variation between years. Accordingly, it is the keystone species due to its high productivity and ability to survive and provide ground cover during drought.

The recovery of key productive and long lived species like *B. ewartiana* appears to be limited by low seed production and probably, inefficient seed dispersal. This reflects the overall growth strategy of many long lived perennial grasses of consolidating soil resources around the tussock and recruiting vegetatively via tillering (O'Connor, 1991, O'Connor and Pickett, 1992). As a result, soil seedbanks are small (and localised) as shown from the seedbank studies at the study site reported previously (Jones *et al.,* 2016; Appendix 14).

Spelling to achieve pasture recovery via recruitment of more desirable species like *B. ewartiana* will thus probably require time frames in the order of 10 years or more, with appropriate sequences of favourable seasons before substantial increases in such species occur (Orr and Phelps, 2013). In the interim, there would be expected to be increases in other useful, albeit shorter lived grasses like *Panicum* and *Digitaria* as reported for the *Ecograze* study (Ash *et al.,* 2011). However, the extent to which such species limit or alternatively, facilitate recruitment and recovery of *B. ewartiana* is unknown and requires investigation. This is particularly true of the stoloniferous exotic *B. pertusa* which forms dense lawns in better seasons which could easily competitively exclude more desirable species like *B. ewartiana*.

The extreme, dry conditions experienced over most of this study period resulted in high mortality and low levels of recruitment and survival of the key perennial grasses. This effect was exacerbated under heavy stocking. However, *B. ewartiana* and *C. fallax* were both able to maintain basal area under moderate stocking, with *B. ewartiana* having a slightly improved survival of seedlings in later years. The larger, original plants of *B. ewartiana* that survived the drought, began to increase their basal area when spelled with the slowly improving seasonal conditions from 2019 onwards. This emphasises the supreme importance of managing to maintain existing established plants through a drought so that a core population exists to drive recovery when conditions improve.

The present study has demonstrated that rainfall and stocking rate are key drivers of pasture condition. This emphasises the overriding importance of managing stocking rates. While the extreme drought was a direct cause of significant mortality of 3P species, the data clearly show that heavy stocking rates amplified this effect with the decline in basal cover occurring earlier and being more severe, than under moderate stocking. While post drought conditions have not been particularly favourable, some recovery has started to occur with spelling under moderate stocking. In contrast, little or no recovery has occurred even with spelling in the heavy stocking rate treatment.

The relatively subdued responses to wet season spelling reported here are in contrast to the significant improvements in pasture condition and yield reported in the Ecograze study (Ash *et al.,* 2011). The present, weaker response may be attributed to a number of factors. First, the fertility of soil at the trial site is inherently lower than the goldfields and basalt soils of the some of the Ecograze study sites. Second, the classification of species as 3P was stricter in the present study; for example species like *Digitaria brownii* and *Panicum effusum* were classified as 3P species in the Ecograze study but as 2 P species here. Such species are not only relatively shorter lived, but also respond faster to improved seasonal conditions or management than most 3P species.

The present results are important for informing management, but importantly, the responses to spelling may be different under other circumstances. First, the present site was in relatively poor C condition in 2011 when the study began after 14 years of heavy stocking. As such, the legacy effects of this previous heavy grazing would undoubtedly have slowed recovery even in those plots which were transferred to 'moderate stocking' in 2012. Second, the severe drought in 2014/15 and the subsequent run of below average rainfall years would also have constrained the response to spelling. With a more favourable sequence of years to promote seeding and allow seedlings to recruit to adulthood, the response may have been greater. Continuing this study for a further five years will thus be important to allow the opportunity for a run of favourable seasons to occur.

Third, at the paddock rather than the small plot scale, spelling would also at least allow the recovery of heavily selected areas or landtypes and possibly prevent permanent degradation. Coupled with fire, spelling would also promote the redistribution of patch grazing allowing overgrazed patches to recover. Taken together, this suggests that a stronger response to spelling may possibly occur at the paddock scale given more favourable seasonal and starting conditions.

These limitations aside, the present results emphasise the fact that without the appropriate stocking rates, spelling is unlikely to improve pasture condition and will be a largely futile exercise, as noted by Scanlan *et al.* (2014). Spelling is obviously important for pasture recovery but on these and other lower fertility soil types, recovery is likely to be a longer term process. It is possible that recovery could be accelerated with other combinations of spelling and grazing, e.g. very short grazing periods and extended spelling such as those promoted by multipaddock systems. These will be investigated if the planned next stage of this project is approved.

9.5 Summary

1. Drought had a major impact on basal cover under both heavy and moderate stocking rates. However, heavy stocking amplified the effect of drought with basal cover declining two years earlier and to a greater extent under heavy compared to moderate stocking.
2. Drought caused a major decline in Digitaria spp., *P. effusum, Aristida* and the 3P species *H. contortus*. In contrast, *B. ewartiana* largely maintained its basal cover under moderate stocking, due to greater survival of existing plants and some recruitment.
3. *C. fallax* was also persistent and drought tolerant but unlike *B. ewartiana* survived under both heavy and moderate stocking.
4. *B. ewartiana* is long lived but recruitment is limited by low seed production and poor survival rates of recruits. It is therefore important to maintain a viable population of existing plants through drought to drive recovery when seasonal conditions improve.
5. While there was little or no recovery with spelling under heavy stocking, spelling resulted in a small but non-significant improvement in basal cover of *B. ewartiana* under moderate stocking.

This subdued response likely reflects the legacy effects of the recent drought as well as the previous history of heavy grazing of the spelled plots.

6. Stocking rate was a far greater determinant of condition and recovery than spelling. This emphasises the fact that spelling without application of the appropriate stocking rate is unlikely to promote recovery.
7. While the relative benefits of spelling reported here appear small, results from other studies and producer experience emphasise its importance in maintaining land condition. Nevertheless, spelling to improve pasture condition via recruitment is likely to be slow and depend upon a favourable sequence of years to get significant results. Despite that, spelling remains a key component of good pasture management.

10. Development of advanced decision tools to predict forage quality

A key management challenge in a highly variable environment is to estimate forage quality and quantity accurately, so as to make management decisions such as destocking or supplementation in a timely manner. Typically, this is done using a combination of cues such as visual estimates of pasture yield and greenness, rainfall, soil moisture and animal condition. The challenge is exacerbated on large properties, with widely dispersed herds and the spatial heterogeneity of paddocks and rainfall distribution. An obvious potential solution is to use satellite-derived information, with or without modelling, to develop decision tools to assist managers to rapidly respond to changing conditions. In this chapter we address this need stated in Objective 5 to:

- Have further developed advanced decision support tools to assist beef producers increase profitability and sustainability through better management of the feedbase.

This chapter focuses exclusively on predicting forage quality using the long term Wambiana data, with chapter 11 focussing on a number of tools to predict or estimate forage availability and stocking rates at the paddock level.

10.1 Forecasting paddock forage quality from satellite data

A summary is provided here of the collaborative work conducted by this project with Matt Pringle, John Carter and other colleagues at the Department of Environment and Science (DES) to develop a satellite-based tool to predict and forecast paddock forage quality using the long term diet quality data from the Wambiana trial. A full description of the methodology and results is provided in the paper published in Ecological Indicators by (Pringle *et al.*, 2021) titled '*Using remote sensing to forecast forage quality for cattle in the dry savannas of northeast Australia*' (see Appendix 3).

10.1.1 Methodology

Faecal samples have been collected every three weeks from all paddocks at the Wambiana trial since 1998. Samples were dried and then analysed using near infra-red spectroscopy (NIRS) to estimate dietary quality (Coates and Dixon, 2007). Data was first collated for the years 1998 to 2018. This was a significant challenge as a number of calibration equations had been used to predict dietary crude protein (CP) and *in vitro* digestibility (IVD) of faecal samples in different batches over the years. This had occurred as calibration equations were successively improved, operators retired and laboratories changed. Initially (1998-2009) all samples were analysed by David Coates (CSIRO). Thereafter, samples were analysed by Peter Martin at the Department of Agriculture and Fisheries (DAF) former Animal Research Institute (2009-2011), with later samples (2012-2018) analysed by Peter Isherwood at the University of Queensland, Gatton.

To ensure that NIRS predictions from different batches could be validly compared across years, the original NIRS spectral scans of all 2938 faecal samples first had to be found. Fortunately, all but 155 of these sample scans were eventually located by Rob Dixon (Queensland Alliance for Agriculture and Food Innovation) and Peter Isherwood. These scans then had to be rerun using the latest calibrations developed by Rob Dixon as described in Milestone 3. The CP and IVD predictions from the 155 missing scans were then adjusted using regression equations developed from the new versus the original predictions of the 2783 located scans. The complete, standardised data set has been processed and collated and is stored on the DAF Charters Towers server.

Statistical modelling was then used to demonstrate a proof-of-concept for how on-ground measurements of forage quality for cattle can be linked with the information derived from satellite imagery. The remote sensing-based information was derived from an archive of Landsat surface-reflectance imagery and used the ratio of 'green grass' (Fractional green cover) cover to 'dead (i.e. non-photosynthetic) grass' cover (Fractional dead cover) here termed the green:dead ratio (GDR). The dates of satellite observations and collection of faecal samples did not have to be temporally coincident, partly because of the lag between ingestion of forage and detection of its quality in the faeces and partly because of the extended periods within and between the wet and dry seasons. For this study, only data from the HSR and MSR treatments was used.

10.1.2 Results and discussion

As mentioned above, the full results of this collaborative project are presented in the attached paper by Pringle et al (2021) titled '*Using remote sensing to forecast forage quality for cattle in the dry savannas of northeast Australia*' (see Appendix 3).

Results suggested that in Australia's dry savannas, it is possible to forecast monthly-average forage quality ahead from the end of May (i.e. approximately the end of wet season), into the relatively lean winter months: dietary crude protein (DCP) was forecast with a median absolute error (MAE) of 0.86%; dry-matter digestibility (DMD) was forecast with MAE = 0.95%. The uncertainty of a forecast is explicitly acknowledged; uncertainty increases with each month after May, but, regardless of the form of the model, is difficult to reliably quantify.

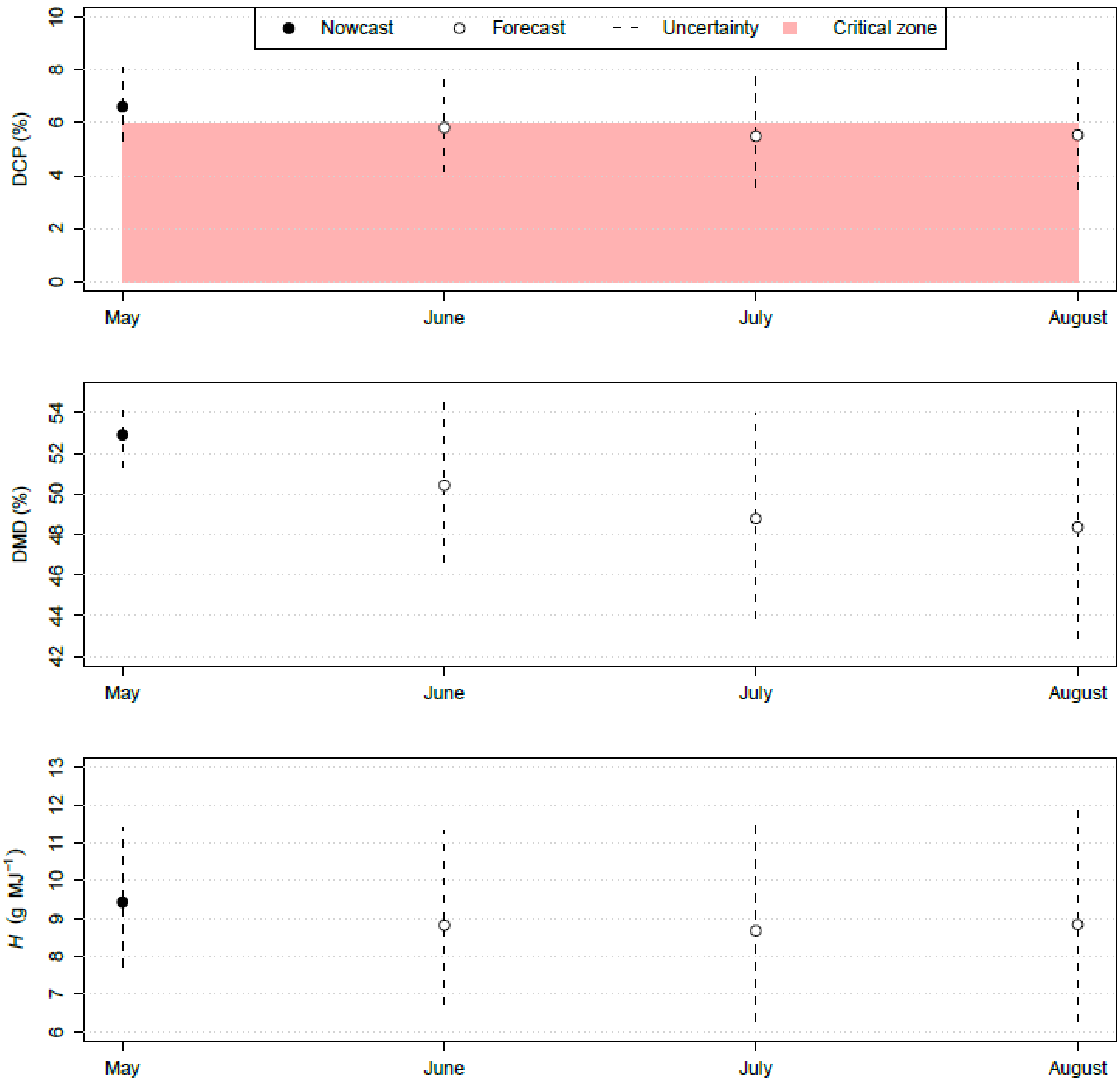
To the best of our knowledge, our study is the first to successfully link forage quality for cattle with remotely sensed information, over a multi-year period. Previous research at the Wambiana grazing trial has linked forage quantity, in the form of total standing dry matter, with remotely sensed information (Schmidt *et al.*, 2016), but did not examine forage quality. The results of our study suggest that, in a southern hemisphere dry savannah that is dominated by C4 grassland, it is possible to forecast monthly-average forage quality ahead from the end of the wet season (approximately May) into the first three months of the dry season, albeit with increasing uncertainty. The end of the wet season is a critical time of year when management interventions may be required to prevent losses in animal production.

A number of previous studies have related forage quality to remotely sensing information: some from faecal sampling (Villamuelas *et al.*, 2016) others with forage quality determined from less-desirable hand-clipped samples. Of these studies, the period of forage-quality sampling was, at most, five years. While (Geremia *et al.*, 2019) tracked pasture green-up with satellite data over 16 years, actual forage quality was only measured in a single five-month period. Possibly the longest was an 11 year study that tracked diet quality estimated from faecal N in desert bighorn sheep over an 11-year period (Creech *et al.*, 2016). In comparison, our study is based on 23 years of forage-quality data, collected from cattle faeces at approximately 3-week intervals. In regard to remote sensing, our analysis was driven by the variable GDR, defined as the cover ratio of 'green grass' to 'dead grass'. GDR had a slightly stronger correlation with forage quality than the conventional NDVI (Appendix 2 Table 1), and makes biological sense given that cattle select strongly for green, rather than dead, forage. Furthermore, by correcting for leaf-litter, we hope that our Landsat-based GDR values can be robustly extrapolated to different landscapes.

Forage quality, particularly DMD, tended to be significantly lower under heavy stocking (Appendix 4: Table 3), although this was dependent on rainfall. The HSR treatment has become associated with a scarcity of palatable perennial species, due to overgrazing. The generally lower quality diet of cattle in the HSR treatment leads to reduced liveweight gain (O'Reagain *et al.*, 2018). However, in years with well-distributed rainfall, the constant supply of short-lived, green regrowth in the HSR treatment allows cattle to select a diet that is, at least in terms of DCP, of relatively high quality.

There is a demand for decision-support tools to assist land-managers in the extensive grazing enterprises of northeast Australia, to make more-informed decisions. Following further development and appropriate testing at other sites, we ultimately anticipate packaging forecasts of forage quality as a simple product. In May of a year of interest, such a product could be available on request for a particular paddock, delineated by the user. The optimised parameters of Model 3 would then be combined with the 100 most-recent local observations of GDR and user-provided DCP or DMD. Predictions for May (the 'nowcast') and forecasts for June to August would be returned, including the ratio of protein to metabolisable energy. We follow (Dixon and Coates, 2010) and set 6% as a threshold for DCP. This is less than the requirement for cow maintenance but acknowledge that operationally the value depends on factors such as the class of cattle and the target market. In the example in Figure 25, it is apparent that the forecast is less-than-desirable.

Figure 25 A prototype summary of results for an individual paddock, representing: the 'nowcast' at the end of May (current status); forecasts for the three following months; and the critical zone (coloured), within which animal nutrition will decline. This example is for the Wambiana study site at the end May in 2019, assuming that stocking rates are moderate. DCP = digestible crude protein; DMD = in vivo dry-matter digestibility; H = ratio of protein to metabolisable energy).



A graphical tool such as the above could, when combined with other sources of information such as seasonal forecasts or ground cover (e.g. www.longpaddock.qld.gov.au), prompt a land-manager to intervene with supplementation, or perhaps reduce the number of animals held. Such a system would be an advance on the conventional industry practice, where forage quality is acknowledged to be crucial to cattle production but is difficult to monitor. Ultimately, the aim is to forecast not just forage quality, but animal liveweight gain; unfortunately, the data to support such an advance is currently too limited.

We envisage packaging these forecasts into a near-real-time system that can inform a land-manager of a paddock's forage quality in May of the current year, but also forecast the likely trend. Such a system would be an advance on the conventional industry practice, where forage quality is difficult to monitor reliably. Future research will involve testing the current model at more locations and investigating alternative explanatory variables for the model.

In summary this proof of concept work showed that it is possible to predict and forecast forage quality with a reasonable accuracy for DMD, and a lesser but still acceptable accuracy for DCP from remote sensing and modelling. This shows promise as an operational tool for managers but will require more work at other sites, and also a deeper investigation of modelling alternatives before that can occur.

10.2 Estimating forage quality from remotely sensed indices

10.2.1 Introduction

Work was conducted to develop relatively simple remote sensing based tools to aid in grazing management. This follows preliminary efforts by Leigo *et al* (2016) in the *Precision Pastoral Management Project* where the Normalised Difference Vegetation Index (NDVI) was used as a management tool and related to cattle weight gains. Recent work in the '*eBeef*' project plotted the trajectory of the NDVI over the wet season and then used the rate of decline to estimate the likely date when NDVI would fall below the threshold level (here 0.2) where diet quality was likely to be limiting (D. Phelps, DAF, Longreach, *pers. comm*.).

Here we related long term diet quality data from the Wambiana trial to remotely sensed based indicators through the grazing season. These relationships were then scrutinised to identify inflexion points where diet quality declined below critical levels for animal production. These were then used to develop and test a simple classification tool that would allow forage quality to be classified from remotely sensed data as being below or above animal maintenance energy and protein requirements.

10.2.2 Methodology

Dietary quality was estimated from faecal samples collected approximately every three weeks from both replicates of all five different grazing strategies at the Wambiana trial. Samples were then analysed using near infra- red spectroscopy (NIRS). For the present project, all faecal data was collated for the years 1998 to 2020 as described above in section 10.1.1.

Remote sensing data from Landsat imagery held by Department of Environment and Science was processed and collated for each paddock as described previously by Pringle *et al* (2021). The remotely sensed indicators used were the normalised difference vegetation index (NDVI), fractional green (FrGreen) cover and the ratio of FrGreen to fractional dead cover (FDR) using the methodology developed by Scarth (2010a). This method identifies tree and shrub cover as 'persistent green cover' i.e. green during the dry season, and the analysis adjusted accordingly. Consequently, FrGreen cover largely represents the greenness level of only the herbaceous layer.

The remotely sensed variables of FrGreen and FrDead were then related to NIRs dietary IVD and CP by matching faecal sample dates with those of Landsat passes as closely as possible. Where dates did not exactly correspond, data was used from the nearest pass within the last 10 days. Alternatively, NDVI, FrGreen and FrDead data was averaged from dates on either side of NIRS sample dates, provided there were no significant events (rainfall, extended dry periods) that could have appreciably changed NDVI or FrGreen values.

Analyses were initially conducted using diet quality data from all treatments. However, in an attempt to minimise instances where forage shortages may have adversely affected diet quality, data was only considered from the MSR and R/Spell treatments. In total there were 22 years of NIRS and satellite data every 3 weeks apart. There was however, no NIRs data following the 1999 fire (three months), before and after the 2011 fire (nine months) and the six months from January to June 2018 when the MSR & and R/Spell paddocks were destocked.

10.2.3 Results and discussion

10.2.3.1 Relationship between diet quality, NDVI and FrGreen cover

To explore general relationships between diet quality and remotely sensed variables, IVD and CP were related via linear regression to NDVI, FrGreen and the FrGreen/Dead ratio. Dietary CP and IVD in MSR & R/Spell was correlated with NDVI, FrGreen, and FrGreen/dead ratio over all years and all months (Table 8) but as expected was negatively correlated with FrDead (n=1031).

Table 8 Relationship (r^2) for the relationship between dietary CP and IVD with NDVI, FrGreen, FrDead and the FrGreen/Dead ratio. Data for the MSR and R/Spell treatments over all months.

	NDVI	FrGreen	FrDead	FrGreen: Dead
IVD	0.292	0.397	-0.247	0.442
CP	0.278	0.315	-0.328	0.368

The relationships were stronger for FrGreen than NDVI, and apart from FrDead, slightly better for IVD than CP (Table 8). This suggests that FrGreen cover is a better predictor of diet quality than NDVI. However, these correlations were not particularly high ranging from -0.247 to 0.397. The correlation of diet quality with FrGreen: Dead ratio was highest for both CP (r=0.368) and IVD (r=0.442).

When relationships were explored at the paddock level, there was considerable variation in the strength of these relationships between paddocks (data not shown). However in all cases FrGreen cover was a better predictor of diet quality than the NDVI with the relationship consistently stronger for IVD compared to dietary CP.

The positive relationship between diet quality and both NDVI and FrGreen over all months of the year is not unexpected as there would obviously be times such as the mid dry season when diet quality would be low simply due to the absence of green grass. Similarly, in the mid wet season, quality would be high because of the ready abundance of green material. A more pertinent question would be how diet quality relates to FrGreen or NDVI in the late wet/early dry season when diet quality is declining, and management decisions on supplementation or marketing are critical. The rest of the year will be either the dry season or wet season when it should be reasonably obvious as to whether supplementation is required or not. Accordingly, to address this question these relationships were explored using only data from the late wet season, here defined as March to July (Table 9).

Table 9 Relationship (r^2) between dietary CP and IVD in the MSR and R/Spell treatments and four remote sensing indices for the late wet season only (March -July).

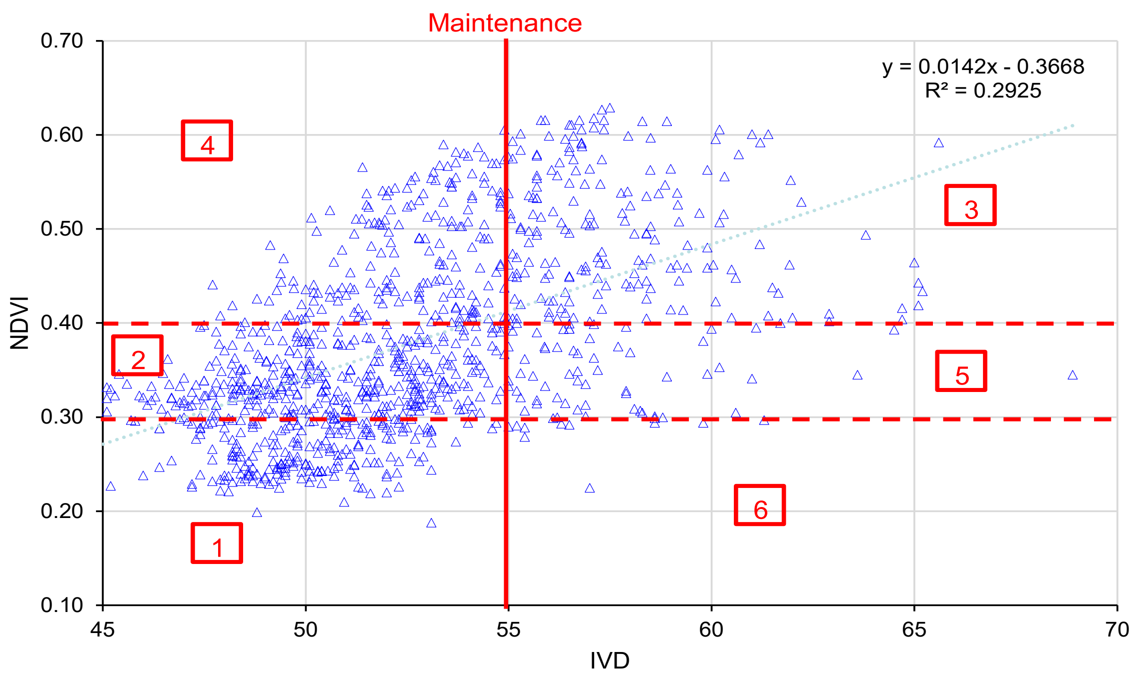
	NDVI	FrGreen	FrDead	FrGreen: Dead
IVD	0.151	0.252	-0.364	0.334
CP	0.268	0.297	-0.394	0.375

Overall, the relationships between diet quality and remotely sensed indices were weaker in the late wet season compared to data over the whole season. This is to be expected for the reasons given above. For both CP and IVD correlations were better with FrGreen than with NDVI (as found when taken over all months). However, in contrast to NDVI, the relationship was stronger for CP (r=0.297) than for IVD (r=0.252) but these values are still relatively low. As before, the best correlation was with the ratio of FrGreen: Dead for both CP (r=0.375) and IVD (r=0.334).

10.2.3.2 Management tools to predict forage quality

To explore the utility of the NDVI and FrGreen signals as simple tools to predict diet quality relative to maintenance requirements to inform management decisions, scatter diagrams relating diet quality to these variables were investigated. These indicated that dietary IVD generally fell below a maintenance level of 55% at a threshold NDVI of less than 0.3-0.4 (**Figure 26**). Dietary CP also fell below a maintenance level of 7 % at these levels (not shown). A similar threshold effect for IVD and CP was also observed with FrGreen cover (not shown).

Figure 26 Dietary in vivo digestibility (IVD) vs NDVI for the MSR and R/Spell from 1998 to 2019. Solid vertical line = maintenance for a mature cow. Numbered text boxes refer to the classification relative to maintenance IVD and NDVI (see text for details).



Based on this, data was initially divided into six classes thought to be of potential use to inform management decisions (Table 10).

Table 10 Categories used in assessing the extent to which NDVI or FrGreen could correctly classify dietary *in vivo* digestibility (IVD) and crude protein (CP) relative to maintenance levels for a cow.

Category	NDVI or FrGreen	IVD %	CP%	Definition
1	<0.3	<55	<7	Correctly classifies IVD or CP as < maintenance.
2	0.3-0.4	<55	<7	Correctly classifies IVD or CP as < maintenance.
3	>=0.4	>=55	>=7	Correctly classifies IVD or CP as > maintenance.
4	>0.4	<55	<7	Incorrectly classifies IVD or CP as > maintenance
5	0.3-0.4	>55	>7	False alarm- IVD and CP adequate for maintenance.
6	<0.3	>55	>7	False alarm- IVD and CP adequate for maintenance.

For simplicity and practicality these categories were then grouped as follows:

- **Correct** (categories 1,2 & 3) - correctly classifies diet as either above or below maintenance.
- **Incorrect/fail** (category 4) - fails to identify diet is below maintenance.
- **False alarm** (categories 5 & 6) - incorrectly identifies diet as being below maintenance.

The distinction between 'failed' and 'false alarm' was based on the reasoning that the consequences of not supplementing when diets were below maintenance could be significant in terms of economic loss due to lost animal production. In contrast, a 'false alarm' could result in supplementation being provided when it was not required. However, the economic consequences would be far smaller because the supplement would not be wasted through decay should the animals not immediately consume it and would likely consume it later in the dry season anyway.

Classifications were then conducted for all data over all years and the number of 'correct', 'fails/incorrect' or 'false alarm' classifications counted and presented as a percentage of the total number of data points. To explore whether the type of year in terms of rainfall had any effect on outcomes, years were categorised as either dry years (annual rainfall <400 mm), wet years (rainfall>800 mm) or average years (rainfall 400-800 mm) with classifications then done separately for each of these three year types.

Table 11 Error matrix for feed quality, describing the consequence of getting a prediction correct or incorrect. ('Poor quality' is defined based on maintenance requirements of an animal class).

	Observed 'poor quality'	Observed 'good quality'
Predicted 'poor quality'	Supplementing or destocking applied	Some cost associated with unneeded action
Predicted 'good quality'	Lost opportunity for animal production	No action required

10.2.3.3 Classification of forage quality using NDVI

The results of the classifications of dietary CP and IVD over all months for cows based on maintenance requirements of 7% for CP and 55 % for IVD respectively are shown in Table 12. Overall the NDVI was reasonably accurate in discriminating between situations where diets were below maintenance for cows with an overall accuracy of 73% for IVD and 75 % for CP. Nevertheless, the number of 'fails' where diets were estimated to be above maintenance suggesting that no action was required was 19 % for IVD and 12 % for CP. However, discriminating between years based on rainfall showed that the accuracy for IVD was considerably higher for dry years (83 %) with only 8% of fails.

In contrast, accuracy in predicting IVD was lowest for wet years (66%) with more significantly, nearly one third of situations, failing to detect below maintenance IVD levels. The accuracy of classifying forage CP across all years was similar to that of IVD (75%) but the decline in accuracy in wet years was far less marked with only 19% of classification 'fails. The reduced accuracy in wet years particularly in IVD is logical: in wet years, swards may remain green giving a high NDVI or FrGreen reading late into the season but digestibility may be relatively low due to increased stemminess and lignification. In contrast, CP levels may still remain relatively elevated in such years by simple virtue of the presence of chlorophyll protein in plant tissue.

Table 12 Cows: Accuracy of classifications of dietary IVD and CP as being above or below maintenance levels for cows based on a threshold NDVI of 0.3-0.4 for average, wet and dry rainfall years. (*n=number of NIR samples classified*). *See text for details.*

	All years	Average years (400-800 mm)	Wet years (>800mm)	Dry years (<400 mm)
In vivo digestibility: Maintenance 55%				
	n=978	n=529	n=220	n=229
Correct	73%	72%	66%	83%
Failed	19%	19%	31%	8%
False Alarm	8%	9%	2%	9%
Crude Protein: Maintenance 7%				
Correct	75%	71%	75%	82%
Failed	12%	12%	19%	7%
False Alarm	8%	17%	6%	10%

The ability of NDVI to classify forage quality above and below maintenance was also explored for steers *(*Table 13*).* With steers having lower maintenance requirements, the chances of a false alarm (a false positive) i.e. diets being above maintenance despite NDVI being below the threshold, increased by 2 to 15-fold depending upon the year type, relative to cows. However, the chances of failing to detect below maintenance CP or IVD declined from about 19% for IVD and 12 % for CP down to 2 and 4 % respectively i.e. there was a much lower chance of failing to detect low forage quality with steers compared to cows.

Table 13 Steers: Accuracy of classifications of dietary IVD and CP as being above or below maintenance levels for steers based on a threshold NDVI of 0.3-0.4 for average, wet and dry rainfall years. (n=number of NIR samples classified). See text for details.

	All years	Average years (400-800 mm)	Wet years (>800mm)	Dry years (<400 mm)
In vivo digestibility: Maintenance 50%				
	n=978	n=529	n=220	n=229
Correct	60%	56%	70%	62%
Failed	2%	1%	1%	3%
False Alarm	38%	42%	30%	35%
	Crude Protein: Maintenance 5.5%			
Correct	68%	64%	78%	69%
Failed	4%	4%	7%	3%
False Alarm	28%	33%	15%	29%

There was also a reduction in the number of correct classifications from 7 to 21 % for steers relative to cows in most year types. The exception was wet years when the % of correct classifications slightly increased. The number of false alarms also increased the most with IVD in wet years from 2 % in cows to 30 % in steers, although false alarms with CP% only increased two-fold. This probably reflects the fact that in wet years, while pastures may remain green, dietary digestibility can be relatively low due to the increase in stemminess with greater pasture yields, and for CP, the greater N dilution in the sward.

10.2.3.4 Classification of diet quality using fractional green cover

The ability of FrGreen to discriminate between different levels of dietary CP and IVD relative to maintenance was also explored for cows (Table 14). As before, classification were first run over all years and then for different year types based on rainfall as described previously. Exploratory analysis of scatter diagrams and preliminary classifications showed that the best results were obtained using a threshold FrGreen cover % of 0.4. In contrast a level of 0.3 reduced the accuracy of classifications particularly in wet years with up to 45 % of IVD classifications and 30% of CP classifications incorrect (data not shown).

Table 14 All months: Accuracy of classifications of dietary IVD and CP as being above or below maintenance levels for cows using a FrGreen threshold of 0.4 threshold for average, wet and dry years. (n=number of NIR samples classified). See text for details

All Years	All years	Average years (400-800 mm)	Wet years (>800mm)	Dry years (<400 mm)
In vivo digestibility: Maintenance 55%				
	n=1010	*n=551*	*n=222*	*n=237*
Correct	80%	78%	77%	86%
Failed	5%	3%	14%	0%
False Alarm	16%	19%	9%	14%
Crude Protein: Maintenance 7%				
Correct	72%	66%	74%	82%
Failed	2%	1%	7%	0%
False Alarm	26%	32%	19%	18%

Use of FrGreen cover improved IVD classifications slightly relative to the NDVI with the % of correct classifications increasing to 80% from 73% (Table 15). In contrast there was a slight decrease in the 'correct' classifications using FrGreen for CP%. More significantly, use of the FrGreen decreased the number of 'failed' classifications to a negligible amount for both IVD and CP. Although the number of 'false alarms' doubled for both variables, these are of far lesser consequence than failures to detect below maintenance situations.

Table 15: Comparison of classification success for forage quality using NDVI and FrGreen cover for dietary IVD and CP% for all months over all year types from 1998 to November 2019. See text for details.

	In vivo digestibility %		Crude Protein %	
	NDVI	FrGreen	NDVI	FrGreen
Correct	73%	80%	75%	72%
Failed	19%	5%	12%	2%
False alarm	8%	16%	13%	26%

As explained earlier the importance of correctly classifying diet quality in the late wet season would be of greatest practical value for making management decisions. Accordingly, classifications of dietary quality were made using only data collected from the approximate 'traditional' end of the wet season i.e. March to July (Table 16). Given the slightly stronger relationship between FrGreen and diet quality results are not presented for the NDVI classifications.

Table 16 Late wet season: Accuracy of classifications of dietary IVD and CP as being above or below maintenance level for cows using a FrGreen threshold of 0.4 for average, wet and dry years. (n=number of NIR samples classified).

Years	All years	Average years (400-800 mm)	Wet years (>800mm)	Dry years (<400 mm)
In vivo digestibility: Maintenance 55%				
	n=430	*n=236*	*n=91*	*n=103*
Correct	72%	69%	68%	82%
Failed	10%	7%	26%	0%
False Alarm	18%	23%	5%	18%
Crude Protein: Maintenance 7%				
Correct	69%	64%	67%	83%
Failed	5%	3%	16%	0%
False Alarm	26%	33%	16%	17%

Using a FrGreen cover level of 0.4, classifications using the late wet season data only, were slightly lower than for those using data from all months being correct for 72% of occasions for IVD and 69% of occasions for CP. There was also a big difference between year types with no decline in accuracy for dry years with more than 80% correct for both IVD and CP. Although there were approximately 17 % 'false alarms' importantly, there were no (0%) failed classifications. In contrast, the number of correct classifications in wet years decreased by 7-10% relative to using data from all months with the number of fails almost doubling. For average years, there was a slight decline in the number of correct classifications for IVD but there was no difference for CP %.

These results indicate that FrGreen cover can be used with relative confidence to classify diets in the late wet season relative to animal maintenance requirements. However, the variation in accuracy between rainfall year types shows that its accuracy will vary with the type of season.

10.2.4 Suggestions for further work

In the present study, NDVI and FrGreen values are paddock averages i.e. the average of all 30 by 30 m pixels within a paddock. However, paddocks consist of three landtypes with different soil water availabilities and hence rates of green-up/haying off. Cattle are also very selective both for and within landtypes, so diet quality may often only be relatively weakly related to a paddock's average greenness. Future research should investigate the relationship between diet quality and the FrGreen of individual landtypes or even patches. Identifying whether a threshold also exists between % of pixels above a certain threshold FrGreen value and diet quality would also be very worthwhile.

The conditions under which NDVI/FrGreen are more or less reliable for classifying diet quality need to be investigated. This would allow the factors that discriminate between correct and incorrect classifications to be identified and would allow confidence levels to be attached to predictions.

Factors to be investigated in particular are those affecting forage quality. These include wet season rainfall, days since start of wet season, previous year's rainfall, pasture TSDM, years since fire, accumulated growth days and land condition, out of season rainfall etc. The % non-grass in diets likely to be a particular problem as legumes would significantly increase diet quality particularly late in the wet season or in the early dry season without having any discernible effect on NDVI or FrGreen.

Preliminary analysis showed that if length of period since it last rained was greater than approximately 30 to 70 days, it was highly likely that IVDMD would be over 55 % i.e. even if NDVI was above threshold value, IVDMD would probably be limiting.

Lastly, possibly the most important factor that needs to be investigated is that of predicting or estimating forage availability at the paddock scale to guide management decisions around stocking rates. While forage quality is obviously very important, quality deficits can at least be partly remedied by provision of supplements such as urea which are relatively cheap compared to providing hay or agistment, which are far more expensive. In the next chapter we present three tools ranging in complexity and development that can be used to estimate paddock forage availability and/or stocking rates.

10.2.5 Summary

1. Dietary CP and IVD were positively related to NDVI and in particular FrGreen, but negatively related to FrDead cover. However, there was a large amount of variability in these relationships which is to be expected given the range of conditions over the 22 years of data collection.
2. Exploration of the relationships showed that both dietary CP and IVD tended to fall below animal maintenance requirements below thresholds of 0.3 and 0.4 for NDVI and FrGreen, respectively.
3. Using these thresholds, it was possible to classify data into different dietary quality classes relative to maintenance requirements and subsequently evaluate the accuracy of these classifications.
4. Three categories were developed where these thresholds either correctly categorised quality as above or below maintenance, incorrectly categorised quality as being above maintenance (a fail) or incorrectly categorised quality as being below maintenance (false positive, false alarm). Based on the likely consequences i.e. failure to intervene when quality was below maintenance, ‘fails’ were regarded as being more significant for production than ‘false alarms’.
5. Testing of these categories against the 22 years of data showed that the NDVI and particularly FrGreen, were of moderate to high accuracy in classifying forage quality into broad classes relative to maintenance.
6. The degree of accuracy varied between year types being highest for dry years and lowest for wet years. Accuracy was also higher for cows than that for steers i.e. than animals with lower maintenance requirements. Nevertheless, the chance of a ‘fail’ declined as maintenance requirements declined.
7. The level of accuracy of these thresholds declined only slightly when tested over the late wet season when diet quality is most likely to fall below maintenance levels and the timing of management interventions most critical.

11 Development of advanced tools to predict forage availability

As mentioned in Chapter 10, a key challenge for managers is estimating or predicting forage quality and availability. Here the focus is on the prediction of forage availability using tools based on long term Wambiana data on paddock yields and cover.

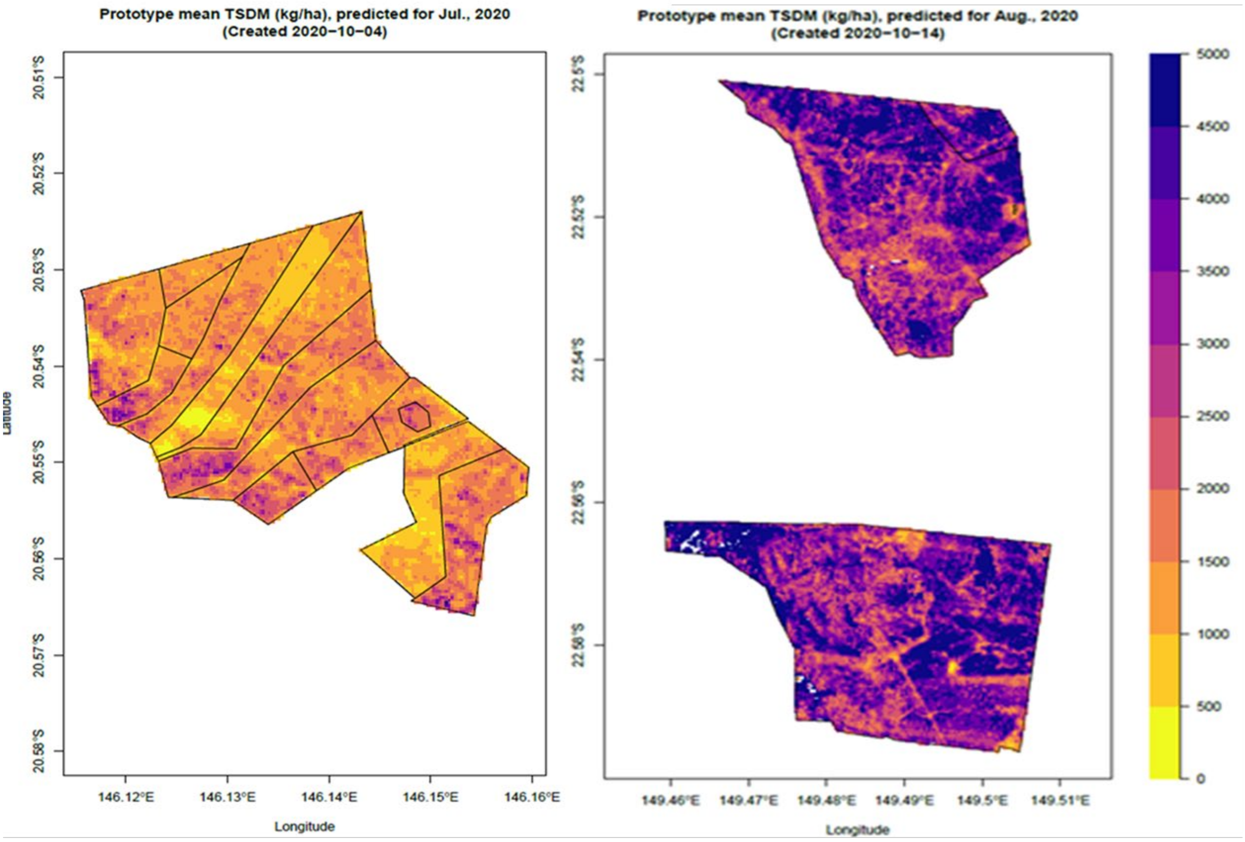
11.1 Prototype paddock forage biomass tool

The prototype forage biomass tool developed by DES is based on Landsat estimates of cover and parameters from the Wambiana trial as well as the former Toorak and Pigeonhole grazing trials (Schmidt *et al.*2016). The tool is run monthly using the Wambiana parameter sets for both the Wambiana trial site and the Ametdale on-property demonstration site at Marlborough (Figure 27). The Wambiana parameter sets for the GRASP model are based on an extremely detailed data set collected over the first ten years of the Wambiana trial on so called SWYFTSYND sites. This data includes the pasture growth responses to rainfall on all soil types, pasture nitrogen uptake rates and detailed water holding capacity data down the profile of these soil types (See O'Reagain *et al.*, (2008) for more detail). These parameter sets have been used to calibrate the GRASP model for the trial on a number of occasions and generate carrying capacity estimates for these and many other landtype in the Burdekin.

The Wambiana parameter set is also used to run the tool for Spyglass Beef Research Facility, Belmont Research Station and two other properties in western Queensland that are part of the Smart Farm eBeef project run by Southern Gulf Natural Resource Management Group (http://www.southerngulf.com.au). These estimates are then circulated for feedback to some of the sites involved.

While the forage biomass tool produces reasonable paddock scale estimates for the Wambiana trial, not surprisingly, it requires more calibration and parametrisation with on-ground data for the other sites. This is continuing. As an example, following anomalous biomass estimates for a particular landtype on Spyglass in February 2020, on-ground clipped and visual estimates of pasture biomass were made, in the hope that, in future, these new data could be used to improve model calibration. Known problems with the tool include the fact that it can confuse tree cover with forage biomass. The tool is relatively naïve in that it is based on relatively few parameters with the regression model based on a single explanatory variable i.e. the ratio of bare soil to dead cover averaged for each month. Work is continuing to refine and improve the underlying algorithms

Figure **27 Estimates of paddock TSDM for July/August 2020 from the prototype forage biomass tool for the Wambiana trial (left) and the Ametdale NGD paddocks (right). Note the differences in pasture TSDM between the two sites.**



11.2 Carrying capacity ready reckoner

Bob Shepherd (DAF, Charters Towers) has, in collaboration with DES, developed a relatively simple, long term carrying capacity 'Ready Reckoner' for the Burdekin catchment (See Appendix 6). The Ready Reckoner is based on GRASP based predictions of pasture growth adjusted for land condition (A, B, C or D), rainfall (low, median, high) and one of three categories of soil fertility. A substantial proportion of the parametrisation of GRASP to make these predictions was based on the detailed SWYFTSYND and other paddock data collected at the Wambiana trial and reported earlier (O'Reagain *et al.*2008). The Ready Reckoner has been used at all of the NGD sites to guide stocking rate decisions and was presented to graziers at NGD field days. It has also been widely used and tested by DAF extension colleagues at field days and property visits in North and central Queensland.

11.3 The FORAGE on-line tool

The on-line FORAGE tool on the Long Paddock website (http://www.longpaddock.qld.gov/au) developed by DES (Stone *et al.*, 2021) has been used and tested at the Wambiana trial and all of the NGD sites (see Milestone 6). Feedback from these sites has been very positive and has resulted in improvement of FORAGE e.g. in refinement of landtype mappings. The more recent addition of the FORAGE Growth Alert has been particularly useful at the Ametdale NGD site (see section 15.4.3). Between 2011 and March 2022 there have been 155,761 requests for FORAGE reports. In the period January – March 2022 the area covered by report requests is 12.5 million ha in (Grant Stone, DES, *pers. comm*).

11.4 Improving the ability of GRASP to model pasture change

The GRASP model is the foundation of all tools and modelling almost anywhere in Australia and is used to predict how pasture growth, pasture composition and animal production change in response to management, climate and landtype. It has been used widely in numerous applications, the most notable being the FORAGE online tool that predicts pasture biomass and carrying capacity.

This chapter presents work done to test and improve the GRASP model by Jo Owens (University of Southern Queensland) in the DCAP program as well as colleagues in the Department of Science and the present project team. As before, the data collected in the present Wambiana project as well as in previous years was foundational to this work.

11.4.1 Introduction

The GRASP model is the foundation of the operational FORAGE and AussieGRASS tools used widely by government, advisors and land managers in a wide variety of decision making. A prototype long term carrying capacity estimator (Zhang *et al.*, 2021) is also now operational on the Longpaddock website (https://www.longpaddock.qld.gov.au/forage). GRASP is also used to model grazing management outcomes in terms of animal production, pasture change and runoff into reef catchments, and explore options to increase profitability in grazing enterprises e.g. (Bowen and Chudleigh, 2021).

These applications are all currently done with the Cedar version of GRASP. In the current Cedar version, pasture condition is largely determined by the % of perennial (3P) grasses. The 3P grasses are the foundation of ecosystem function and productivity and drive TSDM production, cover and hence carrying capacity and runoff. Modelling how pasture condition changes under different management and rainfall scenarios is essential in testing and developing management recommendations as done in Phase 3 of this project (O'Reagain *et al.*, 2018). These recommendations in turn feed directly into government management recommendations to reduce sediment delivery in reef catchments.

GRASP currently models pasture condition based on % 3P grasses with allocation to eleven condition states covering the range of the four A, B, C, D land condition states. Changes between states are driven by pasture utilisation rate with a step function determining changes between states (Owens *et al.*, 2021). Pasture utilisation is modelled as the average annual utilisation rate. As such the model cannot easily account for the timing of grazing, for example between wet and dry season grazing, which are known to have differential effects on pasture composition. Accordingly wet season spelling or rotational grazing can't effectively be simulated in the current version without considerable effort.

To address these issues a new pasture condition model for use in GRASP was developed and evaluated in collaboration with the Wambiana project team and DES colleagues (Owens *et al.*, 2021). A summary of the work is presented below but full details are provided in the paper by Owens *et al.*2021 in Appendix 7.

11.4.2 Methodology

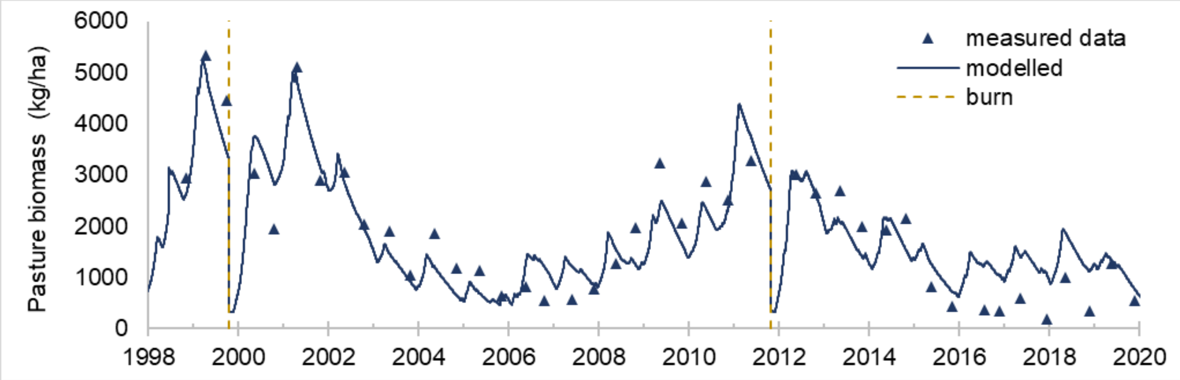
The GRASP pasture utilisation: condition relationship was changed from a step function to one that allowed a continuous change in land condition (3P%) with increasing utilisation rate. A resilience/hysteresis function was also added to slow down/accelerate changes in condition depending upon state. A new sub model was also added with modifications to allow the impact of utilisation rate to be weighted by month with heavier weighting for the impact of early vs late wet season utilisation.

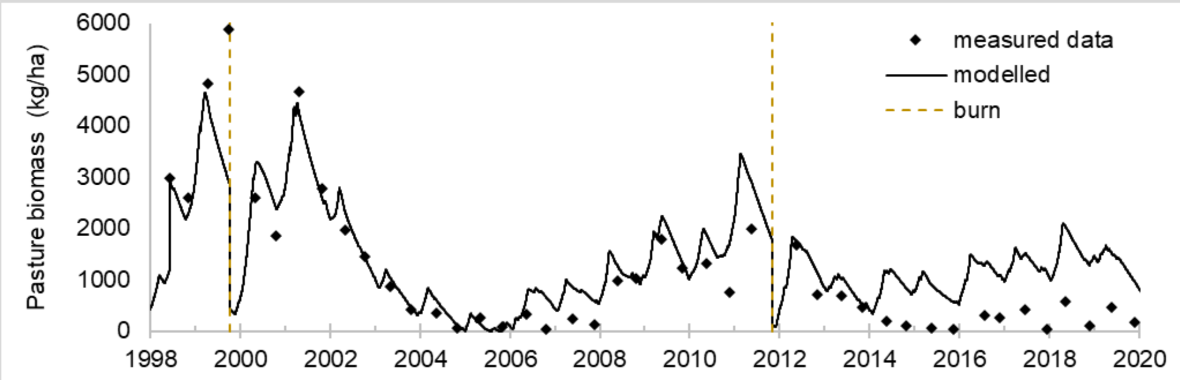
The modified model was then parameterised and tested against the long term yield and species composition data from the two adjacent heavy and moderate stocking rate paddocks at the Wambiana trial. Remotely sensed persistent green, fractional green and total ground cover from the Wambiana site was also used.

11.4.3 Results and discussion

The modified model was able to successfully simulate effects of rainfall and management on pasture TSDM and 3P % composition over the period from 1998 to about 2016 which included two wet phases and one drought phase (Figure 28).

Figure **28 Predicted and measured pasture biomass for the moderate stocking rate (top) and heavy stocking rate (bottom)**. The site was burnt in October 1999 and 2011 to manage woody vegetation.





However, model predictions separated from observed values under both heavy and moderate stocking rates from 2012 onwards with the model consistently overpredicting TSDM (Figure 28) and 3P % composition (not shown). This happened even after stocking rates were significantly reduced in the HSR during the later drought from 2014/15 onwards and in the MSR in the 2017/18 wet season (Figure 28).

The results show that the degradation processes due to drought and overgrazing were not captured after about 2014. The overestimation of standing dry matter begins at the same time as 3P% begin to decline. There are a number of likely causes for the model overpredicting both pasture TSDM and the 3P% in the second half of the trial.

Firstly, Basal cover, a major driver of pasture production, declined sharply in the trial paddocks due to drought and grazing (Chapter 9; (Macor, 2019)). The modelling of pasture basal cover has always represented a major challenge as noted previously (Day, 1997) Nevertheless, the strong effect of rainfall variation and to a lesser extent, grazing management have been reasonably modelled up to 2012 for grass basal area (Owens *et al.*, 2021). Improved modelling of the grazing management effects represents the next major challenge.

Secondly, while GRASP accounts for tree competition, there is no data on how *Carissa* impacts pasture production. The large increase in *Carissa* cover and density undoubtedly increased competition with the grass layer. Reduced grass production would also invariably increase grazing pressure on existing plants, further accelerating degradation.

Thirdly, the ingress and expansion of *B. pertusa* at the trial also possibly retarded the recovery of 3P species, which might have recovered faster without this competition.

Lastly, the current simulation was only run for the box soils (approximately 50 % of paddock area). However, cattle obviously have access to the whole paddock and as such, utilisation rates on the box may have been much higher or lower than assumed depending upon relative use of other landtypes. This illustrates the complexity of trying to model pasture and animal processes in the large, spatially variable paddocks that are a feature of all extensive grazing enterprises.

11.4.4. Conclusions

1. GRASP successfully captured the first 16 years of the trial. However, despite intensive calibration and parametrisation the model was unable to capture the complex degradation processes during the last drought period and the subsequent lack of recovery using the existing model structure.
2. Nevertheless this study provided parameterisation for improving GRASPs ability to model grazing lands of northern Australia, especially during prolonged droughts, and provided insights on missing processes, giving us greater confidence in identifying degradation and recovery signals.
3. Compiling and updating the 23 year data set from the Wambiana trial has also built a foundation for the testing of a wide variety of modelling applications and ground truthing of satellite tools.
4. The findings will contribute directly to current applications of GRASP addressing the issue of long-term carrying capacity and pasture biomass available for sustainable grazing.
5. The study also demonstrated how satellite-derived vegetation cover data can be used to evaluate and support modelling of ground cover in grazing systems
6. The study revealed several known but unrepresented processes in the GRASP model. Some of these are the subject of current research but others, such as the impact of *Carissa*, *B. pertusa* and reduced rainfall infiltration on pasture production, urgently need addressing.
7. Finally, long-term datasets and modelling can help diagnose the patterns of degradation and provide a platform for the generation and testing of algorithms that more accurately describe aspects of the degradation and recovery process.

12 Walk over weighing technology

12.1 Introduction

This chapter continues the theme of Chapters 10 and 11 and helps to address, objective 5:

- to '*have further developed advanced decision support tools to assist beef producers increase profitability and sustainability through better management of the feedbase'.*

The relatively recent development of walk-over-weighing technology for cattle by Precision Pastoral Technology allows real-time collection of cattle weights. This data, coupled with other tools, has significant potential to assist managers to respond far more rapidly and efficiently to changing seasonal and/or market conditions (Leigo *et al.*, 2016). Data on weekly weight changes was collected from two WOW units with the key objective of relating weekly changes in live weight gain to rainfall, diet quality, stocking rate and management. It was hoped that this data could be used to develop a model to forecast live weight changes from a combination of remote sensing and the GRASP pasture growth model.

This work aimed to build on, but also significantly advance the key foundational work of Leigo *et al* (2016) by using higher resolution imagery (Landsat vs MODIS), more advanced metrics (fractional green cover vs. NDVI) and diet quality (faecal NIRS) rather than green biomass. The work would also be done under the more controlled conditions of a replicated grazing trial and potentially utilise the existing NIRS, liveweight and pasture dataset compiled over the last 20 years at the Wambiana trial site.

12.2 Methodology

Two walk-over–weigh (WOW) units with auto-drafters were installed at the WGT to allow real-time measurement of steer weights in each of two adjacent treatments i.e. four paddocks in total. One unit was set up to sample the adjacent Flexible stocking +spelling (paddock 10) and Heavy stocking rate treatment (paddock 9). The second unit was set up to sample the adjacent Flexible stocking (paddock 3) and the Heavy stocking treatment (paddock 4). In all four paddocks the second water points were turned off to force animals to enter the WOW yards to access water.

12.3 Results

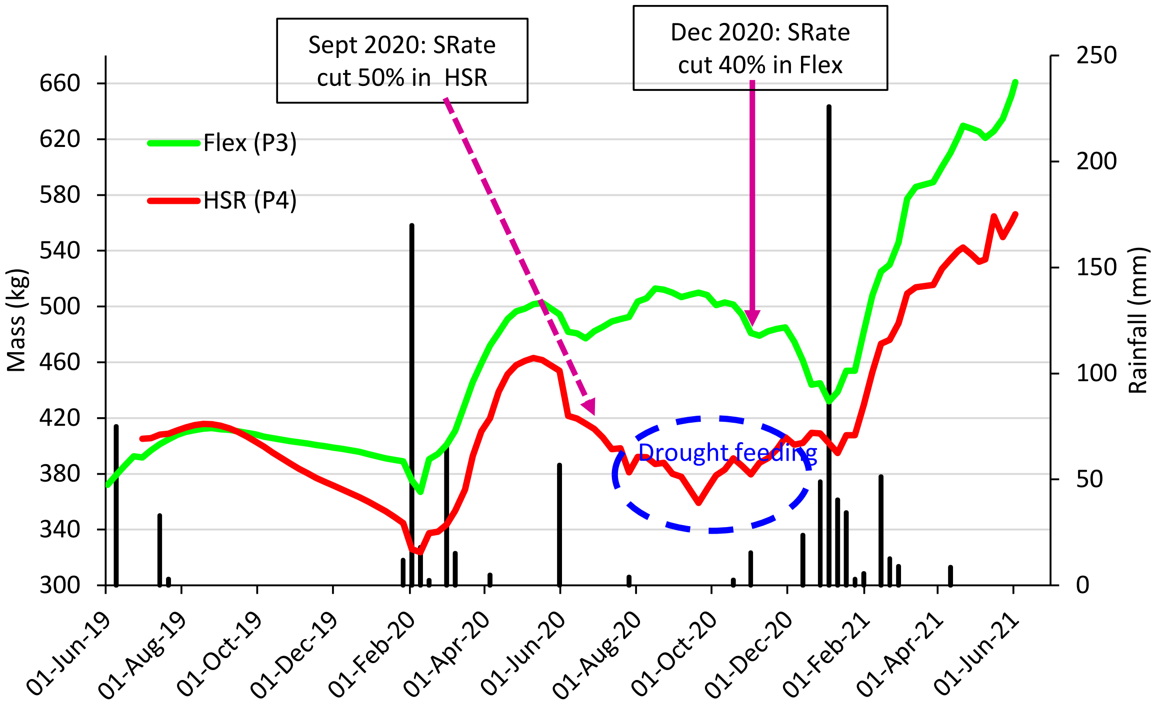
The collection of LWG data with the WOWs was complicated by a number of technical and operational issues relating to the WOW units, the software and the data that needed addressing. Detailed data for the first year of operation (2018/19) was also only received from TruTest in late February 2020 which significantly delayed data analysis. Similar problems were also experienced by United States Department of Agriculture (USDA) colleagues at the Central Plains Experimental Range, Colorado (Melissa Johnson, USDA, *pers. comm*).

The movement of data handling away from the Trutest MiHub site in June 2021 to another company, Datamars, added to the issues and confusion. The new Datamars staff were very helpful but took a number of months to become acquainted with the WOW system. These and other issues are listed in more detail below.

12.3.1 Liveweight changes vs rainfall

In the 2019/20 season steer weights in both the HSR and Flex paddocks declined steadily through the long 2019 dry season with HSR steers losing the most weight (Figure 29). Following good rains in late January, weights temporally dipped due to changing gut fill (purging), but thereafter increased rapidly through the wet season. However, with the below average rainfall and short wet season, weight gain had ceased by mid-May with weights then falling as pasture quality declined, despite rain (56 mm) in late May.

Figure 29: Change in mass of #8 steers as recorded by walk-over -weighing versus rainfall in the Flex (P3) and HSR (P4) strategies from 1 June 2019 until 31 May 2021.



By late June, steers in the Flex strategy had resumed gaining weight in response to green growth resulting from the May rain. However, the rain had no effect in the HSR with weight loss continuing. This lack of response to the late rain is a direct result of the decline in land condition HSR paddocks and the associated loss of 3P grasses and presumably, reduced infiltration capacity. Accordingly by late August, the Flex steers were nearly 115 kg heavier than those in the adjacent HSR paddock.

Weight loss was so severe in the HSR that in September 2020 stocking rates were cut by half from 7 ha/AE to over 14/ha with excess animals sold. Due to the almost complete absence of forage, the remaining steers were then fed molasses and urea (M8U), and later hay, with feeding continuing in this paddock until January 2021.

In contrast, steers in the Flex paddock largely maintained mass until early December 2020. Following the usual end of dry season pasture yield assessment in November, a forage budget was performed which indicated a possible shortage of forage going into the wet season. Accordingly, stocking rates in the Flex were cut from 14 to 22 ha/AE on 7 December 2020 to avoid overgrazing. Following good rains post- Christmas, steers in both paddocks gained weight rapidly but the HSR steers were still 100 kg lighter than those in the adjacent paddock. Similar trends were observed at the second WOW over the 2019-2021 period (data not shown).

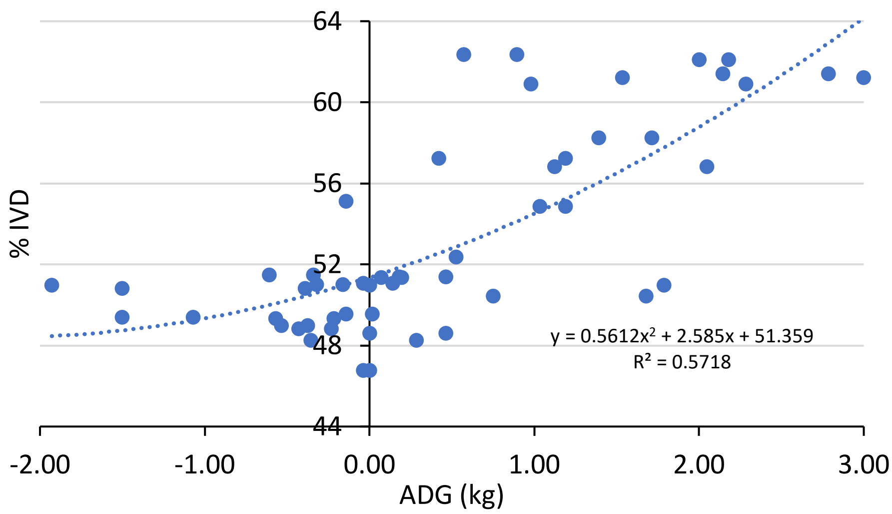
12.3.2. Visual vs actual liveweight change in cattle

On a number of occasions, visual observation of the steers indicated that they were in good condition and maintaining weight. However, the WOW data indicated that steers were on a declining plane and had already lost 5 to 10 kg or more of weight. This highlighted the potential value of the WOWs in enabling early management decisions e.g. marketing, that would have a direct financial benefit.

12.3.3 Relationship between diet quality and liveweight gain

As expected, average daily gain over the 2019-2021 period was positively related to *in vivo* dietary digestibility, shown below for the Flex+S strategy at the second WOW (Figure 30). A similar relationship with dietary crude protein was also observed (not shown).

Figure 30 Average daily gain (ADG) for steers in the Flex+S strategy (P10) vs *in vivo* digestibility (IVD) of diets selected for the period June 2019 to May 2021.



12.3.4 Forecasting and predicting liveweight gain

The WOW and other detailed diet data from the trial was shared with DES colleagues with the aim of building a prototype tool to predict and/or forecast changes in liveweight. An attempt was made using first, the WOW data and later, the coarser scale LWG data (i.e. traditional yard weights) collected from the trial. The approach was to adopt a similar modelling-remote sensing approach to what was first used in the forage quality prediction tool. However, a number of difficulties were encountered. The first was that the WOW data covered only two or three years and hence was relatively short term for the task at hand. There were also a number of gaps (weeks to a month) in the WOW data due to either equipment failures or animals accessing standing water in the paddock and hence not using the WOW yards.

The second major problem was that of matching the temporal scale of data (weekly, 6 monthly or yearly) with the twice monthly Landsat imagery, the three-weekly NIRS diet quality data and the *AussieGRASS* daily time step. These were not trivial issues and despite substantial effort, ultimately could not be satisfactorily addressed to allow the modelling to proceed.

In retrospect, the objective of predicting or forecasting liveweight was possibly over-ambitious. Aside from the issues mentioned above, trying to predict (as opposed to simulate) animal performance without having a good estimate of paddock forage availability and land scape selection patterns will always be extremely challenging. The relatively ‘noisy’ relationship between LWG and dietary IVD (r^2=0.571) in Figure 30 is a good illustration of this complexity. However, as tools to estimate both forage quality and availability improve, and knowledge improves on landscape selection, forecasting live weight gain using a combination of modelling and remote sensing is entirely feasible. It is hoped that the data collected in this project and that from other WOW units e.g. at Spyglass Beef Research Facility, can be used in future work to improve modelling of liveweight change under different management, land condition and climate scenarios.

12.4 Issues with the use of walk-over-weighing

- Training is needed in the installation and use of the WOW equipment and technology. A simple, operator’s manual would be extremely helpful and would have avoided some of the many of the problems encountered.
- Animal training: animals need to be trained over a few weeks to use spear gates, the WOW units and the automatic drafters, which is time consuming. Even so, a small proportion of animals will refuse to use the spear gates and will need to be removed.
- Where WOW yards are the only source of water, such as at the WGT, animals that won’t use spear gates to access the water yard are in danger of perishing and thus need to be watched very closely. This can be a significant investment in time and labour.
- Incorrect drafting of steers due to software problems occurred in the 2019/20 season for a number of weeks. This issue was only detected after trail cameras were installed on the WOW units and hundreds of images carefully scrutinized to detect mis-drafting. MiHub was notified of this issue and it the problem was subsequently resolved.
- The harsh conditions in north Queensland are a challenge to the electronic equipment and have led to equipment failures including the modems and batteries. These require constant checking.
- While technical support from the Datamars web site has improved dramatically since July 2021, there can be delays in getting good support for on-ground equipment issues. This is an issue to consider for research projects and graziers alike.
- Animal behaviour: some animals learn to outsmart the automatic drafter simply through trial and error learning – these animals thus consistently end up in the wrong paddock. This issue was overcome to some extent by changing the settings on the drafting gate.
- Data issues 1: there were periodic fluctuations in weekly animal weights that were difficult to explain. While these have been relatively rare at the WGT, these anomalies have been far worse at other on-property projects in Queensland (J. Rolfe & L. Hardwick, DAF, *pers.comm*.).
- Data issues 2: the current Datamars support staff are very helpful but lack detailed understanding of how the ‘smoothing’ algorithms work. They thus find it difficult to answer some more technical queries regarding data anomalies.

12.5 Summary

1. The WOWs allowed collection of unprecedented data on daily weight changes in extensive paddocks under different grazing treatments and seasonal conditions with no disturbance to animals.
2. The objective of using the WOW data to develop decision tools to predict or forecast liveweight changes was not achieved. This was due to issues matching the temporal scale of different data sources, the relatively short term WOW data (3-4 years) and the sheer complexity of predicting daily live weight changes in large, spatially diverse paddocks.
3. In the longer term, as more WOW data accumulates and other decision tools to predict for example, paddock yields improve, a decision tool to predict or forecast liveweight gains is achievable. However this will require ongoing investment in grazing trials, modelling and remote sensing.
4. The results clearly show how stocking rate directly effects animal performance through the season with weight gains declining far sooner in the dry season under heavy stocking. Despite rapid weight gains in the wet season, animals under heavy stocking never match the weight gains of those in adjacent, moderately stocked paddocks.
5. These results provide an excellent graphic example of how a decline in land condition reduces the capacity of country to respond to rainfall and drive production. Conversely, they provide crucial evidence of how good land condition can improve the response to rainfall and so increase productivity.
6. Nevertheless, there are a number of technical and operational issues that need to be addressed to improve performance and reliability of the WOWs.
7. While WOWs are a very valuable research tool, our experience as well as that of colleagues overseas in the USDA and locally in DAF, is that WOWs cannot be regarded as low input, ‘off the shelf’ or ‘plug and play’ technology.

13 Extension and adoption activities-Wambiana project

13.1 Grazier advisory committee

The Wambiana trial grazier advisory committee (GAC) has been active in advising on important management decisions for the Wambiana trial. This has become of increasing significance over time as unexpected circumstances and novel combinations of climate, fire and grazing have arisen. To this end, they have been invaluable in ensuring that treatments are managed in a manner consistent with a particular management philosophy. These include the decision to destock the MSR and R/Spell for the 2017/18 wet season and to reduce stocking rates and implement drought feeding in the HSR in September 2020. More recently, in December 2021, they advised on further cuts to the stocking rates in the Flex and Flex+Spell strategies due to the shortage of forage. In January this year, the GAC recommended delaying locking-up of wet season spelling sub-section in the R/Spell and the Flex+S sections to prevent overgrazing of the non-spelled remainder of the paddock. As a result of the extremely low rainfall subsequently received this season, spelling was not implemented in any of the spelling treatments.

Figure 31 By late December 2017 the MSR and R/Spell paddocks were extremely short and overgrazed. Based on what a 'moderate stocker' would do, the GAC advised on destocking these strategies for the 2017/18 wet season to avoid severe degradation.

13.2 Site visits and presentations

Between January 2018 and April 2022, there have been 30 sites visits by a total of 657 visitors. These were comprised of: graziers (172), agency staff (146), students (191) and 'other' (129). Agency staff included DAF, CSIRO and staff from various NRM groups such as NQ Dry Tropics and Southern Gulf NRM. The 'other' category included Agri bankers, Rural Fire officers and MLA staff (Table 17). Visiting groups varied from the Wambiana Grazier Advisory Committee to Agricultural Science (UQ) or Wildlife Ecology (JCU) students, Agribankers, extension officers, other grazier groups, scientists and rural fire officers (Appendix 11).

Table 17 Number of visitors to Wambiana trial site and total audience at Wambiana presentations by category between 1 January 2018 and April 2022.(NB: International audiences excluded).

	Total	Agency staff	Graziers	Students	Other
Additional Presentations audience	**328**	187	141	-	-
Site visitors	**657**	146	172	191	129
Target: 110 graziers advocating for WGT	**108**		108		

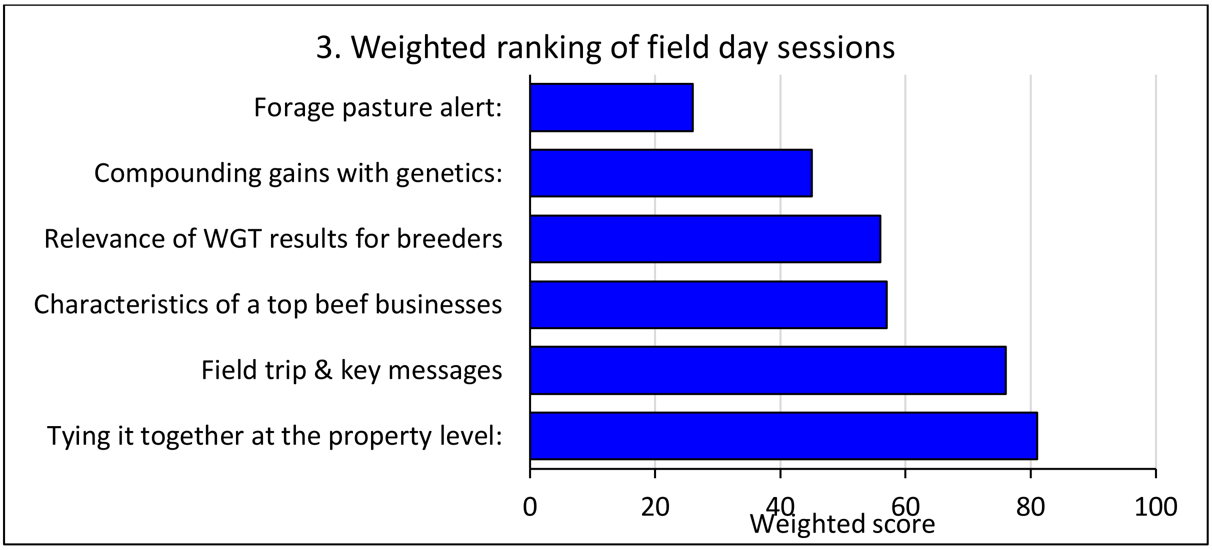
A total of 16 other presentations on the Wambiana project were made at other venues to a combined audience of 408 people with the audience comprising graziers (151) and various agency staff (257). These ranged from presentations at the Northern Grazing Demonstration sites in different catchments, to extension officers and the Office of the Great Barrier Reef. A particular highlight was the invited presentation at the annual Society for Range Management Meeting in Denver, Colorado in February 2020.

13.3 Field days

13.3.1 October 2019 field day

A large field day was held on 17 October 2019 which was attended by about 100 people with producer attendees managing a combined total of 536 163 ha. The field day was ranked highly in feedback sheets with 94% of respondents rating the information as highly relevant. The relative ranking of the different field day sessions is shown in Figure 32.

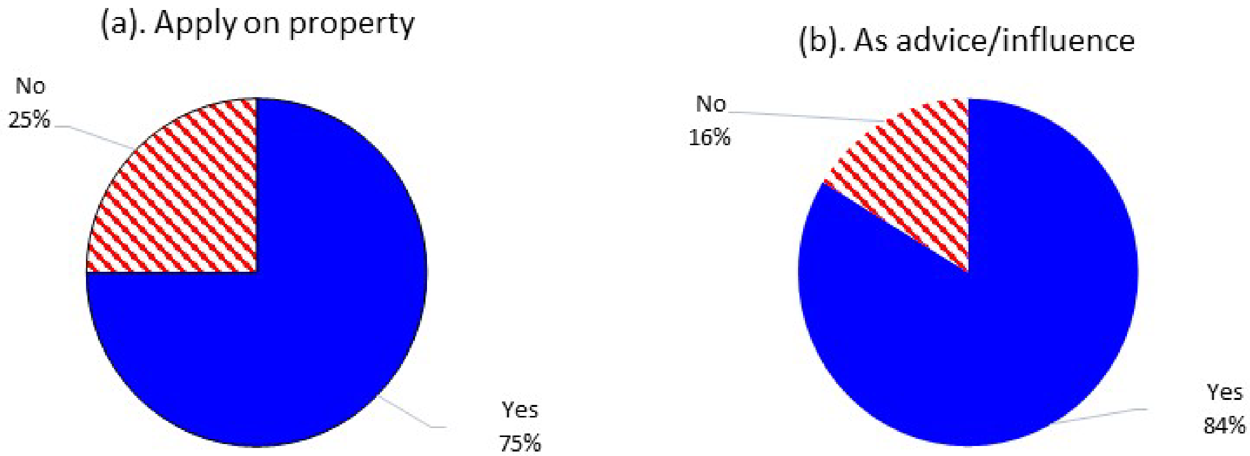
Figure 32 Weighted ranking of field day sessions in terms of relevance. Sessions ranked first, second and third were given weights of 3, 2 or 1 respectively. The weighted score for each session was calculated from the sum of the weightings across all feedback sheets.



A very large proportion of both producers (75%) and agency /agribusiness staff (84%) said they would apply the information learnt on their properties or as advice to clients, respectively (Figure

33). In this respect, stocking rate and pasture management (48%) as well as improving breeder efficiency (13%) were mentioned most frequently. For a more detailed report consult Milestone 6.

Figure 33 Percentage of respondents who plan to apply new information either on property or as advice/influence to clients or other graziers.



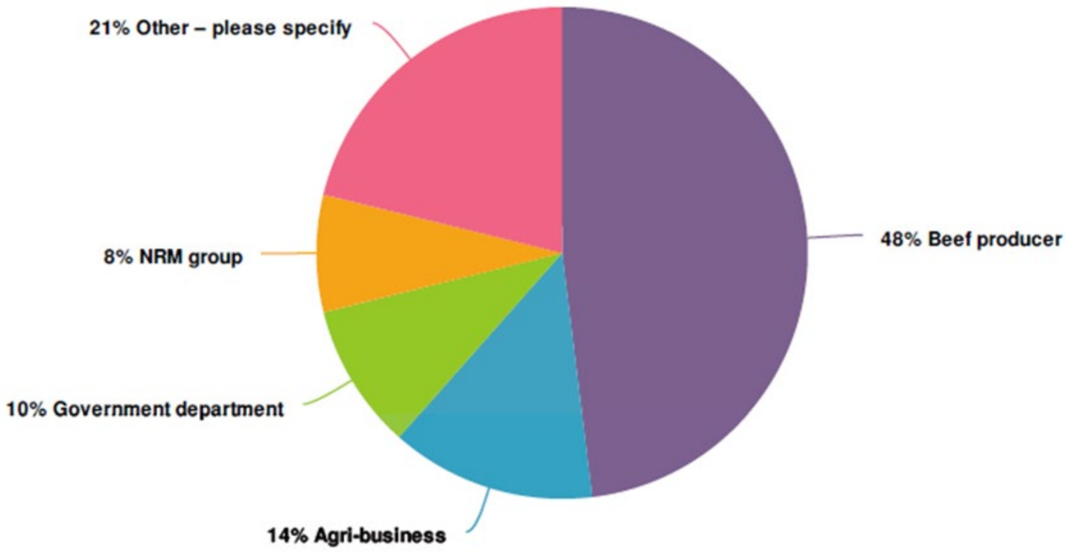
An unexpected outcome: Bunuro property demonstration

However, possibly one of the most positive outcomes was the self-volunteering and subsequent establishment of the 'Bunuro' on-property demonstration site near Torrens Creek. As mentioned, there were a number of producer presentations on the day, one of whom was David and Donna Rankine of 'Bunuro'. Following the field day, the Rankines volunteered to have a demonstration site established on their property to demonstrate what could be achieved with good grazing management. This demonstration was established in 2020 and showcases two systems: multipaddock grazing and a simpler system, run according to basic 'Wambiana' principles. This five year extension project is funded by Reef with data collected by the producers themselves in collaboration with DAF and consultants from Resource Consulting Services. The Bunuro site will be one of the demonstration sites in the proposed next phase of the Wambiana project.

13.3.2 September 2021 field day

A second field day was held on 15 September 2021. The day was attended by 82 people, of which 48 % were beef producers (Figure 34) with the remainder comprised of a range of people including extension officers and agribusiness staff, all of whom could be termed 'influencers'. The producers attending collectively managed a total of 877 460 ha with property sizes ranging from 240 to 243 000 ha.

Figure 34 Breakdown of occupations of people attending the September 2021 Wambiana field day.



The 2021 field day followed a slightly different format to the previous one with a field trip to see the impact of the different grazing strategies on land condition and animal performance (Figure 35). Issues highlighted were the general decline in land condition in all treatments due to the long lasting impacts of the drought and the increase in Currant bush (*Carissa ovata*), particularly on the box soils. Each field stop was selected to show the impact of applying or not applying a key management principle e.g. wet season spelling or adjusting stocking rates. These stops then combined to emphasise the four key 'Wambiana' management principles. In the afternoon, producers Michael Lyons (*Wambiana*), Jamie Gordon (*Mount Pleasant*) and Fran Lyons (*Basalt River*) outlined their own, different grazing management systems and how they applied these principles in practice.

Figure 35 The September 2021 field day included field and producer presentations as well as small group sessions to determine future project directions.

The total of 52 feedback sheets were completed. The 2021 field day was rated as being very useful (score: 6.1 out of 7). Producers indicated significant improvements in knowledge and understanding regarding the trial and in particular, in their understanding of wet season spelling and managing stocking rates (Table 18).

Table 18 Scored responses to key feedback questions relating to knowledge and understanding at the September 2021 Wambiana field day (Rating scale 1 (least) to 7 (most)).

Question	Before	After
Q3a: What was your knowledge and understanding of managing stocking rates BEFORE vs AFTER the day?	4.73	5.94
Q4a: What was your knowledge and understanding of wet season spelling BEFORE vs AFTER the day?	5.02	6.04
Q5a: What was your knowledge and understanding of the Wambiana Trial results BEFORE vs AFTER the day?	4.02	6.23

Importantly, producers reported that it was highly likely (score:6 out of 7) that they would use the information to make a management change in the next 12 months (Table 19). They also indicated that the Wambiana trial was highly useful for the beef industry and should continue, albeit in a slightly modified form (Table 19). Suggested modifications included treatments to rehabilitate poor condition land in the heavy stocking rate paddock, in particular, some form of 'regenerative grazing' i.e. long periods of rest, short grazing periods and possibly, 'animal impact'. There was also strong support for investigations into currant bush control. Detailed work on understanding the population biology of key grass species, in particular desert bluegrass was also suggested by some respondents.

Table 19 Scored responses to key feedback questions relating to usefulness, the likelihood of using information and support for the Wambiana trial at the September 2021 Wambiana field day (Rating scale 1 (least) to 7 (most)).

Q2: Overall, how useful was the field day for your business or work role?	6.10
Q6b: As a result of what you learnt, how likely are you to use this information in your management or your situation in the next 12 months?	6.00
Q9: How do you rate the usefulness for industry for the Wambiana Grazing Trial to continue in its present form?	5.80
Q10: How do you rate the usefulness for industry for the Wambiana Grazing Trial to continue - in a modified form?	6.75
Q11: How do you rate the usefulness of the 3 producer presentations on how to start managing stocking rates or using wet season spelling for your property or in your recommendations?	6.67

14 Extension of Wambiana information through MLA EDGE training

Information and data from the Wambiana trial features prominently in the EDGE Grazing Land Management (GLM) training package. This information covers issues ranging from managing 3P grasses, to detailed case studies on fire, the effects of management on soil loss and runoff and how grazing strategies affect animal production and profitability. Wambiana is by far the most quoted study in the course notes. The GLM course has been presented a total of four times between 2018 and 2022 at locations ranging from Rockhampton to Burketown, to a total of 60 attendees managing 33 different properties (

Table 20).

Table 20: Number of MLA EDGE courses and attendance between 2018 and 2022.[1]

Edge Course	Locations	Number	Attendees	Properties
Grazing Land Management	Qld	4	60	33
Grazing Fundamentals	WA, NT, QLD	15	178	80

[1] Source: MLA 26/07/2022

Wambiana project results are also used in the shorter Grazing Fundamentals workshop which were presented on 15 occasions at locations across northern Australia including Alice Springs, Derby, Hughenden and Toowoomba.

15 The Northern Grazing Demonstration project: demonstrating Wambiana management principles

15.1 Introduction

This chapter addresses Objectives 2 and 3 i.e.

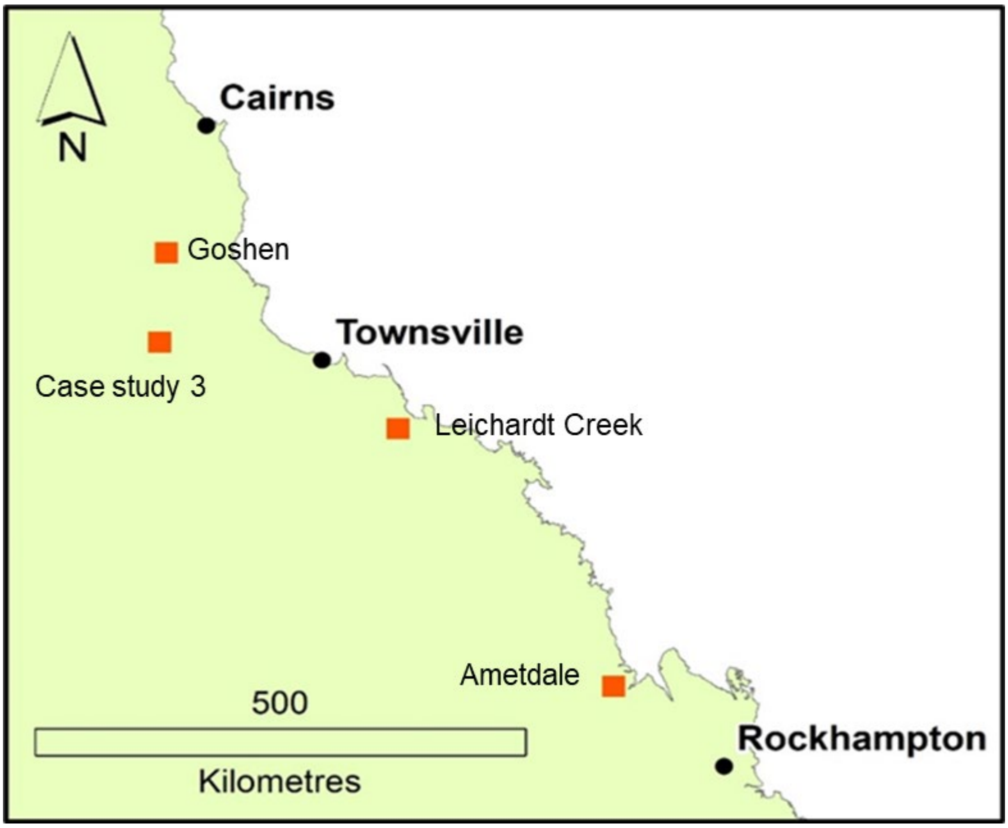
- 'Have four demonstration sites each of which will have their own producer group. Producers will be involved in the management of these sites and will advise on the creation of adaptive grazing management guidelines', and
- 'Conduct field days at each of the sites, to build awareness of developed grazing management strategies. These will link directly to the Grazing BMP program training courses and one-on-one extension —delivered by QDAF - to extend findings and build awareness'.

This objective arose from the Wambiana Grazing Trial (WGT) extension and planning workshop (2016), where producers identified several actions to increase adoption (O'Reagain *et al.*2018). One key action was to inspire managers to adopt better grazing management by on-property demonstrations of what can be achieved with good, conservative grazing management practices. In response to the above, the Northern Grazing Demonstration (NGD) project led by Dave Smith (DAF, Charters Towers) and co-funded by the Department of Environment and Heritage Protection (DEHP) was established to demonstrate the key principles from the Wambiana trial on four commercial properties in different catchments (Smith et al., 2020).

15.2 Synopsis

The demonstration sites were set up with one each in the priority catchment areas of Upper Herbert (*Goshen*), Upper Burdekin (*Case study 3*), Bowen Broken Bogie (*Leichardt Creek*) and Fitzroy regions (*Ametdale*) within the Great Barrier Reef catchment (Figure 36). These sites were used to showcase best animal and pasture management practices to cost effectively and sustainably maximise the productivity the country types can provide. We primarily targeted raising producer awareness of the fundamental productivity and performance measures of a beef business and how they are driven by sound stocking rate management and, in addition, provide advice on the most appropriate grazing land management strategies to realise the productivity benefits for the short and long term. Three of the four sites were used purely to demonstrate the producer's current good practice and the fourth (Ametdale) introduced a new management system by subdividing two larger paddocks (Well and Top9) and implementing rotational grazing. At all sites management was conducted by the property owner with input from a local grazier group of four to eight members and DAF staff. This input varied from discussions on what areas to spell, supplementation, stocking decisions and suggestions for improving land condition or profitability. Three of the four sites also worked in partnership with a Northern Genomics project with the University of Queensland. [Note that activities at the Case study 3 site were severely curtailed by illness.]

Figure 36 Location of the four northern grazing demonstration project sites.



It is important to emphasise this project was not designed to further test or compare different practices. Its purpose was to extend and demonstrate current research knowledge, and best practice, in grazing land management by on-property demonstrations using collaborators that are recognised as managing their land well.

The WGT outcomes were fully integrated and provided a solid extension platform based on peer reviewed research. These results were extrapolated to multiple regions to emphasise local relevance to producers. In addition, this project formed part of the DAF Reef Water Quality Activities 'Grazing Extension Support Project' work plan for the Burdekin and Fitzroy Catchments and collaborated closely with the Office of the Great Barrier Reef Major Integrated Project, "Landholders Driving Change' in the Bowen, Broken and Bogie catchment (https://ldc.nqdrytropics.com.au).

Measurements

A number of permanent pasture monitoring sites were established in all demonstration paddocks**.** Sites were monitored twice yearly late in the dry and wet season and photographed. Visual assessments were made of pasture yield, species composition, tree density and the presence or absence of weeds using the Stocktake methodology (Aisthorpe *et al.,* 2004). Estimates were then made of forage availability and a forage budget calculated for the paddock and shared with co-operators. Animal data was collected by property owners. A basic economic analysis of the management actions in the demonstration paddocks relative to 'business as usual' was then made by DAF economists using 'Breedcow and Dynama' (https://breedcowdynama.com.au/) and shared with property owners (see Smith *et al.* 2020).

Extension activities

The NGD sites were used as an 'extension hub' with a range of activities occurring including the formation of a producer consultative group for each site, the holding of field days and occasional pasture walks. A number of media articles were also published as listed in the final report to DEHP. Field days included presentations by a range of technical specialists on issues ranging from grazing management to improving breeder reproduction, nutrition, the use of decision tools and genetics (Table 21).

Table 21. Field days and consultative group meetings held at Northern Grazing Demonstration (NGD) sites.

NGD site	Date	Graziers	Agency	Meeting type & topics
Ametdale	22/05/2018	13	5	Consultative group meeting: project management, stocking rates, paddock fencing plan etc
Goshen	6/06/2018	12	8	Field day-project results, sown pastures, pasture response, bull selection, Wambiana update etc
Case study 3	12/06/2018	17	3	Project overview, Northern Genomics project, matching stocking rate to carrying capacity
Leichardt Creek	8/03/2019	12	2	Consultative group meeting & field day; breeder performance, Breedcow & Dynama
Leichardt Creek	3/05/2019	17	2	Consultative group meeting: Bob Shepherd's Ready Reckoner, land condition indicators, cull cow options analysis
Ametdale	11/06/2019	9	2	Consultative group meeting aims of NGD, patch grazing, Stocktake, Wambiana update
Ametdale	7/08/2019	26	8	Open field day- project overview: Wambiana trial results, breeder management, FORAGE tool
Goshen	9/10/2019	18	9	Field day- Goshen project results, Wambiana update
Kangaroo Hills	28/11/2019	12	3	Wambiana results, breeder management, Bob Shepherd's Ready Reckoner stocking rate calculator.
Ametdale	20/10/2020	9	4	Consultative group meeting: pasture response, cattle etc
Ametdale	10/11/2020	25	5	Final field day: project results, pasture die back, breeder linkages to Wambiana,
Goshen	12/11/2020	12	14	Field day- Wambiana & Goshen results
Case study 3	16/12/2020	9	5	Project results, Wambiana outcomes, FORAGE reports, linking breeder performance to steer data
Leichardt Creek	18/12/2020	21	4	Field day- weed management, establishing sown pastures, grazing management to control weeds.

COVID 19 restrictions curtailed a number of events in 2020. A serious illness in 2019/20 also curtailed field days at Case study 3 with the co-operators away from the property for most of 2019.

15.3 Key learnings

Key learnings from the four demonstration sites are listed below

15.3.1 Long term approach essential

Maintaining and improving land condition requires a long-term approach. A realistic estimate would be a 10% increase in long term carrying capacity (LTCC) for the demonstration paddocks over three years. Major challenges to implementing good grazing practices are (a) the time required to improve land condition and (b) infrastructure costs for paddock subdivision to implement more spelling or rotational grazing.

Looking after land that is in good condition is thus of critical importance. As an example, at Ametdale despite some poor seasons, there was a small improvement in pasture condition over three years as a direct result of Ian and Penny McGibbon's good management. This included stocking around long-term carrying capacity (LTCC), reducing stock numbers by around 40% and 15% for 2018-19 and 2019-20 respectively, and wet season spelling over both summers.

15.3.2 Stock around long-term carrying capacity

All Northern Grazing Demonstration (NGD) sites stock around a benchmark carrying capacity and apply relatively conservative long term stocking rates to cater for rainfall and seasonal variability. Generally this is based on long term experience and 'common sense'. At Case study 3, the aim is also to leave enough fuel in the paddock at the end of the dry season for a fire (1500 kg/ha), which translates to a stocking rate of around 10 ha/AE.

In regard to stocking rates, the Leichardt Creek managers noted that '*Six to seven years ago, this place ran around 3200 head to supply 1000 weaners a year. Since we came here that number has come back to around 2400. We still wean around 800 a year, getting more calves from the cows we have. Overall, those animals leaving the place are better. So, our overall kg/ha has increased. We think that's largely due to having a mindset of producing grass for cattle to eat.*'

15.3.3 Adjusting numbers with seasonal conditions

Despite the importance of stocking around LTCC, stocking rates need to be adjusted to seasonal conditions. This requires continual observation of cattle and pastures '*to ensure cattle have adequate grass and there is sufficient break of season cover to minimise soil loss and maximise pasture response to storm rains*'. Graziers generally used 'common sense' which combines long-term experience with hands-on (visual) evaluation of available pasture, water distribution, water permanency and grazing behaviour. A key principle with adjusting numbers was to sell early rather than wait out the season.

As an example, at Ametdale numbers were sharply reduced in early April 2018 due to drought conditions with very low rainfall (20-30 percentile) for both 2018 and 2019 and very low pasture growth: all non-pregnant cows were culled as well as any older cows over seven years of age to ensure only the most productive cattle were retained. Young cows were also put on agistment and two year old heifers sent to a feedlot. As a result paddock were run at 49% of LTCC for Top9 and at 71% of LTCC for Well paddock.

The 2018/2019 season was also poor but with 2019/20 being a better season and pastures responding well to the reduced stocking rates, numbers were increased slightly in Well paddock to 108% of LTCC but left at 73% of LTCC at Top9 paddock. Despite the 2019-20 summer pasture response being very good, Ian and Penny kept numbers relatively low (at around 70% of LTCC) across both paddocks until after the 2020-21 summer.

15.3.4 Importance of trigger points for management and having a plan

All producers emphasised the importance of having management trigger points and having a plan on what to do if seasons were poor. This was underpinned by the concept that selling animals early is far better than holding animals too long. At Goshen, a simple approach of combining experience with continuous visual pasture assessment and use of end of February and Easter 'cattle sell-down' trigger points when required is used.

At Ametdale, following the April 2018 reduction in stocking rates, it was decided in November 2019 that if there was no effective rain by the end of January 2020, calves would be weaned early and fed in the yards. Six weeks later all cows would be pregnancy tested and the 'empties' sent to a feedlot and sold. At this stage, cows were holding condition well (condition score: 3 – 4/5) although the first calf heifers had lower condition scores. Fortunately, late summer rain began in early January 2020 and the planned action was not needed.

Failure to reduce numbers early can also lead to overgrazing with long term adverse consequences. For example in 2011 at Leichardt Creek, steers were not sold due to the live export ban resulting in numbers increasing to 4000 head. '*It was a bad idea; even though it was a good year and we thought we had the grass; we are only now recovering.'*

Selling early in the season also allows country to have a late season spell. At Leichardt Creek, if prices are good, steers are sold two months early (March) with the owners forgoing the extra weight gain in order to spell paddocks at the end of the wet season (March/April).

15.3.5 Wet season spelling

Wet season spelling was also seen as being important but was applied slightly differently at the four NGD sites. In most cases spelling was somewhat limited by the availability of paddocks.

At Ametdale, sub-division fencing resulted in five sub-paddocks which facilitated flexibility in both the area and duration of spelling. This allowed eight weeks rest and 20 days grazing over the wet season i.e. approximately two grazes over the wet season and two in the dry season. If there was an extended wet season then the number of grazes was increased.

Wet season spelling is applied in a two-three year systematic system at Goshen which allows native species to regenerate and fuel loads to accumulate for burning after the first storms. Spelling also provides a feed buffer during the lean low rainfall years. The planned next step at Goshen is to mob cows up into fewer and bigger herds to allow more resting of paddocks.

At Leichardt Creek, paddocks are run together through most of the year. However, during the wet season animals are rotated between paddocks to allow some rest for the pasture. Non-performing animals are also sold as early as possible to reduce grazing pressure through the season. At Case study 3, areas are also routinely wet season spelled, especially in high traffic areas.

15.3.6 Managing grazing distribution

Even in well managed paddocks stocked at LTCC and with a regular wet season spelling program, selection for preferred areas can result in degradation. Co-operators all agreed on the need to try and achieve more even utilisation of paddocks and allow degraded areas to recover.

At Ametdale, paddocks were subdivided into 5 subsections to control the pressure on overgrazed flats and allow recovery of these areas. In the bigger paddocks at Case study 3, grazing pressure is moved by shutting off waters and moving lick troughs. At Leichardt Creek, cattle over- utilise sweeter Blue Gum frontage country; this was exacerbated by retaining too many cattle in 2011 following the live export ban. This has been partly rectified by reducing the overall paddock stocking rates with FORAGE reports showing ground cover back within regional averages.

15.3.7 Improved breeder management

Use of progressive herd management strategies like pregnancy testing, foetal aging, culling, segregation and use of EBV (expected breeding value) bulls is used at all sites to select for female fertility and maximise breeder efficiency. These are all powerful tools that can be used to manage stocking rates and manage for seasonal conditions in both the short and the long term. These were promoted at all sites as part of the 'whole of business approach' adopted in the DAF Reef Extension and Grazing Futures extension programs. Involvement with Meat and Livestock Australia's Northern Genomics Project at Case study 3 and Leichardt Creek also helped benchmark herd performance and identify high fertility cows.

In the long term, increased herd efficiency can allow breeder numbers to be reduced without adversely impacting overall productivity. Bull numbers can also be reduced if only fully tested, fertile animals are used.

In the short term, pregnancy testing allows non-pregnant cows to be identified. If seasonal conditions are deteriorating, such animals can be disposed of along with older animals to reduce stocking rates. This ensures only the most productive cattle are retained. Similarly, keeping younger animals ensures the fastest genetic gain. Thus at Leichardt Creek '*A key plan is to have a core group of females or breeding nucleus, usually younger heifers, with everything else being expendable if need be'.*

Control mating narrows the calving window and makes it easier to select non-performing cull cows at the end of the wet season if numbers need to be reduced early. Foetal aging is another powerful tool that allows breeders to be segregated based on predicted calving date and managed or marketed accordingly.

At Ametdale, numbers were reduced through pregnancy testing and culling all non-pregnant cows as well as any over seven years of age. Agistment was also used as a tool while two year old heifers were transferred to a feedlot. As a result, the total number of cows and hence the stocking rate was reduced with little impact on herd productivity.

15.3.8 Strategic use of sown pastures

Establishment of introduced pasture on higher potential areas can also be used to reduce stocking pressure on native pastures and finish stock early. At Goshen, the 1620 ha of sown pastures on cleared country reduces pressure on native pastures, allows wet season spelling of native pastures and also gives improved weight-for-age. Oversown legumes like Seca stylo on lighter soils also increase carrying capacity.

At Leichardt Creek, a planned leucaena paddock would involve use of a two-cycle grazing policy with early grazing by turn-off steers to around June, spelling for 8-10 weeks and then grazing again with cull cows. This would turn off cattle quicker and reduce stocking pressure on the native pasture areas by incorporating more rest periods. Turning off cull cows earlier would also reduce the stocking rate of other retained breeders and allow a greater wet season pasture response.

15.4 Testing decision tools at Northern Grazing Demonstration sites

15.4.1 StockTake

Stocktake fodder budgeting https://stocktakeglm.com.au was used at Case study 3, Goshen and Ametdale as a preliminary tool to assist in setting stocking rates. A Stocktake assessment by a project team member (Paul Jones) contributed directly to the Ametdale decision to reduce stocking rates in April 2018 and subsequent stocking rate decisions. However, experience with using Stocktake on the NGD sites identified a number of issues that possibly limit its use by producers:

- A number of yield estimates are needed across often highly variable paddocks with multiple soil types.
- Accessing large parts of the paddocks to make yield estimates can be difficult, hence estimates may be unrepresentative of the whole paddock and unreliable.
- The complex system in Stocktake to calculate accessible yields in large paddocks is challenging for producers.
- Correction factors in Stocktake e.g. leaf detachment rates or wastage, are questionable due to the scarcity of suitable data i.e. more research is needed.

These observations are supported by the experience of DAF staff at the Spyglass Beef Research Facility north of Charters Towers where paddocks are very large and access limited. At the Wambiana trial, our experience is that stocking rates estimated with the Stocktake methodology can be unrealistically high. This is particularly so when pasture yields are relatively low and minor adjustments to correction factors can have major impacts on calculated stocking rates.

In summary, using pasture budgeting tools to determine a ‘safe’ stocking rate, is often difficult in large variable paddocks with widely spaced waters. Despite or possibly because of this, there were valuable discussions with producers in the NGD project around the practical difficulties of assessing paddock yields, forage budgeting and the possible tools that could be used in large, diverse paddocks with areas of very limited accessibility.

The common-sense approach of the better managers in this study was to combine long-term experience with relatively informal (i.e. not using fixed monitoring sites) visual evaluation of pasture yields, while accounting for water distribution, water permanency and landtype selection.

15.4.2 The FORAGE on-line tool

The ‘FORAGE’ tool on the Long Paddock web site https://www.longpaddock.qld.gov.au/forage was used at all sites and proved very useful in tracking ground cover change and identifying over-utilised areas in paddocks that required management intervention or change. FORAGE directly aided in the decision to reduce cattle numbers at Ametdale in 2018 and implement a rotational spelling/grazing system.

The FORAGE Pasture Growth Alert (PGA) was very useful for risk warnings for pasture growth and resilience during the dry conditions. The Total Cover Percentile map also aligned well with the paddock StockTake data to show the improvements achieved to the targeted Indian couch areas at Ametdale. The FORAGE cover map also showed the relatively good cover on the collaborator properties relative to the district. While FORAGE is very useful, its 5km^2 scale nevertheless reduces the utility of the estimates of pasture mass and growth for paddock level stocking rate decisions.

Inaccurate land type mapping can also sometimes be a problem with FORAGE. Early field work at Case study 3 identified inaccurate descriptions (e.g. silver-leaved ironbark country mapped as box country) and boundary errors for the demonstration paddocks. However, these were subsequently remapped under the guidance of Case study 3 management (see updated landtype mapping).

15.4.3 Ready Reckoner stocking rate tool

The ‘Ready Reckoner’ tool, developed by Bob Shepherd (DAF Charters Towers) in collaboration with colleagues in DES, is a new practical method for producers to estimate seasonal ‘safe’ stocking rates. Recommended stocking rates are based on GRASP pasture modelled data for different landtypes, again, based to a large extent on detailed soil and pasture data collected at the Wambiana site. Stocking rates were then adjusted for local knowledge and seasonal conditions. It works on a basic understanding of a paddock’s soil inherent fertility (high, medium or low), seasonal rainfall (above, below or average), tree basal area and land condition (A, B, C or D) to recommend appropriate stocking rates.

The Ready Reckoner was successfully trialled at Case study 3 and Leichardt Creek and was positively received by producers due to its ease of use and the credibility of the recommended stocking rates. However it has presently only been developed for soils in the Burdekin catchment and needs adaptation and background GRASP modelling for other areas such as the Mitchell grass downs.

15.4.4 Land Condition Assessment tool (LCAT)

The Land Condition Assessment Tool (LCAT: https://www.stateoftheenvironment.des.qld.gov.au) developed by Rob Hasset (DAF) was trialled at some of the NGD sites and is being utilised by DAF to provide an easy, time effective and comparable assessment of land condition on areas of grazing land being managed for an improvement in land condition. LCAT has been adopted as the standard assessment methodology for all Reef funded projects. While LCAT is relatively easy to use it still requires training. It is also it is likely to be of limited practical use for the majority of producers in the extensive pastoral regions because of the time required to assess sites. Previous experience by both DAF and NRM staff is that few producers are willing to conduct even the most basic forms of pasture monitoring e.g. repeat photographs.

15.4.5 Breedcow and Dynama

‘Breedcow and Dynama’ (https://breedcowdynama.com.au/) and its suite of economic tools (Bullocks and Cowtrade) were used to support several stocking decisions, primarily at Leichardt Creek. Cowtrade was used to analyse turn-off options for cull cows and to evaluate the cost/benefit of pregnancy testing. This enabled non-performing cows that were in good condition to be identified and sold early in the season to reduce grazing pressure. The ‘Bullocks’ tool was also used to develop an options analysis for steer and cull cow turn-off in terms of gross margins per AE to support a return on investment study on establishing intensive pasture options like leucaena.

15.4.6 Validation and improvement of remote sensing

Pasture and land condition data from all sites was used to improve and validate remote sensing data, land type mapping and stocking rate assessment tools such as FORAGE and as the Ready Reckoner. Staff from the Department of Science also established their own detailed monitoring 'star' sites at Case study 3, Ametdale and Goshen.

15.4.7 Review of engagement with producer groups and field days

The network of sites in the Northern Grazing Demonstration (NGD) project successfully provided an essential platform for the Wambiana Grazing Trial to discuss and extend its findings and recommendations. The project also functioned as an important extension hub with many learnings for producers and the project team alike. Without exception, all producers involved in the communication events rated them highly. The demonstration sites also provided an ideal forum to show that graziers can, and are, managing their land well, while remaining productive and viable.

Although this type of awareness project will contribute to increasing adoption, it is a slow process. It is also becoming increasingly apparent that many producers do not recognise that they have a grazing land management issue and this is therefore not a priority to them. Unfortunately, some still show little understanding of how poor grazing land management links to, and impacts, both cattle production and downstream ecosystems. However, there are new and accessible tools such as FORAGE, StockTake and more recently the Ready Reckoner that are making inroads for improving understanding of 'my property' GLM issues. There is also increasing awareness of these and other issues driven by projects such as this and the new MLA funded Northern Breeding project.

In future, land condition and grazing management projects need to be over a longer time frame and should include more 'whole of business' themes to achieve success. Realistically, the NGD only planted the seed for practice change. The project will nevertheless leave a legacy of practical messaging and improved management tools for those producers ready for change.

Based on the experiences of running the NGD and engagement with producers the project team offer a number of reflections and suggestions. First, we identify the positives from the project followed by a list of issues identified. We end with a list of recommendations for future projects of this nature.

15.4.8 Project achievements

- The NGD was an essential platform to discuss Wambiana Grazing Trial and extend its findings and recommendations to four major catchments in Queensland. It also provided critical feedback to the trial essential to extend findings and modify grazing principles and management recommendations. The NGD was thus an excellent extension pathway for the twenty three years of WGT research outcomes and provided a two way flow of information and feedback to/from the four different catchments.
- The NGD sites highlighted the good land management in reef catchments demonstrating the commitment of the beef industry to improving sustainability and water quality. Sites also provided an ideal forum to showcase good grazing management to other managers and demonstrate how it is possible to manage sustainably but be productive and viable.

- The sites were also valuable as extension hubs and provided an important learning opportunity for graziers. This involved raising awareness of products like the Long Paddock website, peer to peer learning and presentations by a wide array of technical specialists. These included extension officers, nutritionists, soil conservation officers and animal health experts. Producers were also kept informed on the latest research addressing major problems like pasture dieback.
- The project was also an important learning opportunity for advisors and researchers regarding applying recommendations in the real world. These included discovering the complexities of forage budgeting and monitoring in large, spatially diverse paddocks, adjusting stocking rates in breeder herds and how small areas of introduced pasture could be used to reduce grazing pressure or implement spelling.
- Trialling of decision tools such as StockTake, FORAGE and the Pasture Growth Alert on commercial properties was also a valuable learning experience. While these were found useful at some sites, producers at other sites preferred the new, simpler stocking rate Ready Reckoner. This demonstrated that there is no single tool that suits all producers and shows that a variety of tools can be used to achieve similar outcomes.

Figure 37 Grant Fraser (DES) discussing climate tools with a producer (left) and producers inspecting the Ametdale demonstration with Paul Jones (right).

- Data collected at the four NGD sites was shared with DES and assists in ground truthing and calibrating forage prediction tools under development by DES. The DES research team also set up new 'star-transect' sites for ground truthing remote sensing products and further calibration of products like AussieGrass and FORAGE. The DES team also trialled new drone technology measuring woodland structure using LIDAR technology. All of these will improve the decision tools available to producers such as FORAGE and the new on-line carrying capacity calculator.
- The involvement of some sites in the Northern Genomics project highlighted issues of low breeder fertility and provided an opportunity for those involved to identify the most productive animals in their herds. In the longer term this will also help to increase the fertility of the beef herd in northern Australia.

Despite these very positive outcomes a number of issues were identified as listed below

15.5 Issues and challenges

- At three years the NGD project was short term. In contrast, extensive beef operations have very long production systems (i.e. from conception to sale) and land management changes do not show immediate production benefits. Land condition changes are also very dependent upon rainfall, as shown in the current report (section 9). It was therefore very difficult to show real change in land condition or animal production over the three years of the project.
- Engaging with some managers or 'non-adopters' in the various districts was very difficult as some don't see the need to change and/or may be outside social group. The incentive and

pressure to change is also likely to diminish given current good seasons and high cattle and property prices.

- In some cases there is social pressure on collaborators who do not want to be held up as ‘leaders’ or being better than their peers.
- Costs of collaboration – any collaboration involves a time and labour commitment from the host site. Hosting field days was also a pressure in terms of firstly, time and secondly, being held up to scrutiny by peers and technical experts.
- Demonstration sites vs whole of property case studies – comparing the economics of a practice in a demonstration paddock to the rest of the property is often desirable but usually limited by incomplete cattle records to do herd modelling and/or confidentiality regarding finances. Such whole property analyses also require a big time commitment from both operators and staff.
- Time constraints often limit the involvement of producers in advisory groups, particularly under drought conditions. This could possibly be overcome with an attendance fee.
- Maintaining interest- a mix of other topical, practical issues is needed to maintain interest around the key problem. Achieving engagement and change might need to be via a different but closely related issues e.g. linking improved reproductive performance to managing the feedbase.

From the above experiences, the NGD team make the following recommendations for future projects of this nature:

15.6 Recommendations arising from NGD

- Demonstration sites need to be long term and appropriately funded. Funding needs to account for the large scale of operations in north Queensland, the time costs of producer involvement, distances between properties and the long term nature of achieving change.
- Demonstration sites need to also function as extension hubs to increase awareness, knowledge and increase adoption.
- The expected level of producer commitment to advisory group meetings and field days needs to be realistic. Accordingly, the frequency of field days and meetings should be limited, especially if there is nothing to show.
- Communication between events is important to maintain producer interest. This could involve simple emails giving updates on the site and/or technical issues.
- Sites should be a platform for multiagency collaboration where possible, for example testing of products and decision tools with DES and involvement by reef staff.
- Collaboration and integration with regional NRM group projects is very important if at all possible. In the past this has sometimes been restricted by differences in approaches with for example, DAF science driven and some NRM groups more open to ‘innovative’ or untested forms of management. More recently, collaboration has improved markedly.
- Demonstration sites must confer some benefit to producers involved i.e. infrastructure like fencing, access to technical expertise, extra farm planning, access to decision tools etc
- Awareness and knowledge based activities like the NGD on their own will not drive rapid adoption. One solution is to assist graziers to identify a grazing land management problem through relatively simple business analysis to understand their current situation e.g. poor reproductive rates due lack of forage as is happening in the MLA funded NB2 project. Once identified and understood, producers can then be assisted with specific needs e.g. matching stock numbers with forage supply, in turn massively increasing the chance of adoption.

16 Key findings

This section presents the key findings from the Wambiana trial; the main findings from the NGD are listed in the previous chapter. Both chapters are the foundation for Chapters 16 and 17 where management guidelines and a series of short technical 'how to' guides are presented, respectively.

16.1 Heavy stocking is unsustainable and unprofitable

Individual animal LWG and carcass value were by far the lowest in the HSR. Although total LWG/ha was highest in the HSR in most years, drought feeding was required in seven out of 24 years, compared to only one year in the other strategies. Due to greater costs and lower product value, average gross margin per ha in the HSR ($7/ha) was thus only half that ($13/ha) in the other strategies. Income variability was also far greater, with the HSR having a negative gross margin in eleven of the 24 years of the trial.

Pasture condition declined drastically under heavy stocking with 3P grasses declining almost linearly over the course of the trial. The exotic grass *B. pertusa* also increased the most in the HSR. Ground cover and pasture yields were by far the lowest and inter-annual variability in yields the highest, in the HSR. This directly reduced drought resilience. The results clearly show that heavy stocking rates are both unprofitable and unsustainable, and that carrying capacity inevitably declines as shown by the forced reductions in stock numbers in a number of drier years.

16.2 Fixed moderate stocking is not sustainable in the long term

Moderate stocking at long term carrying capacity (LTCC) gave far better individual live weight gains (LWG), growth rates and carcass values than heavy stocking. Although total LWG per ha was lower than under heavy stocking, drought feeding was only required once in 24 years compared to seven out of 24 years for the latter strategy. Moderate stocking was accordingly far more profitable and annual returns far less variable, than heavy stocking.

Based on the first 16-20 years of the trial, constant stocking at LTCC appeared to sustainable, with pastures generally maintaining a high proportion of 3P grasses. However, pasture condition declined sharply in later years due largely to the severe drought, particularly in 2014/2015. Despite the 'moderate' stocking rate, overgrazing also undoubtedly played a role as paddocks were overstocked for the dry conditions. This strongly suggests that constant moderate stocking even at LTCC will be unsustainable unless stocking rates are adjusted downwards in drought years.

The need for wet season spelling was also indicated by insights gained through this project as well as the slightly better pasture composition in the R/Spell. This is directly supported by results from the spelling project (Chapter 9) showing faster recovery post drought with spelling.

16.3 Rotational wet season spelling at LTCC is better but ….

Moderate stocking with wet season spelling as applied in the R/Spell was also far more profitable and gave far better individual animal performance than heavy stocking. Individual LWGs also tended to be slightly better than in the MSR suggesting that spelling was indirectly improving animal production through its effects on pasture condition.

Pasture condition in the R/Spell was also somewhat better than in the MSR highlighting the positive impact of spelling. Nevertheless, pasture condition in the R/Spell also declined sharply in the recent drought with a significant drop in the frequency and contribution to yield of 3P species. Aside from the direct effect of drought, the fixed stocking imposed in the R/Spell also led to overgrazing as happened in late 2017 and in more recent years. This underscores the fact that stocking rate is the primary driver of land condition and that adjusting stocking rates is essential in dry years irrespective of whether wet season spelling is applied.

16.4 Flexible stocking essential for sustainability and profitability

Viewed over the full 24 years of the trial, or over the last 8 dry years, there was little, if any difference in individual LWG, total LWG per ha or gross margins between fixed stocking at LTCC and Var/Flex stocking. Nevertheless, progressively adjusting stocking rates both between and within seasons in the flexible strategies (Chapter 5.2) avoided the need to destock as happened in the MSR and R/Spell in 2017/18. The Flexible strategies thus had a GM of $9.50/ha compared to a negative GM of -$17/ha in the latter strategies.

Despite progressive reductions in stocking rate to relatively low levels, pasture condition also declined sharply in both Flexible strategies largely due to the severity of the 2014/15 drought and the subsequent years of below average rainfall. However, after 24 years pasture TSDM in May 2021 and ground cover was higher in the Flex+S, and to a lesser extent, the Flex, than in the MSR. While there is no apparent difference in pasture composition, the higher TSDM and the greater density of 3P plants in the Flex+S suggest that these strategies will have faster recovery trajectories when a wetter sequence of years returns.

These results clearly show that flexible stocking rates, preferably with wet season spelling, are essential for managing sustainably and profitably in these variable climates. Further evidence for the advantages of flexible stocking is shown by the fact that these strategies will be the only ones to with sufficient forage to carry stock through the 2022/23 season. In contrast, the R/Spell, MSR and HSR strategies will all be destocked due to the prolonged drought.

16.5 Drought had a major impact on pasture composition

The severe drought of 2014/15 significantly reduced pasture condition in all treatments. This effect was amplified by heavy stocking but was, to some extent, modulated slightly under more moderate stocking rates. This is an important observation. While the fact that drought can adversely affect pasture composition appears self-evident it highlights the fact its effects can only be partially ameliorated by management. This is counter to the previous findings from the trial and the consensus in the literature that management is a more important driver of pasture condition than rainfall e.g. (Ash *et al.*, 2001).

16.6 Indian couch increased in all treatments especially under heavy stocking

Indian couch (*B. pertusa*) was virtually absent from the site in 1998 but spread rapidly through all treatments in the wet period following the first drought. While the increase and spread in *B. pertusa* was greatest under heavy stocking, the fact that it increased in all treatments highlights its capacity to spread under even moderate stocking with spelling, given the right conditions. These conditions appear to be (i) an available seed source, (ii) drought and/or overgrazing to create bare areas for colonisation and (iii) late wet season/autumn rains to allow seeding to drive further spread the following wet season (Howden, 1988).

16.7 Woody plant cover increased despite fires and drought

Woody plant cover increased significantly on the box and brigalow soils between 1998 and 2021 despite two droughts and two 'hot fires' in 1999 and 2011. Woody cover also increased on the ironbark soils but declined sharply post 2012 due to significant drought induced mortality of adult *E. melanophloia.*

A significant part of the increase in woody cover has been due to the ongoing expansion of the native shrub *Carissa ovata* which was well established before the trial started. Despite the fires and droughts, *Carissa* cover has more than doubled (+114%) since the trial began on the box soils, the dominant soil type on the WGT area. While fire resulted in complete top-kill of *Carissa*, there was little if any mortality, with *Carissa* cover regrowing to, and then passing, pre-fire levels within five to six years.

This overall increase in woody cover, particularly by *Carissa*, is a significant issue and has undoubtedly contributed to the decline in pasture production, carrying capacity and reduced land condition over the course of the trial. There is hence an urgent need to develop cost effective methods to control *Carissa* in woodlands e.g. more frequent fire, selective thinning, where broad scale clearing is not permitted.

16.8 Land condition has declined in all treatments

While land condition has declined the most in the HSR, after 24 years land condition has declined significantly in *all* treatments irrespective of the stocking rate or spelling strategy applied. This is shown by the marked decline in 3P species like *B. ewartiana* and the increase in *B. pertusa* that has occurred to a greater or lesser extent across all treatments. Much of this decline is undoubtedly due to the effects of the severe drought; as such, land condition should improve when favourable conditions return. However, the management applied before, during and after the ongoing drought will significantly impact the rate and extent of recovery that subsequently occurs.

Given the current dry conditions, it remains to be seen to what extent recovery occurs in the different strategies if and when seasonal conditions improve. Monitoring this recovery will be vital to help inform industry on how to manage for recovery after this and the subsequent droughts that will inevitably follow.

16.9 Wet season spelling and moderate stocking improved recovery rates

Drought had a major impact on the basal cover of 3P grasses, but this effect was amplified by heavy stocking. In contrast to other species, *B. ewartiana* was relatively resilient to drought, emphasising its role as a keystone species for sustainable production. While *B. ewartiana* is long lived, recruitment rates are low. This highlights the importance of maintaining existing plants through drought through good management to drive post-drought recovery.

Basal cover of *B. ewartiana* improved slightly but non-significantly in later, slightly better years with spelling but only under moderate stocking. Spelling without applying the appropriate stocking rate is therefore unlikely to promote recovery. Spelling to improve pasture condition via recruitment is likely to be slow, at least for *B. ewartiana and* depend upon a favourable sequence of years to get significant results. Nevertheless spelling will encourage shorter lived species like *Panicum* which provide useful feed and facilitate recovery the longer term. Wet season spelling is thus an essential component of good pasture management.

16.10 Remote sensing can be used to classify forage quality relative to animal nutritional requirements

The remotely sensed greenness indices NDVI and fractional green cover (frGreen) were of moderate to high accuracy in classifying paddock forage quality relative to animal maintenance requirements. However, the degree of accuracy varied between year types being highest for dry years and lowest for wet years. Accuracy was also higher for animals with higher maintenance requirements i.e., cow's vs steers.

The accuracy of these thresholds declined only slightly when tested over the late wet season when diet quality is falling and the timing of management interventions most critical. More detailed analysis of the data would enable the exact conditions under which the thresholds were most or least accurate to be determined.

16.11 A prototype decision tool to forecast forage quality

Using the long term Wambiana data, a protype decision tool based on remote sensing was developed with DES to predict forage quality and forecast changes in quality going into the dry season. The model was able to forecast forage quality ahead from the end of May, into the first three months of the dry season with a reasonable accuracy for dry matter digestibility (DMD), and a lesser but still acceptable accuracy for digestible crude protein (DCP), albeit with increasing uncertainty.

This shows promise as an operational tool for managers but requires more work at other sites with appropriate data, and also a deeper investigation of modelling alternatives. Nevertheless, the work is a significant advance as it is the first time that such a tool has been developed for tropical rangelands.

16.12 Models needs refining to capture long term grazing impacts

In collaborative work with the DCAP project, an upgraded, well parametrised GRASP model successfully predicted pasture yield and 3P composition over the first 16 years of the Wambiana trial. However, the model was unable to capture the degradation through the last drought and the subsequent lack of recovery. Nevertheless this study provided parameterisation to improve GRASPs ability to model grazing lands, especially during prolonged droughts, and provided insights on missing and/or underrepresented processes that require further work.

The work also built a foundation for the testing of a wide variety of modelling applications and ground truthing of satellite tools with the trial data. The findings will contribute directly to current applications of GRASP such as those on FORAGE predicting long-term carrying capacity and pasture availability.

16.13 Walk over weighing is a valuable research tool

Trutest Walk-over weigh (WOW) units allowed collection of unprecedented data on daily weight changes under different grazing treatments and seasonal conditions. The units were also very useful for monitoring animal performance in real time. The results demonstrated how animal weight gains directly respond to stocking rate, rainfall and drought conditions. Importantly, they provided some of the first data showing how poor land condition reduces the capacity of country to respond to rainfall and drive production. Conversely, they provided crucial evidence of how good land condition can improve the response to rainfall and so increase productivity.

There are however a number of technical and operational issues that need to be addressed to improve performance and reliability of the WOWs. As such they cannot be regarded as low input, ‘off the shelf’ technology, particularly for producers. Despite that, WOWs are a valuable research tool and will continue to be used on the trial.

16.14 On property demonstration occurred in four catchments

The Northern Grazing Demonstration (NGD) project demonstrated good pasture management (‘Wambiana principles’) on four properties in different catchments. The project also identified key management principles for sustainable animal production. The main learnings from the project were that improving land condition and animal production requires a long term approach with change being gradual and season dependent. Producers emphasised the importance of stocking *around* long term carrying capacity but highlighted the need to adjust numbers as conditions deteriorated. Here, having trigger points and an action plan was essential. This was demonstrated at ‘Ametdale’ with sharp cuts in stocking rate in April 2018 due to poor conditions.

Improved breeder management was also an important feature to manage stocking rates. This included control mating, pregnancy testing and foetal aging to better manage breeder numbers. Improving reproductive efficiency was also seen as a way to reduce breeder numbers but maintain production.

Wet season spelling was also seen as important and applied either in a simple rotational grazing system with two or three rests through the season or as periodic wet season spells every few years. At all sites, countering area-selective grazing was also seen as important and managed by shutting off waters, moving lick troughs or subdividing paddocks for rotational grazing.

Sown pastures could also be used to reduce stocking rates or allow spelling of native pasture paddocks by finishing younger stock earlier. Breeder culls could also be put on sown pastures to improve marketability and reduce stocking rates in breeder paddocks. Overall, the NGD demonstrated the principles of good animal and pasture management to a large number of producers and identified a range of ways to help implements these principles at a property scale.

16.15 The Wambiana project resulted in significant practice change

A survey on the impact of the project on the knowledge, attitudes skills and aspirations (KASA) of graziers by an independent consultant showed that 90% of the 30 graziers surveyed gained new knowledge from the WGT. For some, the project also provided reinforcement of previously held management ideas. As a result, 73% reported an attitudinal change to management with the trial providing the evidence needed to change management. The power of the visual message of the paddocks and cattle at WGT i.e. the ‘power of seeing’, was strongly emphasised in this respect.

Sixty three percent (63 %) of graziers reported learning new skills from the project while 70% aspired to make a change regarding wet season spelling, more observation of the pasture and adjusting stocking rates with seasonal conditions. As a result, 60% had made one or more positive management practice changes based on their experience of the project.

The WGT also reinforced the use of sustainable management and kept graziers committed to applying using sustainable principles i.e. focussing on stocking rate and pasture. The project thus also had meaning for those learning from other sources, indicating broad impact. Graziers rated the WGT as being of high to very high relevance for industry, particularly because of its long term nature. There was strong (100 %) support for its continuation, albeit with some modification.

Their overall ratings, however, suggests that a large proportion of grazing business are yet to fully utilise the results from WGT. Producers also need to see (understand) how to do it on their property and in their circumstances. Suggestions were to also deliver activities that provide a pathway to practice change. The WGT could also be used as a training ground for things like moving to rotational grazing or implementing wet season spelling. In conclusion, the KASA survey showed that the trial is delivering information and results that graziers use in decision making and is providing support for graziers to make positive management changes.

17 Development of grazing management guidelines

This chapter partly addresses Objective 8 i.e.:

- 'Develop a set of grazing management guidelines based on the above' i.e. the work described in previous chapters.

In the chapter that follows i.e., chapter 18, these management guidelines are developed into a series of 'how to' or technical guides to assist managers to apply these recommendations in their own situations.

17.1 Stock around long term carrying capacity:

In all but the driest years, stocking *around* long term capacity (LTCC):

- Maintains land condition and carrying capacity and reduces variability in pasture production between years (Section 7.2.1).
- Gives the best individual animal performance, reduces turn off time by 12 to 18 months and gives price premiums at the meatworks (Section 6.2.1).
- Maximises longer term profitability and reduces income variability due to little or no drought feeding, reduced costs and better prices (Section 6.2.4).

Conversely, stocking above long term carrying capacity for extended periods:

- Causes land condition to decline, reduces carrying capacity and amplifies variation in year to year pasture availability (Section 7.2.1).
- Increases runoff and reduces the effectiveness of rainfall - 'droughts' thus are more frequent, and the effects felt sooner (Section 5.2).
- Gives higher total animal production in most wetter years but dramatically increases costs and risk (Section 6.2.2).
- Reduces drought resilience and in the longer term (>5 years) is less than half as profitable as stocking at LTCC (Section 6.2.4).

Note that even if stocked at LTCC, failure to reduce stock numbers in very dry years is likely to cause long lasting damage to land condition and productive capacity.

17.2 Adjust stocking rates in a risk averse, flexible manner

Adjusting stocking rates to match forage availability:

- Prevents overgrazing in dry years and reduces the impact of drought on land condition (Section 8.2).
- Promotes faster pasture recovery post drought (Chapter 9).
- Maintains acceptable individual animal production and avoids expensive drought feeding (Section 8.1).
- Increases production and gross margins in wetter years through increased animal numbers (Section 8.1).

However:

- Stocking rates need to be increased cautiously as seasons improve for example, at a maximum of 20% increase in numbers from year to year (Section 5.2).
- Upper limits need to be set on stocking rates e.g. within of 25% above LTCC, in even the best seasons (Section 5.2).

- Stocking rates must be reduced rapidly and early with the approach of dry conditions to have marketable animals and avoid long lasting degradation.

17.3 Wet season spell pastures as often as possible

Provided stocking rates are appropriate, wet season spelling:

- Maintains and improves pasture condition allowing recovery of overgrazed patches and landtypes (Section 9.3.2).
- Reduces drought impacts on pastures and accelerates post drought recovery (Section 9.3.2).
- Gives increased pasture production and better animal production in the longer run (Section 6.2.2).
- Allows accumulation of a fodder bank for later use.
- Does NOT buffer the impacts of higher stocking rates on land condition (Section 5.2; O'Reagain *et al.*2008).

Note that the initial effects of spelling may be gradual, particularly on C condition land, but the rate of improvement accelerates with spelling over time.

17.4 Use fire to maintain an open savanna structure

Appropriate use of fire:

- Maintains an open woodland by suppressing woody species and keeping trees and shrubs in the' fire trap' where they can be managed (Section 7.2.2; O'Reagain *et al.*2008).
- Does not kill Carissa ovata (Currant bush) but suppresses it and keeps it at manageable levels (Section 7.2.2).
- Will favour H. *contortus* (Black Speargrass) but seems to have neutral effect on *B. ewartiana* (desert bluegrass) O'Reagain *et al.*2008).

However, fire must be used with caution; applied at the wrong time, too frequently or when followed by drought it can be very damaging (Section 4.5).

Post fire spelling is also essential to allow pasture recovery.

17.5 Manage for area selective grazing

Managing for area selective grazing will

- Ensure more even utilisation of paddocks and increase carrying capacity.
- Allow more preferred, over utilised areas to recover.
- Maintain and improve overall land condition.

18 Technical 'How to' guides

In this section the management guidelines presented earlier in Chapter 17 are developed into a series of draft technical notes or 'how to guides. These are also presented as draft extension notes in Appendix 13.

18.1 Stock paddocks around long-term carrying capacity

Why? Stocking *around* LTCC is essential to maintain pasture composition and carrying capacity, improve animal performance and increase profitability.

Indicators of overstocking

- Ground cover consistently low (<60% on the FORAGE tool) and/or lower than regional averages for landtypes in question especially in dry years as shown on FORAGE or VegMachine www.vegmachine.net.
- Pastures dominated by unpalatable species like wiregrass, annual grasses and/or forbs.
- 3P grasses less than 40% by weight of pasture, existing tussocks/plants are small in diameter, lack vigour, seldom produce seed, don't respond well to rain.
- Very few recruitment events i.e. there are few if any smaller, younger plants.
- Feed often in short supply in dry season; drought feeding required sooner/more often than neighbours.
- Animals perform very well in some wet years due to short green feed/annual grasses but rapidly decline in condition and weight at end of wet season as annuals die off.
- High level of runoff with break of season rain and reduced response to rainfall.

Evidence

- Evidence from the long term Wambiana Grazing Trial (WGT) shows stocking around LTCC gives best individual animal production, the best carcass grades and highest prices. Stocking around LTCC will also increase reproductive performance and minimise mortality rates in drought.
- Stocking around LTCC increases drought resilience i.e. far fewer 'droughts' and is most profitable in the long term due to lower costs (especially avoiding cost of drought feeding).
- Grazing trial evidence e.g. WGT, Ecograze (Ash *et al.*, 2001, Burrows *et al.*, 2010) also shows stocking around LTCC (conservative stocking; removing 30% or less of growth each season) maintains or improves pasture composition, reduced runoff, increase rainfall infiltration etc. Conversely heavy stocking rates result in a loss of important perennial grasses and loss of land condition and carrying capacity.
- Pasture and animal response to out of season or early wet season rainfall is often greater with stocking rates close to LTCC (as shown with Walk-Over-Weigh data).

How to implement

Stock paddocks *around* LTCC using the LTCC of constituent landtypes as a general guide as follows:

- Attend an MLA *Edge* Grazing Land Management course where managers get to plan their properties and calculate LTCC.

Alternative A:

- Identify and map paddock land types and areas; broad landtypes can also be mapped using the FORAGE Landtype tool www.longpaddock.qld.gov.au/forage.
- Assess land condition (A, B, C or D) using condition indicators on landtype sheets on www.futurebeef.com.au/ ; estimate tree densities visually.

- FORAGE or VegMachine can also be used as an aid in determining land condition or condition trends.

Alternative B:

- Use the '*Bob Shepherd's Ready Reckoner*' (Burdekin catchment only) to estimate or,
- Access the FORAGE Long term carrying capacity report www.longpaddock.qld.gov.au/forage.

For all of the above:

- Apply factor to determine proportion of paddock accessible to animals based on water distribution, grazing radius and topography. Use an online mapping tool.
- Discount for differences in landtype preferences; utilisation will be non-uniform so some landtypes may be severely overgrazed and others only lightly grazed.

Importantly: do a reality check of the estimated LTCC:

- Compare estimated LTCC with that applied by 'good' managers on similar country or compare intuitively with historical paddock records.
- Apply adaptively: monitor trends in pasture composition, yield and animal performance over time and adjust accordingly.
- Remember: LTCCs are a guide only; it is essential to adjust and reduce stocking rates in dry years even if stocked at LTCC.

Suggestions for reducing stocking rates

- Increase reproductive efficiency so that fewer cows produce the same number (or more) of calves e.g. reduce bull %s, buy only tested bulls, preg test and cull non-pregnant, older cows, non-performers & others.
- Use BreedCow and/or Dynama to compare options for reducing stock numbers www.breedcowdynama.com.au/.

18.2 Match stocking rates with available forage

Why? Adjusting stocking rates in line with seasonal conditions to match stocking rates to available forage ensures that animals have sufficient feed at all times, avoids or reduces the costs of drought feeding (or selling poor condition animals) and minimises drought impact on pastures. Stocking rates can also be adjusted upwards in good years to increase production without damaging pastures. However, this needs to be done with appropriate checks and balances.

Indicators that stocking rates are not being matched with available forage

- Ground cover and yields are often extremely low at the end of the dry season i.e. cover often less than 50 % and yields less than 600-800 kg/ha.
- Ground cover consistently lower than regional averages for landtypes in question especially in dry years as shown on FORAGE or VegMachine www.vegmachine.net.
- Drought feeding required sooner and more often than others in region.
- High runoff rates with break of season storms, reduced response to rain and effects short lived. Runoff water consistently high in sediment etc.
- Land in C condition or B condition and species composition deteriorating.

Evidence

- Evidence from the long term WGT shows that failure to reduce stocking rates in dry years results in reduced animal production and pasture degradation even if stocked around LTCC. These effects are even more marked if stocked above LTCC (as in the HSR)
- Conversely, the WGT also shows that adjusting stocking rates to match available forage reduces the impact of drought/dry years but also takes advantage of better years i.e. it increases drought resilience and is most profitable in the long term due to lower costs (especially by avoiding cost of drought feeding).
- However, evidence from the WGT also shows the long term, negative effects on land condition of overstocking in good years and the failure to cut numbers sufficiently fast as drought approaches. Stocking rates must thus be adjusted with caution as indicated below.
- Ecograze (Ash *et al.*, 2011) showed that adjusting stocking rates to achieve correct pasture utilisation rates (20-30%) maintained land in good condition in drought years and allow land in poor condition to improve in good years.

How to implement

The *primary* or main stocking rate adjustment point should be around the end of the wet season, as at this time there is the greatest certainty about *how much* feed there is likely to be available for the next 6-9 months (end of growing season; further rainfall and growth is unlikely) and how long forage has to last (for the entire dry season until the expected start of the next wet).

Other suggested *secondary stocking rate adjustment points* are in the mid and late dry season and in the early-mid wet season.

Adjust stocking rates in a constrained, flexible manner as seasons vary, based on available forage, animal performance, seasonal conditions and where appropriate, climate forecasts.

Use some or all of the following:

Do a forage budget- attend a Stocktake Forage budgeting course, use the Stocktake App or see note 'doing a fodder budget' attached.

Use the '*Shepherd Carrying Capacity Ready Reckoner*' (see Appendix 6)

Use Grazing charts as used by Resource Consulting Services Australia (www.rcsaustralia.com.au). Even if not running a cell grazing/multi-paddock system working out grazing days per hectare in relation to rainfall is a very good way of keeping check on stocking rates relative to seasonal conditions.

Whatever the method used it is important that upper limits be set on stocking rates in even the best seasons to prevent overgrazing e.g. set LTCC +20% as an upper limit to stocking rate irrespective of how good the season is.

Adjusting stocking rates

Changes in stocking rate should be made in a risk averse manner i.e. cut stocking rates sharply e.g. 20-40% with the approach of poor seasons but increase stocking rates gradually e.g. 10-15% in good seasons. Degree of change will also depend on:

- Current stocking rates relative to LTCC.
- Land condition trends and the risk of degradation i.e. if pasture condition is declining or recovering post drought and/or seasonal outlooks are negative, err on the side of caution.

Procedure

Stocking rates may be increased or decreased at the end of wet. However, the secondary adjustment points at the end of the dry and early wet are *correction* points to ensure earlier stocking rate adjustments were appropriate i.e. stocking rates should be reduced or left as is. They should not be increased given the uncertainty around rainfall and/or upcoming seasons at these times.

Importantly: forage budgeting stocking rate estimates are very broad – use with caution and apply adaptively.

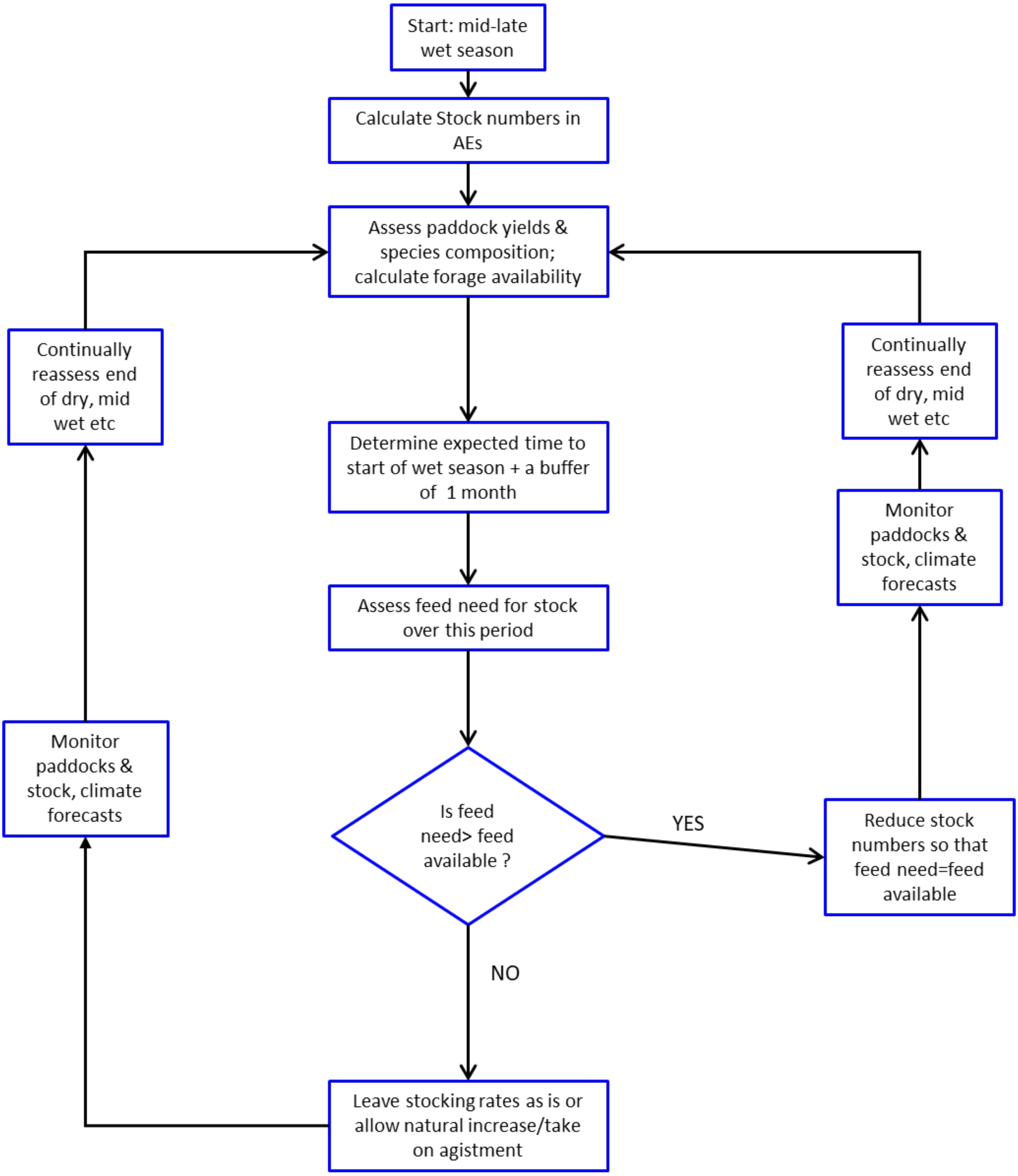
- Constantly assess available feed and animal condition as described above.
- Set firm decision points for early-mid February and Easter in case wet season fails (section 15.3).
- Monitor on-going seasonal forecasts- note that seasonal climate forecasts have relatively low confidence at the end of the wet season but forecasts increase in accuracy and may indicate whether the start of the wet season is likely to be earlier (or later in El Nino years).

[But based on WGT experience be cautious of forecasts for a La Nina – it hasn't rained until it has!]

Rules of thumb

- Stocking rates chosen at the end of the wet season must allow for sufficient forage to allow stock to survive through the dry season (plus a buffer period) without drought feeding.
- Any increases in stocking rate at the end of the wet should obviously not be done with stock that will increase exposure to risk, but with animals that can be marketed relatively easily in the event of a poor wet season the subsequent year. The most appropriate stock will vary enormously depending upon specific conditions. Or consider agistment to utilise excess forage.

Figure 38: Suggested flow diagram for matching stocking rates with forage availability.



18.3 Apply wet season spelling

Why?

Cattle graze selectively which means that preferred grasses tend to get overutilised irrespective of stocking rate. Wet season spelling gives preferred grasses a chance to rebuild reserves, increase vigour and set seed; it also gives new plants a chance to establish without being disturbed by grazing or being pulled out. Spelling is also a good way to ensure there is a feed reserve for later in the year or for animals that need special care e.g. weaners. Spelling during the dry season when plants are dormant is of far less benefit to the plant but will have some benefit to soil health due to the removal of compaction.

Nevertheless, spelling is of little benefit unless subsequent stocking rates are appropriate i.e. no more than 35 % pasture utilisation over a year.

Indicators of the need for spelling

<u>All paddocks</u> need occasional spelling. That aside, indicators of the need to spell are:

- 3P grasses are less than 40% by weight of pasture, with pastures dominated by unpalatable species like wiregrass, annual grasses and/or forbs.
- Tussocks of preferred (3P) grasses lack vigour and/or are relatively small, of low diameter seldom produce seed, don't respond rapidly to rain.
- Paddocks grazed short, yields are low and cover declining
- Very few recruitment events (?)
- Marked patch grazing with some areas very heavily grazed, other areas rank and seldom grazed.

Evidence

- *Ecograze* project data (Ash *et al.*2011) showed rapid improvements in yield and composition with early wet season spelling on goldfields and other soils provided pasture utilisation rates were appropriate (25-35% utilisation)
- In contrast, spelling trial data at WGT show recovery with wet season spelling can be very low but spelling does allow faster recovery post drought.
- WGT data also shows that stocking rate is more important than spelling in determining pasture condition i.<u>e</u>. spelling does not buffer effects of higher stocking rates.
- WGT data showing (slightly) better LWG with spelling compared to same conservative stocking rate with no spelling.
- Numerous lines of evidence in the Scanlan *et al* review (Scanlan *et al.*, 2014).

How to implement

- Spelling is the complete destocking of a paddock from at least the first significant summer rains until the middle or end of the wet season. Macropods and feral animals may thus also need to be controlled.
- Spelling should be targeted at paddocks that need spelling the most i.e. those in poor/declining condition, low vigour, declining species composition and/or
- Vegmachine can also be used to identify paddocks with consistently low cover/cover trending downwards relative to regional averages.
- Time since last spell is also important; all paddocks need periodic spelling say every 4-5 years if possible.
- Based on condition and time since last spell, paddocks should be prioritised for spelling based on need i.e. condition and time since last spelled.

- Spell paddocks after about 50 mm of rain in two days after 1 December or earlier in very wet La Nina type years.
- Early wet season spells are most beneficial but spell paddocks for the full wet season if possible- the longer the better.
- In good seasons spell as much as possible. In dry years spelling is still very important but can be difficult to implement if forage is in short supply (see below).
- Closely monitor unspelled, grazed paddocks – over utilisation of these areas can easily outweigh the benefits of spelling. If this occurs, open up spelled paddocks progressively to reduce grazing pressure. Open lower priority spelled paddocks i.e. those least in need of a spell, first followed by higher priority paddocks.
- Note that while spelling is very important, in poor seasons when pasture production is low it may be better not to spell to avoid severely overgrazing unspelled areas i.e. spread grazing pressure over the entire property.
- Where patch grazing is an issue, fire may also be needed to remove rank feed to even out grazing pressure once spelled paddocks are opened. If so, burn paddock before spelling and then rest until pasture has regrown sufficiently for grazing to occur.

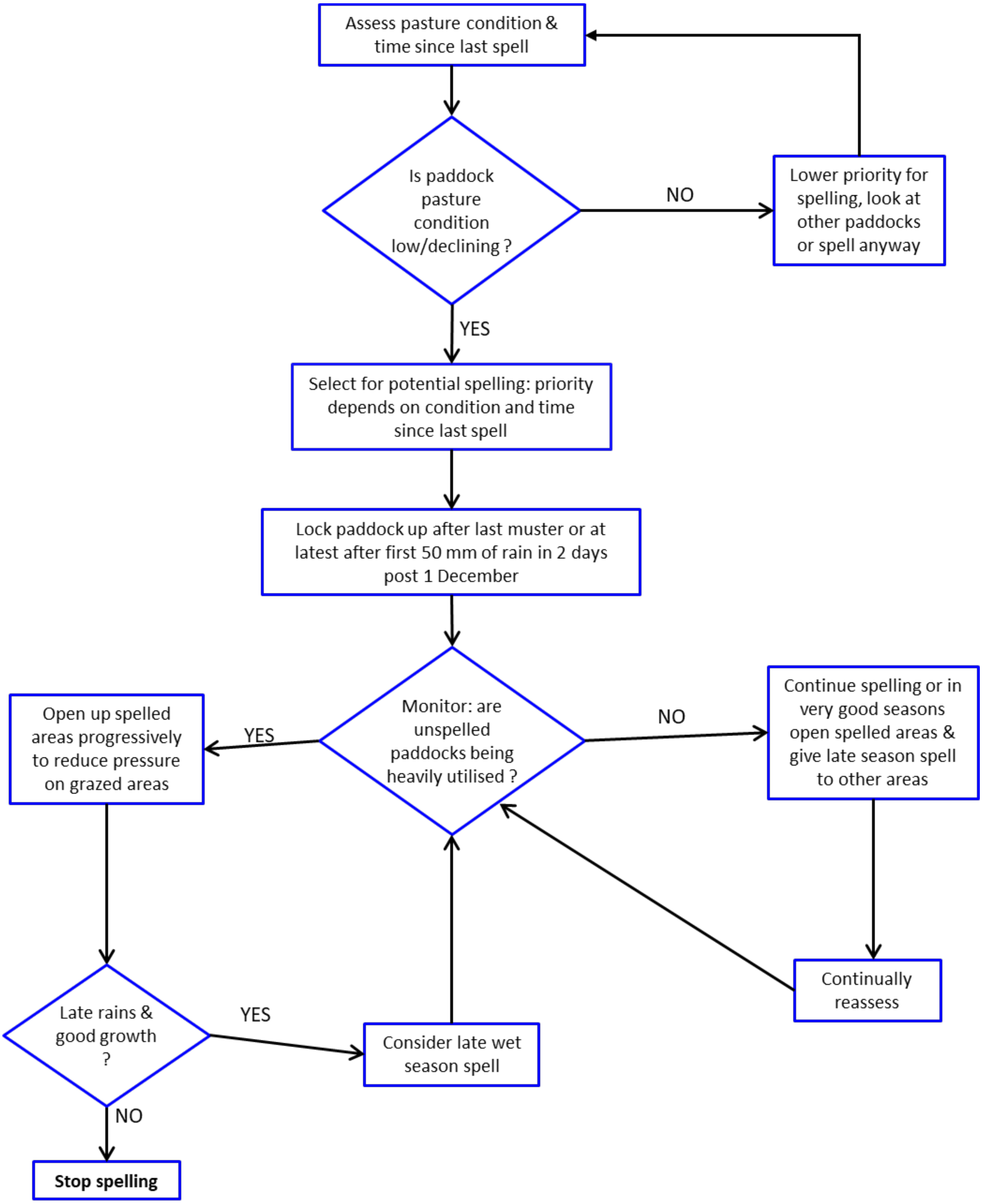
Suggestions for implementing WS spelling

- First, adjust stocking rates to be in line with LTCC and seasonal conditions - spelling does not buffer the effects of higher stocking rates.
- Extra fencing may be required for additional paddocks – however the payback time may be extremely long. Use electric fencing?
- To avoid extra musters to move cattle, paddocks can be locked up late in the dry season after the second round muster.
- If insufficient paddocks are available, mobbing up herds may be the best option (but care must be taken to avoid overgrazing of non-spelled areas & may be other issues with animal management e.g. difficulty in targeting supplementation for certain age/condition classes)

Possible simple management systems

- Two paddock system- paddock A spelled in wet season, all animals in paddock B; both paddocks grazed in dry season; the following year, paddock B wet season spelled, all animals in paddock A.
- ‘WGT’ system – 6 paddocks, 1-2 paddocks spelled each wet season depending on rainfall, remaining paddocks are grazed, all paddocks grazed in dry season. In the next wet season, another 1 to 3 paddocks are spelled and so on, so over 3 years each paddock has a spell.
- Two herd – 3 paddock ‘Ecograze’ system (Ash *et al.*2001) - paddock A rested in early wet, paddocks B & C grazed; paddock B rested in late wet, other two grazed; then paddock C rested for late dry season & early wet; paddocks A & B grazed; and so on ….

Figure 39 : Suggested flow diagram for implementing wet season spelling



18.4 Fire as a tool to manage the grass: tree balance

Why Burn?

- Fire is important to maintaining the grass: woody balance and keeping woody spp. suppressed.
- Fire can even out patch or uneven grazing and prevent degradation.
- It can also improve pasture composition through encouraging species like black speargrass & can be used to reduce Stylo dominance.

Indicators of the need to burn

- Patch grazing with very short, grazed patches and areas of rank unused pasture.
- Woody thickening, especially shrubby native weeds like Currant bush and/or exotic weeds like rubbervine (*Cryptostegia grandiflora*).
- Stylo dominance with declining grass yields.

Evidence

- Evidence from the WGT (O'Reagain *et al.*2008) shows that while fire doesn't kill many trees/woody species outright, it opens up the woodland and can be used to suppress woody species and keep them short enough to control with fire (the fire trap). If trees are kept below 2-3 m, they can be top killed with fire forcing them to regrow from their bases. Once trees are too tall, they are beyond the reach of serious fire damage and can resprout from their crowns.
- Evidence from the WGT also shows how fast native woody weeds like *Carissa* can expand, compete with the grass to reduce yields and reduce carrying capacity.
- Some 3P species like *H. contortus* (black speargrass) and *T. australis* (kangaroo grass) are favoured by fire while some wiregrasses are set back. The effects of fire on *B. ewartiana* (desert bluegrass) appear to be neutral or slightly negative.

How to implement

- A suggested minimum fuel load for a burn is about 1500 kg/DM/ha. For woody plant suppression, fuel loads in excess of 2000 kg/ha are desirable.
- Ensure sufficient paddocks are available for post-fire spelling. If the subsequent season is poor and rainfall is low, paddocks may have to be spelled for an entire year post-fire.
- To remove moribund material and promote 3P grasses, burn with a head fire at the start of the wet and immediately after rain (*c.* 50 mm) i.e. before grasses start growing; burning when grasses are growing will set pastures back significantly.
- Ensure moderate stocking rates are applied to allow sufficient fuel to accumulate in the majority of years e.g. 7 out of 10 years. Burning will frequency depend upon the rainfall, landtype and feed availability.
- Fire frequency should not exceed once every 5 to 10 years. Fire frequency is likely to be greater in higher rainfall regions and on higher fertility landtypes.
- Match fire frequency to country type:
- Every 10 to 20 years on less fertile, fragile country.
- Every 5-10 years on more fertile, productive country.
- Wet season spell paddocks immediately following burning to allow recovery and prevent pasture degradation. If seasons are poor, paddocks may need to be spelled for a year or consecutive wet seasons (or even longer on more fragile country) to allow recovery.
- Avoid burning when seasonal forecasts for approaching wet season indicate below average rainfall e.g. www.longpaddock.qld.gov.au/seasonal-climate-outlook.
- Use fire with caution – 'Burning is a good servant but a bad master'.

19 Benefits of the present project to industry

This project has demonstrated clear benefits to industry as shown by the KASA survey in chapter 22. An independent cost benefit analysis of the Wambiana project undertaken in 2021 also reported a benefit to cost ratio of investment in this project as 11:1 (Chudleigh and Hardaker, 2021).

Management recommendations and guidelines for industry are presented in Section 16 of this report. The Wambiana trial is the first to provide long term, peer reviewed data showing the economic benefits of adopting more sustainable grazing strategies. More recent data from the trial has also shown that even if stocked at long term carrying capacity, degradation and economic loss can occur in drought unless stocking rates are adjusted appropriately.

Industry would benefit in the following ways from adopting the management guidelines generated from this project:

- Improved individual animal production resulting in faster turnoff, improved prices per kilogram and better grades at the meatworks.
- For breeders, heifers would reach puberty sooner while breeders would have greater re-conception rates and reduced calf mortality.
- Improved profitability through greater product prices and importantly, reduced costs particularly of drought feeding.
- Greater drought resilience resulting from reduced variability of forage production, improved rainfall infiltration and improved rainfall use efficiency.
- Reduced runoff from grazing lands and improved biodiversity both of which would improve the social licence of the grazing industry.

Aside from these direct benefits, the data collected in the trial and the trial itself have provided significant indirect benefits to industry through the development, testing and ground truthing of a range of monitoring and decision tools as shown in section 14 and noted in Chudleigh and Hardaker 2021.

20 Future research and recommendations

Based on the results and experiences gained through the current project, consultation with GAC members, feedback from producers at field days and the KASA survey of 30 beef producers, the following areas of important future research were identified:

20.1 Developing advanced management strategies to manage climate variability

There is a need to further develop profitable, sustainable management strategies and tools that producers can use to manage for current and predicted future climate variability. To do this it is important to continue most of the trial treatments to determine their long term effects, in particular to quantify the extent and rate of recovery in land condition and carrying capacity that might occur with a return to more favourable seasons. This will increase the level of confidence in the data and ensure results are meaningful for the industry. The resultant management recommendations also need to be integrated with new and developing decision tools (see below) to help producers react early and appropriately, to changing seasonal conditions.

20.2 Accelerating recovery of carrying capacity on C condition land

There are significant and increasing areas of C condition land with reduced carrying capacity throughout northern Australia e.g. (Hassett, 2021). This is a major threat to the long term carrying capacity and viability of many properties. The current work has also shown that recovery is frustratingly slow using only wet season spelling in a continuous grazing system, particularly when combined with drought years. There is thus an urgent need to develop evidence-based strategies to accelerate the recovery of productivity and carrying capacity of these areas through grazing and spelling i.e. not simply through removal of grazing. This might include specific elements from adaptive multi paddock/regenerative grazing systems e.g. short, high density grazing combined with long rest periods, and even the use of evidence-based soil amendments. This could include biological soils crusts identified as being important in N fixation or C sequestration within the current MLA funded University of Queensland soil biocrust project.

20.3 Managing the tree: grass balance and controlling *Carissa*

As observed in the present project (section 7), many properties are experiencing a seemingly inexorable increase in woody vegetation. There is thus the need to develop burning and grazing strategies to manage the tree: grass balance and in particular at Wambiana, the native woody weed *Carissa ovata.* The latter is a serious issue as shown by the large increases in *Carissa* cover on the trial. Similarly, in the Dalrymple shire soil survey in 1991, *Carissa* was identified as the most important weed in the shire with 47 % of sites affected (Rogers *et al.*, 1999). The problem is even more marked on some landtypes: in the 1991 survey, 73 % of sites on sedimentary landtypes were affected with *Carissa* comprising up from 1 to 99% of ground cover (De Corte *et al.*, 1991). Based on the increases in *Carissa* cover observed in the present trial, these 1990-era results are likely to be significant underestimates of the current extent of the problem in through central and north Queensland.

With legislation restricting broadscale mechanical or chemical control, control methods would have to focus on economically viable tools such as fire (frequency, intensity and timing). Grazing management would also be critical to ensure sufficient fuel for fire, suppress *Carissa* through increased grass competition and possibly, physically damage *Carissa* through e.g. high impact grazing, and/or co-grazing with browsers. It is also essential to study the basic ecology of *Carissa* to determine what controls its recruitment and spread and possibly, identify opportunities for its control.

20.4 Increasing understanding of the ecology of key pasture species

Research into the basic ecology of key 3P species in particular, desert bluegrass (*B. ewartiana*) and Queensland bluegrass (*D. sericeum*) is urgently needed. This would identify opportunities to better target management interventions to encourage recruitment and also manage risks when plants are particularly vulnerable, so as to reduce mortality or loss of vigour. Given the importance of *B. ewartiana* in many Queensland pasture communities, it is surprising that far more research has not been done on this species before.

20.5 Improving modelling and decision tools for management

Further development is needed on predicting and forecasting forage quality from satellite imagery (section 10.1). This would require refinement of the existing model or new models, and their testing at a range of other research sites where diet quality data is available. These improved models could then potentially be customised for individual properties with limited faecal analysis data using, for example, artificial intelligence.

As shown in section 11.4 the GRASP model also needs further refinement in terms of modelling changes in pasture condition, production and carrying capacity. In particular, more data is required on how basal cover changes with grazing, the factors driving species composition change and the relationship between woody plant density (particularly *Carissa)* and pasture production. Better relationships on how rainfall infiltration rates change as land condition declines also need to be developed. Improving GRASP would directly improve the reliability of estimates of pasture production and carrying capacity provided to industry via the FORAGE web site and extension via for example, the MLA Grazing Land Management Edge package.

21 Summary of data collected in 2021/22 season

This section addresses Milestone 10 specifically

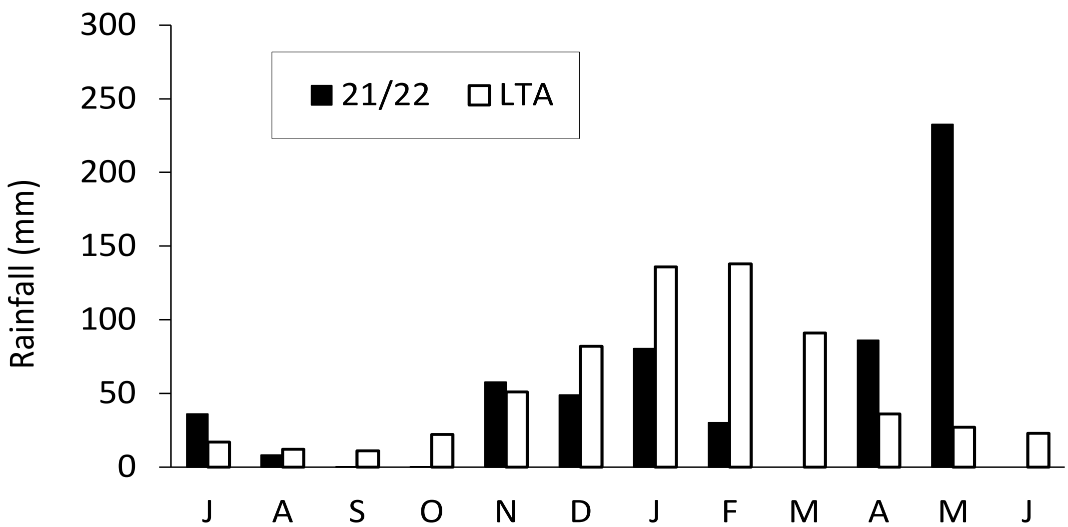
- *'9.1 a summary of the data collected (but not statistically analysed) 2021/22 seasonal data'*

21.1 Introduction

The 2021/22 season has been challenging with extremely variable conditions throughout. Despite the very positive forecasts for a La Nina above average wet season, the first half of the season was very disappointing. This resulted from below average rainfall at the start of the wet season, followed by a long dry period from 6 February through until late April. These dry conditions were exacerbated by record high temperatures with five consecutive days above 40 C. Consequently by April, pasture yields were extremely low and most paddocks overgrazed.

Conditions changed abruptly in late April with good rain around Anzac Day. This was followed by record breaking rain in early May with 233 mm over four or five days. This is almost five times the long-term May average of 53 mm (Figure 40). The previous highest record for May was 198 mm in 1977 (based on Trafalgar station rainfall data).

Figure 40: Monthly trial rainfall for the 2021/22 season relative to the long term average (LTA) for Trafalgar station 17 km NW from the trial site.



21.2 Data collection

Data collection has largely proceeded as planned with the pasture frequency surveys completed on the Box and Ironbark soils (Table 22). However, frequency surveys for the heavy clay Brigalow vegetation has been postponed to June or July due to the extremely wet conditions. The paddock level end-of-wet season pasture yield and composition surveys have similarly been postponed to by two to three weeks until June due to the extreme May rainfall.

Table 22: Data collected and progress of field work for 2021/22 season at the Wambiana trial.

Data	Status	Comment
Animal weight changes	Weighed December 2021 (end of dry) and 2 June 2022.	Completed, data being collated.
Faecal samples for NIRS analysis	3 weekly samples collected from all paddocks – up to date	NIRS analysis delayed while lab issues resolved
Walk over weighing	Daily weights collected and processed as weekly weights for 4 paddocks	Both units working; some interruptions due to equipment malfunctions.
Pasture- end of dry (EOD) and end of wet season (EOW) yields and composition	EOD yields assessed November 2021; EOW surveys completed June 2022	Proceeding as planned; slight delay due to rain
Pasture frequency surveys	Completed for Ironbark and Box; Brigalow postponed until August due to record breaking May (233 mm) and July (181 mm) rainfall.	Proceeding as planned; some delay due to rain
Runoff flumes	One runoff event in May; no previous events due to drought	Dependent upon rainfall
Rainfall- amount and intensity	Ongoing	Ongoing
Soil moisture monitoring	Ongoing on Box and Ironbark soils	Ongoing

Collection of cattle data has similarly proceeded as planned with end of dry season weights recorded in late 2021 (Table 23) and end of wet weighing conducted on 2 June 2022.

Table 23 Stocking rates (S. Rates), dry season weight change and end of dry season total standing dry matter (TSDM) measured in December 2021 in different treatments at the Wambiana trial.

Treatment	Stocking rate (ha/AE)	Dry season live weight change(kg)	End of dry TSDM (kg/ha)	Comment
Flexible stocking	15.8	-10	453	S. Rates set in May 2021 on EOW yield.
Flexible stocking +Spelling	10.3	-22	495	S. Rates set in May 2021 on EOW yield but cut further Dec 2021 to 16 ha/AE to spell.
HSR	8.8	-49	108	S. Rates low due to severe feed shortage
MSR	9.7	-22	292	S. Rates reduced by 20% due to lower carrying capacity.
R/Spell	11.9	-12	405	S. Rates reduced by 20% due to lower carrying capacity.

21.3 Trial management in 2021/22 season

Two major management decisions were made in 2022. First, one of the management objectives of the WGT is to spell as much as possible for as long as possible in the spelling treatments i.e. the R/Spell and the Flex+Spell, without overgrazing non-spelled sections. With the poor start to the wet season in 2021/22 and low forage availability there was a real danger that the grazed, unspelled sections might be overutilised. Accordingly, the GAC were consulted as to whether spelling should actually be implemented. Based on their feedback, it was decided not to spell any sections or at possibly, wait until sufficient rain had fallen, possibly later in the season Accordingly, with the late rain in May (see below) one section each in the Flex+Spell was closed off in the hope of gaining at least some benefit. However, none of the R/Spell sections were spelled due to the higher stocking rates and hence grazing pressure in these paddocks.

Second, the GAC were again consulted in early April 2022 when pasture yields in almost every paddock were extremely low with forage completely dried off (Figure 41). Given the conditions and the lateness of the season, it appeared that animals were going to be extremely short of forage in the dry season and that drought feeding would be needed. Paddocks were also likely to be severely overgrazed, causing a further decline in land condition.

After consultation with the GAC it was decided that the HSR, MSR and R/Spell strategies should be completely destocked at the end of May when the usual cattle changeover occurred. It was also suggested that because pasture TSDM was slightly higher in the Flexible and Flex+Spell, the decision on whether to keep these treatments stocked and at what stocking rate, be delayed until after a forage budget had been completed.

Since then, there has been very good rainfall. Although the pastures have completely greened up, growth has been relatively muted, probably because of ongoing drought legacy effects, the lateness of the season and the cooler temperatures. Therefore despite the very good May rainfall, the MSR, R/Spell and HSR were destocked as planned on the 2 June 2022. In contrast the Flex and Flex+Spell have remained stocked, albeit at a very low level of approximately 22 ha/AE.

Figure 41: By mid-April, pasture yields and cover were extremely low due to below average rainfall and unprecedented heat in February–March. Shown here are the R/Spell (left) vs MSR (right)

22 KASA survey of the impact of the Wambiana project on industry

21. 1 Introduction

This section addresses Objective 1 of the current project i.e.:

- ‘Complete a full monitoring and evaluation plan to evaluate KASA (knowledge, attitude, skills and aspirations) of producers involved’.

[The following is an edited extract from the KASA survey report provided by Gerry Roberts of GR consulting, Longreach. For more detail see Appendix 12].

As part of the Phase 4 MLA contract a supplementary survey of KASA (Knowledge, Attitudes, Skills and Aspirations) on practice change resulting from the WGT project and its associated activities was commissioned. This involved interviewing 30 selected beef producers and posing a series of questions. The beef producers were interviewed by phone in November/December 2021 and their responses uploaded to the *Your Data* site provided by DAF. This report was prepared using that data.

21.2 Qualitative research surveying

The qualitative surveying method used in this research required a methodology which allowed the interviewees to provide their information in an in-depth way. This approach is to enable them to talk of their reasoning and motivations when rating and commenting in responses. Because it is data of each person’s experiences, it is a less structured approach that was taken to allow for the differences and similarities to be made apparent by the respondent. Semi-structured interviewing allows for individuality of grazier response, and it is the approach used with topics in this survey, where they were introduced as open-ended questions to initiate topic relevant responses.

As well conducted semi-structured process allows the interviewer to use ‘probe’ questions to expand on any topic. An interview guide was prepared from the research questions and sent to graziers before the interview if they wanted it.

This surveying methodology enabled the researcher to develop a deeper understanding of the role the Wambiana Grazing Trial (WGT) results filled for each respondent. It did so through hearing from respondents on the level of change in their knowledge, attitude, skills, and aspirations to change, as well as the trial’s level of impact on any grazing management practice change made.

21.3 Respondents and response numbers

WGT project staff provided the names and contact details of graziers who had participated in the trial activities previously in one or other of three ways. They also provided WGT events or activities graziers attended as part of the extension work of the Trial. Staff made the initial contact seeking agreement to be interviewed. These two pieces of information were used by the interviewer to make connection to the landholders. Confidentiality of survey information has been assured because the project team agreed to anonymity through separation of landholder details and survey responses.

All surveys were arranged via phone and conducted by phone at a time chosen by the grazier respondent. Responses were collected from 30 graziers. Staff provided the names of 43 graziers and from these the researcher selected potential respondents. These were based on the type of connection to WGT, their location by district/region and a range of known experiences with the trial and its activities so they were as representative as possible of the group on offer. Some were selected on the basis of the researcher's knowledge of grazing management from having previously surveyed some in the districts/regions.

Of the potential contacts one chose not to be involved and another responded to a text that they'd make contact however they had not done so in the time available for surveying. About a third of graziers needed to make a change to the time due to their working commitments and this was accommodated by the researcher.

All of the 30 graziers surveyed had connections with Wambiana Grazing Trial (WGT) in one or more of three ways:

- Attended field days at WGT site
- A member of the Grazier Advisory Committee (GAC)
- Being in a group attending activities on one (1) of three (3) Northern Grazing Demonstration project properties demonstrating WGT principles.

For those interviewed the majority had attended field days on the WGT site, and attendees at only one demonstration property (Ametdale) were made available for interview. A few were, or had been, members of the Grazier Advisory Committee.

For more detail on the Methodology and Results consult the full KASA report in Appendix 12.

21.4 Results

A summarised version of results are presented below- for more detail see Appendix 12.

1 Snapshots

Results from phone surveys of 30 graziers familiar with Wambiana Trial results

90% of graziers gained new **KNOWLEDGE** from the WGT results

'New' for them:

"WGT illustrated there was no more money in having more cattle and there were more costs e.g. supplements etc."

'New' as reinforcing their practices:

"It reinforces what you think you might know from the experience of doing management and the Trial results put figures on it."

NEW knowledge gained:

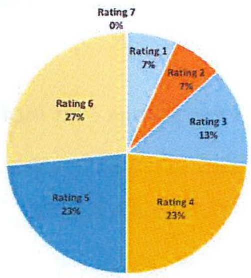
23/30	Profitability
19/30	Stock numbers & feed supply
18/30	Stock numbers drive performance/land condition
16/30	Wet season spelling
11/30	Ecology of native grasses

"Good to have profitability results in black and white as my parents said don't overstock but couldn't explain their reasons."

"I have been working to understand how we can incorporate wet season spelling without damaging the paddocks where extra stock are held during the wet season."

"I got new knowledge that they probably didn't expect us to get and it is that moderate continuous stocking doesn't maintain land condition."

73% identified their change in ***ATTITUDE*** *at rating of 4 or above*



"I used to be thinking about cattle and their production and I now look at pasture and how it is going."

"Mostly we have refined what we do from WRT results and we use the results when making decisions."

63% gained new **SKILLS**

For five (5) options offered by WGT team,

'Yes' responses = **5 or less** for any one

30% gave 'Other Skills'

Most said it was SEEING the paddock at the trial site and learning what TO DO or NOT TO DO.

"Being in a paddock where a particular stocking strategy has been used to see what's happening."

"To increase ground cover for water penetration."

70% of graziers **ASPIRING** to make change

Frequent mentions:

Wet season spelling - *"To put wet season spelling in place."*

More observation of pasture - "(Because)Now we understand you need to have grass left at end of year to get water into the soil."

Varying stocking rate - *"We considered using forage budgets more for stocking rate decisions rather than doing it on an ad hoc basis."*

60% report **MAKING A PRACTICE CHANGE**

"I started wet season spelling and also control stock numbers to not overstock."

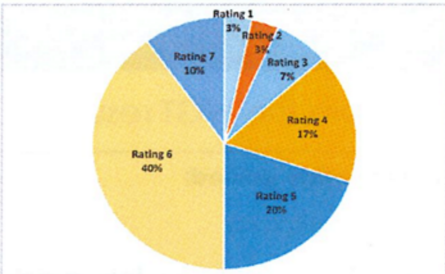
"Vary the stocking rate through trading cattle as different seasons require."

"Using pasture budgeting to match our stocking rate to carrying capacity."

Not all can change yet

"No (change) because I don't yet understand how."

87% Acknowledge **RELEVANCE** of results to own property (Rating >4 out of 7)



Reasons

"They are relatable and apply to here as we know that if we flog country we lose grass and we don't want that."

" Certainly, the flexible stocking rate aligns with what we are doing and we do pasture budgeting."

53% (16 of 30) rate **VALUE TO BUSINESS** as greater than 4 out of 7

16 **as a proportion of** 18 **graziers who made a change** is 89% who find their change of greater than average value to their business.

"Very valuable as it means we make decisions before our backs are to wall and look for other options to reduce stocking rates."

"Valuable as WGT gave us the figures for costs and the impact on pasture and income so (now) we do not overstock."

"Rated lower at the present as for these changes it is too early to tell."

100% rate **USEFULNESS** of WGT results to industry at 4 or more out of 7

60% rate USEFULNESS of WGT results to industry it at 6 or 7

"It is the best thing ever and if people would look at it they could see that. For example, we sell bullocks at 3.5 years, at 360 to 400kg, our neighbour sells at 4.5 years and 340kg and neighbour stocks more heavily than we do."

"I don't think type of country matters as the principles apply to all types."

"Quite high as there have not been too many trials that have run over long times and that makes the results more powerful."

The most important message from WGT

Five (5) initial categories:

- To not overstock
- Longer-term perspectives
- Profitability impacts
- Management of pasture, and
- Whole grazing system perspectives.

Sixth category here of **contrasting views**

"Unfortunately, WGT is out of date with what is needed and even GAG members are convinced to stick to science only and not explore other things such as improved pastures or treating berry bushes to give mulch even though it takes machinery."

Current level of use in the industry

23% rated **USE BY INDUSTRY** at highest 5 or 6 on the 7-point scale

Ratings suggests that a large proportion of grazing business are yet to fully utilise the results from WGT.

Thoughtful first, then qualifying their rating,

"There are a lot of principles and maybe in terms of 'how widely' it is a Yes and a No situation i.e. some are, some aren't, and they may do one of many practices."

Optimism – "Probably in the last 20 years people are looking differently at how they manage and that's due to things like Wambiana Grazing Trial and RCS."

23 Report on planning review actions

This chapter reports on MS 10 c. i.e.:

- 'Report on planning review actions including stakeholder workshop, September 2021 Field Day responders (past and present needs)'

A number of activities were held to gauge the level of support for the continuation of the trial and to identify future research directions should the trial continue. These activities included grazier feedback at field days or advisory group meetings, a technical review with other technical staff and a meeting/paddock walk with graziers, consultants and technical staff on possible new treatments. These are reported below.

23.1 Feedback from graziers

22.1.1 Wambiana Grazier Advisory Committee meeting March 2021

Key research issues identified and suggested actions

Restoration of poor condition land

- Investigate restoration & regeneration options (and profitability thereof) (X5)*
- Grazing density – what are the effects of mobbing cattle: 'Regen Ag' approach? (X2)
- Investigate different grazing regimes/management styles i.e. 'Regen Ag' type treatments.
- Investigate lack of pasture response to rain.

*[*NB: Numbers in brackets indicate number of times issue identified]*

Currant bush thickening

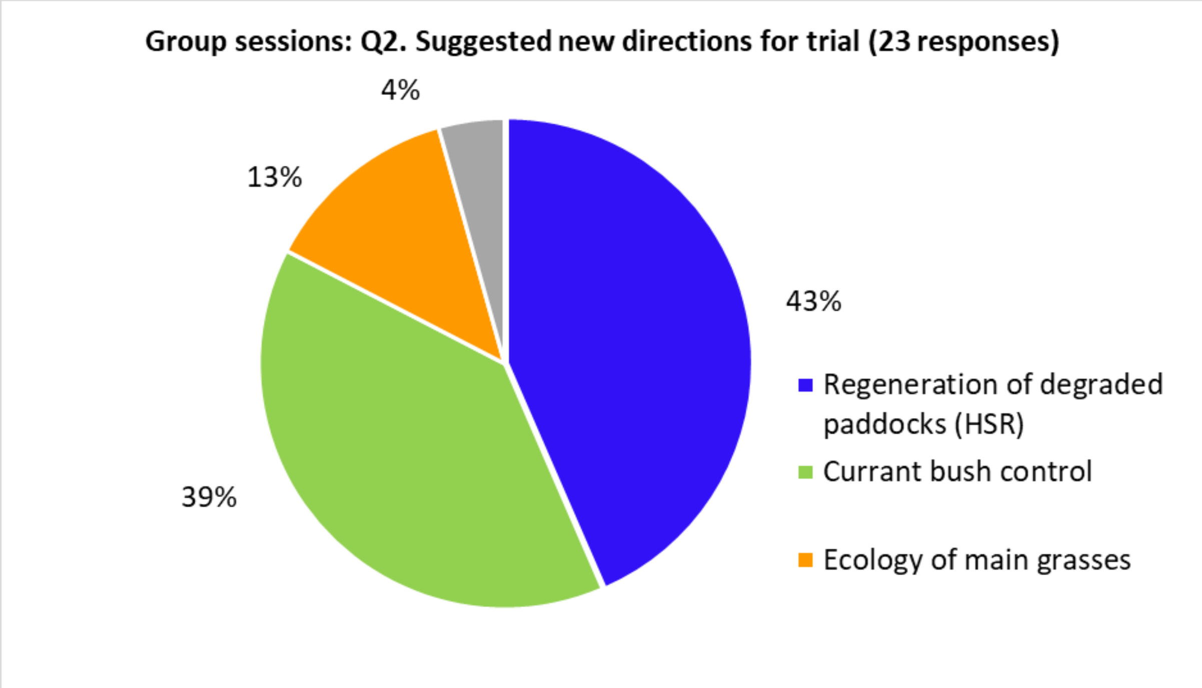
- Currant bush control – look at effects of fire frequency, intensity, timing etc (X2).
- Investigate use of other grazing/browsing animals, e.g. Goats (to control *Carissa*).
- Trial high impact grazing (trampling, forced grazing) to suppress *Carissa*.

Other

- Lack of knowledge on (ecology of) key pasture species (desert bluegrass etc).
- Use data to identify thresholds for change – e.g. woodland thickening or degradation.
- Ground truthing satellite data (and resultant satellite tools)

22.1.2 Wambiana Field Day 15 September 2021 - group discussions

Figure **42: Suggestions for new direction for the trial gathered from group sessions at the Wambiana field day September 2021**



Regeneration of degraded areas

- Wet season spelling +/- high or low intensity grazing ('HRM' type grazing/mob grazing) (X8).
- Over sowing with legumes (Verano) or other pasture seed (native grasses).
- Continue HSR and measure recovery with good seasons (may recover anyway).
- Fertilisation.
- Dung beetles.
- Restoration of degraded areas and research into recovery of desert bluegrass.

***Carissa*/woody species management**

- Fire: different types, frequency, timing (X5).
- Browsers (goats or camels) +/- fire (X4).
- Improve acceptability of *Carissa* to cattle (rumen bugs, supplements).
- Other controls (chemical or mechanical).
- Determine thresholds and impacts of *Carissa* on grass production.
- High impact grazing to control woody and *Carissa* regrowth.

Other research suggestions

- Measure C sequestration (under different treatments?).
- Continue trial to show beneficial effects of grazing on environment.
- Methane emissions- reduce.
- Better legumes.
- Managing out Indian couch and increasing 3P grasses.
- Consider seed banks of native spp and intervene if required (with seed).
- Continue measuring desert bluegrass to see how it responds to different treatments.

22.1.3. DAF ‘Bunuro’ grazing demonstration site: Torrens creek meeting

Following their presentation at the Wambiana field day in October 2019, David and Donna Rankine of ‘Bunuro’ near Torrens Creek, suggested that a demonstration be set up on their property to demonstrate the advantages of good grazing management. This would involve showcasing their multipaddock grazing systems and a simple system based on ’Wambiana’ principles. This demonstration began in 2020.

As part of the project a meeting was held with 17 graziers from around the Bunuro demonstration site on 6 October 2021. Following a presentation on the Wambiana project some key research areas identified and actions suggested by the group were:

- Demonstrate how to restore/improve land condition while also running stock (X3)
- Quantifying the commercial benefit of interventions and recording benefits and losses is important (X2).
- Intervention to bring set stocking rate (MSR) back to original condition
- Need to match stocking rate to carrying capacity
- Question moderate stocking rate on trial – believe it is still too high.

22.2 Technical review

A technical panel (Table 24) was formed to review the trial results and explore possible future directions. The first meeting held on 4 November 2021 was online due to covid restrictions.

Table 24: Members of trial technical review panel held on 4 November 2021

Andrew Ash (ex CSIRO)	Steven Bray (DAF)	Peter O’Reagain (DAF)
Bob Shepherd (DAF)	Robyn Cowley (NTDPI)	John Bushell (DAF)
Nic Spiegel (DAF)	Paul Jones (DAF)	Simon Hunt (DAF)

Some key points raised at this *first* meeting were:

- Current studies on recovery at the trial have been hampered by unprecedented and extended dry conditions
- Need strategies to cope with changed climate patterns i.e. longer drought periods and short, intense wet seasons. Will recovery occur on MSR when good season return?
- Need to document and better understand recovery of poor land condition through better seasonal conditions
- Compare high intensity short duration grazing vs lower density, flexible stocking with spelling.
- Conduct replicated trials on spelling regimes at the WGT, Oaklands exclosure trial and a replicated trial on property
- Extend current wet season spelling work to the ironbark and brigalow land types
- Investigate the ecology of native pastures in more detail.
- Controlling woody weeds and use of fire
- Modelling opportunities:
- Opportunities to model degradation (i.e., system shocks of high pasture utilisation with no rest and drought episodes).

- Modelling recovery of degraded (C condition land) is something to aim for (and the more desirable outcome).
- Reduce stocking rates and pasture utilisation across all treatments and keeping highly adaptive in this process.
- Test intervention treatments such as: reseeding native plant species (e.g., easy to source *H. contortus* seeds from road reserves; application of fertiliser, sow introduced grasses and legumes.

22.3 Advisory group for new 'regenerative' treatments

Following the consultations above, a group of graziers, advisors and technical staff was formed to initiate discussion on how 'regenerative type 'grazing treatments could be applied on parts of the existing HSR paddocks to try and accelerate recovery.

Table 25 Preliminary advisory group for Phase 5 'regen grazing' treatments.

Michael & Michelle Lyons (Graziers)	Bec Clapperton (DAF)	Peter O'Reagain (DAF)
Jamie Gordon (Grazier)	Joe O'Reagain (NQDT)	John Bushell (DAF)
Raymond Stacey (RCS)	Chris Poole (NQDT)	

This initial group was the *start* of the process of selecting what and how any 'regen' type treatments might be applied. This was a preliminary step and ultimately an advisory group of regen practitioners and advisors will be formed to advise and guide management to ensure treatments remain relevant to industry. The group included an advisor from Resource Consulting Services (RCS), staff from North Queensland Dry Tropics (NQDT), experienced 'regen' practitioners and DAF staff (Figure 43).

Figure **43: (Left) Raymond Stacey (RCS) inspecting paddock condition and (right) the group discussing treatment options at the first 'regen' treatments meeting at Wambiana.**

The main consensus of the meeting was that the heavy stocking rate paddocks should be destocked at the end of May 2022 and allowed to rest for the whole of the 2022/23 wet season. Sub-paddocks could then possibly be installed within these paddocks to allow various forms of 'regenerative' management to be applied. These would include comparison of some or all of the following:

- Complete grazing exclusion.
- Wet season spelling with a background of moderate stocking.
- Short grazing periods of varying intensity i.e. forms of adaptive, multi-paddock grazing.
- As above but with different stock densities i.e. to achieve animal impacts.
- Some form of Currant bush control e.g. spot spraying with herbicide.
- Control- no resting and heavy/moderate stocking.

These ideas will be explored more thoroughly and final treatments decided upon in further meetings over the next few months as the next phase is developed.

24 New and confirmed information products

This section reports on Milestone 9 d, 9 e and 9 f i.e.

- Milestone 9 d: 'New and confirmed information product updates (lessons from Wambiana booklet, Guidelines and Rules of Thumb and associated draft fact sheets based on 'How do I format?'
- Milestone 9 e: 'Summary report on wet season spelling strategies to regenerate C condition land'.
- Milestone 9 f: 'Following consultation with MLA publish 4 cases studies from NGD project'

Progress on these milestones is presented below in Table 26.

Table 26: Progress on new and confirmed information products.

'Lessons from Wambiana' booklet (Update of *Key learnings from the Wambiana* trial 2011)	As reported in milestone 7.3. this has not been fully completed due to uncertainty on the structure, content and audience for the booklet. Discussion with MLA comms was suggested but has yet to occur.
Guidelines & technical notes	These are presented in Chapter 15.
Fact sheets in 'How do I format'	These are completed and presented in Appendix 13. Final input from graphic artists and/or MLA comms still required.
Summary report of wet season spelling strategies to regenerate C condition land	Completed: see Appendix 9.
Following consultation with MLA publish 4 cases studies from NGD project	Case studies completed: see Appendix 8. These could be published on-line in Futurebeef site. Consultation required with MLA.

25 Wambiana project publications: 2018-22

25.1 Popular publications

Table 27: Popular publications in printed media

Title	Publication/Website
Currant bush studies reveals fire is best form of eradication	Qld. Country Life, 2 May 2022
Desert bluegrass can be a massive help for Queensland graziers	North Qld Register, 1 May 2022
Giving nitrogen a boost	*Qld. Country Life*, 20 August 2020
Take a long term view of stocking rates	*MLA Feedback*, Sept-Oct 2020, p.16
Cattle performance data aids grazing decisions	*Qld. Country Life & North Qld. Register, 19 October 2020*
Boost pasture recovery	*North Qld Register*, 26 September 2019 p.11
Summer spelling vital	*Qld. Country Life*, 26 September 2019 p. 26
Recovery of perennial grasses after drought	*Qld. Country Life*, 18 April 2019 p. 49:
Can we predict animal performance from space?	*Northern Muster* & *CQ Beef*, December 2018, p. 2
Summer spelling vital	*Qld. Country Life*, 26 September 2019 p. 26

Table 28. Web pages with articles or information on Wambiana trial or NGD sites

Page	Web address	Date
Wambiana grazing trial field day take home messages -	https://futurebeef.com.au/wambiana-grazing-trial/	29/09/2021
'TERN data assist government and industry-led sustainable grazing practices in Great Barrier Reef catchments'	https://www.tern.org.au/news-brigalow-belt-science-impact/	30/08/2021
Addressing land condition issues at Ametdale: part of the Northern Grazing Demonstration project –	https://futurebeef.com.au/resources/addressing-land-condition-at-ametdale/	26/02/2021
Graziers gather where science meets practice	https://futurebeef.com.au/graziers-gather-where-science-meets-practice/	7/11/2019
The Wambiana grazing trial: key learnings for sustainable and profitable management in a viable environment	https://futurebeef.com.au/resources/the-wambiana-grazing-trial-key-learnings-for-sustainable-and-profitable-management-in-a-viable-environment/	26/04/2017
Managing for a variable climate: long-term results and management recommendations from the Wambiana grazing trial	https://futurebeef.com.au/resources/managing-variable-climate-long-term-results-management-recommendations-wambiana-grazing-trial/	18/04/2017
Wambiana grazing trial	https://futurebeef.com.au/resources/wambiana-grazing-trial/	22/03/2017
Grazing in the Burdekin region - achieving better returns and saving soil	https://www.reefplan.qld.gov.au/land-use/grazing/case-studies/grazing-in-burdekin	17/07/2015
Degradation - a gradual process or event driven?	https://futurebeef.com.au/resources/degradation-gradual-process-or-event-driven/	20/09/2011

Table 29: Circulation figures of printed media.

Periodical	Circulation
CQ Beef	9000[1]
MLA Feedback	50000
Northern Muster	9000[1]
NQ Register	9000[1]
Qld Country Life	50000[1]

[1] Enhanced Media Metrics Australia

25.2 Scientific papers

24.2.1. Trial based papers with project team as (co) authors

Pringle MJ, **O'Reagain P**J, Stone GS, Carter JO, Orton TG, **Bushell JJ** (2021) Using remote sensing to forecast forage quality for cattle in the dry savannas of northeast Australia. Ecological Indicators 133, 108426.

Owens, J, McKeon G., **O'Reagain P**, Carter J., Fraser G., Nelson B. & Scanlan J. 2021. Disentangling the effects of management and climate on perennial grass pastures and the degradation that follows multi-year droughts 106-112. In: Vervoort, R.W., Voinov, A.A., Evans, J.P. and Marshall, L. (eds) MODSIM2021 24th International Congress on Modelling and Simulation, mssanz.org.au/modsim2021

Williams, Schmidt, Alchin, **O'Reagain, Bushell**, JJ *et al* 2022 Resting Subtropical Grasslands from Grazing in the Wet Season Boosts Biocrust Hotspots to Improve Soil Health. Agronomy 12(1), 62.

24.2.2. Trial based papers – other authors

Neilly, H., Nordberg *et al.*2018. Arboreality increases reptile community resistance to disturbance from livestock grazing." Journal of Applied Ecology 55(2): 786-799.

Neilly H, &. Schwarzkopf, L. 2018. Heavy livestock grazing negatively impacts a marsupial ecosystem engineer. Journal of Zoology. 305:35-42.

Neilly H, &. Schwarzkopf, L. 2018. The response of an arboreal mammal to livestock grazing is habitat dependant. Nature.com/Scientific Reports DOI:10.1038/s41598-017-17829-6

Nordberg, E. J., *et al.*2018. Abundance, diet and prey selection of arboreal lizards in a grazed tropical woodland." Austral Ecology 43(3): 328-338.

Neilly, H. and L. Schwarzkopf 2019. The impact of cattle grazing regimes on tropical savanna bird assemblages." Austral Ecology 44(2): 187-198.

Nordberg, E. J. and L. Schwarzkopf 2019. Predation risk is a function of alternative prey availability rather than predator abundance in a tropical savanna woodland ecosystem. Nature.com/Scientific Reports 9(1).

Nordberg, E. J. and L. Schwarzkopf 2019. Reduced competition may allow generalist species to benefit from habitat homogenization." Journal of Applied Ecology 56(2): 305-318.

Neilly, H., H. Jones, and L. Schwarzkopf. 2020. Ants drive invertebrate community response to cattle grazing. Agriculture, Ecosystems & Environment 290:106742.

25.3 Conference proceedings

O'Reagain, P.J., Bushell, J.J & Anderson A. 2021. Managing sustainably and profitably in a highly variable climate: results from the long term Wambiana grazing trial. Proceedings of the Australian Rangelands Society Conference, Longreach, Queensland, 5-7 October 2021.

O'Reagain, P.J., Bushell, J.J, Hough, B & Dunbar I. 2021. The effect of fire on the long-term dynamics of *Carissa ovata* (Currant bush) Proceedings of the Australian Rangelands Society Conference, Longreach, Queensland, 5-7 October 2021.

O'Reagain, P.J. & Bushell, J.J. 2019. Long term effects of different stocking strategies on sustainability and profitability in a variable climate. *Proceedings of the Northern Beef Research Update Conference, Brisbane, August 2019.*

25.4 Academic theses

Macor, Justin. P. 2019 Long-term changes in native pasture composition in North Queensland under different grazing management strategies. *Honours Thesis,* School of Agriculture & Food Science University of Queensland. 50 pp.

Bock, Kate. 2019. Estimating the effects of grazing on biodiversity through the use of grazing MSc Thesis, James Cook University, Townsville.

Nordberg, Eric J. 2018. The impacts of cattle grazing on arboreal reptiles, PhD Thesis James Cook University, Townsville, 225 pp.

Neilly, Heather L. 2017. Balancing beef with biodiversity. PhD Thesis James Cook University, Townsville, 183 pp.

Russel, Kaleigh. 2014. Invertebrate community response to cattle grazing regimes in the woodland rangelands of Queensland, Australia. MSc Thesis, James Cook University, Townsville.

Heilbron, Lauren. 2014. Ecology of inland snake-eyed skinks in a grazing landscape. MSc Thesis, James Cook University, Townsville.

Murray, Paul. 2016. Comparing microscopic and molecular methods of diet description in native house geckos (*Gehyra dubia*). MSc Thesis, James Cook University, Townsville.

26 Appendices

26.1 Appendix 1: Paper 1: Draft: Long term effects of different stocking strategies on animal production

26.2 Appendix 2: Supplements fed and costs for WGT trial 1998-2021

26.3 Appendix 3: Paper 2: Pringle et al 2021 Predicting and forecasting forage quality

26.4 Appendix 4: Paper 3: O'Reagain et al 2022 Managing for rainfall variability

26.5 Appendix 5: Paper 4: Neilly et al 2018 Profitable grazing and reptile biodiversity

26.6 Appendix 6: Carrying Capacity Ready Reckoner

26.7 Appendix 7: Paper 5: Owens et al 2021 Modelling the effects of drought and grazing

26.8 Appendix 8: Northern Grazing Demonstration project case studies

26.9 Appendix 9: Recovering C condition land: Technical note

26.10 Appendix 10: Poster paper: The effects of fire on *Carissa*

26.11 Appendix 11: Wambiana project presentations and site visitors

26.12 Appendix 12: KASA survey report of Wambiana project

26.13 Appendix 13: Draft technical/'how to guides'

26.14 Appendix 14: Draft paper : Demography of perennial grasses under varying resting and grazing regimes in central Queensland

27 References

AISTHORPE, J., PATON, C. & TIMMERS, P. 2004. *Stocktake: balancing supply and demand,* Brisbane, Queensland Department of Primary Industries and Fisheries.

ASH, A., CORFIELD, J. P. & KSIKSI, T. 2001. *The Ecograze project: developing guidelines to better manage grazing country,* Townsville, CSIRO.

ASH, A., O'REAGAIN, P. J., MCKEON, G. & STAFFORD SMITH, D. M. 2000. Managing climate variability in grazing enterprises: a case study of Dalrymple Shire, north-eastern Australia. *In:* HAMMER, G. L., NICHOLLS, N. & MITCHELL, C. (eds.) *Applications of seasonal climate forecasting in agricultural and natural ecosystems: The Australian experience.* Dordrecht, The Netherlands: Kluwer Academic Publishers.

ASH, A. J., CORFIELD, J. P., MCIVOR, J. G. & KSIKSI, T. S. 2011. Grazing management in tropical savannas: Utilization and rest strategies to manipulate rangeland condition. *Rangeland Ecology and Management,* 64**,** 223-239.

BASTIN, G., CARTER, J. & TICKLE, P., STONE, G., TREVITHICK, R., O'REAGAIN, P. J., PHELPS, D., COWLEY, R. A., PRINGLE, M., SCANLAN, J. C. AND HOFFMANN, M. B 2016. Remotely sensed and modelled pasture biomass, land condition and the potential to improve grazing management decision tools across the Australian rangelands. MLA Project report ERM.0098. Sydney: Meat and Livestock Australia.

BASTIN, G., SCARTH, P., CHEWINGS, V., SPARROW, A., DENHAM, R., SCHMIDT, M., O'REAGAIN, P., SHEPHERD, R. & ABBOTT, B. 2012. Separating grazing and rainfall effects at regional scale using remote sensing imagery: A dynamic reference-cover method. *Remote Sensing of Environment,* 121**,** 443-457.

BELOVSKY, G. E., BOTKIN, D. B., CROWL, T. A., CUMMINS, K. W., FRANKLIN, J. F., HUNTER, M. L., JOERN, A., LINDENMAYER, D. B., MACMAHON, J. A., MARGULES, C. R. & SCOTT, J. M. 2004. Ten Suggestions to Strengthen the Science of Ecology. *BioScience,* 54**,** 345-351.

BOND, W. J. & MIDGLEY, G. F. 2000. A proposed CO2-controlled mechanism of woody plant invasion in grasslands and savannas. *Global Change Biology,* 6**,** 865-869.

BOWEN, M. K. & CHUDLEIGH, F. 2021. Achieving drought resilience in the grazing lands of northern Australia: preparing, responding and recovering. *The Rangeland Journal,* 43**,** 67-76.

BURROWS, W. H., ORR, D. M., HENDRICKSEN, R. E., RUTHERFORD, M. T., MYLES, D. J., BACK, P. V. & GOWEN, R. 2010. Impacts of grazing management options on pasture and animal productivity in a *Heteropogon contortus* (black speargrass) pasture in central Queensland. 4. Animal production. *Animal Production Science,* 50**,** 284-292.

CHUDLEIGH, P. & HARDAKER, T. 2021. An impact assessment of DAF investment into the long term grazing trial at Wambiana 1998-2021 *Economic analysis of six research, development and extension investments by the Department of Agriculture and Fisheries, Queensland. Appendix F. Unpublished Report by AgTrans Research & AgEconPlus.* Brisbane.

COATES, D. B. & DIXON, R. M. 2007. Faecal near infrared reflectance spectroscopy (F.NIRS) measurements of non-grass proportions in the diet of cattle grazing tropical rangelands. *Rangeland Journal,* 29**,** 51-63.

COATES, D. B. & DIXON, R. M. 2011. Developing robust faecal near infrared spectroscopy calibrations to predict diet dry matter digestibility in cattle consuming tropical forages. *Journal of Near Infrared Spectroscopy,* 19**,** 507-519.

CREECH, T. G., EPPS, C. W., MONELLO, R. J. & WEHAUSEN, J. D. 2016. Predicting diet quality and genetic diversity of a desert-adapted ungulate with NDVI. *Journal of Arid Environments,* 127**,** 160-170.

DAY, K. A., MCKEON, G.M. AND CARTER, J.O. 1997. Evaluating the risk of pasture and land degradation in native pastures in Queensland, Final Report on DAQ124A Canberra: Rural Industries Research and Development Corporation.

DE CORTE, M., CANNON, M., BARRY, E., BRIGHT, J. & SCANLAN, J. 1991. Land degradation in the Dalrymple Shire: a preliminary assessment. Townsville: CSIRO, Davies Laboratory.

DIXON, R. M. & COATES, D. B. 2010. Diet quality estimated with faecal near infrared reflectance spectroscopy and responses to N supplementation by cattle grazing buffel grass pastures. *Animal Feed Science and Technology,* 158**,** 115-125.

FOLEY, J. C. 1957. *Droughts in Australia: Review of Records from Earliest Years of Settlement to 1955.*

GEREMIA, C., MERKLE, J. A., EACKER, D. R., WALLEN, R. L., WHITE, P. J., HEBBLEWHITE, M. & KAUFFMAN, M. J. 2019. Migrating bison engineer the green wave. *Proceedings of the National Academy of Sciences,* 116**,** 25707.

HASSETT, R. C. 2021. Land Condition Assessment Tool - implementation, opportunities and risks- twelve month review.: Dept. Agriculture and Fisheries, Queensland.

HOWDEN, S. M. 1988. *Some aspects of the ecology of four tropical grasses with special emphasis on Bothriochloa pertusa.* Ph.D, Griffiths University.

ISBELL, R. F. 1996. *The Australian Soil Classification,* Melbourne, Australia, CSIRO, Publishing.

JONES, P., SILCOCK, R., SCANLAN, J. & MORAVEK, T. 2016. Final report of project B.NBP.0555. Spelling strategies for recovery of pasture condition.: Meat and Livestock Australia, North Sydney, Australia.

LEIGO, S., PHELPS, D. & DRIVER, T. 2016. Precision Pastoral Management System: Automated 'Big Data' Analysis for Pastoral Properties. *Proceedings of the 10th International Rangeland Congress* Saskatoon, Canada.

MACOR, J. P. 2019. *Long-term changes in native pasture composition in North Queensland under different grazing management strategies* Honours Thesis, University of Queensland. .

MCGOWAN, M., MCCOSKER, K. & FORDYCE G, S. D., O'ROURKE PK, PERKINS N, BARNES T, MARQUET L, MORTON J, NEWSOME T, MENZIES D, BURNS BM AND JEPHCOTT S 2014. North Australian beef fertility project: Cash Cow. Final Report, Project B.NBP.0382 Sydney: Meat and Livestock Australia

MCLEAN, I., HOLMES, P. & COUNSELL, D. 2014. The northern beef report: 2013 northern beef situation analysis. Final report B.Com.0348. North Sydney, NSW: Meat and Livestock Australia.

MCLEAN, I., HOLMES, P., WELLINGTON, M., WALSH, D., PATON, C. & FREEBAIRN, R. 2020. The Australian Beef Report: 2020 Vision. Toowoomba, Qld.: Bush Agribusiness, Pty. Ltd.

NEILLY, H., O'REAGAIN, P., VANDERWAL, J. & SCHWARZKOPF, L. 2017. Profitable and Sustainable Cattle Grazing Strategies Support Reptiles in Tropical Savanna Rangeland. *Rangeland Ecology & Management,* 71 205-212.

O'CONNOR, T. G. 1991. Local extinction in perennial grasslands: a life-history approach. *American Naturalist,* 137.

O'CONNOR, T. G. & PICKETT, G. A. 1992. The influence of grazing on seed production and seed banks of some African savanna grasslands. *Journal of Applied Ecology,* 29**,** 247-260.

O'REAGAIN, P. & BUSHELL, J. Testing grazing strategies for the seasonably variable tropical savannas. *In:* ELDRIDGE, D. & FREUDENBERGER, D., eds. People and rangelands: building the future. Proceedings of the VI International Rangeland Congress, 19-23 July, 1999. ,Townsville, Queensland, Australia,. 485-486.

O'REAGAIN, P., BUSHELL, J., HOLLOWAY, C. & REID, A. 2009. Managing for rainfall variability: effect of grazing strategy on cattle production in a dry tropical savanna. *Animal Production Science,* 49**,** 85-99.

O'REAGAIN, P. J., BUSHELL, J., PAHL, L. & SCANLAN, J. C. 2018. Wambiana grazing trial Phase 3: stocking strategies for improving carrying capacity, land condition and biodiversity outcomes. B.ERM.0107 North Sydney, Australia: Meat and Livestock Australia.

O'REAGAIN, P. J. & BUSHELL, J. J. 2008. Sustainable and profitable grazing management in a highly variable environment - evidence and insights from a long term grazing trial in northern Australia. *Multifunctional Grasslands in a Changing World, Proceedings of the XXI*

International Grassland Congress-VII International Rangeland Congress. Hohhot, Inner Mongolia.: Guangdong People's Publishing House, Beijing.

O'REAGAIN, P. J. & BUSHELL, J. J. 2011. *The Wambiana grazing trial: Key learnings for sustainable and profitable management in a variable environment,* Brisbane, Queensland Government

O'REAGAIN, P. J., BUSHELL, J. J. & HOLLOWAY, C. H. 2008. Final report: B.NBP.0379. Testing and developing grazing principles and management guidelines for the seasonably variable tropical savannas Sydney: Meat and Livestock Australia.

O'REAGAIN, P. J., BUSHELL, J. J. & HOLMES, W. 2011. Managing for rainfall variability: long-term profitabilty of different grazing strategies in a north Australian tropical savanna. *Animal Production Science,* 51**,** 210-224.

ORR, D. M. & O'REAGAIN, P. J. 2011. Managing for rainfall variability: impacts of grazing strategies on perennial grass dynamics in a dry tropical savanna. *Rangeland Journal,* 33**,** 209-220.

ORR, D. M. & PHELPS, D. G. 2013. Impacts of grazing on an *Astrebla* (Mitchell grass) grassland in north western Queensland between 1984 and 2010. 1. Pasture biomass and population dynamics of *Astrebla*. *Rangeland Journal,* 35**,** 1-15.

OWENS, J., MCKEON, G., O'REAGAIN, P., CARTER J, FRASER G, NELSON B & J, S. Disentangling the effects of management and climate on perennial grass pastures and the degradation that follows multi-year droughts *In:* VERVOORT, R. W., VOINOV, A.A., EVANS, J.P. AND MARSHALL, L. , ed. MODSIM2021 24th International Congress on Modelling and Simulation, December 2021 2021 Sydney. Modelling and Simulation Society of Australia and New Zealand 106-112.

PARTRIDGE, I., MIDDLETON, C. & SHAW, K. 1996. *Stylos for better beef,* Brisbane, Department of Primary Industries, Queensland.

PRINGLE, M. J., O'REAGAIN, P. J., STONE, G. S., CARTER, J. O., ORTON, T. G. & BUSHELL, J. J. 2021. Using remote sensing to forecast forage quality for cattle in the dry savannas of northeast Australia. *Ecological Indicators,* 133**,** 108426.

QUEENSLAND, S. O. 2017. Reef 2050 Water quality improvement plan: 2017-2050. Brisbane, Queensland: Queensland Reef Water Quality Protection Plan Secretariat.

ROGERS, L. G., CANNON, M. G. & BARRY, E. V. 1999. Land resources of the Dalrymple shire. Brisbane: Department of Natural Resources, Queensland.

SCANLAN, J. & MCIVOR, J. 2010. Enhancing adoption of best practice grazing management in northern Australia: Phase one - integration and scenario testing. Final report: Caring for our Country project OG084273. North Sydney: Meat and Livestock Australia.

SCANLAN, J. C., MACLEOD, N., WHISH, G., COWLEY, R. & PAHL, L. 2011. Modelling the impact of grazing rest on northern Australian rangelands. *In:* FELDMAN, S. R., OLIVA, G. E. & SACIDO, M. B. (eds.) *Proceedings of the IX International Rangelands Conference: Diverse rangelands for a sustainable society.* Rosario, Argentina.

SCANLAN, J. C., MCIVOR, J. G., BRAY, S. G., COWLEY, R. A., HUNT, L. P., PAHL, L. I., MACLEOD, N. D. & WHISH, G. L. 2014. Resting pastures to improve land condition in northern Australia: guidelines based on the literature and simulation modelling. *The Rangeland Journal,* 36**,** 429-443.

SCARTH, P., RODER, A. & SCHMIDT, M. Tracking grazing pressure and climate interaction – the role of Landsat fractional cover in time series analysis. . Proceedings of the 15th Australasian Remote Sensing and Photogrammetry Conference, Alice Springs, Australia 2010. 13-17.

SCARTH, P., RÖDER, A, SCHMIDT, M. 2010a. Tracking grazing pressure and climate interaction—the role of Landsat fractional cover in time series analysis. *In: Proceedings of Australasian Remote Sensing and Photogrammetry Conference,* Alice Springs.

SCARTH, P., RODER, A. & SCHMIDT, M. Tracking grazing pressure and climate interaction – the role of Landsat fractional cover in time series analysis. . Proceedings of the 15th Australasian Remote Sensing and Photogrammetry Conference, , 2010b Alice Springs, Australia. 13-13.

SCARTH, P., TREVETHICK, R. & TINDALL, D. 2020. RPG105G-Monitoring ground cover patchiness and land condition in the grazing lands of the Great Barrier Reef Catchments. Brisbane: Department of Environment and Science, Queensland Government.

SCHMIDT, M., CARTER, J., STONE, G. & P.J., O. R. 2016. Integration of optical and X-band radar data for pasture biomass integration estimation in an open savannah woodland. *Remote Sensing of Environment* [Online], 8.

SHAW, K. A., ROLFE, J. W., BEUTEL, T., ENGLISH, B. H., GOBIUS, N. D. & JONES, D. E. 2022. Decline in grazing land condition and productivity in the Northern Gulf region of Queensland 1990 - 2016. Unpublished report. *$avannaPlan-Beef$ense project, Queensland Gulf.*

SMITH, D., O'REAGAIN, P., JONES, P., ENGLISH, B., FLETCHER, J. & . 2020. Final report: Project TF11.13 Demonstrating adaptive grazing management for sustainable and profitable management-Northern Grazing Demonstration Brisbane: Department of Environment and Heritage.

STONE, G., ZHANG, B., CARTER, J., FRASER, G., WHISH, G., PATON, C. & MCKEON, G. 2021. An online system for calculating and delivering long-term carrying capacity information for Queensland grazing properties. Part 1: background and development. *The Rangeland Journal,* 43**,** 143-157.

TEAGUE, R. & BARNES, M. 2017. Grazing management that regenerates ecosystem function and grazingland livelihoods. *African Journal of Range & Forage Science,* 34**,** 77-86.

TOTHILL, J. C. & GILLIES, C. 1992. *The pasture lands of northern Australia. Their condition, productivity and sustainability,* Brisbane, Tropical Grassland Society of Australia.

TOTHILL, J. C., HARGREAVES, J. N. G., JONES, R. M. & MCDONALD, C. K. 1992. BOTANAL - a comprehensive sampling and computing procedure for estimating pasture yield and composition 1. Field sampling. *Tropical Agronomy Technological Memorandum # 78.* Brisbane: CSIRO.

VILLAMUELAS, M., FERNÁNDEZ, N., ALBANELL, E., GÁLVEZ-CERÓN, A., BARTOLOMÉ, J., MENTABERRE, G., LÓPEZ-OLVERA, J. R., FERNÁNDEZ-AGUILAR, X., COLOM-CADENA, A., LÓPEZ-MARTÍN, J. M., PÉREZ-BARBERÍA, J., GAREL, M., MARCO, I. & SERRANO, E. 2016. The Enhanced Vegetation Index (EVI) as a proxy for diet quality and composition in a mountain ungulate. *Ecological Indicators,* 61**,** 658-666.

ZHANG, B., FRASER, G., CARTER, J., STONE, G., IRVINE, S., WHISH, G., WILLCOCKS, J. & MCKEON, G. 2021. An online system for calculating and delivering long-term carrying capacity information for Queensland grazing properties. Part 2: modelling and outputs. *The Rangeland Journal,* 43**,** 159-172.

Long term effects of different stocking strategies on cattle production in a highly variable rainfall environment

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Abstract

Rainfall variability is a major challenge to sustainable and profitable management in the savannas of northern Australia. Recommended strategies exist to manage for this variability, but adoption rates are often low due in part to the perceived unprofitability of such strategies. We present data from a large, long term trial comparing animal production in five different stocking strategies over 23 years of highly variable (246-1223 mm) rainfall. Strategies involved heavy stocking, moderate stocking, moderate stocking with spelling and application of flexible stocking rates with or without spelling.

Animal performance varied markedly over the trial period due to rainfall. Nonetheless, in nearly all years, moderate stocking rates around long term carrying capacity (LTCC) gave the highest individual live weight gain (LWG) per annum (average : 116 kg/hd), as well as the best carcass weight and price per kilogram. Conversely, average liveweight gains were lowest under heavy stocking (average: 99 kg/hd) with the lowest carcass mass and carcass prices. In the Flexible stocking strategies, LWG varied with the stocking rate applied but was (average: 114 kg/hd) was markedly better than under heavy stocking.

In contrast to individual production, average LWG per unit area was highest in the heavy stocking rate (19 kg/ha) but this strategy required drought feeding in seven of the 23 years and was unsustainable. While average LWG/ha was lower in the other strategies (range: 14-16 kg/ha), partial drought feeding was only required once in the 23 years of the trial.

Overall, heavy stocking gave the poorest individual animal production and was clearly unsustainable. Fixed, moderate stocking at LTCC generally performed well but in severe droughts stocking production declined and overgrazing occurred when stocking rates were not reduced. Wet season spelling had a relatively small positive effect on animal production but was clearly beneficial for pasture condition. Flexible or variable stocking performed well, provided numbers were adjusted in a risk averse fashion with limits set on upper stocking rates. In summary, flexible stocking combined with wet season spelling is recommended to maintain long term productivity and sustainability in a variable climate.

Introduction

Rainfall variability is a major challenge facing land managers in most extensive grazing systems with variability operating at seasonal, annual and decadal time scales. Consequently, forage availability can vary sharply between years making management extremely difficult. This variability is likely to increase, as climates change in unpredictable ways with global climate due to both higher temperatures, and rainfall possibly concentrated in fewer, more intense events (Ref.). Rainfall in the extensive grazing lands of Northern Australia is particularly variable with a catalogue of exceptionally wet years, catastrophic droughts and average years often in no particular sequence, recorded since white settlement. Failure to manage for rainfall variability and in particular, delays in selling stock and reducing stocking rates, have led to a number of severe degradation events in Australia with large shifts in vegetation composition to other, far less productive states (McKeon, Stone *et al.* 2009).

A number of management recommendations to manage rainfall variability have been developed, based partly on research e.g. (Danckwerts, O'Reagain *et al.* 1993) but often, on the practical experience of land managers. These include stocking at long term carrying capacity ((Landsberg, Ash *et al.* 1998; Purvis 1986)), spelling pastures to accumulate forage for use in drier times and maintain land condition and in particular, adjusting stock numbers proactively to avoid drought loss and take advantage of good years with greater forage availability (Mann 1993).In Australia the development of seasonal climate forecasting based on phases of the southern oscillation index (SOI) and recent more advanced systems like

POAMA (Access) and others, could also be used to help inform stocking rate decisions for the approaching wet season

While there are many managers who apply these strategies, in one or other form, unfortunately, the wider adoption of these strategies is disappointing (Queensland 2017). Accordingly many properties appear to be stocked above carrying capacity and/or respond to drought reactively with stock numbers only being reduced once paddocks have been overgrazed.

The consequences of this management are obvious with significant land degradation, reduced productivity and major economic loss. The off-site consequences are also significant with increased erosion and nutrient loss from grazing lands directly impacting important downstream systems like the world heritage listed Great Barrier Reef (Waterhouse *et al.* 2017). The reasons for the low levels of adoption of recommended strategies are extremely complex and result from a range of interlinked cultural, economic, societal, financial and legislative factors (Rolfe, Star *et al.* 2020). One key factor, however, appears to be the perception that recommended strategies such as stocking to long term carrying capacity are unprofitable and stocking rates must be maximised in order to remain economically viable.

It has been difficult to refute this assumption because of the paucity of evidence to counter it. Case studies of graziers who achieve both good land condition and economic performance by stocking to carrying capacity, matching stock numbers to available herbage and/or wet season spelling e.g. (Landsberg, Ash et al. 1998) (Mann 1993; Purvis 1986), are very powerful. However, these case studies are often discounted by other managers due to real or perceived differences in circumstances such as indebtedness, family arrangements, property size and landtypes rather than management practice (Rolfe, Larard et al. 2016)

While a number of grazing trials have been conducted many are of limited relevance in directly addressing this issue. For example, while Ash et al (2011) convincingly demonstrated the benefits of lighter utilisation rates and spelling on native pasture condition, no animal production data was collected. Other, earlier studies focussed on introduced exotic grasses or legumes, and/or involved tree clearing or fertilisation (e.g. (Winks, Lamberth et al. 1974), (Gillard 1979; Jones 2003). Most studies also had relatively small, uniform paddocks often less than 10 ha (Ash et al. 2011) although some had a few larger paddocks of up to 18 ha (Hall, Silcock et al. 2020) or 40 ha (Burrows, Orr et al. 2010). Grazing in such relatively small, uniform paddocks is unlikely to reflect the highly selective grazing patterns of cattle on larger, more spatially heterogenous commercial paddocks. While two large scale commercial trials were conducted in the Northern Territory, these were unreplicated and only ran for six years ((Cowley, McCosker et al. 2007; Hunt, Petty et al. 2013).

A key issue limiting adoption of better management strategies has thus been the lack of long term, empirical data collected at a relevant scale and over a long enough period, showing the relative costs and benefits of different grazing management strategies. To address this issue we established a large grazing trial in 1997 near Charters Towers, Australia. The key objective was to compare the ability of different stocking strategies to cope with rainfall variability in terms of their effects on animal production, land condition and profitability. This would generate empirical data to inform managers of the relative cost and benefits of following different strategies.

We aimed to make the work as relevant to the extensive grazing industry of northern Australia as possible by involving graziers with the planning and the conduct of the trial from the outset, ensuring the trial was conducted at a reasonable scale and for an appropriate time period and having spatially variable paddocks to simulate grazing patterns under typical property conditions.

In this paper we present data on the long term effects of different grazing strategies on animal liveweight gain and carcass characteristics. It builds on an earlier paper presenting results from the first ten years of trial (O'Reagain, Bushell *et al.* 2009b; O'Reagain, Bushell *et al.* 2011) and extends these out to 23 years. Data on the long term effects of the different strategies on pasture composition and profitability will be published in later papers.

Materials and methods

Site description

The trial was located on 'Wambiana' a commercial cattle station (20° 34' S, 146° 07' E) 70 km south west of Charters Towers, north Queensland, Australia. Long term (111 year) mean annual precipitation for the nearest Bureau of Meteorology rainfall station at Trafalgar, 17 km NW of the trial is 640 mm (C.V. = 40%). Rainfall is generally highly seasonal with most (70%) falling between December and March (Clewett, Clarkson *et al.* 2003). Soils are relatively infertile and include kandosols, sodosols, chromosols and vertosols (Isbell 1996).

The study area is located in the Aristida-Bothriochloa pasture community (Tothill and Gillies 1992) and is an open savanna dominated by Eucalypt, and to a lesser extent, Acacia, woodland species. The native shrub *Carissa ovata* is also very common on some soils. These overlie a range of native C4 tropical perennial grasses including Aristida spp., *Bothriochloa ewartiana, Chrysopogon fallax, Dichanthium sericeum,* and various *Digitaria* and *Panicum* species (O'Reagain et al., 2009) as well as a number of annual grasses and forbs. The exotic stoloniferous grass *Bothriochloa pertusa* has also emerged as a significant component of pasture since 2007. Cattle have grazed the area for at least the last 150 years and pastures were in moderate to good condition when the trial started.

Paddock layout

The trial site has 10 paddocks ranging in size from 93 to 117 ha, laid out in a randomised block design, with two blocks of five treatments (see below). Paddocks contain a similar proportion of each of the three soil-vegetation associations present. These associations and their % of total paddock area are a *Eucalyptus melanophloia* (silver leaf ironbark) community on yellow/red kandosols (23%), an *Acacia harpophylla – Eucalyptus brownii* (brigalow-Reid River box) community on grey vertosols/grey earths (22 %) and a *E. brownii* community (Reid River box) on brown sodosols and chromosols (55%). The maximum distance to water in any paddock is less than 1.2 km.

Site management

A ten person grazier advisory committee (GAC) was used to advise on treatments, stocking rates and general management issues. The primary aim of the GAC was to ensure that grazing strategies were applied and managed in a manner relevant to the grazing industry.

Treatments and stocking rates

Five grazing strategies that were either currently practised in the area e.g. Landsberg *et al* (1998); Mann (1993) or were recommended to manage for rainfall variability e.g. McKeon et al. 2001; were selected. A key criterion was that they be a practical management option for extensive operations characterised by large paddocks and limited labour. Stocking rates and the long term carrying capacity of the site were determined as described by O'Reagain et al (2009). These five strategies were run largely unchanged for the first ten years (1998-2010), hereafter referred to as Phase 1. These treatments and their nominal stocking rates were:

Phase 1 grazing strategies (1998-2010)

(i) Moderate stocking rate (MSR) **-** continuously stocked at the estimated long term carrying capacity (LTCC) of between 8 -10 ha/animal equivalent (AE= 450 kg steer).

(ii) Heavy stocking rate (HSR) - continuously stocked at about twice the LTCC i.e. around 4-5 ha/AE. However, these stocking rates had to be reduced a number of times through the trial due to drought and the lack of forage (Figure 1).

(iii) Rotational wet season spelling (R/Spell) – paddocks divided into three similarly sized sub-sections with one sub-section spelled annually for the wet season. The R/Spell was initially stocked at 6.5 ha/AE but in 2003 this was reduced to 8 ha/AE (see O'Reagain et al 2009).

(iv) Variable stocking (VAR) - stock numbers adjusted annually at the end of the wet season (May) using a forage budget based on available pasture and the expected time until the first effective rains (range: 3-10 ha/AE). Based on historical rainfall data this was taken as the 28 January.

(v) Southern Oscillation Index – Variable stocking (SOI)- stock numbers adjusted annually at the end of the dry season (November) according to available pasture and the expected pasture growth according to whether the SOI seasonal forecast was below -5, neutral (-5 to +5) or positive (>5). Pasture growth was derived from GRASP based estimates of pasture growth calibrated for the relevant landtypes in each paddock for SOI based years in question (range: 3-12 ha/AE).

Both the VAR and SOI strategies were very heavily stocked in the early years of the trial due to good rainfall and exceptional pasture yields (Figure 1). However, with the advent of drought in 2001/02 stocking rates were slashed to arrest overgrazing and poor animal performance (O'Reagain et al. 2009). This experience showed that it was essential to be more risk averse in varying stocking rates in such strategies. Specifically, maximum limits were needed on stocking rates in even the best years to avoid severe overgrazing, particularly if good years were followed by drought. Stocking rates changes also needed to be made in a risk-averse manner i.e. slow increases in good years, but sharper reductions in stocking rate with the approach of drought. These rules were fully incorporated into the VAR and SOI by around 2005.

Phase 2 (2011-2020)

A technical review in 2010 recommended that while the HSR and MSR should remain unchanged the remaining strategies should be adjusted to incorporate learnings from the first ten years of the project and current best practice. In consultation with the GAC, the VAR and SOI were further adapted to incorporate the need for more than one potential stocking rate adjustment through the year. To reflect these changes and the implied message to land managers the names of the two strategies were changed from '*Variable*' to '*Flexible*' stocking. Stocking rates in both were thus adjusted as described above based on available forage and seasonal climate forecasts.

Four potential stocking rate adjustment/check points through the year were also incorporated to increase flexibility. The major adjustment point was at the end of the wet season when no further pasture growth was expected, and animals had to exist on existing forage for the next 8 to 10 months. Here, stocking rates could be either increased or decreased. Three further stocking rate adjustment/check points were set in the middle and end of the dry season, and the early to mid-wet season. However, at these points, stocking rates could not be increased but only reduced or left unchanged. This rule was in accord with the risk averse approach in this strategy.

Wet season spelling was also incorporated with Flexible stocking in some paddocks due to its importance in improving pasture composition e.g. (Ash, Corfield *et al.* 2011). Flexible stocking was thus applied with or without wet season spelling giving two strategies i.e. Flexible stocking without spelling (Flex) and Flexible stocking with spelling (Flex+Spell). To minimise carry over effects from Phase 1, one of the two replicate paddocks in each of the VAR and SOI strategies were allocated to either the Flex or Flex+Spell treatment i.e. both new treatments had two replicate paddocks, one of which was formerly in the Variable treatment and one of which was formerly in the Variable-SOI treatment.

In Phase 2, wet season spelling was also applied 'adaptively' with the total area spelled and length of the spell depending upon seasonal condition. Accordingly, Flex+Spell paddocks were fenced into six subdivisions while existing R/Spell paddocks were further subdivided to give six rather than the existing three subdivisions to give greater flexibility in the total area and length of spell applied.

Management of grazing strategies

All strategies were applied adaptively to ensure maximum relevance to the grazing industry. In essence, strategies were thus applied as management *philosophies* rather than rigid treatments as conditions changed and unforeseen circumstances arose. Strategies were thus adjusted in consultation with the GAC, when it became obvious that a manager following a particular management *philosophy* would probably do likewise given the assumed beliefs or values associated with a particular strategy. For example, in drought 'heavy stockers' typically delay destocking and drought feed in the hope of early rains and increased market prices post drought. In contrast, better managers are more proactive and tend to reduce stock numbers far earlier both to maintain land condition and market stock while in saleable condition. (e.g., Mann 1993).

For example, stocking rates in the heavy stocking rate (HSR) strategy were sharply reduced in extreme drought years when even the 'heaviest stocker' would cut stocking rates to avoid the ongoing costs of drought feeding. Similarly, in late December 2017 the MSR and R/Spell paddocks had extremely low ground cover and yields (<200 kg/ha) due to ongoing drought and the fixed stocking rates in these treatments. Here continued grazing into the wet season would have resulted in significant pasture degradation. These paddocks were accordingly destocked from January – May 2018 based on the philosophy that under similar circumstances a 'moderate stocker' would act in a similar fashion to avoid degrading the resource.

Fire management

The entire site was burnt in October 1999 and 2011, to manage the tree:grass balance as is recommended practice (Bortolussi, McIvor *et al.* 2005). In 1999 cattle were removed a few weeks before the fire and agisted nearby. However in 2011, the site was destocked in late May to preserve fuel loads. The site was spelled for three months to allow recovery following both fires, Accordingly, in 1999, cattle spent 8 months in their treatment paddocks and 4 months grazing together while on agistment. Conversely, cattle were only on the trial for 4 months in the 2011/12 season.

Fires were also applied to two different subsections of the R/Spell immediately prior to spelling in 2000 and 2001. Unfortunately the 2001 fire was followed by six consecutive below-average rainfall years, which adversely impacted pasture condition and animal production (O'Reagain and Bushell 2011) and necessitated reducing the R/Spell stocking rate from 6.5 to 8 ha/AE.

Experimental animals and husbandry

Experimental animals were 3/4 Brahman-cross steers from 1997/98 to 2003/04 inclusive. However, from 2004 onwards, steers were 7/8 Brahmans. Paddocks were usually stocked with 11-35 steers, depending upon treatment and year. Between 1998 and 2000, all animals were about two years of age and were replaced annually in May. From 2000 onwards, paddocks contained two similar sized cohorts of two and three year old steers, with the older cohort being replaced by new, younger animals each year. This allowed a longer period for treatment effects to emerge and enabled older, heavier animals to be sent to the meatworks to allow assessment of carcass grades and values. Animals thus generally spent two years on the trial (O'Reagain, Bushell *et al.* 2009a) unless they needed to be sold early because of drought.

Animal measurements

Cattle were weighed at the start and end of each grazing year in late May and in the late dry season (December) following overnight fasting on water. Live weight change was calculated as the difference between fasted start- and end-weights. Carcass data was obtained for individual steers from meatworks feedback sheets.

Animal husbandry and supplementary feeding

Animal husbandry followed industry practice. Cattle were initially unsupplemented, but dry-season urea (32 % urea) and wet season phosphorous supplementation (14.76 % P, 4.75% urea) was provided from May 2003 onwards. Steers were inoculated for botulism C and D, and from May 2003 were also implanted with Compudose 400 (Elanco Animal Health, Australia) hormonal growth promotants (HGP).

Drought feeding

Drought feeding, as molasses and 8% urea (M8U) or M8U with copra meal, was provided due to extreme forage scarcity and poor body condition as needed as documented in Tables 11-16. This occurred in one or both HSR paddocks in seven out of the 24 years of the trial). Steers also had to be withdrawn and fed hay and M8U for various periods from one or both HSR paddocks in 2004/05, 2014/15, 2015/16, 2017/18 and 2020/21 to maintain animal welfare. In 2004/05 withdrawn steers were returned to the HSR following rain in January 2005. However, in 2014/15 most withdrawn HSR steers were sold early (25 March 2015) due to the failed wet season. In 2017/18 withdrawn steers from 1 replicate of the HSR were also sold early in January 2018; accordingly this replicate was stocked considerably lighter than its target rate (8 vs. 5 ha/AE). In 2020/21 conditions were so bad in one replicate of the HSR that in September 2020 half the animals were sold and the remainder put on drought feeding until the wet season in January 2021.

In the remaining treatments, drought feeding was only required in 2015/16, an extremely dry year. A few poor condition steers were also withdrawn for eight weeks from some of these treatments late in the dry season but were returned to their paddocks late in January 2016.

Statistical analysis

The trial was laid out as a randomised complete block design with two replicates of the five grazing strategies. The experimental unit was the paddock to which these grazing strategies were applied. As described two of the five strategies changed in 2010/11. To enable all years of data to be considered in the one analysis, the data was analysed as effectively having seven strategies (Treatments), comprising of the five original plus the two new strategies, over the lifetime of the trial.

Live weight gain and carcass data analysis

Total live weight gain per hectare (LWG/ha), per paddock (Pdk) and average LWG per head (LWG/hd) data were analysed by linear mixed models using residual maximum likelihood (REML) in Genstat v21. The fixed effects included Treatment (Trt), Year and their interaction (Treatment.Year). The random effects included the Replicate effect, the individual paddock effects and the interaction of the paddock and year effect (Paddock.Year). Because the same paddock was assessed over time, various covariance models were trialled for the

Paddock.Year effect, including: Identity, Unstructured and Autoregressive (order 1 and 2). The best model was assessed as that with the lowest Akaike Information Criteria (AIC). Fixed effects were tested using Wald statistics. Pairwise comparisons were made for Treatment effects using Fishers' Protected LSD. These were only used for within year comparisons. Normality assumptions were assessed using standardised normal plots of residuals. The threshold used for statistical significance was an alpha level of 0.05.

Note (a) that there are only 22 years of dry season weight change data; there is no 1997/98 dry season weight change data as the trial only started in December 1997. There is also no 2011/12 dry season data as all steers were removed to conserve fuel for the planned burn in late October 2011. Note (b) that in comparing within-year treatment effects for LWG/hd, the HSR can only be validly compared to other treatments for 23 of the 24 years of data, with the 2015/16 HSR data needing to be excluded. This was because there were only five steers in each HSR paddock due to drought resulting in an extremely low stocking rate (23 ha/AE). Stocking rates in the HSR were subsequently increased to about 10 ha/AE in 2016/17 ( ). As explained earlier there was also no 2017/18 LWG/hd data for the R/Spell and MSR due to the destocking of these treatments for the 2017/18 wet season.

The carcass data was also analysed using the same methods as live weight gain. The only differences being that carcass data was only recorded from 2004 onwards and that a natural logarithm transformation was applied where necessary to improve the residual plots. As the price of cattle more than doubled over the course of the trial, price/kilogram data was indexed relative to the 'North Queensland over-the-hooks cattle indicator' (MLA 2021). This was done by dividing the price received by the indicator price ($/kg) for May of each year.

Results

Rainfall

There was a large variation in rainfall over the trial period with extended sequences of wet and dry years (Figure 2).Thus the first four years of good rainfall were followed by six consecutive, below average rainfall years (2001/02 - 2006/07). In contrast, the following years were extremely wet, with 2010/11 the wettest year in 50 years. Thereafter, drought conditions returned, with below average rainfall from 2013/14 onwards. The 2014/15 season was particularly dry (246 mm) having the fourth lowest rainfall in 111 years. With the exception of 2016/17 (554 mm) rainfall in later years was also generally poorly distributed with short wet seasons and extended dry seasons.

Dry season liveweight change per animal

Dry season LWG was significantly affected by year, treatment and the interaction of these factors (Table 1). Substantial dry season (DS) weight loss occurred in all treatments in at least half of the years of the trial period with animals losing an average of from -40 kg/hd in 2006/07 to as much as -69 kg/hd in 2015/16. Conversely, in other years appreciable DS weight gain occurred with LWGs of as much as +71 kg/hd in 2005/6 and 2016/17 (Table 3). These marked differences in dry season performance were largely rainfall driven with weight gain in years with above average 'dry season' rainfall such as 2010/11. Good LWGs however, also occurred in years with relatively low 'dry season' rainfall such as 2005/6 and 2016/17 where precipitation was well distributed through the year. These instances e.g. 2005/06, often immediately followed a succession of very dry years with the high dry season LWGs in 2016/17 following the previous two extremely dry years being particularly noteworthy.

While the effect of treatment varied with year (**Error! Reference source not found.**), dry season LWG was highest in the MSR (Phase 1) and/or the R/Spell (Phase 2) in most years (Table 3). Dry season LWG in the Var/Flex strategies varied relative to other strategies, depending upon the stocking rate applied in a particular year. Dry season LWG in the HSR was by far the poorest, having the lowest LWG in 15 out of the 23 years where direct comparisons can be made. This difference was extreme in drought years; in 2006/07 for example, HSR steers lost 93 kg in body weight which was 55 - 69 kg/hd more than in the other strategies. Similarly, in the 2014/15 drought, HSR steers lost 39 kg more weight than the other strategies (Table 3). While good dry season LWGs were recorded in the HSR in some years e.g. 2016/17, this only occurred due to the extremely light stocking rates in the HSR imposed in that and the previous season due to drought (Figure 1).

Total liveweight gain per animal

Total liveweight gain per animal per year was significantly affected by year, treatment and the interaction of these factors (Table 1). In all treatments total LWG per animal varied markedly between years with average LWGs varying from 43 kg to 168 kg/yr depending upon rainfall (Table 4). In drought years like 2005/6 and 2014/15 however, animals barely maintained weight and, in the HSR, actually lost weight over the year.

Overall, the effect of treatment was significant (P<0.05) in sixteen out of the 24 years of the trial, with obvious, but non-significant treatment differences apparent in nearly all other years). While the effect of treatment varied with year, in general LWG was highest in the MSR (average: 115 kg) in Phase 1, and the R/Spell (average: 124 kg) in Phase 2. Individual LWG in the Var/Flex strategies varied and was very dependent upon the stocking rate applied in any particular year.

Total LWG in the HSR was by far the worst, being the lowest of all treatments in fifteen out of twenty three years (excluding 2015/16). These differences were strongly amplified by drought, with the HSR steers losing an average of -54 kg over the full 2014/15 season. Overall, average LWG in the HSR (100 kg) was thus 12-21 kg lower than the average of other treatments in Phase 1, and from 18 to 27 kg lower than other treatments in Phase 2.

The non-significance of treatment differences in some years despite marked differences in LWG e.g. in 2010/11 and 2013/14, reflects between-replicate variation in LWG and reduced statistical power inherent with limited replication (n=2). For example, in 2013/14 the HSR had the lowest LWG (81 kg/hd) of all strategies in replicate 1 but the second highest LWG (147 kg/hd) in replicate 2. These between-replicate differences likely reflect the spatial variability in rainfall frequently observed across the 1000 ha site and possibly, inherent paddock differences (O'Reagain unpublished data).

The very low LWG in the R/Spell in 2008/09 (89 kg/hd) compared to that in the HSR (114 kg/hd) is surprising given the greater forage availability in R/Spell and can only be attributed to some random effect. In particular, bovine ephemeral fever was prevalent that year and possibly had a greater impact in R/Spell than in HSR paddocks.

Total liveweight gain per hectare

Total liveweight gain per hectare (LWG/ha) was also significantly affected by year, treatment and the interaction of these factors (Total LWG/ha varied markedly with rainfall going from 34 kg/ha (averaged over all treatments) in 2000/01 to as little as 5 kg/ha in 2006/07 and -1.2 kg/ha in 2014/15, both drought years.~~).~~

Significant (P<0.05) between strategy differences in LWG/ha occurred in most years in both Phase 1 and 2 (Table 5). Overall, LWG/ha in the HSR was highest (or at least, joint highest) in 18 out of the 23 years in which valid comparisons can be made. In particular, LWG/ha in the HSR was nearly always greater (17 out of 23 years) than in the moderately stocked MSR and R/Spell. LWG/ha in the Var/Flex strategies varied with stocking rate, with LWG/ha similar or even higher than the HSR in earlier good years (1998/99 to 2001/02) when the Var/Flex strategies were heavily stocked. In contrast, in later years when lighter stocking rates in the Var/Flex strategies were lighter, LWG/ha were closer to even less than those in the MSR or R/Spell (Table 5).

Average LWG/ha over the trial period years was thus higher in the HSR (20 kg/ha) than in both the MSR (14 kg/ha) and the R/Spell (15 kg/ha). However, treatment differences varied markedly between years with LWG/ha in the HSR up to 12 to 16 kg/ha greater than other strategies in really good years like 2000/01 and 2009/10, but only two or three kg/ha greater in other years. In contrast, in drought years, LWG/ha in the HSR was generally lowest, with for example, a net loss (-16 kg/ha) in 2014/15. While LWG/ha were also very low in other treatments that year (range: 1-5 kg/ha), these were at least positive.

Carcass variables

Carcass weight, fat depth and price per kg also varied sharply between years (Table 9) due to rainfall. However these variables were also affected by differences in steer age (usually 3.5 years but sometimes 2.5 years) and time spent on the trial (generally two years but sometimes only one year). Price per kg was also obviously driven by market factors, in particular the more than doubling of cattle prices between 2013 and 2021.

Treatment affected all carcass variables but this effect was strongly dependent upon year (Table 2). Overall carcass weight (Table 6) and fat depth (Table 7) were markedly lower in the HSR than in the other strategies in most years. Consequently price per kg (Table 8) and total carcass value also tended to be lowest in the HSR. Although treatment differences were relatively minor in good seasons, these differences were far more marked in drier years, with carcass weights in the HSR from 70 kg to 100 kg lighter in drought years like 2003/04 and 2014/15. The only exceptions to this trend were when the HSR was relatively lightly stocked such as in 2016/17 and/or seasons were relatively good.

The average price/kg of HSR steers received was -$0.14/kg to -$0.18/kg lower than that in other treatments over all years. Overall, average carcass price in the HSR was thus $73 to $134 lower than in the other treatments (data not shown). Again, these differences varied with seasonal conditions with the price/kg in the HSR up to $0.50/kg lower and carcass value up to $326 dollars less in drought years like 2014/15, but these differences were far less marked in good rainfall years like 2008/09 (Table 9.

While the carcass characteristics were nearly always better in the other strategies than in the HSR, no one treatment consistently performed the best. For example, carcass weights and values tended to be highest in the Var/Flex strategies in drier periods like 2004/05 to 2007/08, when these strategies were lightly stocked. Conversely, carcass weights were heavier in the R/Spell and MSR in wetter periods like 2010/11 and 2012/13, when the Var/Flex strategies were relatively heavily stocked (Table 6).

Discussion

This paper confirms results from the first ten years of the trial ((O'Reagain, Bushell *et al.* 2009b; O'Reagain, Bushell *et al.* 2011)) and adds further weight to previous findings. It also extends these results considerably and adds fresh insights in that it considers a much wider range of rainfall years and also allows greater time for treatment effects on land condition and hence feedback on animal production to emerge.

As in the previously reported, rainfall was the dominant driver of animal performance with both live weight gain per animal and per unit area varying markedly over the 23 years of the trial. Nevertheless, as shown previously, treatment also had a strong effect with animal performance driven strongly by stocking rate within rainfall years (O'Reagain et al. 2009). Thus in nearly all years, individual LWG was highest in moderately stocked strategies like the MSR and R/Spell but lowest under heavy stocking. Averaged over all years LWG/hd was accordingly greater in the MSR (116 kg/hd) and R/Spell (114 kg/hd) than in the HSR (99 kg/hd). Individual animal performance in the VAR/Flex strategies varied relative to these latter strategies based on the stocking rate applied in particular years. Nevertheless, average LWG/hd in the Flex (114 kg/hd) and Flex+S (114 kg/hd) strategies was the same as that in the MSR and R/Spell and far greater than that in the HSR.

Although LWG/hd was generally markedly lower in the HSR, in some years individual LWG was as good or even better than other more lightly stocked treatments. However, this only occurred in better years with well distributed rainfall when stocking rates in the HSR had been reduced in response to recent drought such as 2007/08 and 2016/17. Here, HSR cattle had a relatively constant supply of short, high quality green grass giving exceptional weight gains. However, such years were rare and heavy stocking rates invariably reduced individual animal performance. The effect of heavy stocking rates on individual LWG was most evident in drier years when LWG/hd was far below that in the more moderately stocked strategies. Here weight gains were minimal and in extreme droughts like 2014/15 HSR steers lost weight (-45 kg) over the grazing year, despite drought feeding and a much reduced stocking rate.

As a consequence of the lower LWG/hd under heavy stocking, after two years these steers were often 30 to 60 kg lighter (depending upon the season) than their more moderately stocked peers. This resulted in markedly lighter carcasses and less fat cover which in turn, adversely affected grading, reducing price/kg and overall carcass price. Conversely, carcass price was generally highest under more moderate stocking rates because of the greater carcass weight, fat coverage and better meatworks grades. In below average rainfall or drought years, the adverse effects of heavy stocking were extreme, with carcass prices up to AU$170 lower than in other treatments. In commercial operations, these carcass price differences could be even greater; with meatworks price grids strongly geared for weight-for-age, cattle with slower growth rates would take up to a year or two longer to reach target weight, adversely impacting price/kg even further.

The superior animal performance under more moderate stocking rates directly reflects not only greater forage availability but in particular, higher diet quality (O'Reagain *et al.* 2008; unpublished data). This was obvious even in the early years of the trial when despite more than adequate forage under heavy stocking, dietary quality and LWG/hd were still lower than in the MSR. While the observed differences in dietary digestibility and crude protein appear relatively minor (O'Reagain unpublished data), these small differences can profoundly affect liveweight gain (O'Reagain 1996) in these tropical savannas where forage quality is a major limitation to animal production (McCown 1981).

In contrast to individual animal production, LWG/ha was generally higher under heavy stocking and lowest under light or moderate stocking rates, as would be expected ((Jones and Sandland 1974)). Again, total production in the VAR/Flex strategies varied with the stocking rate applied in any year. Average LWG/ha was thus highest in the HSR (19 kg/ha) and lowest in the MSR (14 kg/ha), with the R/Spell (15 kg/ha) and the two VAR/Flex strategies (16 kg/ha) marginally better than the MSR. Again, these results confirm and extend earlier data (O'Reagain *et al.* 2009) and are consistent with previous studies e.g. Jones (2003;(Burrows, Orr *et al.* 2010) that also showed maximum production per ha at heavier stocking rates. Hall et al 2020, found that after four years LWG/ha under heavy grazing pressure declined below that under moderate grazing due the decline in pasture condition (Hall, Silcock *et al.* 2020).

Critically, the higher average LWG/ha in the HSR was only achieved via subsidization with drought feeding in seven of the 24 years of the trial. A significant number of animals also had to be withdrawn from the HSR for welfare reasons in some years. Major stocking rate reductions were also required for extended periods in the HSR with stocking rates having to be reduced by more than a third from 4 ha/AE to about 6 ha/AE between 2005/06 and 2008/09. In the later droughts even more drastic stocking rate reductions were necessary with stocking rates reduced to 30 ha/AE in 2015/16.

In contrast, aside from a relatively short period in 2014/15, an extreme (decile 1) drought year, drought feeding was not required in the other strategies. This was because stocking rates were close to carrying capacity in the MSR and R/Spell while stock numbers were adjusted proactively in the VAR/Flex strategies as seasonal conditions declined. A small number of steers also had to be withdrawn from these strategies for a few weeks in this same season but were returned to their paddocks within a few (?) weeks.

Comparison of remaining strategies

The most obvious difference in production in the present study was the contrast between the heavy stocking rate and the other four strategies i.e. the moderately stocked MSR and R/Spell, and the two flexible/variable stocking strategies. However, there were also differences in the performance of the latter four strategies with their relative performance varying over time as conditions changed.

First, although overall average individual LWG was very similar in the R/Spell (113 kg/hd) and MSR (115 kg/hd) there were marked differences in their relative performance between the two phases of the trial. Thus in Phase 1, individual animal production in the R/Spell was slightly poorer than the MSR. This is somewhat surprising, as wet season spelling would be expected to improve pasture condition and hence animal production, at least in the medium term. However this discrepancy may be attributed to first, the slightly heavier stocking rate employed for the first six years in the R/Spell (6.5 ha/AE) compared to the MSR (8 ha/AE). And second, to the combined effects of an ill-timed fire in part of the R/Spell in 2001 and the subsequent drought (O'Reagain et al. 2009).

In Phase 2 however, this trend was somewhat reversed, with individual LWG generally (7/10 years) higher in the R/Spell relative to the MSR (125 vs 117 kg/hd respectively: Table 4). This is noteworthy because despite the same overall stocking rate (8ha/AE), spelling inevitably results in a higher wet season stocking rate (approx. 5.5 ha/AE) in the R/Spell than in the MSR where no spelling occurs, and the whole paddock is open to grazing. Given that most (>70%) LWG occurs in the wet season, these heavier stocking rates might be expected to depress gains relative to those in the MSR. The higher LWG in the R/Spell thus suggests that spelling has improved pasture condition somewhat, possibly buffering the effects of the increased wet season stocking rates on animal production. These results show that compared to stocking rate, the effect of spelling on animal production was relatively insignificant. Nevertheless, evidence from the trial shows clear benefits of wet season spelling for long term pasture condition.

The performance of the two Var/Flex stocking strategies relative to the set stocked MSR and R/Spell varied depending upon the season and the stocking rate applied in the former strategies. Individual LWG was thus relatively good in years like 2014/15 when these strategies were very lightly stocked but conversely, relatively poor in a year like 2000/01 when these strategies were very heavily stocked.

In the early wet years of the trial, very heavy stocking rates in the VAR/SOI gave total LWG/ha similar to HSR and markedly better than in the R/Spell and MSR. However, this heavy stocking ultimately resulted in overgrazing and poor animal production going into the first drought. Nevertheless, the subsequent sharp cut in stocking rates first in the SOI and then in the VAR avoided the costs of drought feeding and the very poor animal production that occurred in the HSR where stocking rates remained unchanged. Nevertheless, the downwards adjustment of stocking rates in the VAR/SOI was too late to avoid inflicting some moderate, but long lasting (>10 years) damage to pasture condition in these strategies (O'Reagain et al. 2018).

Limitations

At 23 years, this is a unique data set covering a wide range of seasonal conditions from very wet to extreme drought. Nevertheless, all experimental results are to some extent time and location specific. While the absolute results would undoubtedly be different had the experiment been conducted on other landtypes and/or with a different sequence of rainfall years, it is extremely unlikely that the relative animal performance of the different strategies would be appreciably different. Thus while the absolute differences may vary, the principles generated here should be applicable to other areas and other sequences of rainfall years.

Nevertheless, with most North Queensland properties being mainly cow-calf operations, a key question is how these results relate to breeder performance. Conventional wisdom is that steer performance does not translate directly to that of breeders (Ash and Stafford-Smith 1996). However, there is a growing evidence that steer weight gains are directly indicative of breeder performance under similar management. A relatively new gauge of female productivity is to measure the average kg weaned per cow retained (weaner production). Although not routinely measured in northern Australia, this measure is being promoted as a practical and unambiguous measure of live weight produced from a breeding herd. Recent studies (McGowan 2014, Smith, 2020 unpublished) have also shown a good relationship between steer and breeder performance expressed as weaner production when grazed under the same conditions.

This link is logical: a recent survey of herd performance across northern Australia showed that cow body condition was a key determinant of reproductive performance (Fordyce, McKosker *et al.* 2021; McGowan MR 2014) Body condition is obviously a function of live weight gain, which as shown here, declines with increasing stocking rate. Heifers with faster growth rates will reach puberty earlier, conceive and calve sooner in the season, and therefore produce a heavier calf at weaning, than those with slower growth rates. Cows in better body condition are also far more likely to conceive, raise a calf and have a shorter inter-calving interval than those in poorer condition. All are key factors directly affect breeder herd performance and profitably.

Poor body condition resulting from under nutrition has also been identified as a key risk factor for cow mortality. High cow mortality rates of *c.* 10 % are a major cost to beef enterprises in N Australia and a major constraint to production efficiency (Fordyce, McKosker *et al.* 2021; McGowan MR 2014). Provision of adequate forage through the application of appropriate grazing management is one of the four key management interventions to reduce risk ((Fordyce, McKosker *et al.* 2021)). Accordingly, it is very hard not to conclude that moderate stocking rates not only give better steer performance as shown here but are also likely to significantly improve breeder efficiency and herd performance.

The applicability of results from stocking rate experiments to commercial situations has also been questioned due to the small, relatively uniform paddocks often used in research trials (Ash and Stafford-Smith 1996; Teague and Barnes 2017)). In large paddocks, spatial variability could potentially buffer stocking rate effects on animal performance leading to better than expected performance under heavy stocking (Ash & Stafford Smith 1996). While the present experimental paddocks were far larger than those in most other grazing trials, they are still relatively small (100 ha) relative to commercial paddocks which are often well over 1000 ha in extent. However, the marked variability in land types in the study paddocks should have at least captured a significant amount of the magnitude/range of variability that animals might encounter in bigger, commercial paddocks.

Managing for rainfall variability

The present results clearly show that heavy stocking rates above carrying capacity are not sustainable in the medium to long term and can only be partly maintained with extensive drought feeding in dry years and large reductions in stocking rates. Significantly, resilience to drought also declined significantly over time with animal performance far more sensitive to reduced rainfall and management intervention required far sooner in the later drought compared to previous years. Thus in the first drought (2002-07), M8U feeding was only initiated in October 2003 while the withdrawal of poor condition animals was only necessary a year later in November 2004. However in the second later drought (2014-19?), M8U feeding had to be initiated in the first year of the drought in (November 2014) with poor condition stock having to be withdrawn only a month after feeding started. In contrast, animals in other treatments were still in very good condition in late 2014, and despite extremely low rainfall (247 mm), performed very well in 2014/15 season. For example, LWG/hd in the moderately stocked R/Spell was 159 kg/hd compared to only 98 kg/hd in the HSR for the 2014/15 season. The decline in resilience in the HSR was undoubtedly due to the combined impacts of heavy grazing and drought on pasture species composition with a decline in perennial grasses directly impacting forage production (O'Reagain et al. 2018).

In contrast in the MSR and the R/Spell which were stocked at or around carrying capacity, the original stocking rates were able to be maintained for at least the first 20 years. Although, the R/Spell and MSR strategies had to be destocked for six months in 2017/18 this was not in response to poor animal condition but an attempt to avoid permanent degradation to already overgrazed, drought affected paddocks. This was intended to emulate a 'conservative stocker' who in a similar situation would arguably remove stock temporally, possibly via agistment, to avoid long term loss of land condition.

Nevertheless, the need to destock the MSR and R/Spell was unexpected as both were stocked at or around the calculated long term carrying capacity. As such, these strategies should have been 'safe in most years' with the underlying assumption that while overgrazing might occur in drought, recovery would occur under the much lighter pasture utilisation rates in wetter years. The present results indicate that while this may generally be correct in the medium term, even if stocked at LTCC, stocking rates still need to be cut in severe droughts to avoid possibly permanent land degradation. At present (2021) it is too early to determine if destocking occurred early enough to have avoided degradation in these paddocks.

The present trial also clearly demonstrated the benefits, but major risks associated with less risk-averse versions of variable stocking. While the VAR strategy capitalised on the initial good seasons, it also resulted in overgrazing which adversely impacted pasture condition in the longer term (O'Reagain et al. 2018). Nevertheless, in contrast to the HSR, the rapid cut in stocking rates avoided the need to drought feed in the years that followed. The subsequent adoption of more flexible, risk-averse adjustments to stocking rates in these strategies ensured that in drier years, individual animal production was as good or even better than in the MSR or R/Spell because of the reduced stocking rates. Importantly, the gradual reduction in stocking rates in the two flexible strategies as the second 2013-2019 drought advanced, ensured that these remained stocked and productive, albeit at a very low rate, while the fixed MSR and R/Spell had to be destocked. Conversely, increasing stocking rates in higher rainfall years in a more risk averse fashion than in early years, gave *slightly* better LWG/ha than the latter fixed MSR and R/Spell stocking strategies. In summary these results provide further longer term support for the contention of O'Reagain et al. (2009) that heavy stocking rates are not sustainable in the long term and inevitably lead to a decline in animal production and land condition. However, in contrast to the previous study it raises serious doubts about the long term sustainability of simply stocking at LTCC and suggests that stocking rates need to be adjusted flexibly as seasons change in concert with changing forage availability.

Animal ethics

Approval for this work was granted via Animal Ethics approval projects CA 2016/05/963 and SA 2019/06/691.

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Table 1 **Significance of model terms for annual live weight gain per head (LWG/hd), LWG over the dry season, and total LWG per hectare.** See text for details.

Variable	Year	Treatment	Treatment.year
LWG/hd: Total	<0.001	<0.001	0.002
LWG/hd: Dry season	<0.001	<0.001	<0.001
LWG/ha	<0.001	<0.001	<0.001

Table 2 **Significance of model terms for carcass characteristics**

Variable	Year	Treatment	Treatment.Year
Carcass weight	<0.001	<0.001	0.012
Fat depth	<0.001	<0.001	<0.021
Price per kg	<0.001	<0.001	<0.001
Carcass value	<0.001	<0.001	<0.001

Table 3 **Mean dry season liveweight change per head (kg) for (a) Phase 1 treatments from 1997/98 to 2009/10 and (b) Phase 2 treatments from 2010/11 to 2020/21.** Treatment abbreviations as before. Means with different letters within the same columns differ significantly (P<0.05).

(a) Phase 1

	Dry season LWG (kg)												
	1997/98[A]	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
HSR	-	38	22	71 ab	-48 bc	-9 a	-24 a	-48 a	47 a	-93 a	32	-3	-34 a
MSR	-	56	28	89 b	-13 a	29 c	14 b	-6 b	68 b	-38 b	36	0	-21 ab
R/Spell	-	45	26	66 a	-27 ab	26 bc	-12 a	3 b	78 b	-24 b	28	-10	-7 b
SOI	-	41	20	68 a	-39 bc	4 a	-4 ab	-3 b	79 b	-24 b	44	0	-26 ab
VAR	-	52	25	72 ab	-52 c	6 ab	-8 a	1 b	82 b	-25 b	37	1	-40 a

(b) Phase 2

	Dry season LWG (kg)										
	2010/11	2011/12[A]	2012/13	2013/14	2014/15	2015/16[B]	2016/17	2017/18	2018/19	2019/20	2020/21
HSR	49 a	-	8 a	-40 a	-72 a	*	86 c	-30 a	14 a	-12 a	-39 b
MSR	65 ab	-	28 ab	-4 b	-30 b	-65	58 a	2 b	44 b	5 ab	5 a
R/Spell	77 b	-	36 b	0 b	-25 b	-65	62 ab	18 bc	47 b	22 b	15 a
Flex	65 ab	-	31 b	-16 b	-33 b	-68	76 abc	21 bc	31 ab	8 ab	8 a
Flex+S	58 ab	-	29 b	1 b	-28 b	-78	74 abc	24 c	25 a	5 ab	8 a

[A] No dry season LW data for 2011/12 as steers were on agistment. [B] HSR data for 2015/16 not presented – see text for details.

Table 4 **Mean liveweight gain per head (LWG) per year (kg) for (a) Phase 1 treatments from 1997/98 to 2009/10 and (b) Phase 2 treatments from 2010/11 to 2020/21.** Treatment abbreviations as before. Means with different letters within the same columns differ significantly (P<0.05).

(a) Phase 1

	Liveweight gain per animal (kg)												
	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
HSR	66	126 b	117	152 b	50 a	52 a	76 a	81 a	127 a	5 a	147	114 a	105
MSR	80	152 a	130	180 a	80 b	90 b	122 b	119 b	139 ab	39 b	135	115 a	118
R/Spell	71	137 ab	113	145 b	74 abc	87 b	97 ab	120 b	148 ab	53 b	129	89 b	108
SOI	73	134 ab	115	138 b	70 abc	69 ab	104 b	119 b	151 b	53 b	145	123 a	114
VAR	78	141 ab	114	154 b	52 ac	68 a	110 b	132 b	152 b	63 b	140	125 a	98

(a) Phase 2

	Liveweight gain per animal (kg)										
	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16[A]	2016/17	2017/18[B]	2018/19	2019/20	2020/21
HSR	112 a	126 ab	116 a	97	-54 a	*	184 a	96 b	150	48 b	135
MSR	132 ab	126 ab	137 ab	145	12 b	97	156 b	-	162	82 a	146
R/Spell	154 b	142 b	150 b	159	18 b	88	161 ab	-	165	85 a	160
Flex	125 a	131 ab	128 ab	140	12 b	98	179 ab	156 a	160	84 a	144
Flex+S	132 ab	117 a	137 ab	142	44 d	93	162 ab	120 b	146	95 a	150

[A]HSR data for 2015/16 not presented – see text for details. [B] No MSR or R/Spell data for 2017/18- see text for details

Table 5 **Mean liveweight gain per hectare (LWG/ha) per year for (a) Phase 1 treatments from 1997/98 to 2009/10 and (b) Phase 2 treatments from 2010/11 to 2020/21.** Treatment abbreviations as before. Means with different letters within the same columns differ significantly (P<0.05).

(a) Phase 1

	Liveweight gain per ha (kg/ha)												
	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
HSR	19 a	29 c	27 b	36 a	14	15 ab	24 c	25 b	20	1	23 b	16 b	26 b
MSR	10 b	17 a	15 a	20 b	10	12 a	19 b	17 a	18	5	18 a	13 a	14 a
R/Spell	13 b	22 ab	19 a	26 b	13	18 b	11 a	14 a	16	6	15 a	11 a	13 a
SOI	10 b	26 bc	28 b	39 a	12	11 a	13 a	16 a	17	5	17 a	15 ab	13 a
VAR	11 b	29 c	27 b	48 c	14	11 a	11 a	14 a	15	6	16 a	16 b	16 a

(b) Phase 2

	Liveweight gain per ha (kg/ha)										
	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
HSR	29 b	31 b	26 a	27 c	-16 a	*	23 b	15 a	16 a	10	17 a
MSR	18 a	15 a	16 b	20 a	2 b	13	21 ab	0.3 c	21 b	10	15 a
R/Spell	19 a	19 a	17 b	22 ac	2 b	12	22 b	2 c	15 a	9	14 a
Flex	23 a	19 a	17 b	19 a	1 b	8	16 a	8 b	15 a	7	7 b
Flex+S	22 a	17 a	19 b	20 a	5 b	8	16 a	8 b	15 a	9	8 b

[1] R/Spell and MSR destocked for 2017/18 wet season

Table 6 **Average carcass weight for (a) Phase 1 treatments from 2003/04 to 2009/10 and (b) Phase 2 treatments from 2010/11 to 2020/21**. Treatment abbreviations as before. Means with different letters within the same columns differ significantly (P<0.05).

(a) Phase 1

	Carcass weight (kg)						
Treatment	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
HSR	198 a	210 a	270 a	246 a	287	330	269 a
MSR	242 b	249 b	303 b	269 ab	286	328	304 b
R/Spell	222 b	237 b	310 b	277 bc	293	311	299 b
SOI	231 b	241 b	312 b	297 c	304	330	319 b
VAR	238 b	256 b	315 b	293 bc	308	322	300 b

(b) Phase 2

	Carcass weight (kg)										
Treatment	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16[A]	2016/17	2017/18[B]	2018/19	2019/20	2020/21
HSR	262 a	246	296	239 a	188 a	-	287	288 a	297 c	282 a	289 c
MSR	279 ab	254	317	266 b	244 bc	250	302	-	264 a	315 bc	306 bc
R/Spell	297 b	257	313	280 b	256 c	255	301	-	265 ab	324 c	332 ab
Flex	271 a	253	302	260 ab	229 b	261	301	350 b	293 bc	319 bc	352 a
Flex+S	274 ab	238	302	265 b	261 c	272	303	304 a	294 bc	295 ab	331 ab

[A]HSR data for 2015/16 not presented – see text for details. [B] R/Spell and MSR destocked for 2017/18 wet season.

Table 7 **Average fat thickness (means of back transformed data) in mm by treatment for (a) Phase 1 treatments from 2003/04 to 2009/10 and (b) Phase 2 treatments from 2010/11 to 2020/21**. Treatment abbreviations as before. Means with different letters within the same columns differ significantly (P<0.05).

(a) Phase 1

	Fat thickness (mm)						
Treatment	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
HSR	5.4 abc	6	14.1	8.6 a	9.4 a	10.2	7.7 a
MSR	6.5 c	7.3	12.8	11.6 ab	11.8 ab	10	11.9 b
R/Spell	4.3 a	7.8	14.9	11.7 ab	12.5 ab	8.3	8.6 a
SOI	4.5 ab	6.5	15.3	12.3 b	13.1 b	10.8	8.9 ab
VAR	6 bc	7.4	15	12 b	11.6 ab	10.2	9.3 ab

(b) Phase 2

	Fat thickness (mm)										
Treatment	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16[A]	2016/17	2017/18	2018/19	2019/20	2020/21
HSR	8.5	6.6	12.6 a	6	2.2 a		14.8	7.7 a	10.1	7.2 a	9.1 a
MSR	9	7.6	18 b	7.2	6.8 b	8.3	17.6		10.1	11.7 c	9.2 a
R/Spell	9.8	8.3	14.5 ab	8.2	7.7 b	9.4	15.5		9.8	10.3 c	13.2 b
Flex	9	7.4	15.9 ab	8.2	7.4 b	10.7	16.7	17 b	13.4	9.2 abc	12.9 b
Flex+S	8.7	7	13.7 ab	7.2	7.9 b	8.4	14.3	12.9 b	10.9	8.4 ab	13.1 b

[1]HSR data for 2015/16 not presented – see text for details. [2] R/Spell and MSR destocked for 2017/18 wet season

Table 8**. Average price per kg for (a) Phase 1 treatments from 2003/04 to 2009/10 and (b) Phase 2 treatments from 2010/11 to 2020/21.** Treatment abbreviations as before. Means with different letters within the same columns differ significantly (P<0.05).[1/10/2021: Prices in $ but significance tests based **on indexed price**]

(a) Phase 1

	Price per kg ($/kg)						
Treatment	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
HSR	1.56 a	2.78 c	3.22 a	2.69 a	2.83 a	2.59 a	2.75
MSR	2.75 b	2.96 a	3.28 a	2.84 ab	2.83 a	2.60 a	2.82
R/Spell	2.26 c	2.93 ac	3.28 a	2.79 ab	2.85 a	2.58 a	2.80
SOI	2.27 c	2.97 a	3.29 a	2.94 b	2.87 a	2.60 a	2.82
VAR	2.05 c	2.96 a	3.30 a	2.92 b	2.90 a	2.59 a	2.81

(b) Phase 2

	Price per kg ($/kg)										
Treatment	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16[A]	2016/17	2017/18	2018/19	2019/20	2020/21
HSR	2.82	2.79	2.64 a	2.80 a	3.34 a	-[1]	4.74	4.33	5.25	5.63	6.48
MSR	2.87	2.83	2.72 cd	2.95 b	3.83 cb	4.64	4.72	-[2]	5.20	5.69	6.44
R/Spell	2.89	2.86	2.74 d	2.99 b	3.87 cb	4.68	4.73	-[2]	5.19	5.71	6.49
Flex	2.85	2.83	2.67 ac	2.94 b	3.80 b	4.69	4.73	4.35	5.19	5.70	6.49
Flex+S	2.88	2.79	2.66 ac	2.91 ab	3.94 c	4.72	4.72	4.35	5.20	5.72	6.49

[1]HSR data for 2015/16 not presented – see text for details. [2] R/Spell and MSR destocked for 2017/18 wet season

Table 9 **Average carcass price (means of back transformed data) in $ for (a) Phase 1 treatments from 2003/04 to 2009/10 and (b) Phase 2 treatments from 2010/11 to 2020/21.** Treatment abbreviations as before. Means with different letters within the same columns differ significantly (P<0.05).

(a) Phase 1

	Carcass price ($)						
Treatment	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
HSR	508 a	566 a	870 a	664 a	813	856	741 a
MSR	674 b	739 b	993 b	768 bc	809	853	859 b
R/Spell	599 c	696 b	1018 b	782 dc	833	802	838 b
SOI	603 c	717 b	1025 b	875 e	871	855	901 b
VAR	593 c	758 b	1037 b	861 ce	892	837	846 b

(b) Phase 2

	Carcass price ($)										
Treatment	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16[A]	2016/17	2017/18[B]	2018/19	2019/20	2020/21
HSR	739 a	690	781	671 a	629 a	-	1361	1239 a	1533	1591 a	1869 c
MSR	802 abc	722	860	786 b	939 bc	1158	1425	-	1374	1793 b	1980 bc
R/Spell	859 c	737	856	840 b	994 c	1196	1412	-	1486	1852 b	2152 ab
Flex	773 ab	718	807	768 b	868 b	1221	1426	1520 b	1524	1813 b	2276 a
Flex+S	790 abc	666	804	778 b	1028 c	1284	1431	1319 ab	1530	1689 bc	2147 ab

[A]HSR data for 2015/16 not presented – see text for details. [B] R/Spell and MSR destocked for 2017/18 wet season

Figures

Figure 1 Change in stocking rate (expressed as AEs/100 ha) over different years at the Wambiana trial for (top) the R/Spell, MSR and HSR and (below) the VAR, SOI and then Flex and Flex(+Spell) strategies.

Figure 2 Annual rainfall (July-June) from 1997/98 to 2020/21 at the Wambiana grazing trial (Dotted line=long term average).

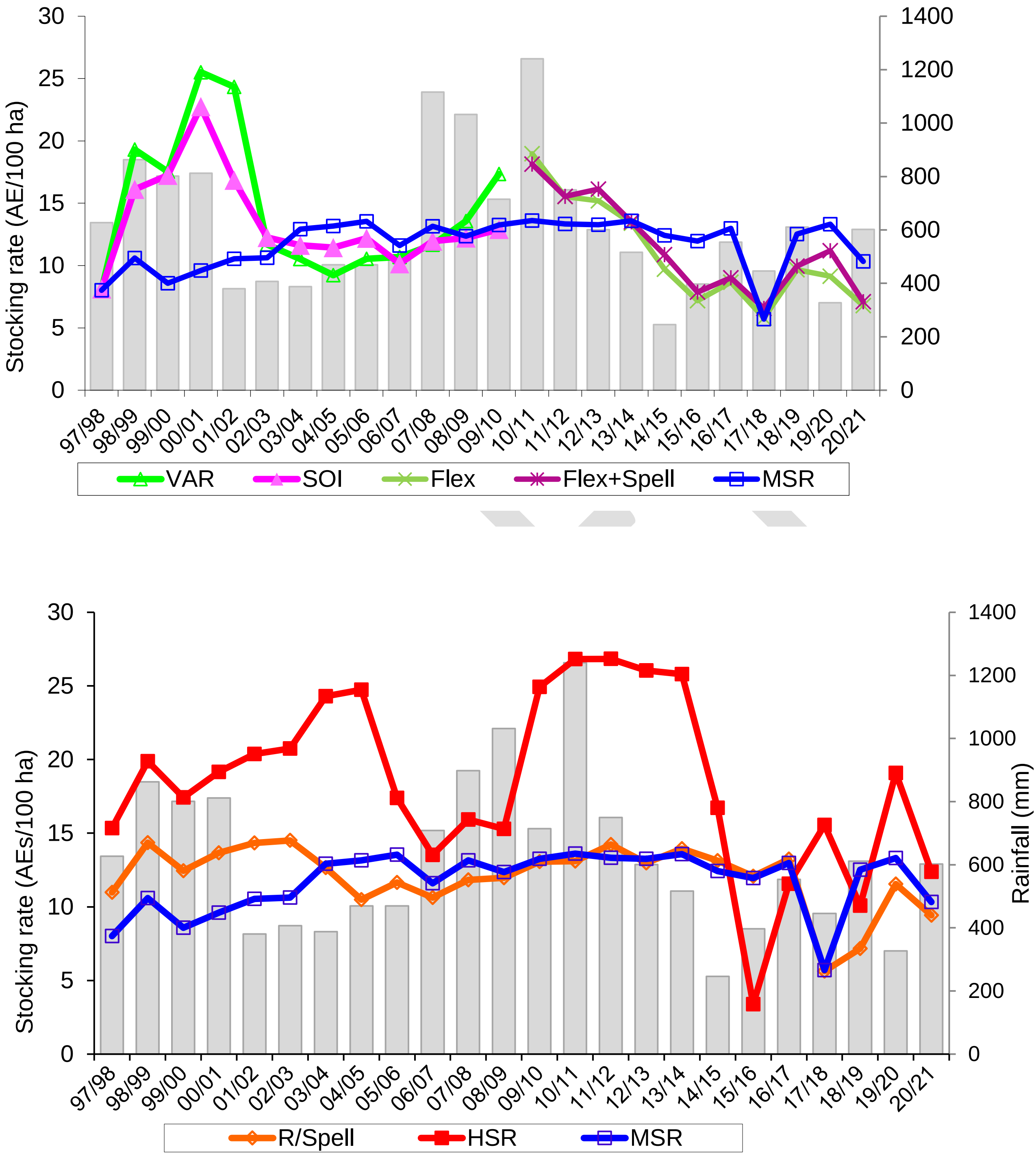

Figure 1 Change in stocking rate (expressed as AEs/100 ha) over different years at the Wambiana trial for (top) the R/Spell, MSR and HSR and (below) the VAR, SOI and then Flex and Flex(+Spell) strategies.

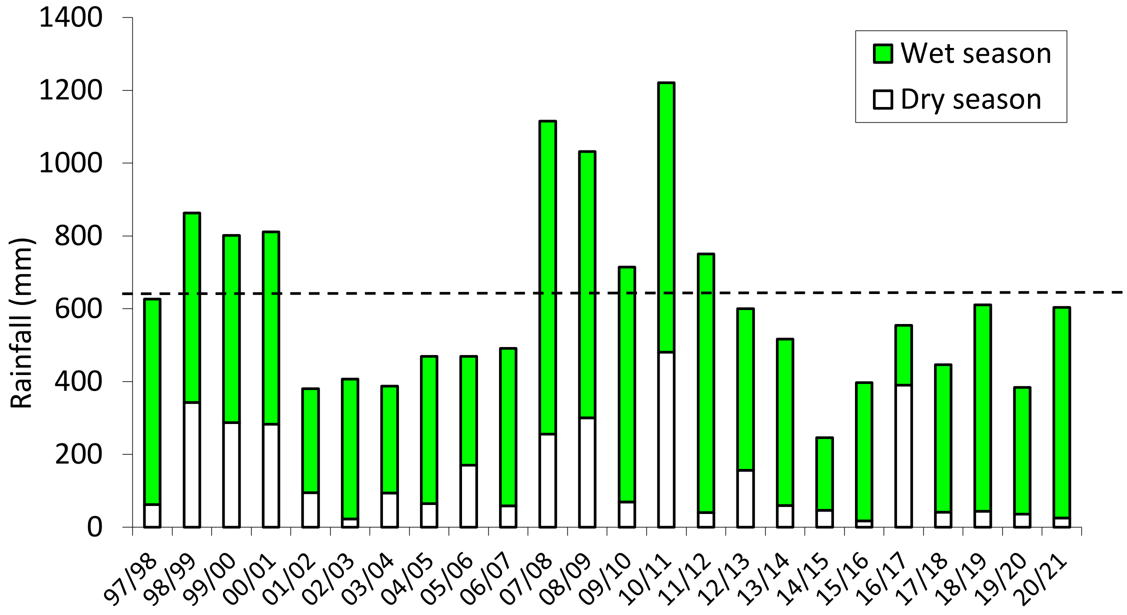

Figure 2 Annual rainfall (July-June) from 1997/98 to 2020/21 at the Wambiana grazing trial with long term average (LTA) rainfall (dotted line).

References

Ash AJ, Corfield JP, McIvor JG, Ksiksi TS (2011) Grazing management in tropical savannas: Utilization and rest strategies to manipulate rangeland condition. *Rangeland Ecology and Management* **64**(3), 223-239.

Ash AJ, Stafford-Smith DM (1996) Evaluating stocking rate impacts in rangelands: animals don't practice what we preach. *Rangeland Journal* **18**, 216-243.

Bortolussi G, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005) The northern Australian beef industry, a snapshot. 4. Condition and management of natural resources. *Australian Journal of Experimental Agriculture* **45**(9), 1109-1120.

Burrows WH, Orr DM, Hendricksen RE, Rutherford MT, Myles DJ, Back PV, Gowen R (2010) Impacts of grazing management options on pasture and animal productivity in a *Heteropogon contortus* (black speargrass) pasture in central Queensland. 4. Animal production. *Animal Production Science* **50**(4), 284-292.

Clewett JF, Clarkson NM, George DA, Ooi SH, Owens DT, Partridge IJ, Simpson GB (2003) Rainman Streamflow version 4.3: a comprehensive climate and streamflow analysis package on CD to assess seasonal forecasts and manage climate risk. In. ' 4.3 edn. (Department of Primary Industries)

Cowley RA, McCosker KD, MacDonald RN, Hearnden MN (2007) Optimal pasture utilisation rates for sustainable cattle production with a commercial Brahman herd in the Victoria River Downs region of the Northern Territory. In 'Proceedings of the Northern Beef Research Update Conference. ' (Eds B Pattie and B Restall) pp. 34-44. (North Australia Beef Research Council: Park Ridge, Qld.: Townsville, Australia)

Danckwerts JE, O'Reagain PJ, O'Connor TG (1993) Range management in a changing environment: A southern African perspective. *Rangeland Journal* **15**(1), 133-144.

Fordyce G, McKosker KD, Smith DR, Perkins NR, O'Rourke PK, McGowan MR (2021) Reproductive performance of northern Australia beef herds. 7. Risk factors affecting mortality rates of pregnant cows. *Animal Production Science*.

Gillard P (1979) Improvement of native pastures with Townsville stylo in the dry tropics of sub-coastal northern Queensland. *Australian Journal of Experimental Animal Husbandry* **19**, 325-336.

Hall TJ, Silcock RG, Mayer DG (2020) Grazing pressure and tree competition affect cattle performance and native pastures in Eucalypt woodlands of Queensland, north-eastern Australia. *Animal Production Science* **60**(7), 953-966.

Hunt LJ, Petty S*, et al.* (2013) Sustainable development of Victoria River District (VRD) grazing lands. Final report, Project No. B.NBP.0375. . In. ' pp. 448 (Meat and Livestock Australia, : North Sydney)

Isbell RF (1996) 'The Australian Soil Classification.' (CSIRO, Publishing: Melbourne, Australia) 143

Jones RJ (2003) Effects of sown grasses and stocking rates on pasture and animal production from legume-based pastures in the seasonally dry tropics. *Tropical Grasslands* **37**(3), 129-150.

Jones RJ, Sandland RL (1974) The relation between animal gain and stocking rate. *Journal of Agricultural Science* **83**, 335-342.

Landsberg RG, Ash AJ, Shepherd RK, McKeon GM (1998) Learning from history to survive in the future: management evolution on Trafalgar Station, north-east Queensland. *Rangeland Journal* **20**, 104 -118.

Mann TH Flexibility - the key to managing a northern beef property. In 'Proceedings XVII International Grasslands Congress', 18-21 February 1993, 18-21 February, Rockhampton, Australia, pp. 1961-1964

McCown RL (1981) The climatic potential for beef cattle production in tropical Australia: Part I-Simulating the annual cycle of liveweight change. **6**(4), 303-317.

McGowan MR MK, Fordyce G, Smith D, O'Rourke PK, Perkins N, Barnes T, Marquet L, Morton J, Newsome T, Menzies D, Burns BM and Jephcott S (2014) North Australian beef fertility project: Cash Cow. Final Report, Project B.NBP.0382 In. ' pp. 301. (Meat and Livestock Australia Sydney)

McKeon GM, Stone GS*, et al.* (2009) Climate change impacts on northern Australian rangeland livestock carrying capacity: a review of issues. *Rangeland Journal* **31**(1), 1-29.

MLA (2021) North Queensland over the hooks cattle indicators-monthly. In. ' (Meat and Livestock Australia)

O'Reagain P, Bushell J, Holloway C, Reid A (2009a) Managing for rainfall variability: effect of grazing strategy on cattle production in a dry tropical savanna. *Animal Production Science* **49**(2), 85-99.

O'Reagain PJ (1996) Predicting animal production on Sourveld: a species-based approach. *African Journal of Range & Forage Science* **13**(3), 113-123.

O'Reagain PJ, Bushell JJ, Holloway CH, Reid A (2009b) Managing for rainfall variability: effect of grazing strategy on cattle production in a dry tropical savanna. *Animal Production Science* **49**, 1-15.

O'Reagain PJ, Bushell JJ, Holmes W (2011) Managing for rainfall variability: long-term profitabilty of different grazing strategies in a north Australian tropical savanna. *Animal Production Science* **51**, 210-224.

Purvis JR (1986) Nurture the land: my philosophies of pastoral management in central Australia. *Australian Rangelands* **8**, 110-117.

Queensland So (2017) Reef 2050 Water quality improvement plan: 2017-2050. Queensland Reef Water Quality Protection Plan Secretariat, Brisbane, Queensland.

Rolfe J, Star M, Curcio A (2020) Can extension programs improve grazing management in rangelands: a case study in Australia’s Great Barrier Reef catchments. *The Rangeland Journal* **42**(6), 447-459.

Rolfe JW, Larard AE*, et al.* (2016) Rangeland profitability in the northern Gulf region of Queensland: understanding beef business complexity and the subsequent impact on land resource management and environmental outcomes. *The Rangeland Journal* **38**(3), 261-272.

Teague R, Barnes M (2017) Grazing management that regenerates ecosystem function and grazingland livelihoods. *African Journal of Range & Forage Science* **34**(2), 77-86.

Tothill JC, Gillies C (1992) 'The pasture lands of northern Australia. Their condition, productivity and sustainability.' (Tropical Grassland Society of Australia: Brisbane)

Winks L, Lamberth FC, Moir KW, Pepper PM (1974) Effect of stocking rate and fertilizer on the performance of steers grazing a Townsville stylo- based pasture in north Queensland *Australian Journal of Experimental Agriculture* **14** 146-154.

Appendix 2: Supplementation cost and supplements fed at the Wambiana grazing trial 1997/98 to 2020/21

Table 1 Costs used in calculations (based on 2010 prices in Charters Towers). See text for further details.

Supplement	**Price ($/kg)**
Dry season lick	$0.81
Wet season lick	$1.12
Molasses and 8% urea mix	$0.26
Cottonseed meal	$0.76
Copra	$0.76
Agistment cost ($/week)	$3.00

Table 2 : Total supplementation costs for different treatments (averaged over two replicate paddocks) over the trial period from 1997/98 to 2020/21. Supplements include dry season and wet season lick as well as drought feeding (includes an agistment cost in lieu of hay feeding). See text for details

(a) Phase 1

	Supplement costs ($/ha)												
	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
HSR	0.0	0.0	0.0	0.0	0.2	13.8	11.5	29.2	14.5	5.6	0.8	2.6	5.0
MSR	0.0	0.0	0.0	0.0	0.0	8.4	6.0	4.6	1.5	1.4	0.9	2.5	2.9
R/Spell	0.0	0.0	0.0	0.0	0.0	12.9	5.9	3.2	1.0	1.1	0.5	1.8	2.6
SOI	0.0	0.0	0.0	0.0	4.6	10.5	4.2	3.8	1.3	1.1	0.9	2.4	2.6
VAR	0.0	0.0	0.0	0.0	1.4	10.8	4.3	3.6	1.1	1.7	0.7	2.5	3.3

(b) Phase 2

	Supplement costs ($/ha)										
	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
HSR	5.0	5.3	5.3	8.3	14.1	9.9	1.9	4.4	4.2	6.5	19.5
MSR	3.1	2.4	2.4	3.7	3.8	7.8	2.3	3.7	5.4	3.9	3.4
R/Spell	2.6	2.9	2.9	4.3	4.0	6.8	2.3	3.4	3.8	3.9	2.9
Flex	3.2	2.8	2.8	4.6	3.3	5.6	2.0	1.6	3.5	2.6	2.0
Flex+S	2.7	3.2	3.2	4.5	3.7	5.4	2.0	2.4	3.7	3.4	2.5

Table 3 : Dry season lick (kg/ha) fed to different treatments (averaged over two replicate paddocks) over the trial period from 1997/98 to 2020/21. See text for details

(a) Phase 1

	Dry season lick (kg/ha)												
	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
HSR	-	-	-	-	-	16.9	9.5	6.3	0.9	0.8	0.7	2.4	4.9
MSR	-	-	-	-	-	10.3	7.4	5.7	1.2	1.3	0.8	2.3	2.7
R/Spell	-	-	-	-	-	15.8	7.2	3.9	1.0	0.8	0.4	1.6	2.6
SOI	-	-	-	-	-	12.9	5.2	4.7	0.9	0.9	0.8	2.2	2.3
VAR	-	-	-	-	-	13.3	5.3	4.4	0.6	1.6	0.6	2.4	3.1

(b) Phase 2

	Dry season lick (kg/ha)										
	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
HSR	4.9	4.6	4.6	7.0	5.5	0.3	1.1	4.7	3.7	6.1	3.8
MSR	3.0	1.8	1.8	2.7	3.6	1.3	1.6	4.1	4.4	3.4	2.4
R/Spell	2.6	1.9	1.9	3.1	3.7	1.6	1.2	3.4	3.0	3.3	2.2
Flex	3.0	2.4	2.4	3.3	3.2	1.1	1.0	1.8	2.8	2.1	1.5
Flex+S	2.4	2.7	2.7	3.5	3.3	1.1	1.1	2.7	3.1	3.2	2.2

Table 4 : Wet season lick (kg/ha) fed to different treatments (averaged over two replicate paddocks) over the trial period from 1997/98 to 2020/21. See text for details

(a) Phase 1

	Wet season lick (kg/ha)												
	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
HSR	-	-	-	-	-	-	-	-	0.2	0.3	0.2	0.5	0.9
MSR	-	-	-	-	-	-	-	-	0.5	0.3	0.2	0.5	0.7
R/Spell	-	-	-	-	-	-	-	-	0.2	0.4	0.1	0.5	0.4
SOI	-	-	-	-	-	-	-	-	0.5	0.3	0.2	0.5	0.6
VAR	-	-	-	-	-	-	-	-	0.6	0.4	0.2	0.5	0.7

(b) Phase 2

	Wet season lick (kg/ha)										
	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
HSR	0.9	1.4	1.4	2.3	0.8	0.8	0.9	0.5	1.1	1.3	1.8
MSR	0.7	0.8	0.8	1.3	0.8	0.9	0.9	0.4	1.6	1.0	1.2
R/Spell	0.4	1.2	1.2	1.6	0.9	1.0	1.2	0.6	1.2	1.1	1.0
Flex	0.7	0.8	0.8	1.7	0.6	0.9	1.0	0.2	1.0	0.8	0.7
Flex+S	0.6	0.9	0.9	1.4	0.9	0.8	0.9	0.2	1.1	0.7	0.6

Table 5 : Molasses and urea (8%) mix (kg/ha) fed to different treatments (averaged over two replicate paddocks) over the trial period from 1997/98 to 2020/21. See text for details

(a) Phase 1

	M8U fed (kg/ha)												
	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
HSR	0	0	0	0	0	0	14	90	52	18	0	0	0
MSR	0	0	0	0	0	0	0	0	0	0	0	0	0
R/Spell	0	0	0	0	0	0	0	0	0	0	0	0	0
SOI	0	0	0	0	0	0	0	0	0	0	0	0	0
VAR	0	0	0	0	0	0	0	0	0	0	0	0	0

(b) Phase 2

	M8U fed (kg/ha)										
	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
HSR	0	0	0	0	18	14	0	0	0	0	17
MSR	0	0	0	0	0	8	0	0	0	0	0
R/Spell	0	0	0	0	0	12	0	0	0	0	0
Flex	0	0	0	0	0	5	0	0	0	0	0
Flex+S	0	0	0	0	0	6	0	0	0	0	0

Table 6 : Cotton seed (kg/ha) fed to different treatments (averaged over two replicate paddocks) over the trial period from 1997/98 to 2020/21. See text for details

(a) Phase 1

	Cotton seed (kg/ha)												
	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
HSR	-	-	-	-	-	-	-	0.81	0.15	-	-	-	-
MSR	-	-	-	-	-	-	-	-	-	-	-	-	-
R/Spell	-	-	-	-	-	-	-	-	-	-	-	-	-
SOI	-	-	-	-	-	-	-	-	-	-	-	-	-
VAR	-	-	-	-	-	-	-	-	-	-	-	-	-

(b) Phase 2

	Cotton seed (kg/ha)										
	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
HSR	-	-	-	-	-	-	-	-	-	-	-
MSR	-	-	-	-	-	-	-	-	-	-	-
R/Spell	-	-	-	-	-	-	-	-	-	-	-
Flex	-	-	-	-	-	-	-	-	-	-	-
Flex+S	-	-	-	-	-	-	-	-	-	-	-

Table 7 : Copra (kg/ha) fed to different treatments (averaged over two replicate paddocks) over the trial period from 1997/98 to 2020/21 See text for details

(a) Phase 1

	Copra (kg/ha)												
	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
HSR	-	-	-	-	-	-	-	-	-	-	-	-	-
MSR	-	-	-	-	-	-	-	-	-	-	-	-	-
R/Spell	-	-	-	-	-	-	-	-	-	-	-	-	-
SOI	-	-	-	-	-	-	-	-	-	-	-	-	-
VAR	-	-	-	-	-	-	-	-	-	-	-	-	-

(b) Phase 2

	Copra (kg/ha)										
	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
HSR	-	-	-	-	5.0	1.0	-	-	-	-	2.8
MSR	-	-	-	-	-	0.6	-	-	-	-	-
R/Spell	-	-	-	-	-	0.8	-	-	-	-	-
Flex	-	-	-	-	-	0.3	-	-	-	-	-
Flex+S	-	-	-	-	-	0.4	-	-	-	-	-

Table 8 : Agistment periods (steer.weeks per ha) for different treatments over the trial period from 1997/98 to 2020/21. See text for details

(a) Phase 1

	Agistment (steer.weeks /ha)												
	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
HSR	-	-	-	-	-	-	1.3	-	-	-	-	-	-
MSR	-	-	-	-	-	-	-	-	-	-	-	-	-
R/Spell	-	-	-	-	-	-	-	-	-	-	-	-	-
SOI	-	-	-	-	-	-	-	-	-	-	-	-	-
VAR	-	-	-	-	-	-	-	-	-	-	-	-	-

(b) Phase 2

	Agistment (steer.weeks/ha)										
	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
HSR	-	-	-	-	-	0.5	-	-	-	-	0.9
MSR	-	-	-	-	-	0.4	-	-	-	-	-
R/Spell	-	-	-	-	-	0.1	-	-	-	-	-
Flex	-	-	-	-	-	0.3	-	-	-	-	-
Flex+S	-	-	-	-	-	0.2	-	-	-	-	-

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Original Articles

Using remote sensing to forecast forage quality for cattle in the dry savannas of northeast Australia

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ABSTRACT

In the dry savannas of northeast Australia, forage quality is just as important for cattle production as forage quantity. The seasonal trend of forage quality is broadly predictable by land managers, but it is more difficult to predict the point when quality—which depends on local climate, management, and pasture condition—falls below the requirement for animal maintenance. In this study we use statistical modelling to forecast how forage quality might change at the crucial time of year, i.e., as the summer wet season transitions to the dry winter. We do this with the aid of historical information associated with a long-term cattle-grazing trial in the dry savannas. We combined multiple years of two measures of forage quality (dietary crude protein and *in vivo* dry-matter digestibility; respectively DCP and DMD) and ground cover information (specifically the ratio of 'green grass' cover to 'dead (i.e., non-photosynthetic) grass' cover, derived from an archive of Landsat satellite imagery) into a linear mixed model that explicitly considered the correlations with time and between variables. DCP and DMD were estimated by near-infrared spectroscopy of fresh faecal samples; values did not have to be temporally coincident with the satellite imagery. With the end of May considered a nominal decision-point, we forecast monthly averages of forage quality for June to August, over a 12-year period at the study site. Over all months and all years, the median absolute error of the forecasts was DCP = 0.86%, and DMD = 0.95%. The remote sensing information served as a correlated, oft-sampled covariate that helped to guide the forecasts of forage quality. We propose summarising the forecasts (and their uncertainty) as a near-real-time graphical tool for decision-support. Such a product could potentially benefit cattle-grazing enterprises in the northeast of Australia, enabling more timely management of herds through the dry season.

1. Introduction

Forage quality, as distinct from quantity, is a major constraint to cattle production in the dry savannas of northern Australia. Forage quality is highest during the summer wet season, but declines rapidly when pastures senesce at the onset of the long dry season (McCown, 1981). Cattle can consequently lose body condition and substantial mass during the dry season, even if there appears to be abundant forage (Norman, 1965; Siebert and Kennedy, 1972). The seasonal variability of forage quality is superimposed on a background of highly variable rainfall, with northern Australia marked by runs of multi-year wet or dry periods (McKeon et al., 2021).

It has long been known that forage quality in northern Australia is directly related to the availability of green leaf (McCown, 1981; McIvor, 1981; Poppi et al., 1981). The seasonal trend of forage quality is thus broadly predictable, but the nature of the transition to low-quality forage can vary markedly, depending on the distribution and amount of rainfall (McCown, 1981). For example, very wet years with large growth events can lead to nutrient dilution, while the converse may be true in droughts.

Managers can respond to the decline in forage quality by marketing cattle early, moving the cattle, or providing supplements. In the dry savannas, non-protein nitrogen, in the form of urea (Callaghan et al., 2014), is widely used as a supplement when dietary crude protein (DCP) is perceived as limiting. When energy in the diet is perceived as limiting, supplements such as molasses, often mixed with urea, may also be considered for animals with higher energy requirements (Callaghan et al., 2014). Deploying supplements before they are actually required is

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an unnecessary cost. Conversely, delaying supplementation too long can result in reduced production.

A key challenge facing land managers in the dry savannas is thus to assess forage quality in an accurate and timely matter. Typically, this is done vaguely, using a combination of cues such as pasture greenness, rainfall received (and forecast), soil moisture, and animal condition. The last may seem an obvious proxy, but can be associated with large uncertainty (Fordyce et al., 2013; Tolleson et al., 2020). The challenge is exacerbated by extremely large grazing properties (typically 20,000–500,000 ha) and widely dispersed herds. The spatial heterogeneity of large paddocks, coupled with the spatial variability of rainfall, adds further complexity. With access to paddocks usually limited, roadside visual assessments of forage quality are unlikely to be representative of a paddock as a whole. While some land managers may monitor forage quality via faecal near-infrared spectroscopic analysis (fNIRS; Dixon and Coates, 2009), samples still need to be collected and dispatched for analysis, which involves time and cost.

An obvious potential solution is to use satellite-derived information, such as the Normalised Difference Vegetation Index (NDVI; Tucker, 1979) or the Enhanced Vegetation Index (EVI; Huete et al., 2002) as a proxy for forage quality (Pettorelli et al., 2011). Both NDVI and EVI have been used to study the foraging behaviour of wild ungulates, including buffalo in the savannas of Africa (Ryan et al., 2012) and Australia (Campbell et al., 2021), chamois in Europe (Villamuelas et al., 2016) and bighorn sheep and bison in the USA (Creech et al., 2016; Geremia et al., 2019). There are fewer published applications that focus on domestic ungulates like cattle and sheep. Notable studies in this space are Phillips et al. (2009), Zengeya et al. (2013), and Panda et al. (2020), who each calibrated a variable related to forage quality—respectively, a C:N ratio, N concentration, and extractable condensed tannin—with a remote sensing-derived vegetation index, and extrapolated the results across their study areas. While insightful, these three studies were each limited to, at most, a single growing season, hence the inter-annual variability of forage quality was not considered. In Queensland's rangelands, Barnetson et al. (2020) found that forage quality for grazing animals was correlated with the red and red-edge regions of the electromagnetic spectrum.

The vast archive of freely available Landsat imagery (landsat.gsfc.nasa.gov) provides a means to investigate—in greater depth than has yet been attempted—the relations with forage quality. In this study we combine Landsat imagery with 23 years of forage quality data from a long-term grazing trial. In contrast to some previous studies, we determine forage quality by fNIRS, sampled from free-ranging cattle. Faecal sampling provides an integrated estimate of the diet selected over the preceding few days, which is more representative of forage quality than either oesophageal fistula or hand-cut forage samples (Coates and Dixon, 2007). Due to the ability of cattle to distinguish green and dead forage (Hendricksen et al., 1982), we contend that NDVI or EVI are sub-optimal variables to link with forage quality. Instead, the pixel-wise spectra of satellite imagery should be calibrated to biophysically meaningful components of green cover, dead cover, and bare soil (Scarth et al., 2010; Terrestrial Ecosystem Research Network, 2017).

It would represent a novel advance for grazing management—beyond northern Australia's savannas—to be able to forecast forage quality as related to the temporal dynamics of remotely sensed cover components. A practical difficulty in this pursuit is that forage quality will rarely be measured on the same day as a satellite overpass. This can be an important consideration, due to the variation in forage quality even over short time scales. A further difficulty is creating a framework that yields not only realistic forecasts of forage quality, but also realistic forecasting uncertainty. We propose that these difficulties can be overcome with an appropriately parameterised linear mixed model (Marchant et al., 2009).

The aim of this study was to combine field observations of forage quality with remotely sensed cover components, to develop a linear mixed model that can forecast forage quality for cattle in the dry savannas of northeast Australia. Forecasts were to be made three months ahead of a key decision date, over a 12-year period. We set the date of interest as May 31, a time when the wet season is typically transitioning to the dry, and forage quality can change rapidly. Accurate forecasts, associated with realistic uncertainty, will potentially benefit land managers in northeast Australia, allowing them act in a timely manner.

2. Methods

2.1. Study site

Our study focussed on the long-term cattle-grazing trial at Wambiana station (20°32'24″ S, 146°08′2″ E), in the dry savannas, approximately 50 km south-west of Charters Towers, Queensland, Australia (Fig. 1). Median annual rainfall for Trafalgar Station (17 km from the grazing trial) is 605 mm but 87% of this is typically received between November and March (Bureau of Meteorology, 2021). The site contains three main soil-vegetation communities (with soil nomenclature from International Union of Soil Sciences, Working Group WRB, 2015): *Eucalyptus melanophloia* on Ferralsol soil; an *Acacia harpophylla–Eucalyptus brownii* community on a complex of Ferralsol and Vertisol soil; and *E. brownii* on Solonetz soil. The herbaceous layer consists of a range of native C_4 tropical perennial grasses such as *Aristida* spp., *Bothriochloa ewartiana, Chrysopogon fallax, Dichanthium sericeum,* and various *Digitaria* and *Panicum* species (O'Reagain et al., 2009) as well as various annual species and forbs. The exotic grass *Bothriochloa pertusa* has emerged as a substantial component of pasture since 2007, and the native shrub *Carissa ovata* is particularly associated with the *E. brownii* community.

The trial was conceived to test the ability of different stocking strategies to cope with rainfall variability (O'Reagain et al., 2009). Its longevity—and the volume of data collected—make the trial unique to northern Australia. In 1997 ten contiguous paddocks, all approximately 100 ha, were randomly allocated to one of five grazing treatments (two replicates per treatment; Fig. 1). All paddocks contain similar proportions of the three main soil-vegetation communities. We focussed on the two treatments that have the greatest contrast: (i) moderate stocking rate (MSR), stocked at an average of 9.0 ha per animal equivalent (AE; defined as a 450-kg steer) located in paddocks *A* and *B*; and (ii) heavy stocking rate (HSR), stocked at an average of 6.5 ha per AE in paddocks *C* and *D*. Paddocks are grazed year-round with free-ranging Brahman steers. Following industry practice, animals are supplemented with urea in the dry season and phosphorous in the wet season. In severe droughts, cattle are supplemented with molasses and urea, or removed altogether (O'Reagain et al., 2009).

2.2. Forage quality

We quantified forage quality through two variables: dietary crude protein (DCP) and *in vivo* dry-matter digestibility (DMD). These were estimated by fNIRS, collected from cattle in Paddocks *A*–*D*, approximately every three weeks between June 1998 and November 2019. For operational reasons, the collection of faecal samples temporarily ceased during October to December 1999, and from June 2011 to January 2012.

Samples were composites, collected from fresh dung pats from at least five animals in each paddock. Faecal samples were air-dried at 60 °C for 48 h, sealed, then stored. Prior to analysis, samples were ground (1-mm screen, Model 1093 Cyclotec mill; Foss Tecator AB, Hoganas, Sweden), redried (65 °C), cooled in a desiccator, then scanned (400–2500-nm range) using a monochromator fitted with a spinning cup module (Foss 6500; NIRSystems, Silver Spring, MD, USA), as described by Coates and Dixon (2011). DCP and DMD were estimated from faecal spectra, using established calibration equations appropriate for the tropical pastures of northern Australia (Dixon and Coates, 2009; Coates and Dixon, 2011).

Faecal samples collected during periods of drought-feeding were

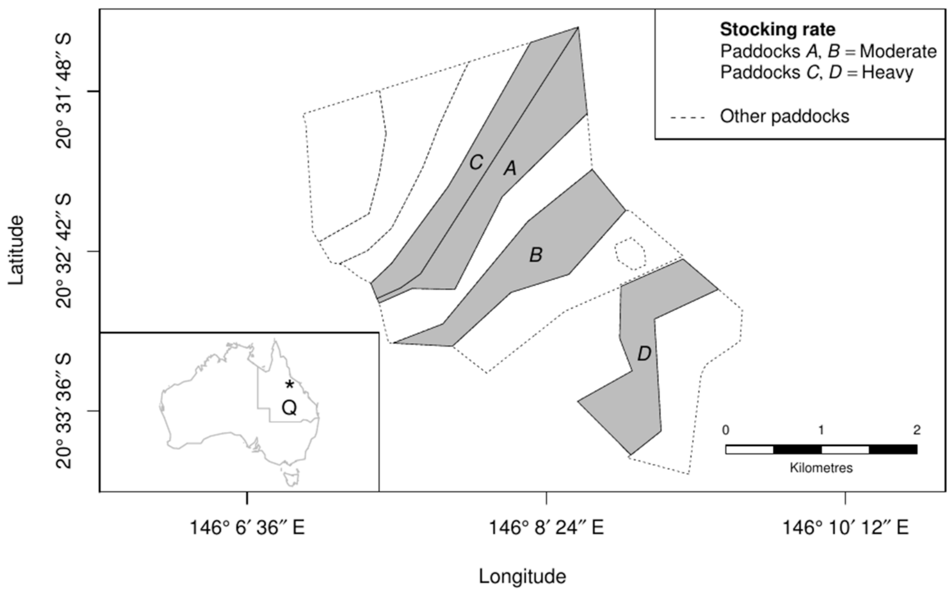

Fig. 1. Layout of the Wambiana grazing trial. Of the ten paddocks available, we consider only Paddocks *A–D* for analysis, which have been under heavy or moderate stocking rates since 1997. Inset: the asterisk shows the location of the trial site relative to the state of Queensland (denoted 'Q'), within Australia.

excluded from the analysis, leaving a total of 1271 faecal samples from the four paddocks. To account for transit through the cattle, we subtracted three days from each sampling date.

2.3. Satellite imagery

Satellite imagery that intersected the study site was collated for the period 1st January 1997 to 29th February 2020, from Landsat-5 TM (Thematic Mapper; images acquired 1997–2011), Landsat-7 ETM+ (Enhanced Thematic Plus; 1999–2020), and Landsat-8 OLI (Operational Land Imager; 2013–2020). Imagery was pre-processed to surface reflectance (Flood et al., 2013). We applied a spectral-unmixing algorithm (Scarth et al., 2010) to every Landsat image, to split pixel-wise surface reflectance into cover proportions of 'bare soil', 'green vegetation', and 'dead (i.e. non-photosynthetic) vegetation'. An in-house algorithm then minimised the influence of tree foliage (thus converting 'green vegetation' to 'green grass'), and simultaneously further split 'dead vegetation' into edible 'dead grass' and inedible 'litter' (see Supplementary Material). Masks were applied to filter undesirable effects from the imagery, e.g. cloud contamination (Zhu et al., 2015), or open water (Fisher et al., 2016). If, following this step, >50% of a paddock's pixels were observed on a particular date—and the paddock was not detected as burnt in the preceding 90 days (Goodwin and Collett, 2014)—then the ratio of paddock-average 'green grass' to 'dead grass' was calculated for further analysis. We herein refer to this variable as GDR.

2.4. A statistical model that forecasts forage quality

We simultaneously modelled DCP, DMD, and GDR, justifiable on the basis that, through their correlation, knowledge of one could help to forecast the other. All three variables are observed irregularly in time. GDR is observed more often than DCP and DMD, but not necessarily on the same day. For simplicity, we first describe the modelling setup as if there were only one response variable—represented generically as z—and then describe extension to the multivariate case.

2.4.1. Basic setup—univariate case

A linear mixed model (LMM) was used to describe the variation of z through time. A LMM splits z into components associated with 'fixed' and 'random' effects: fixed effects describe deterministic responses to given input variables and associated parameters (for instance, a treatment effect that we would like to learn about), while random effects describe probabilistic responses (for instance, a paddock effect that we would like to control for, but are not specifically interested in). The central assumption of the LMM is that the random effects are normally distributed. To this end, we transformed z to natural logarithms prior to fitting. Working backwards from a date of interest, only the 100 most-recent observations of z in each paddock were considered for modelling, and concatenated into a column vector of length $n = 400$:

$$\mathbf{z} = \left[z_{A,1}, \cdots, z_{A,100}, z_{B,1}, \cdots, z_{B,100}, z_{C,1}, \cdots, z_{C,100}, z_{D,1}, \cdots, z_{D,100}\right] \quad (1)$$

where: subscript letters are paddock identifiers, and subscript numbers index the timing of observations, from the newest ('1'), to oldest ('100'). Note that, due to irregular sampling, time '1' of one paddock does not necessarily equal time '1' of another paddock.

The form of the LMM was:

$$\mathbf{z} = \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\varepsilon}_{\mathrm{t}} + \boldsymbol{\varepsilon}_{\mathrm{p}} + \boldsymbol{\varepsilon}_{\mathrm{tp}} \quad (2)$$

where: $\mathbf{X}$ was a $n \times q$ design matrix that contained the fixed effects, i.e. values of the q variables with which $\mathbf{z}$ varied linearly; $\boldsymbol{\beta}$ was a length-q vector that contained the parameters that described the relation between $\mathbf{X}$ and $\mathbf{z}$; $\boldsymbol{\varepsilon}_{\mathrm{t}}$ was a length-n vector of random effects that described the time-specific variation of $\mathbf{z}$ (common for all paddocks); $\boldsymbol{\varepsilon}_{\mathrm{p}}$ was a length-n vector of random effects that described the paddock-specific variation of $\mathbf{z}$ (common for all time); and, $\boldsymbol{\varepsilon}_{\mathrm{tp}}$ was a length-n vector of random effects that described a time-by-paddock effect on the variation of $\mathbf{z}$. We defined the fixed effects of Eq. (2) in three different ways.

Model 1. Experimental treatments MSR and HSR only, i.e. the dimension of $\mathbf{X}$ was $n \times 2$. The first column of $\mathbf{X}$ was filled wholly with ones; the second column was filled with ones only where the treatment was HSR.

Model 2. Experimental treatments MSR and HSR, and the linear function $\ln(r+1)$, where r was the sum of rain received in the 28 days before a date of interest, averaged from five pluviometers spread across the grazing trial. The dimension of $\mathbf{X}$ was $n \times 3$, i.e. columns 1–2 were as above, and column 3 contained the rain information.

Model 3. Experimental treatments MSR and HSR, plus a cyclic cubic regression spline (Wood, 2017) that was a function of day-of-year, defined with four knots and a period of 365.25 days. The

Box 1
. Procedure to split the dataset for modelling.

Specify the set of years: $Y = \{2008, \cdots, 2019\}$
Choose $y \in Y$

Training

- Make $\mathbf{z}$ from the 100 most-recent observations of ln(DCP), ln(DMD) and ln(GDR) in each paddock, available to 31 May of y
- Fit a linear mixed model

Forecasting

- Use the linear mixed model to simulate 10,000 forecasts of ln(DCP) and ln(DMD), daily between 1 June and 31 August of y
- Back-transform to DCP and DMD
- Average the simulated daily forecasts by month

dimension of $\mathbf{X}$ was $n \times 4$, i.e. columns 1–2 were as above, and columns 3–4 contained the spline.

We denote as $\boldsymbol{\theta}$ the vector of parameters that describe the random effects in Eq. (2). The time-specific random effects were distributed as $\boldsymbol{\varepsilon}_t \sim \mathscr{N}(0, \mathbf{C}_t)$, where the $n \times n$ covariance matrix $\mathbf{C}_t = \mathbf{R}_t \boldsymbol{\eta}_t \mathbf{R}_t$. Matrix $\boldsymbol{\eta}_t$ is itself the sum of two structures:

$$\boldsymbol{\eta}_t = c_1 f(\mathbf{d}_t) + c_2 g(\mathbf{d}_t, \varphi_t) \quad (3)$$

where: c_1 and c_2 were variance parameters; f was the nugget autocorrelation function; and g was the spherical autocorrelation function (range parameter of φ_t), applied to $\mathbf{d}_t$, the $n \times n$ matrix of absolute time-differences between observations. Following Marchant et al. (2009), $\mathbf{R}_t$ was a $n \times n$ diagonal matrix, with a value of 1.0 when the month of observation was February to October (inclusive), and parameter r_t (where $r_t > 1.0$) elsewhere. This term addressed the non-stationary temporal variance found during exploratory analysis (not shown); in other words, $\mathbf{R}_t$ adjusts variance upward during those months associated with the onset of the wet season.

The paddock-specific random effects were distributed as $\boldsymbol{\varepsilon}_p \sim \mathscr{N}(0, \mathbf{C}_p)$, where $\mathbf{C}_p$ was a $n \times n$ covariance matrix. The element of $\mathbf{C}_p$ at row i and column j was coded as zero, except when the pair of observations was from the same paddock, in which case the element was coded as parameter c_3.

The time-by-paddock random effects were distributed as $\boldsymbol{\varepsilon}_{tp} \sim \mathscr{N}(0, \mathbf{C}_{tp})$, where the $n \times n$ covariance matrix $\mathbf{C}_{tp} = \mathbf{R}_{tp} \boldsymbol{\eta}_{tp} \mathbf{R}_{tp}$. The element of $\boldsymbol{\eta}_{tp}$ at row i and column j was coded as zero, except when the pair of observations was from the same paddock, in which case the element was coded as $c_4 f(d_{i,j}) + c_5 g(d_{i,j}, \varphi_{tp})$, where c_4 and c_5 were variance parameters, $d_{i,j}$ was the absolute time difference between the pair, and φ_{tp} was the range parameter of the spherical autocorrelation function. Matrix $\mathbf{R}_{tp}$ was defined analogously to $\mathbf{R}_t$, where parameter $r_{tp} > 1.0$, depending on the month of observation. Note the constraints that $\mathbf{C}_{tp}$ and:

$$\mathbf{V} = \mathbf{C}_t + \mathbf{C}_p + \mathbf{C}_{tp} \quad (4)$$

must be positive definite, while $\mathbf{C}_t$ and $\mathbf{C}_p$ must be only positive semi-definite.

We optimised $\boldsymbol{\theta} = [c_1, c_2, \cdots, r_t, r_{tp}]^T$ by using the Nelder-Mead simplex (Nelder and Mead, 1965) to maximise the residual log-likelihood function (Patterson and Thompson, 1971), with the aid of scripts custom-written for the R statistical software (R Core Team, 2020). Appropriate values for φ_t and φ_{tp} were pre-determined for each model prior to analysis, based on a grid search, and held constant throughout. The parameters $\boldsymbol{\beta}$ were available analytically for any given combination of values in $\boldsymbol{\theta}$, through generalised least-squares.

The ultimate aim of the modelling was to forecast DCP and DMD. We cycled through the dataset according to the procedure described in Box 1, optimising $\boldsymbol{\theta}$ once per year, based on $\mathbf{z}$ formed at the end of May, i.e. approximately when land managers in the dry savannas decide what to do with their herd in the coming dry season. Forecasts were made three months ahead, on the basis that they would cover the period when a management decision is essential; little further change in the grazing system is expected between September and the start of the next wet season.

For a year of interest, y, we define the forecasting target $\mathbf{t}_p$ as a length- n_p column vector of days in a forecasting month, e.g. for June $\mathbf{t}_p = [t_1, \cdots, t_{30}]^T$, for an unsampled paddock. We take $\boldsymbol{\theta}$ from y and calculate the empirical best linear unbiased predictor (EBLUP) for $\mathbf{z}$ at $\mathbf{t}_p$, and its associated covariance matrix, $\mathbf{G}_p$ (Marchant et al., 2009):

$$\widehat{\mathbf{z}}(\mathbf{t}_p) = (\mathbf{X}_p - \mathbf{V}_{po}\mathbf{V}^{-1}\mathbf{X})\widehat{\boldsymbol{\beta}} + \mathbf{V}_{po}\mathbf{V}^{-1}\mathbf{z} \quad (5)$$

$$\mathbf{G}_p = (\mathbf{X}_p - \mathbf{V}_{po}\mathbf{V}^{-1}\mathbf{X})\mathbf{P}^{-1}(\mathbf{X}_0 - \mathbf{V}_{po}\mathbf{V}^{-1}\mathbf{X})^T + \mathbf{V}_{pp} - \mathbf{V}_{po}\mathbf{V}^{-1}\mathbf{V}_{po}^T \quad (6)$$

where: $\widehat{\boldsymbol{\beta}}$ is the vector of estimated fixed effects; $\mathbf{X}$ is the design matrix for the fixed effects at the observation days; $\mathbf{V}$ is from Eq. (4); $\mathbf{X}_p$ is the design matrix for the fixed effects at $\mathbf{t}_p$; $\mathbf{V}_{po}$ is the $n_p \times n$ matrix of covariances between the forecasting target and the data, defined analogously to $\mathbf{V}$; $\mathbf{P} = \mathbf{X}^T\mathbf{V}^{-1}\mathbf{X}$; and, $\mathbf{V}_{pp}$ is the $n_p \times n_p$ matrix of total covariance for the prediction target (i.e. between the forecasting days in the unsampled paddock), defined analogously to $\mathbf{V}$. When forecasting, we ensured conservative values by defining $\mathbf{V}_{po}$ using only the contributions from time-specific covariance (Eq. (3)); the paddock-specific and time-by-paddock covariance terms were set to zero. An advantage of using random effects to model differences between paddocks is that we can learn a more general model about what might happen in other paddocks. Our forecasting setup represents naivety about localised paddock effects, which would be the case if the model were applied outside Wambiana (although such a case would require stringent validation).

While $\widehat{\mathbf{z}}(\mathbf{t}_p)$ and $\mathbf{G}_p$ convey all necessary information about a forecast for $\mathbf{z}$, they do so at the temporal resolution of a single day. To forecast the monthly mean, we used $\widehat{\mathbf{z}}(\mathbf{t}_p)$ and $\mathbf{G}_p$ to simulate 10,000 realisations of correlated multivariate normal deviates. We back-transformed the deviates, then averaged them to create the length-10000 vector $\mathbf{S}$. The forecast value for the month was the mean of $\mathbf{S}$, and the 95% prediction interval given by its 2.5th and 97.5th percentiles (Fig. 2).

2.4.2. Extended setup—multivariate case

We follow Marchant and Lark (2007) and Marchant et al. (2009) in extending a LMM to include DCP, DMD, and GDR as response variables.

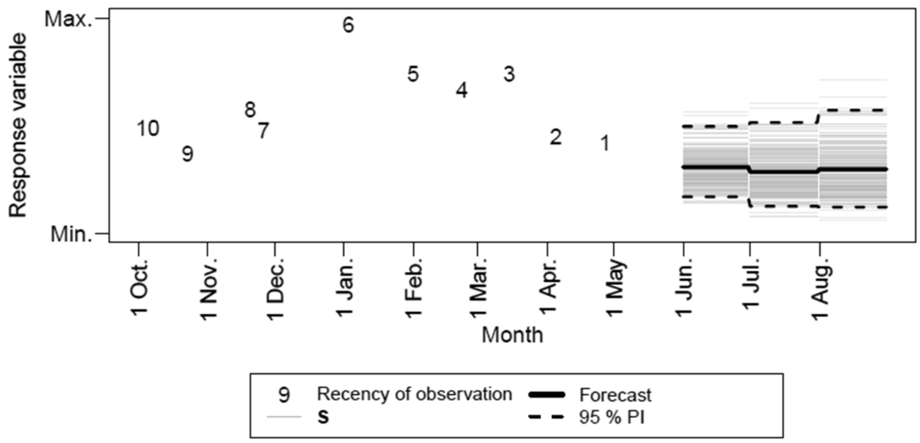

Fig. 2. Forecasting the monthly mean of a response variable, three months ahead from the end of May in a given year. A model is fitted to the 100 most-recent observations of the response variable (only the 10 most recent are shown; note the irregular sampling times). Grey lines are values that comprise the vector **S** (i.e. 10,000 monthly forecasts simulated from the model). The mean value for the forecast and its 95% prediction interval (PI) are obtained from **S**.

In this multivariate case, **z** becomes a concatentation of the response variables, and the dimensions of the remaining terms of Eqs. (2–6) are similarly altered. The most complex aspect of extension concerns the random-effect parameters. These are more numerous in a multivariate case, because it is necessary to account for cross-covariance between each pair of response variables. As in the univariate case, the random-effect parameters must satisfy the condition that $\mathbf{C}_{tp}$ and $\mathbf{V}$ are positive definite, with $\mathbf{C}_t$ and $\mathbf{C}_p$ positive semidefinite. These constraints are pragmatically satisfied by assuming the random effects conform to a linear model of coregionalisation (Marchant and Lark, 2007). In total, the multivariate model has 38 parameters but, for further pragmatism, we only fitted the 15 cross-covariance parameters under the multivariate model; fitted values for auto-covariance parameters and r_t and r_{tp} were inserted from the corresponding univariate models, and held constant.

2.5. Model performance

The splitting procedure in Box 1 created a set of withheld data (i.e. the observations from June to August each year from 2008 to 2019), against which model forecasts could be compared. We assessed the forecasting performance of Models 1–3 for each response variable with: (i) the median absolute error (MAE), where observations in the withheld subset were averaged by month for each paddock, to enable a meaningful comparison; and, (ii) the mean squared deviation ratio (MSDR; Webster and Oliver, 2001):

$$\mathrm{MSDR} = \frac{1}{n_{0,j}} \sum_{i=1}^{n_{0,j}} \left(\frac{\{z_{i,j} - \hat{z}_{i,j}\}^2}{\hat{\sigma}^2_{i,j}} \right) \quad (7)$$

where: $n_{0,j}$ was the number of withheld observations associated with the j^{th} response variable; $z_{i,j}$ was the i^{th} withheld log-transformed observation; $\hat{z}_{i,j}$ was the corresponding log-transformed forecast; and, $\hat{\sigma}^2_{i,j}$ was the corresponding prediction variance, from Eq. (6). For MAE, the smaller the value, the better the model. The log-normal nature of the response variables meant that a conventional measure of model performance, e.g., root-mean-square-error might be impacted by a small number of large prediction errors. MAE is less dominated by these errors and is preferred here. MSDR is used to assess the goodness-of-fit of the model parameters: the target value of 1.0 indicates that the prediction uncertainty is realistic, and that, by extension, the optimised random-effect parameters are appropriate for the data.

3. Results

3.1. Exploratory analysis

The observations of DCP, DMD, and the four cover proportions show prominent seasonality (Fig. 3). Peaks in the time-series of DCP and DMD and green grass tended to have a shorter duration than troughs, reflecting the relatively long dry season that is typical of dry savannas. Note that the density of the cover observations decreased in periods when there was only one Landsat satellite available, i.e. prior to 2003, and 2010–2012.

The three log-transformed response variables were positively correlated, as expected (Table 1), i.e. as the observations of one variable increased, the others tended to increase too, and *vice versa*. In regard to the potential utility of remote sensing, GDR had a stronger correlation with forage quality than NDVI. The distributions of the log-transformed response variables were approximately normal (not shown).

3.2. Model diagnostics

Over the 12 years of analysis, the mean length of time covered by the 100 most-recent observations was 7.4 years for DCP and DMD, and 4.5 years for GDR. These lengths reflect the approximately three-weekly sampling interval of DCP and DMD at Wambiana, and the (at best) 8-day sampling interval for GDR.

For all years, treatments and paddocks, we judged Model 3 to give the most reliable forecasts of the response variables (Table 2). Compared with Models 1 and 2, Model 3 is associated with the smallest values of MAE. Given the data-range of each forage-quality variable (DCP = 2.1–16.1%, DMD = 45.0–70.4%; Fig. 3), DMD was forecast with better relative accuracy than DCP. For MSDR, Model 1 consistently overestimated the forecasting uncertainty of the response variables. And while Model 2 gave realistic forecasting uncertainties for DCP and DMD, GDR was poorly represented. Model 3 underestimated the forecasting uncertainties for DCP and GDR to about the same extent that it overestimated that for DMD. The MSDR values for Model 3 are further from 1.0 than desired, and suggest that some parameters were not completely optimised. This is not surprising given: (i) the pragmatic way that we fitted the 38 parameters of the model, joining univariate optimisations with multivariate; and, (ii) applying MSDR in a forecasting framework is a relatively harsh test, because the model is extrapolating, not interpolating.

We investigated Model 3 further. Optimum values of the range parameters, found by a preliminary grid search then held constant over all years, were $\varphi_t = \varphi_{tp} = 182.6$ days. Over all years, the average amount of

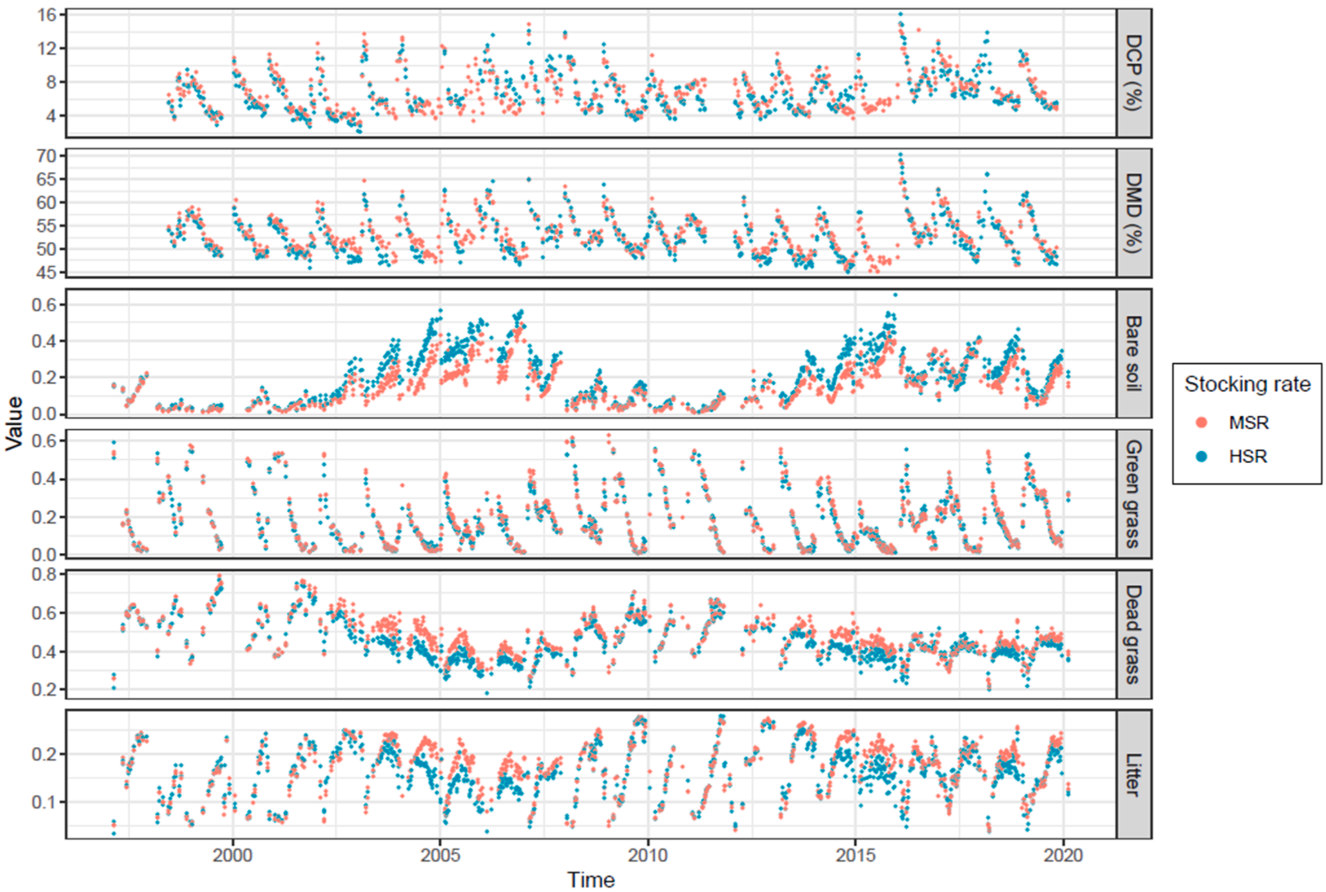

Fig. 3. Observations of relevant variables through time, coloured by stocking rate (MSR = moderate; HSR = heavy).

Table 1
Pearson correlation coefficients of the log-transformed response variables. Log-transformed NDVI is included for comparative purposes. Results have been pooled over paddocks and years.

	ln(DMD)	ln(GDR)	ln(NDVI)
ln(DCP)	0.79	0.65	0.54
ln(DMD)		0.63	0.56
ln(GDR)			0.82

Table 2
MAE (median absolute error) and MSDR (mean squared deviation ratio) when forecasting up to three months ahead from the end of May. Results have been pooled over paddocks, forecasting months, and years. Note that MSDR applies to values of the log-transformed response variable.

	MAE			MSDR		
Response variable	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
DCP (%)	1.17	1.49	0.86	0.83	0.96	1.28
DMD (%)	1.83	2.07	0.95	0.69	0.94	0.71
GDR	0.21	0.25	0.07	0.46	0.45	1.31

variance explained by the fixed effects, $\mathbf{X}\widehat{\boldsymbol{\beta}}$, was 40% for ln(DCP), 56% for ln(DMD), and 49% for ln(GDR). In comparison with Model 1—where the corresponding values were all $\leq$ 1%—the cyclic cubic splines were a key inclusion, enabling Model 3 to capture a substantial amount of the response variables' seasonality, which in turn yielded more sensible values in $\boldsymbol{\theta}$, especially in regard to GDR. When forecasting three months ahead from the end of May, the model reproduced some of the observed correlation of DCP with DMD (Fig. 4), but non-linearity meant that the five largest values of DCP were not well predicted. Three of these five values were from the winter of 2016, which was atypical for two reasons. First, a large outlying observation of DCP collected in early July was associated with a sample that contained an unusually large proportion of non-grass, suggesting that the cattle had found a localised patch of legumes or forbs. Second, there was a 90-mm downpour on 18 July that followed a run of relatively dry summers. This out-of-season rain provided a burst of new plant growth and DCP for the cattle, as grasses were suddenly able to access the mineral N that had been accumulating in the soil.

The inclusion of experimental treatments MSR and HSR in the fixed effects of Model 3 enables a test of the null hypothesis that forage quality is unaffected by stocking rate (Table 3). Over all years, DMD was more sensitive to stocking rate than DCP, with DMD tending to be significantly lower under heavy stocking rates. The strength of the stocking-rate effect from year to year was associated with summer rainfall, being greater in the run of relatively dry years from 2013 onward. This implies that utilisation rate (i.e. the ratio of pasture eaten to pasture grown) is important for determining forage quality.

It is illuminating to see the forecasts of Model 3 compared with corresponding observations as a function of time (Fig. 5). According to the procedure in Box 1, each year is associated with a different set of fitted parameters, and data collected after May 31 are withheld. The monthly forecasts are reasonably accurate in most years, with all three response variables generally declining, as expected, as each winter progressed. Prediction uncertainty increased with each passing month, which was also an expected result. The summer of 2014–2015 was especially dry (Table 3), so forage quality in the post-growth period was particularly poor. As noted above, the winter of 2016 was atypical, so the forecasts and observations diverged strongly.

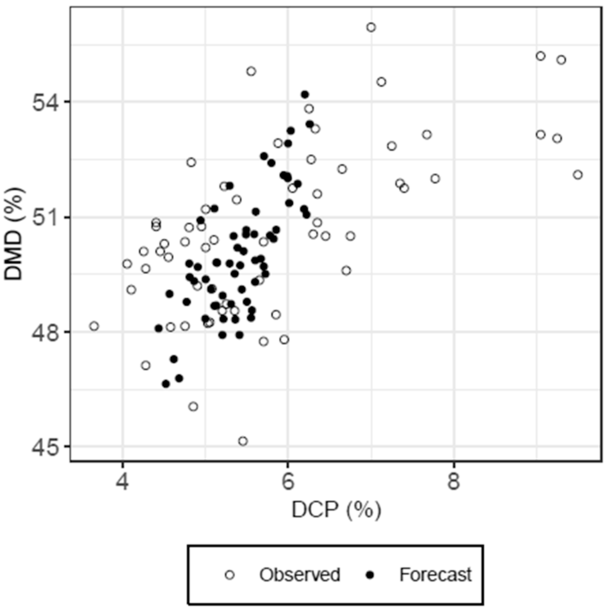

Fig. 4. Monthly-averaged observations and forecasts of Model 3 for DCP and DMD for June–August, pooled over years and paddocks.

4. Discussion

4.1. Implications for cattle management

To the best of our knowledge, our study is the first to successfully link forage quality for cattle with remotely sensed groundcover information, over a > 20-year period. Previous research at the Wambiana grazing trial has linked forage *quantity*, in the form of total standing dry matter, with remotely sensed information (Schmidt et al., 2016), but did not examine forage quality. The results of our study suggest that, in a southern hemisphere dry savanna that is dominated by C_4 grassland, it is possible to forecast monthly-average forage quality ahead from the end of the summer wet season (approximately May) into the first three months of the winter dry season, albeit with increasing uncertainty. The end of the wet season is a critical time of year, when early management intervention can prevent future losses in animal production.

A number of previous studies have related forage quality to remotely sensed information: some from faecal sampling (Ryan et al., 2012; Villamuelas et al., 2016; Tolleson et al., 2020); some with forage quality determined from less-desirable hand-clipped samples (Phillips et al., 2009; Zengeya et al., 2013; Ferner et al., 2015; Barnetson et al., 2020). Of these studies, the period of forage-quality sampling was, at most, five years. While Geremia et al. (2019) tracked pasture green-up with satellite data over 16 years, actual forage quality was only measured in a single five-month period. Possibly the longest study is that of Creech et al. (2016), who tracked diet quality estimated from faecal N in desert bighorn sheep over an 11-year period. In comparison, our study is based on 23 years of forage-quality data, collected from cattle faeces at approximately 3-week intervals. In regard to remote sensing, our analysis was driven by the variable GDR, defined as the cover ratio of 'green grass' to 'dead grass'. GDR had a stronger correlation with forage quality than the conventional NDVI (Table 1), and makes biological sense given that cattle select for green, rather than dead, forage (Hendricksen et al., 1982). Furthermore, by correcting for leaf-litter (see Supplementary Material), we hope that our Landsat-based GDR values can be robustly extrapolated to different landscapes. A disadvantage of Landsat is that it does not sense in the red-edge of the electromagnetic spectrum, which has been shown to correlate with forage quality (Barnetson et al., 2020). This suggests a future role for Sentinel-2 satellites, which, in contrast to Landsat, sense with four red-edge bands (sentinels.copernicus.eu/web/sentinel/missions/sentinel-2).

We have shown that forage quality, particularly DMD, tended to be significantly lower under heavy stocking (Table 3), although this was dependent on rainfall. The HSR treatment has become associated with a scarcity of palatable perennial species, due to overgrazing. The lower quality diet of cattle in the HSR treatment leads to reduced liveweight gain (O'Reagain et al., 2018). However, in years with well-distributed rainfall, the constant supply of short-lived, green regrowth in the HSR treatment allows cattle to select a diet that is, at least in terms of DCP, of relative high quality.

There is a demand for decision-support tools that assist land managers in the extensive grazing enterprises of northeast Australia to make more frequent, better-informed decisions (McCartney, 2017; Paxton, 2019). Following appropriate testing at other sites, we ultimately anticipate packaging forecasts of forage quality as a simple graphical product (Fig. 6). In May of a year of interest, the product would be available on request for a particular paddock, delineated by the user. The optimised parameters of Model 3 would then be combined with the 100 most-recent local observations of GDR and user-provided DCP or DMD. Predictions for May (the 'nowcast') and forecasts for June to August would be returned. Included in this product is the ratio of protein to metabolisable energy:

$$H = (10.0 \times \mathrm{DCP})/(0.17 \times \mathrm{DMD} - 2.0) \quad (8)$$

which has units of g MJ^{-1}. The denominator of Eq. (8) is taken from Standing Committee on Agriculture, Ruminants Subcommittee, 1990, p.9). A separate model is not needed to estimate H ; its distribution is found by simply plugging in the simulated daily predictions for DCP and DMD, then averaging by month, as in Fig. 2. We follow Dixon and Coates (2010) and set 6% as a general threshold for DCP less than the requirement for cattle maintenance, but acknowledge that operationally the value depends on factors such as the class of cattle and the target market. In the example in Fig. 6, it is apparent that the forecast is less-than-desirable.

A graphical product such as Fig. 6 could, when combined with other sources of information such as seasonal forecasts of ground cover (e.g. www.longpaddock.qld.gov.au), prompt a land manager to intervene with supplementation, or to perhaps reduce the number of animals held. Such a system would be an advance on the conventional industry practice, where forage quality is acknowledged to be crucial to cattle production but is difficult to monitor. May is an important period for land managers in northern Australia, but our analysis is not restricted to

Table 3
The estimated fixed-effect parameter, $\hat{\boldsymbol{\beta}}$, in Model 3 that corresponded to the effect of the high stocking-rate treatment (HSR) on ln(DCP) and ln(DMD), relative to moderate stocking rate. Tests of significance were done on the log-transformed scale ($^{+} = P < 0.1$; $* = P < 0.05$; $** = P < 0.01$), but for convenience $\hat{\boldsymbol{\beta}}$ has been back-transformed to represent a multiplicative effect, i.e. a value < 1 indicates HSR proportionately decreased the response variable, and *vice versa*. Summer rain is accumulated between November (of the previous year) and March, based on pluviometers located across the study site.

	$\exp(\hat{\boldsymbol{\beta}})$		
Year	DCP	DMD	Summer rain (mm)
2008	1.039	0.978**	998
2009	1.040	0.982*	665
2010	1.046	0.986^{+}	768
2011	1.028	0.987	666
2012	1.007	0.985^{+}	703
2013	0.958	0.984*	352
2014	0.917**	0.986*	450
2015	0.928**	0.984*	215
2016	0.927**	0.985**	410
2017	0.934**	0.986*	344
2018	0.965	0.985**	509
2019	0.973	0.990^{+}	462

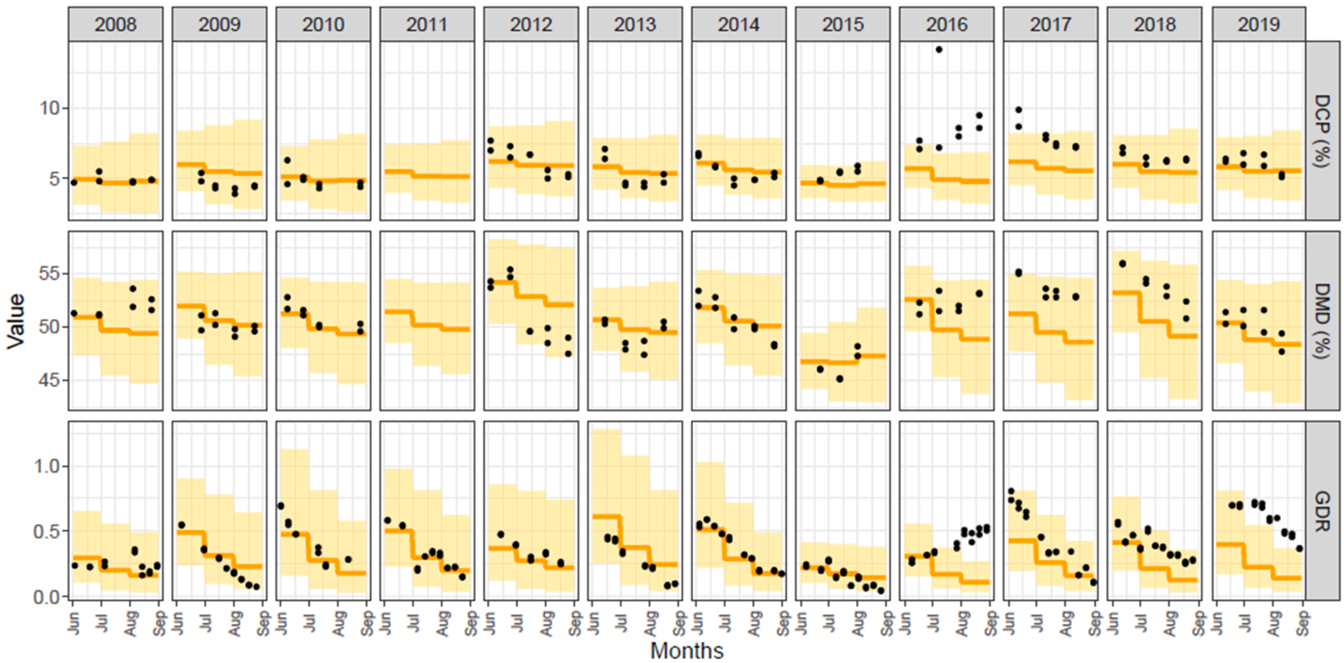

Fig. 5. Monthly forecasts of the response variables for each winter of each year, for the moderate stocking rate (MSR) treatment. The orange line is the predicted mean; the yellow region is the 95% prediction interval. For comparison, observed daily values are also presented. MSR paddocks were destocked for the winter of 2011, so no observations of forage quality were made. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

that month alone; it could conceivably be run each month continuously, over the landscape as new Landsat imagery is acquired. Ultimately, we aim to forecast not just forage quality, but animal liveweight gain. The data to support such an advance are currently too limited.

4.2. Model calibration and behaviour

The cyclic cubic regression spline used as a fixed-effect in Model 3 adequately captured the seasonal behaviour of DCP, DMD, and GDR. When this seasonality was combined with coregionalised random effects, the result was the most reliable of the models investigated, able to forecast with a MAE of 0.86% for DCP and 0.95% for DMD (Table 2). Model 1 was naïve about the recent behaviour of the green signal, so its forecasting accuracy suffered. Despite the inclusion of information about recent rainfall as an explanatory variable, Model 2 performed even worse than Model 1 in terms of MAE, which suggests that recent rainfall at Wambiana is no indicator of future rainfall. The uncertainty of the forecasts, summarised by MSDR in Table 2, was difficult to realistically represent, especially for GDR in Model 1 and Model 2. Note that, to fit the various models, DCP, DMD, and GDR did not have to be temporally coincident, nor did we have to introduce spurious uncertainties into the workflow by *ad hoc* interpolation to common days.

We pragmatically specified that only the 100 most-recent observations of DCP, DMD, and GDR were used for fitting and forecasting the model in each year. The number could be increased, but at an exponential cost to the computing time. The (at best) 8-day sampling interval between overpasses of Landsat satellites meant that 4.5 years were needed, on average, to accumulate the 100 most-recent observations of GDR. If another source of satellite imagery were added into the mix—e.g. Sentinel-2, with its (at best) 5-day temporal resolution—then the 4.5 years would reduce greatly, with the resultant GDR time-series possibly becoming too short to detect seasonal variability. For further pragmatism we also combined the optimised parameter values of both univariate and multivariate runs of the LMM.

Given that fNIRS is not routinely conducted on all cattle properties, the prediction intervals shown in Fig. 5 are probably best-case scenarios. However, consistent Landsat coverage means that all grazing properties in northeast Australia will always have available the 100 most-recent observations of GDR. Thus, if applying our model to a new area, the typical case will be for few observations of DCP and DMD (perhaps even just a single approximate mean for each), and the full quota of GDR observations. This exemplifies the 'undersampling' scenario discussed by Webster and Oliver (2001, p. 206) where multivariate modelling brings benefit over univariate modelling: because correlations are explicitly parameterised, the densely sampled variable will guide the predicted values of a sparsely sampled variable, and do so with greater precision than a univariate method. Model performance in this situation will, however, require rigorous testing.

Four aspects of this study require further exploration. First, we need to incorporate into the model the forage-quality and GDR data from other short-term grazing studies in Australia, e.g. Burrows et al. (2010). Second, to forecast robustly over a very large area, the model will inevitably need to consider climate and soil information as explanatory variables. Tolleson et al. (2020) demonstrated, for example, the utility of growing degree days for predicting forage quality, but we speculate that it may have limited applicability in Australia due to the sparsity of weather stations in rural areas. Third, greater explanatory power at the paddock scale may be achieved by relating forage quality to a weighted function of greenness at the scale of a Landsat pixel. Such an idea might help to streamline the number of random-effect parameters, because the remote sensing information would be used as an explanatory, rather than a response, variable. Finally, we have not yet considered how to deal with local outliers, such as the unusually large DCP datum collected in the winter of 2016 (Fig. 5).

An ultimate limit on forecasting accuracy might well be the error inherent in the fNIRS calibrations relative to wet chemistry, with typical standard errors of cross-validation of 0.9–1.5% for DCP, and 1.1–3.2% for DMD (Dixon and Coates, 2009). As the calibrations improve, so too will our model. Regardless of the form of the model, accurate forecasting of DCP and DMD, guided by GDR, will always be challenging, because it effectively involves calibrating a mass-based quantity from a cover-based quantity, which is a strongly non-linear and complex relation

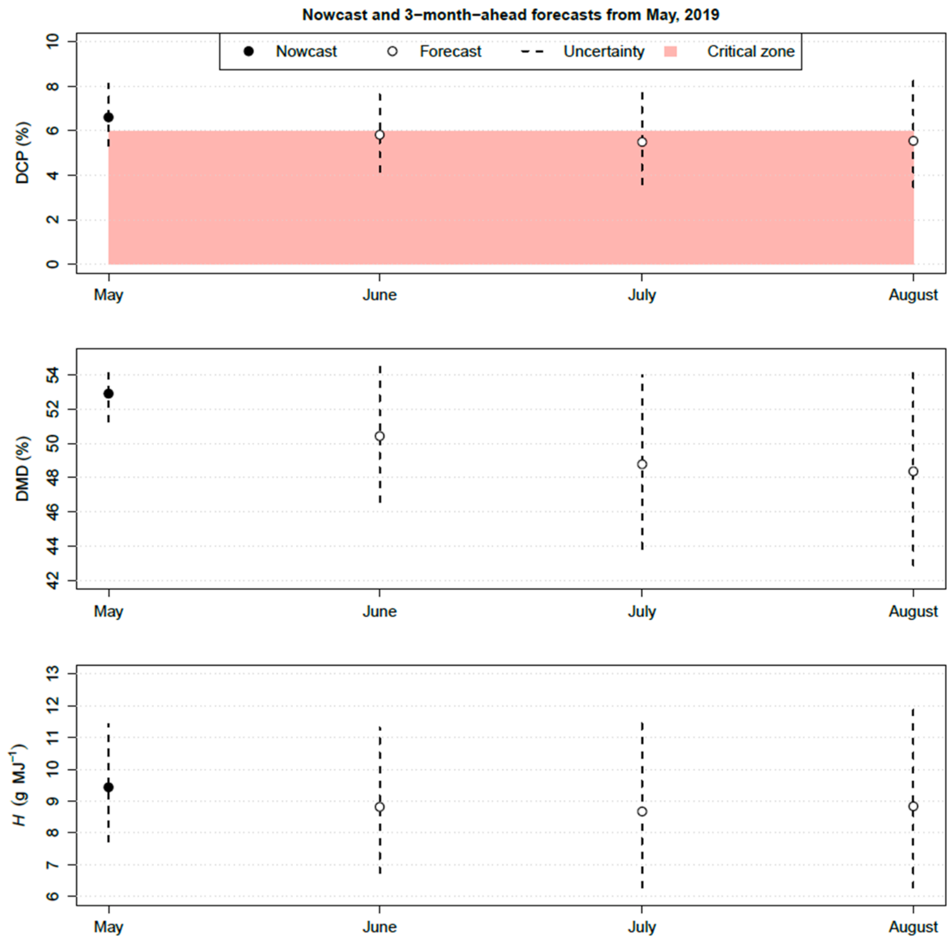

Fig. 6. A prototype summary of results for an individual paddock, representing: the 'nowcast' at the end of May (current status); forecasts for the three following months; and the critical zone (coloured), within which animal nutrition will decline. This example is for the study site at the end May in 2019, assuming that stocking rates are moderate. DCP = digestible crude protein; DMD = *in vivo* dry-matter digestibility; H = ratio of protein to metabolizable energy (Eq. (8)).

(Carter et al., 2015).

4.3. Model assumptions and alternatives

As is necessary for any statistical modelling, we invoked a number of assumptions for this study. The first was that fNIRS indicates what cattle have eaten three days before. Three days reasonably approximates the mean retention time of 65 h reported for cattle (Bartocci et al., 1997), but the same study also found that retention time could be as little as 19 h. Retention time is partly a function forage quality; it may be possible to explicitly incorporate this effect into the modelling, but it would introduce a number of further assumptions, e.g. animal breed, age, and pregnancy.

The assumptions that underly the multivariate LMM are quite stringent. The random effects of the LMM must be normally distributed (which we tried to satisfy with transformation to natural logarithms), and also conform to a coregionalisation (which determines how the random-effect parameters are constrained, to ensure positive definite covariance; Marchant and Lark, 2007). As a result of the coregionalisation, ln(DCP) and ln(DMD) were linearly correlated; upon back-transformation, some non-linearity in the correlation was evident, which agrees with the finding of Lukas et al. (2005). Non-linearity meant that our model could not forecast well the largest values of DCP in winter (Fig. 4). Furthermore, temporal variation was modelled by a spherical autocorrelation function. The φ parameter of the two spherical functions of Model 3 (see Eq. (3)) meant that there was no correlation between observations more than six months apart. A periodic correlation function would be more biologically sensible (Pringle, 2013), but would not enable the use of sparse matrices, whose computational efficiency will help to scale the model-fitting procedure as the dataset inevitably grows. Eventually, the dataset may grow to a point where we need to seek an alternative to a coregionalisation-based model anyway, e.g. the kernel convolution approach (Fanshawe and Diggle, 2012).

Related to assumptions around parameterisation is our use of the Nelder-Mead simplex (Nelder and Mead, 1965) to minimise the residual log-likelihood function. Simulated annealing is an alternative method for the linear model of coregionalisation (Lark and Papritz, 2003), but in our opinion is too slow to converge. Further alternatives may lie in particle swarm optimisation (Freitas et al., 2020), or perhaps a more sophisticated optimisation/interpretation framework such as the PEST ('parameter estimation') software suite (Doherty, 2015).

5. Conclusion

Cattle production in the dry savannas of northern Australia conventionally relies on a combination of experience, intuition, and hope. In this region, the quality of forage is held to be as important as forage quantity. At the end of the summer wet season each year, typically in May, land managers must make a decision about what to do with their stock in the coming winter dry season: sell, move, or supplement. In this study we have proposed a decision-support tool for land managers, where a statistical model is used to forecast forage quality—defined by dietary crude protein and dry-matter digestibility—as monthly-average values for the period June to August. The uncertainty of each forecast value is explicitly acknowledged, which is an honest admission of our model's imperfections, and helps the user ultimately set their own thresholds for action.

To the best of our knowledge, our study is the first to link > 20 years of on-ground measurements of forage quality for cattle with the information derived from satellite imagery. The remote sensing-based information used was the ratio of 'green grass' cover to 'dead (i.e. non-photosynthetic) grass' cover, derived from an archive of Landsat surface-reflectance imagery. Dietary crude protein was forecast with a median absolute error (MAE) of 0.86%; dry-matter digestibility was forecast with MAE = 0.95%. Model forecasts were generally consistent over a 12-year validation period, but broke down if there was atypical winter rain.

Two particularly difficult aspects of the study that we overcame were: (i) how forage-quality measurements were rarely coincident with a satellite overpass; and, (2) how to pragmatically manage computational loads when fitting the model. Future research will involve testing the current model at more locations and investigating alternative explanatory variables for the model.

CRediT authorship contribution statement

M.J. Pringle: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Visualization, Writing – original draft, Writing – review & editing. **P.J. O'Reagain:** Conceptualization, Methodology, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Supervision, Project administration. **G.S. Stone:** Conceptualization, Writing – original draft, Writing – review & editing. **J.O. Carter:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision. **T.G. Orton:** Methodology, Software, Writing – original draft, Writing – review & editing. **J.J. Bushell:** Conceptualization, Investigation, Resources, Data curation, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2021.108426.

References

Barnetson, J., Phinn, S., Scarth, P., 2020. Estimating plant pasture biomass and quality from UAV imaging across Queensland's rangelands. AgriEngineering 2, 523–543. https://doi.org/10.3390/agriengineering2040035.

Bartocci, S., Amici, A., Verna, M., Terramoccia, S., Martillotti, F., 1997. Solid and fluid passage rate in buffalo, cattle and sheep fed diets with different forage to concentrate ratios. Livest. Prod. Sci. 52 (3), 201–208. https://doi.org/10.1016/S0301-6226(97)00132-2.

Burrows, W.H., Orr, D.M., Hendricksen, R.E., Rutherford, M.T., Myles, D.J., Back, P.V., Gowen, R., 2010. Impacts of grazing management options on pasture and animal productivity in a *Heteropogon contortus* (black speargrass) pasture in central Queensland. 4. Anim. Prod. Sci. 50, 284–292. https://doi.org/10.1071/AN09145.

Callaghan, M.J., Tomkins, N.W., Benu, I., Parker, A.J., 2014. How feasible is it to replace urea with nitrates to mitigate greenhouse gas emissions from extensively managed beef cattle? Anim. Prod. Sci. 54, 1300–1304. https://doi.org/10.1071/AN14270.

Campbell, H.A., Loewensteiner, D.A., Murphy, B.P., Pittard, S., McMahon, C.R., 2021. Seasonal movements and site utilisation by Asian water buffalo (*Bubalus bubalis*) in tropical savannas and floodplains of northern Australia. Wildlife Res. 48, 230–239. https://doi.org/10.1071/WR20070.

Terrestrial Ecosystem Research Network, 2017. Fractional cover. URL: www.auscover.org.au/datasets/fractional_cover (accessed 23 November 2021).

Bureau of Meteorology, 2021. Monthly rainfall: Trafalgar Station. URL: http://www.bom.gov.au/jsp/ncc/cdio/wData/wdata?p_nccObsCode=139&p_display_type=dataFile&p_stn_num=034010 (accessed 23 November 2021).

Carter, J., Stone, G., Trevithick, R., O'Reagain, P., Phelps, D., Cowley, R., Pringle, M., Scanlan, J., Hoffman, M., 2015. Estimating Pasture Total Standing Biomass (TSDM) From Landsat Fractional Cover, Final Report—Volume 2, Project ERM.0098 Meat and Livestock Australia Limited 2015 North Sydney, Australia. URL www.mla.com.au/contentassets/17a4e655dc934f02814e17e143ab861f/b.erm.0098_final_report_2_.pdf (accessed 23 November 2021).

Coates, D.B., Dixon, R.M., 2007. Faecal near infrared reflectance spectroscopy (F.NIRS) measurements of non-grass proportions in the diet of cattle grazing tropical rangelands. Rangeland J. 29, 51–63. https://doi.org/10.1071/RJ07011.

Coates, D.B., Dixon, R.M., 2011. Developing robust faecal near infrared spectroscopy calibrations to predict diet dry matter digestibility in cattle consuming tropical forages. J. Near Infrared Spec. 19 (6), 507–519. https://doi.org/10.1255/jnirs.967.

Creech, T.G., Epps, C.W., Monello, R.J., Wehausen, J.D., 2016. Predicting diet quality and genetic diversity of a desert-adapted ungulate with NDVI. J. Arid Environ. 127, 160–170. https://doi.org/10.1016/j.jaridenv.2015.11.011.

Dixon, R., Coates, D., 2009. Near infrared spectroscopy of faeces to evaluate the nutrition and physiology of herbivores. J. Near Infrared Spec. 17, 1–31. https://doi.org/10.1255/jnirs.822.

Dixon, R.M., Coates, D.B., 2010. Diet quality estimated with faecal near infrared reflectance spectroscopy and responses to N supplementation by cattle grazing buffel grass pastures. Anim. Feed Sci. Technol. 158 (3-4), 115–125. https://doi.org/10.1016/j.anifeedsci.2010.04.002.

Doherty, J., 2015. Calibration and Uncertainty Analysis for Complex Environmental Models. Watermark Numerical Computing, Brisbane, Australia.

Fanshawe, T.R., Diggle, P.J., 2012. Bivariate geostatistical modelling: a review and an application to spatial variation in radon concentrations. Environ. Ecol. Stat. 19 (2), 139–160. https://doi.org/10.1007/s10651-011-0179-7.

Ferner, J., Linstädter, A., Südekum, K.-H., Schmidtlein, S., 2015. Spectral indicators of forage quality in West Africa's tropical savannas. Int. J. Appl. Earth Obs. 41, 99–106. https://doi.org/10.1016/j.jag.2015.04.019.

Fisher, A., Flood, N., Danaher, T., 2016. Comparing landsat water index methods for automated water classification in eastern Australia. Remote Sens. Environ. 175, 167–182. https://doi.org/10.1016/j.rse.2015.12.055.

Flood, N., Danaher, T., Gill, T., Gillingham, S., 2013. An operational scheme for deriving standardised surface reflectance from Landsat TM/ETM+ and SPOT HRG imagery for eastern Australia. Remote Sens. 5, 83–109. https://doi.org/10.3390/rs5010083.

Fordyce, G., Anderson, A., McCosker, K., Williams, P.J., Holroyd, R.G., Corbet, N.J., Sullivan, M.S., 2013. Liveweight prediction from hip height, condition score, fetal age and breed in tropical female cattle. Anim. Prod. Sci. 53, 275–282. https://doi.org/10.1071/AN12253.

Freitas, D., Guerreiro Lopes, L., Morgado-Dias, F., 2020. Particle swarm optimisation: a historical review up to the current developments. Entropy 22, 362. https://doi.org/10.3390/e22030362.

Geremia, C., Merkle, J.A., Eacker, D.R., Wallen, R.L., White, P.J., Hebblewhite, M., Kauffman, M.J., 2019. Migrating bison engineer the green wave. Proc. Natl Acad. Sci. U.S.A. 116 (51), 25707–25713. https://doi.org/10.1073/pnas.1913783116.

Goodwin, N.R., Collett, L.J., 2014. Development of an automated method for mapping fire history captured in Landsat TM and ETM+ time series across Queensland, Australia. Remote Sens. Environ. 148, 206–221. https://doi.org/10.1016/j.rse.2014.03.021.

Hendricksen, R., Rickert, K.G., Ash, A.J., McKeon, G.M., 1982. Beef production model. In: Animal Production in Australia: Proceedings of the Australian Society of Animal Production. Pergamon Press (Australia) Pty Ltd, pp. 204–208.

Huete, A., Didan, K., Miura, T., Rodriguez, E.P., Gao, X., Ferreira, L.G., 2002. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. Remote Sens. Environ. 83 (1-2), 195–213. https://doi.org/10.1016/S0034-4257(02)00096-2.

Lark, R.M., Papritz, A., 2003. Fitting a linear model of coregionalization for soil properties using simulating annealing. Geoderma 115, 245–260. https://doi.org/10.1016/S0016-7061(03)00065-X.

Lukas, M., Südekum, K.-H., Rave, G., Friedel, K., Susenbeth, A., 2005. Relationship between fecal crude protein concentration and diet organic matter digestibility in cattle. J. Anim. Sci. 83, 1332–1344. https://doi.org/10.2527/2005.8361332x.

Marchant, B.P., Lark, R.M., 2007. Estimation of linear models of coregionalization by residual maximum likelihood. Eur. J. Soil Sci. 58 (6), 1506–1513. https://doi.org/10.1111/j.1365-2389.2007.00957.x.

Marchant, B.P., Newman, S., Corstanje, R., Reddy, K.R., Osborne, T.Z., Lark, R.M., 2009. Spatial monitoring of a non-stationary soil property: phosphorus in a Florida water conservation area. Eur. J. Soil Sci. 60, 757–769. https://doi.org/10.1111/j.1365-2389.2009.01158.x.

International Union of Soil Sciences, Working Group WRB, 2015. World Reference Base for Soil Resources 2014, update 2015: International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome. URL: www.fao.org/3/i3794en/I3794EN.pdf (accessed 23 November 2021).

McCartney, F., 2017. Factors Limiting Decision Making for Improved Drought Preparedness and Management in Queensland Grazing Enterprises: Rural Specialists' Perspectives and Suggestions. Department of Science, Information Technology and Innovation, Brisbane, Australia. URL: data.longpaddock.qld.gov.au/static/dcap/DCAP1+Social+Science+Final+Report.pdf (accessed 23 November 2021).

McCown, R.L., 1981. The climatic potential for beef cattle production in tropical Australia: Part I—Simulating the annual cycle of liveweight change. Agric. Syst. 6 (4), 303–317. https://doi.org/10.1016/0308-521X(81)90065-2.

McIvor, J.G., 1981. Seasonal changes in the growth, dry matter distribution and herbage quality of three native grasses in northern Queensland. Aust. J. Exp. Agr. Anim. Husb. 21, 600–609. https://doi.org/10.1071/EA9810600.

McKeon, G., Stone, G., Ahrens, D., Carter, J., Cobon, D., Irvine, S., Syktus, J., 2021. Queensland's multi-year Wet and Dry periods: implications for grazing enterprises and land resources. Rangeland J. 43, 121–142. https://doi.org/10.1071/RJ20089.

Nelder, J.A., Mead, R., 1965. A simplex method for function minimization. Comput. J. 7 (4), 308–313. https://doi.org/10.1093/comjnl/7.4.308.

Norman, M.J.T., 1965. Seasonal performance of beef cattle on native pasture at Katherine, N.T. Aust. J. Exp. Agr. 5, 227–231. https://doi.org/10.1071/EA9650227.

O'Reagain, P., Bushell, J., Holloway, C., Reid, A., 2009. Managing for rainfall variability: effect of grazing strategy on cattle production in a dry tropical savanna. Anim. Prod. Sci. 49, 85–99. https://doi.org/10.1071/EA07187.

O'Reagain, P.J., Bushell, J., Pahl, L., Scanlan, J.C., 2018. Wambiana Grazing Trial Phase 3: Stocking Strategies for Improving Carrying Capacity, Land Condition and Biodiversity Outcomes. B.ERM.0107. Meat and Livestock Australia. www.mla.com.au/research-and-development/reports/2018/part-2–-wambiana-grazing-trial-phase-3-stocking-strategies-for-improving-carrying-capacity-land-condition-and-biodiversity-outcomes, North Sydney, Australia. URL.

Panda, S.S., Terrill, T.H., Mahapatra, A.K., Kelly, B., Morgan, E.R., van Wyck, J.A., 2020. Site-specific forage management of Serica Lespedeza: Geospatial technology-based forage quality and yield enhancement model development. Agriculture 10, 419. https://doi.org/10.3390/agriculture10090419.

Patterson, H.D., Thompson, R., 1971. Recovery of inter-block information when block sizes are unequal. Biometrika 58 (3), 545–554. https://doi.org/10.1093/biomet/58.3.545.

Paxton, G., 2019. Towards Greater Drought Preparedness in Queensland Grazing: Lessons from Qualitative Interviews and Discourse Analysis. Department of Environment and Science, Brisbane, Queensland. URL: data.longpaddock.qld.gov.au/static/dcap/DCAP2+DES3+Social+science+report+FINAL.pdf (accessed 23 November 2021).

Pettorelli, N., Ryan, S., Mueller, T., Bunnefeld, N., Jędrzejewska, B., Lima, M., Kausrud, K., 2011. The normalized difference vegetation index (NDVI): unforeseen success in animal ecology. Clim. Res. 46, 15–27. https://doi.org/10.3354/cr00936.

Phillips, R., Beeri, O., Scholljegerdes, E., Bjergaard, D., Hendrickson, J., 2009. Integration of geospatial and cattle nutrition information to estimate paddock grazing capacity in Northern US prairie. Agric. Syst. 100 (1-3), 72–79. https://doi.org/10.1016/j.agsy.2009.01.002.

Poppi, D.P., Minson, D.J., Ternouth, J.H., 1981. Studies of cattle and sheep eating leaf and fractions of grasses. I The voluntary intake, digestibility and retention time in the reticulo-rumen. Aust. J. Agric. Res. 32, 99–108. https://doi.org/10.1071/AR9810099.

Pringle, M.J., 2013. Robust prediction of time-integrated NDVI. Int. J. Remote Sens. 34 (13), 4791–4811. https://doi.org/10.1080/01431161.2013.782117.

R Core Team, 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. r-project.org, Vienna, Austria. URL (accessed 23 November 2021).

Ryan, S.J., Cross, P.C., Winnie, J., Hay, C., Bowers, J., Getz, W.M., 2012. The utility of normalized difference vegetation index for predicting african buffalo forage quality. J. Wildlife Manage. 76 (7), 1499–1508. https://doi.org/10.1002/jwmg.407.

Scarth, P., Röder, A, Schmidt, M., 2010. Tracking grazing pressure and climate interaction—the role of Landsat fractional cover in time series analysis. In: Proceedings of Australasian Remote Sensing and Photogrammetry Conference, Alice Springs, 13–17 September. URL: figshare.com/articles/Tracking_Grazing_Pressure_and_Climate_Interaction_-_The_Role_of_Landsat_Fractional_Cover_in_Time_Series_Analysis/94250/1 (accessed 23 November 2021).

Schmidt, M., Carter, J., Stone, G., O'Reagain, P., 2016. Integration of optical and X-band radar data for pasture biomass estimation in an open savannah woodland. Remote Sens. 8, 989. https://doi.org/10.3390/rs8120989.

Siebert, B.D., Kennedy, P.M., 1972. The utilization of spear grass (*Heteropogon contortus*). I. Factors limiting intake and utilization by cattle and sheep. Aust. J. Agr. Res. 23, 35–44. https://doi.org/10.1071/AR9720045.

Standing Committee on Agriculture, Ruminants Subcommittee, 1990. Feeding Standards for Australian Livestock: Ruminants. CSIRO Publications, Melbourne.

Tolleson, D.R., Angerer, J.P., Kreuter, U.P., Sawyer, J.E., 2020. Growing degree day: noninvasive remotely sensed method to monitor diet crude protein in free-ranging cattle. Rangeland Ecol. Manage. 73 (2), 234–242. https://doi.org/10.1016/j.rama.2019.12.001.

Tucker, C.J., 1979. Red and photographic infrared linear combinations for monitoring vegetation. Remote Sens. Environ. 8 (2), 127–150. https://doi.org/10.1016/0034-4257(79)90013-0.

Villamuelas, M., Fernández, N., Albanell, E., Gálvez-Cerón, A., Bartholomé, J., Mentaberre, G., López-Olvera, J.R., Fernández-Aguilar, X., Colom-Cadena, A., López-Martín, J.M., Pérez-Barbería, J., Garel, M., Marco, I., Serrano, E., 2016. The Enhanced Vegetation Index (EVI) as a proxy for diet quality and composition in a mountain ungulate. Ecol. Indic. 61, 658–666. https://doi.org/10.1016/j.ecolind.2015.10.017.

Webster, R., Oliver, M.A., 2001. Geostatistics for Environmental Scientists. John Wiley & Sons Ltd, Chichester.

Wood, S.N., 2017. Generalized Additive Models: An Introduction with R, 2nd ed. Chapman and Hall/CRC, Philadelphia.

Zengeya, F.M., Mutanga, O., Murwira, A., 2013. Linking remotely sensed forage quality estimates from WorldView-2 multispectral data with cattle distribution in a savanna landscape. Int. J. Appl. Earth Obs. 21, 513–524. https://doi.org/10.1016/j.jag.2012.07.008.

Zhu, Z., Wang, S., Woodcock, C.E., 2015. Improvement and expansion of the Fmask algorithm: cloud, cloud shadow, and snow detection for Landsats 4–7, 8, and Sentinel 2 images. Remote Sens. Environ. 159, 269–277. https://doi.org/10.1016/j.rse.2014.12.014.

Managing sustainably and profitably in a highly variable climate: results from the long term Wambiana grazing trial

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Abstract

Failure to manage for rainfall variability frequently results in a decline in land condition and economic loss. While sustainable management strategies exist, adoption rates are often low due to the perceived unprofitability of such strategies. We present data from a long term grazing trial comparing the performance of different cattle stocking strategies over 24 years of highly variable rainfall. Strategies involved combinations of different stocking rates, flexible versus fixed stocking, and wet season spelling.

Moderate stocking rates with or without spelling, maximised individual animal production and profitability. Although total liveweight gain per hectare was highest at heavy stocking rates, profitability was lowest due to drought feeding costs and reduced product value. Resource condition also declined drastically under heavy stocking, reducing carrying capacity and drought resilience. Land condition was initially maintained under moderate stocking, but in the long term declined partly due to the failure to reduce stocking rates in drought. Flexible stocking was as profitable as fixed moderate stocking, and provided it was applied in a risk averse manner, should have superior outcomes in terms of land condition, as indicated during the recent drought.

Keywords: stocking rates, pasture condition, cattle production, savannas,

Introduction

Rainfall variability is a major challenge to sustainable and profitable grazing management in northern Australia. Failure to manage for rainfall variability frequently results in a decline in land condition and economic loss. While a number of management recommendations exist to manage for this variability, adoption of these strategies has been relatively slow. One important factor limiting adoption is the lack of empirical evidence showing the relative benefits of recommended strategies. Here we present data from a long term grazing trial comparing the relative performance of different cattle stocking strategies over the last 24 years.

Procedure

The trial was established in 1997 on 'Wambiana', 70 km SW of Charters Towers, Queensland, Australia. Long term (111 year) mean annual precipitation is 640 mm (C.V. = 40%). The study area is an open *Eucalyptus* savanna in the *Aristida-Bothriochloa* pasture community (Tothill and Gillies 1992). There are five grazing treatments each replicated twice, in two blocks of five paddocks (93 to 117 ha). Treatments are described in detail elsewhere (O'Reagain *et al* 2009; 2011; 2018) but briefly are: (i) Moderate fixed stocking (MSR), at the estimated long term carrying capacity (LTCC) of 8 -10 ha/animal equivalent (AE= 450 kg steer), (ii) *Heavy stocking (HSR)* at twice the LTCC i.e. around 4-5 ha/AE and (iii) Rotational wet season spelling (R/Spell) stocked at 8-10 ha/AE. There were also two variable stocking strategies (VAR and SOI) with stocking rates adjusted annually based on available forage. In 2010 these were modified to become the (iv) Flexible stocking (Flex) and (v) Flexible stocking with wet season spelling (Flex+Spell) strategies. All strategies were applied as 'management philosophies' i.e., applied adaptively in consultation with the project's grazier advisory committee to ensure maximum relevance to the grazing industry.

Paddocks were stocked with two and three year old Brahman steers managed following industry best practice. Drought feeding was provided as required to maintain animal welfare. Cattle were weighed at the start and end of each grazing year (May) and carcass data compiled from meatworks feedback sheets. Gross margins were calculated as described by O'Reagain *et al.* (2011) but with the interest on livestock capital at 5%. The density of 3P grasses (palatable, productive, perennial grasses) was estimated based on the average number of 3P tussocks in 100 quadrats (0.25m^2) on permanent monitoring sites on all soil types; here only the data from the dominant *Eucalyptus brownii* community is presented. Paddock scale pasture yields were estimated at the end of the wet season (May) using the Botanal methodology (Tothill, Hargreaves *et al.* 1992) along transects that bisected all soil types. Species data was grouped into functional groups i.e. 3P grasses, 2P grasses (perennial, productive and/or palatable), annual grasses, 'other' (other grasses, sedges, forbs, legumes) and unpalatable wire grasses (*Aristida* and *Eriachne* species).

Results

Stocking rates

Rainfall varied markedly (246-1223 mm) over the trial period with two distinct wet and dry cycles and 2014/15 the fourth driest year on record. The heavy stocking rate (HSR) initially performed well with the early good seasons (O'Reagain *et al.* 2009), but stocking rates had to be sharply reduced in drought years (Fig. 1b). Drought feeding also had to be provided to the HSR in seven of the 24 years of the trial compared to only once (2015) in the other treatments. As pasture condition deteriorated with time, resilience declined with management interventions in the HSR required far sooner in the second compared to the first dry phase.

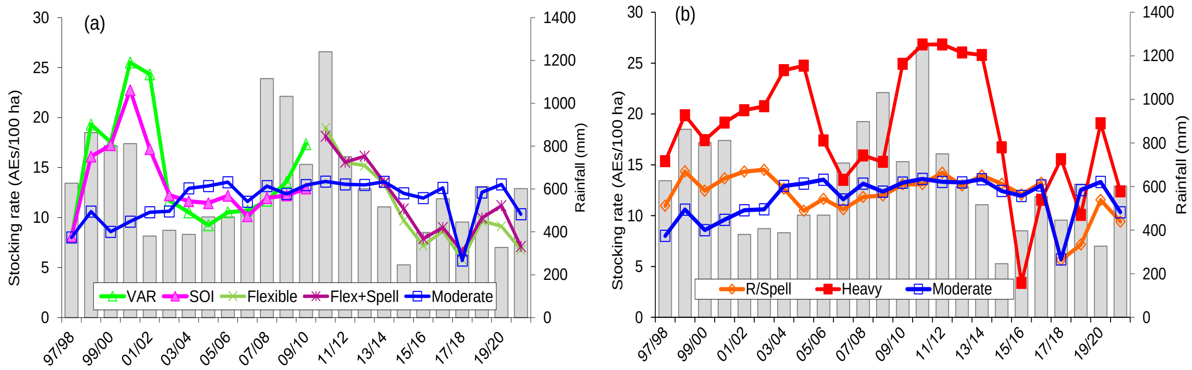

Fig. 1:Stocking rates (AEs/100 ha) and annual rainfall for (a) the moderate stocking rate (MSR) and the variable-flexible strategies; note the change in treatments in 2010. And (b) the MSR, heavy stocking rate (HSR) and rotational spell (R/Spell). See text for details.

Both variable stocking strategies were initially heavily stocked due to the good seasons (Fig. 1a), but stocking rates had to be sharply cut with the advent of drought in 2001/02 to arrest overgrazing and poor animal performance (O'Reagain *et al.* 2009). While this avoided the need to drought feed, the overgrazing going into the drought had a long term, negative impact on pasture condition. This experience emphasised the critical need to be risk averse in varying stocking rates and to set maximum limits to stock numbers in even the best years. These stocking strategies were adapted accordingly and run in this fashion from 2005 onwards.

The fixed, moderately stocked MSR and R/Spell largely maintained pasture condition through the first 15 years of the trial despite the 2002-2007 drought (O'Reagain *et al.* 2018). However, in the second, more severe drought (2014/15 onwards) animal production suffered relative to Flex and Flex+S where stocking rates had been reduced. The fixed stocking rates in the MSR & R/Spell in these drought years also resulted in very heavy pasture utilisation rates. Despite relatively good, well distributed rainfall (554 mm) in 2016/17, by late December 2017 ground cover and pasture yields were extremely low (<200 kg/ha). To avoid severe degradation in the early wet season when pastures are most sensitive to grazing (Ash *et al.* 2011), both treatments were destocked from January – May 2018. This was based on the philosophy that under similar circumstances a 'moderate stocker' would act similarly.

Animal production, economics and pasture condition

Average liveweight gain per head (LWG/hd) over the 24 years was highest in the MSR, R/Spell and Flexible strategies (Table 1). However in dry years, the Flexible stocking strategies often gave the best LWG/hd due to their reduced stocking rates. In contrast, LWG/hd was by far the lowest in the HSR due to reduced feed availability and generally lower diet quality. Consequently, carcasses from the HSR were generally lighter and returned a lower price per kg than those from other strategies (O'Reagain *et al.* 2018).

Total liveweight gain per hectare was highest in the HSR (Table 1) but this was only achieved with expensive drought feeding in seven of the 24 years of the trial. Consequently, average GM/ha in the HSR was only about half ($7/ha) that of the other strategies ($13 $/ha). Income variability was also far greater in the HSR with this strategy having a negative GM/ha in 11/24 years compared to 2/24 years in the MSR and R/Spell and 3/24 years in the Flexible stocking strategies.

Table 1. Average liveweight gain (LWG) per head (hd), LWG per hectare (ha), years (Yrs.) drought feeding was needed, gross margin (GM/ha/yr) over 24 years and 3P grass density in 2021.

Treatment	LWG/hd (kg)	LWG/ha (kg/ha)	Yrs drought feed	GM/ha ($/ha)	3 P density* (tussocks/m^2)
Flex	115	15	1	$13	1.3
Flex+Spell	115	16	1	$13	3.7
HSR	100	19	7	$7	0.5
MSR	117	14	1	$13	2.1
R/Spell	116	15	1	$13	2.4

E. brownii community only

Pasture condition

Heavy stocking resulted in a major decline in pasture condition in terms of the density and yield of 3P species relative to the other four treatments (Fig. 2). This not only shows the deleterious effects of heavy stocking in this variable environment but also shows that adopting basic principles of good management at least partly ameliorated the effects of the recent severe drought relative to heavy stocking. After 24 years it is nevertheless surprising that the differences in pasture condition between the remaining four treatments are relatively small; although TSDM in May 2021 was highest in the Flex+Spell, after 24 years there is still little difference in 3P species yield (Fig. 2). This possibly reflects the legacy effects of heavy stocking in the VAR and SOI strategies at the start of the trial and/or the continuing impact of the recent drought.

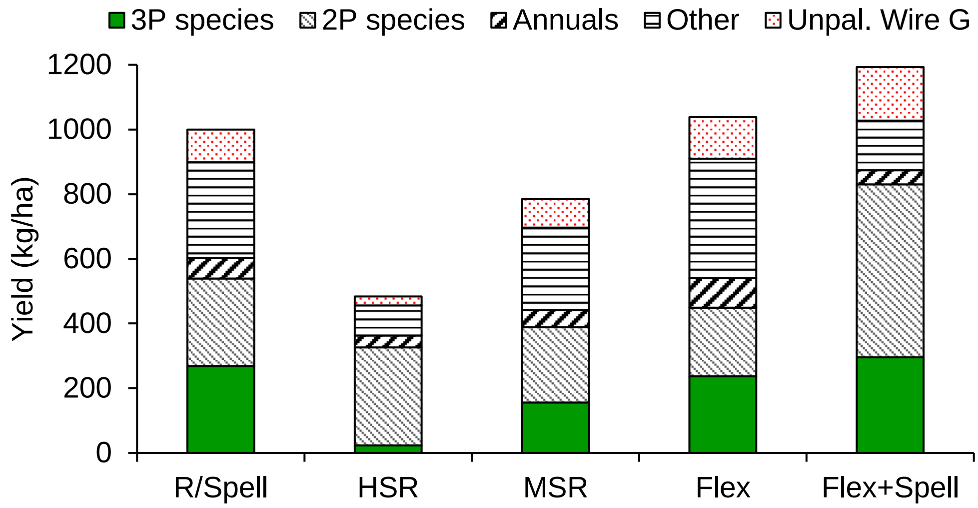

Fig. 1. Pasture species composition in the five grazing strategies in May 2021 after 24 years of application. See text for species group abbreviations.

Experiences through the trial nevertheless clearly highlighted the benefits of flexible stocking rates resulting in greater pasture availability and less overgrazing in the later drought years than in the fixed stocking strategies (pers. obs.). Wet season spelling also obviously benefited pastures but to a lesser extent than reducing stocking rates in drought. The benefits of flexible stocking on pasture condition would probably have been far greater if the MSR and R/Spell had not been destocked for the 2017/18 wet season thus avoiding severe damage to these treatments.

However the fact that pasture condition has declined in even the 'best' treatments is cause for concern and a sobering outcome. While the recent drought undoubtedly caused significant damage through marked mortality of perennial grasses (Jones pers.comm.)[i], recovery with the recent better seasons has been extremely slow. Similar observations have been made on properties throughout north Queensland. Hopefully this situation will resolve with a consistent run of wet years but if not, carrying capacities on many properties may be permanently compromised.

Conclusion

Our data clearly show that heavy stocking was less than half as profitable as the other strategies and resulted in a severe decline in pasture condition and loss of resilience. However, results also indicate that constant stocking even at LTCC without reducing stocking rates in dry years will also cause overgrazing and a decline in pasture condition in the longer term. Evidence from this work and other trials also highlights the importance of wet season spelling. In conclusion, risk-averse flexible stocking with wet season spelling is likely to be the most profitable and sustainable strategy for managing climate variability.

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References

Ash AJ, Corfield JP, McIvor JG and Ksiksi TS (2011) Grazing management in tropical savannas: utilization and rest strategies to manipulate rangeland condition. *Rangeland Ecology and Management* 64(3), 223-239.

O'Reagain P, Bushell J, Holloway, C & Reid A. 2009. Managing for rainfall variability: effect of grazing strategy on cattle production in a dry tropical savanna. *Animal Production Science 49: 1-15*

O'Reagain PJ, Bushell JJ and Holmes W. 2011. Managing for rainfall variability: Long term profitability of different grazing strategies in a north Australian tropical savanna. *Animal Production Science, 51, 210-224.*
O'Reagain PJ and Bushell, JJ (2011) 'The Wambiana grazing trial: Key learnings for sustainable and profitable management in a variable environment.' Queensland Government Brisbane Australia. *https://futurebeef.com.au/resources/projects/wambiana-grazing-trial/*
O'Reagain PJ*, Bushell JJ, Scanlan J and Pahl L*. (2018). Final report: B.ERM.0107. Wambiana grazing trial Phase 3: Meat and Livestock Australia. 149 pp.https://www.mla.com.au/research-and-development/reports/2018/part-2---wambiana-grazing-trial-phase-3-stocking-strategies-for-improving-carrying-capacity-land-condition-and-biodiversity-outcomes/
Tothill JC and Gillies C (1992) 'The pasture lands of northern Australia. Their condition, productivity and sustainability.' (*Tropical Grassland Society of Australia: Brisbane*)
Tothill JC, Hargreaves JNG, Jones RM and McDonald CK (1992) BOTANEL - a comprehensive sampling and computing procedure for estimating pasture yield and composition 1. Field sampling. CSIRO, Brisbane.

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Profitable and Sustainable Cattle Grazing Strategies Support Reptiles in Tropical Savanna Rangeland

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Original Research

Profitable and Sustainable Cattle Grazing Strategies Support Reptiles in Tropical Savanna Rangeland☆

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ABSTRACT

Rangelands are areas used primarily for grazing by domestic livestock; however, because they support native vegetation and fauna, their potential role in conservation should not be overlooked. Typically, "off-reserve" conservation in agricultural landscapes assumes a trade-off between maintaining the ecological processes that support biodiversity and successful food production and profitability. To evaluate this potential biodiversity trade-off in rangelands, we need to understand the effect of different livestock grazing strategies on biodiversity, in relation to their performance in terms of profitability and land condition. We monitored reptile community responses to four cattle-grazing strategies (heavy, moderate, and variable stocking rates and a rotational wet season spelling treatment) in a replicated, long-term grazing trial in north Queensland, Australia. Simultaneously, measures of profitability and land condition were collected for the different grazing strategies. Overall, reptile abundance was not negatively impacted by the more sustainably managed treatments (moderate, variable, and rotational) compared with heavy stocking, although the effect of grazing treatment alone was not significant. Profitability and land condition were also higher in these treatments compared with the heavy stocking rate treatment. As drought conditions worsened over the 3 yr, the negative impact of the heavy stocking treatment on both profitability and biodiversity became more pronounced. Heavy stocking negatively impacted reptiles and was also the least profitable grazing strategy over the long term, resulting in the worst land condition. This suggests that in this tropical savanna rangeland there was no trade-off between economic performance and reptile abundance and diversity. Grazing regimes with a moderate stocking rate or flexible management strategies were better able to buffer the effects of climate variability. The consequence was a more resilient reptile community and better economic outcomes in dry years.

Introduction

Livestock grazing is the most widespread land use in the world, covering 25% of the global land surface (Asner et al., 2004). Most livestock grazing takes place on rangelands, generally defined as open landscapes with naturally occurring forage plants suitable for livestock, and millions of people in both the developed and developing world are dependent upon them economically and socially. In northern Australia, livestock grazing is the dominant land use across the 1.5 million km^2 of tropical savannas and many people depend upon this industry for their livelihood (Crowley, 2015). To ensure a sustainable grazing industry, we need to identify grazing strategies that minimize negative impacts on land condition and biodiversity.

Globally, the impact of livestock grazing on biodiversity is mixed. It can be either positive or negative and depends upon the evolutionary history of the system, its productivity, and the intensity of grazing disturbance (Milchunas et al., 1988; Cingolani et al., 2005). In Australia, grazing by domestic livestock is generally viewed as being negative for biodiversity (Eldridge et al., 2016) and is, in some cases, extremely detrimental (James et al., 1999). Under inappropriate management, particularly when coupled with drought, livestock grazing can lead to the loss of deeper-rooted perennial grasses and reduce ground cover and soil health, leading to increased runoff and reduced ecosystem services (Facelli and Springbett, 2009; McKeon et al., 2009; Eldridge et al., 2011). Subsequently, these changes to vegetation structure can affect the fauna using them as habitat. However, when managed appropriately, rangelands can be maintained in good condition (O'Reagain and Bushell, 2011). Ecological processes on rangelands are often relatively

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"intact" compared with those in more intensive agricultural areas, particularly when trees are not cleared and exotic pasture species are not introduced (McIntyre and Hobbs, 1999). Indeed, the extensive rangelands of northern Australia are largely dominated by native grasses, despite the ingress of exotic grasses like Buffel grass *(Cenchrus ciliaris)* and Indian Couch *(Bothriochloa pertusa)* in some areas. The relatively intact nature of these rangelands suggests that if managed appropriately, they can be used for food production and make a valuable contribution toward achieving landscape-scale conservation objectives (Neilly et al., 2016).

While nature reserves undoubtedly serve a critical role in conservation, they are inadequate on their own to conserve biodiversity into the future (Margules and Pressey, 2000). This is, in part, due to the social and economic limitations on their total area and subsequent management. Therefore, the importance of well-managed rangelands as complementary "off-reserve" conservation areas cannot be overlooked. Furthermore, due to the vast areas covered by rangelands, small management changes could have significant implications for conservation (Niamir-Fuller et al., 2012).

For "off-reserve" conservation to be a success, rangelands need to serve a dual purpose: economically viable animal production for the grazier and, simultaneously, maintenance of the ecological processes that support biodiversity. We need to understand the response of biodiversity to grazing and integrate this knowledge with an understanding of economic and social outcomes. Essentially, we must determine the relative trade-off between conservation and production objectives. In an industry that is facing severe financial challenges, with many operations struggling to remain viable (McLean et al., 2014), integrated information on biodiversity and profitability outcomes is needed to convince land managers to adopt wildlife-friendly practices and inform relevant incentive schemes. Unfortunately, there has been a limited capacity to accurately link measures of economic performance with measures of biodiversity, as a multidisciplinary approach to data collection is rare.

The basic principles of sustainable grazing management are relatively well known (i.e., stock around the long-term carrying capacity of the landscape, adjust stocking rates according to pasture (forage) availability, and regularly spell, or rest, paddocks to allow recovery from grazing (O'Reagain et al., 2014). In northern Australia, these kinds of conservative and flexible grazing strategies achieve the best land condition by maintaining healthy soil and vegetation communities, and they are also most profitable in the long term (O'Reagain and Scanlan, 2012). Therefore, it is reasonable to hypothesize that grazing strategies that maintain land in better condition and are most economically sustainable are also likely to have better biodiversity outcomes for both flora and fauna (Curry and Hacker, 1990).

We are, however, unable to directly compare animal production and biodiversity data unless we have studies designed to do so (Neilly et al., 2016). Rangeland scientists typically utilize grazing trials to assess animal production and land condition under different grazing treatments, and they usually focus data collection on important pasture species or soil characteristics (O'Reagain et al., 2011; Orr and O'Reagain, 2011). Conversely, ecologists often conduct biodiversity surveys in existing grazed environments, where floral or faunal communities in areas of different grazing intensity are compared (e.g., Landsberg et al., 2003; Dorrough et al., 2012). While biodiversity has sometimes been studied within experimental grazing trials (Kutt et al., 2012; Bylo et al., 2014; Villar et al., 2014), the opportunity to combine these data with simultaneously collected economic or land condition data has not been realized. Furthermore, few large-scale grazing trials are conducted over time periods long enough to adequately measure long-term profitability or to capture changes in land condition or biodiversity, particularly in areas with marked climatic variability.

In this study, we examined the effect of four cattle grazing regimes on profitability, land condition, and reptile abundance and species richness over 3 yr, on an existing long-term (19-year) grazing trial in an Australian tropical savanna rangeland. The specific aim of the trial is to assess the performance of different grazing strategies in relation to animal production, economic performance, and resource condition (O'Reagain et al., 2011). We selected reptiles as a biodiversity measure to assess grazing impacts due to their diversity in this location, the fact that their scale of movements are conducive to this grazing trial, and the responsiveness of reptiles to land-use type, compared with more vagile groups, such as mammals or birds (Woinarski and Ash, 2002). We predicted that overall reptile abundance and richness would be higher where profitability was higher and land condition was better. That is, we predicted there would not be a trade-off between biodiversity and profitability among the four grazing treatments, but instead that low profitability and poor biodiversity outcomes would coincide. Additionally, we predicted that season and vegetation type would strongly influence patterns of reptile abundance and richness.

Materials and Methods

Site Description

The grazing trial was established by the Queensland Department of Agriculture and Fisheries in 1997 at "Wambiana," a commercial cattle station (20°34′S, 146°07′E), 70 km south of Charters Towers, Queensland, in northeastern Australia. The property had been grazed by cattle, at relatively moderate stocking rates, since at least the 1870s. The study area was located on relatively flat, low-fertility, tertiary sediments within the greater Burdekin River catchment. The region has a distinct summer wet season and winter dry season. Average annual rainfall is 643 mm but is highly variable (historical range 207 − 1 409 mm) and includes regular droughts.

The 1 041-ha experimental site consists of 10 paddocks ranging from 93 − 115 ha in size, with five grazing treatments each replicated twice. Treatments were selected to reflect either typical or recommended management practices in northern Australian rangelands: 1) heavy stocking rate (H)—4 − 6 ha · Adult Equivalent-1 (AE, defined as 450-kg steer); 2) moderate stocking rate (M)—8 − 10 ha · AE-1; 3) variable stocking rate (V)—stocking rates adjusted annually on the basis of the end of wet season feed availability, range 3 − 12 ha · AE-1; 4) rotational wet season spelling (R)—a third of the paddock spelled each wet season 7 − 10 ha · AE-1 and; 5) Southern Oscillation Index strategy—stocking rates adjusted annually in November based on feed availability and the Southern Oscillation Index forecasts for the next wet season 3 − 12 ha · AE-1 (see O'Reagain et al., 2011 for detailed treatment descriptions). The effects of only the first four grazing regimes were quantified in this study. Following recommended practice, the entire site was burned in October 1999 and October 2011 to suppress woody growth.

The vegetation consists of open Eucalypt and Acacia savanna woodland underlain by C4 tropical grasses. The dominant vegetation communities are 1) Reid River Box *(Eucalyptus brownii)* on texture-contrast soils (sodosols; soil nomenclature follows Isbell and National Committee on Soil and Terrain, 1996), with a ground layer of *Bothriochloa ewartiana, Dichanthium fecundum, Chrysopogon fallax,* and various local *Aristida* species; 2) Silver Leaf Ironbark *(Eucalyptus melanophloia)* on yellow-brown earths (kandosols) with a ground vegetation of less palatable grass species *Eriachne mucronata* and *Aristida* species but also some areas of *C. fallax* and *Heteropogon contortus;* and 3) a small area of Brigalow *(Acacia harpophylla)* woodland on heavy clays (vertosols and gray earths). In the *E. brownii* and *A. harpophylla* vegetation types there is an irregular understory of currant bush *(Carissa ovata)*. All paddocks have similar proportions of the main soil types and vegetation communities.

Cattle Management

Experimental animals were Brahman-cross steers between 18 and 30 mo old, managed according to standard industry practice (O'Reagain et al., 2009). Profitability was calculated as the annual gross margin (i.e., the total mass of beef produced per annum multiplied by its market value less the costs of production, such as interest costs on livestock capital, plus husbandry and supplementation costs) (O'Reagain et al., 2011). As in previous drought years, in 2013 and 2014 and 2014 and 2015, animals in the heavy stocking rate treatment also had to be drought-fed due to the extreme shortage of forage in these paddocks.

Pasture Measurements and Land Condition

Land condition was indexed by total ground cover and the percentage of perennial, productive, and palatable grass species (3P grasses) by dry weight of end-of-wet-season pasture mass. A high proportion of 3P grasses indicates a productive and sustainable landscape (McIvor et al., 1995). Pasture total standing dry matter (TSDM), species contribution to yield, and ground cover were assessed annually at the end of the wet season (May) and in the late dry season (October) using the dry-weight-rank procedure (t'Mannetje and Haydock, 1963) in the program BOTANAL (Tothill et al., 1992). One-hundred quadrat (0.25-m^2) placements were made at regular intervals along each of two permanent transects running the length of each paddock. To ensure representative sampling, the length of transects across each soil type was roughly proportional to the percentage area of that soil in a particular paddock. Major herbaceous plant species were identified to species, while less common species were identified to genus.

Reptile Survey

A total of six reptile surveys were conducted over 3 yr (2013, 2014, and 2015) in April (end of the wet season) and October (end of the dry season). Twenty-four 1-ha sampling sites were established across the four selected grazing treatments (Kutt et al., 2012). Due to the relative size of each vegetation community, 16 sites were located within the Box and 8 within the Ironbark community. A trap array was situated in the bottom right-hand corner of each site consisting of 4×30 cm diameter pitfall buckets spaced 10 m apart arranged in a "T" configuration; 10-m and 20-m lengths of drift fence, intersecting the pitfall buckets; and 6 funnel traps, situated at the ends of the drift fence. Pitfall and funnel traps were checked twice daily over each 10-night trapping session. Captured animals were removed from traps, weighed, measured, marked, and then released.

Statistical Analysis

Reptile abundance and species richness was correlated with profitability and land condition indices across the four grazing treatments using Pearson's correlation coefficients. Analysis was confined to 2 yr: July 2013–June 2014 and July 2014–June 2015, in which there were available paired samples of profitability, land condition, and mean reptile abundance and richness from each treatment paddock ($n = 16$).

To examine the response of reptiles in more detail, reptile abundance and reptile species richness from each sampling site was collated for a trapping session ($n = 144$). Generalized linear mixed models with a negative binomial distribution were used to examine reptile abundance and species richness in relation to grazing treatments, vegetation type, season, year, and the interactions between these factors as fixed effects, with site as a random effect. Variables were explored for collinearity before including them in the model, and model distribution was selected to avoid overdispersion. The optimal models were chosen by comparing models based on corrected Akaike's information criteria (AICc). Pairwise comparisons were made using Tukey's tests. The final models were validated by examining the deviance residuals, and fitted values with 95% confidence intervals were plotted. All analyses were performed in R (R Core Team 2014).

Results

Rainfall varied markedly over the 3 yr of the study from 601 mm in 2012/2013 to as little as 246 mm in 2014/2015, the fourth driest yr in the 105-yr rainfall record for the area (Table 1). As a result, pasture yields in 2014/2015 were extremely low in the H treatment (<200 kg $\cdot$ ha^{-1}) and it was necessary to reduce the stocking rate in this treatment to 6 ha $\cdot$ AE-1.

In total, over the six reptile surveys, 1 386 reptiles were captured in pitfall and funnel traps with 30 different species recorded. Mean reptile abundance and richness from 2013 to 2015 were highest in the moderate grazing treatment (M) followed by the variable (V), rotational wet season spelling (R) and lowest in the heavy-grazing treatment (H) (Fig. 1a), although the effect of grazing treatment alone was not significant. In the optimal reptile abundance generalized linear mixed model, grazing interacted with year. Tukey's tests revealed many significant differences between the grazing-year interaction terms, including that reptile abundance in the H treatment in 2015 was significantly lower than all other grazing-yr interaction terms (Table 2).

In terms of profitability, mean gross margin over the 3 yr of the study was also lowest in H ($-\$15$ ha^{-1}), due largely to the high cost of supplemental feeding. In contrast, gross margins were far higher and positive in the M, V, and R treatments (Fig. 1b). This pattern was similar to that found for the 18-yr mean gross margin, in which values for M, V, and R were the same and H was lower (see Fig. 1b). For land condition indices, the treatment responses of percentage of 3P pasture composition, total standing dry matter, and ground cover all closely followed the trends shown by the 3-yr gross margin (Fig. 1c and d). In each case, land condition indices were highest in the M and R treatments, slightly lower in V, and lowest in the H treatment.

Reptile abundance and richness were more highly correlated with profitability and land condition measures in 2014/2015 than in 2013/2014 (Figs. 2 and 3). Overall, reptile abundance in 2013/2014 was more highly correlated with profitability and landscape condition indices than reptile richness, although these correlations were not significant ($P > 0.05$). In 2014/2015 reptile abundance and richness were most highly correlated with gross margin (abundance: $r = 0.87$, $P < 0.01$; richness: $r = 0.89$, $P < 0.01$). The correlation coefficients in 2014/2015 of both reptile abundance and reptile richness with the three land condition measures were similar, ranging from $r = 0.67$ to $r = 0.78$.

Although not the focus of our study, we also examined the effects of vegetation type, season, and year on reptile abundance and richness. The optimal reptile abundance model contained a significant grazing-year interaction term (Fig. 4a) but also season-year and vegetation-year interaction terms (Table 2, Fig 4b and c). In 2013, there was a higher abundance of reptiles in the ironbark than in the box land type, but the reverse was true in 2015 (see Fig. 4b). In 2013 there was higher reptile abundance in the wet season, whereas there was a higher abundance of reptiles in the dry season in 2015 (see Fig. 4c). The response of reptile species richness to season varied among years.

Discussion

Our results suggest that there is no trade-off between long-term profitability of cattle grazing and reptile abundance and richness in

Table 1
Rainfall and stocking rates applied in different treatments over the 3 yr of the study

	2012/13	2013/14	2014/15
Rainfall (mm)	601	517	246
	Stocking rate (ha $\cdot$ adult equivalent^{-1})		
Heavy	3.84	3.88	5.98
Moderate	7.54	7.36	8.05
Variable	6.63	7.18	9.40
Rotational	7.71	7.17	7.62

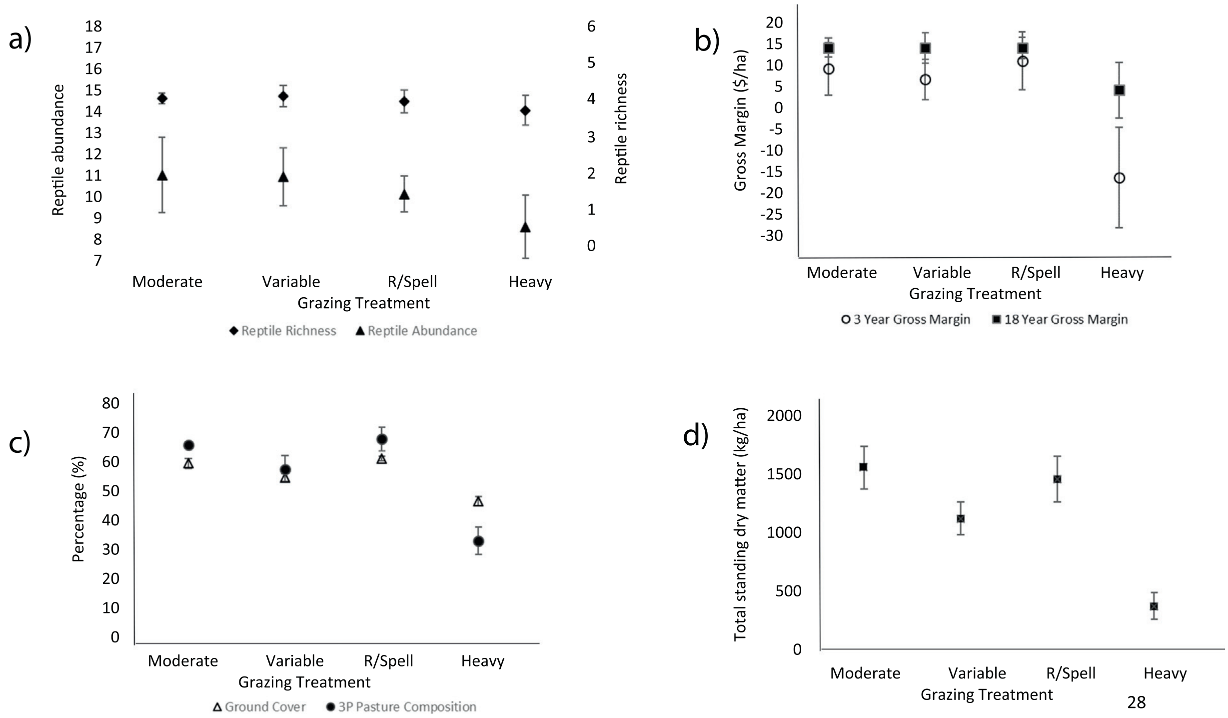

Figure 1. Observed trends among the four grazing treatments: moderate, variable, rotational wet season spelling and heavy, for measures of mean reptile abundance over the six reptile surveys conducted from 2013 to 2015 and (**a**) mean reptile richness, (**b**) profitability as measured by 3-yr gross margin ($ · ha^{-1}) from 2013 to 2015 and the long-term 18-yr gross margin ($ · ha^{-1}) from 1997 to 2015, (**c**) 3P pasture species composition (%) and ground cover (%), and (**d**) total standing dry matter (kg · ha^{-1}). All values are means ± standard error.

this relatively unaltered, tropical savanna rangeland. The H treatment performed the worst economically compared with the M, V, and R treatments. Not only were profits and land condition better in the relatively well-managed M, V, and R treatments, but reptile abundance and richness avoided the negative impacts of the H treatment seen in the drier years. Compared with other grazing trials, the mixture of soil types and use of paddocks 2 − 10 times larger than is typical mean that we can have confidence the results from this study are more likely

Table 2

Relationship between reptile abundance and reptile species richness and grazing treatment, vegetation type, season and year as described by a generalized linear mixed model with a negative binomial distribution. Site is used as a random effect. The top three models are based on corrected Akaike's information criteria (AICc) values. When the terms in the model were significant ($P < 0.05$), post hoc Tukey tests were used to examine the effect of each factor level

Response variable	Model	df	Log likelihood	AICc	ΔAICc	AICc weight	Post hoc test
Reptile abundance	Grazing · Yr	20	−383.145	813.1	0.00	0.621	Grazing · Yr:
	+ Season · Yr						Heavy 2013 > Heavy 2014, Heavy 2015, Rotational 2015, Variable 2015
	+ Vegetation · Yr						Moderate 2013 > Heavy 2015, Moderate 2015, Rotational 2015, Variable 2015
	Grazing	11	−395.659	815.3	2.20	0.207	Rotational 2013 > Heavy 2015, Rotational 2015, Variable 2015
	+ Season · Yr						Variable 2013 > Heavy 2015, Rotational 2015, Variable 2015
	+ Vegetation · Yr						Heavy 2014, Moderate 2014, Moderate 2015 > Heavy 2015
	Grazing · Yr	23	−380.663	816.5	3.41	0.113	Rotational 2014 > Heavy 2015, Rotational 2015
	+ Grazing · Vegetation						Variable 2014 > Heavy 2015, Rotational 2015, Variable 2015
	+ Season · Yr						Season · Yr:
	+ Vegetation · Yr						Dry 2013 > Wet 2013, Dry 2014, Wet 2014, Wet 2014, Wet 2015
							Wet 2013, Dry 2014, Wet 2014, Wet 2015 > Dry 2015
							Vegetation · Yr
							Box 2013 > Box 2015, Ironbark 2015
							Ironbark 2013 > Ironbark 2014, Box 2015, Ironbark 2015
							Box 2014 > Box 2015, Ironbark 2015
							Ironbark 2014, Box 2015 > Ironbark 2015
							Grazing:
							n.s
							Grazing · Vegetation:
							Moderate Box > Heavy Ironbark
							Variable Ironbark > Heavy, Ironbark
Richness	Season · Yr	8	−261.845	540.8	0.00	0.418	Season · Yr
	Season · Yr	11	−258.518	541.0	0.28	0.364	Dry 2013 > Dry 2015, Wet 2014
	+ Vegetation · Yr						Wet 2013, Dry 2014, Wet 2015, > Dry 2015
	Season · Yr	9	−261.780	542.9	2.15	0.143	Vegetation · Yr
	+ Vegetation						Box 2013 > Ironbark 2015
							Ironbark 2013 > Ironbark 2015
							Vegetation
							n.s

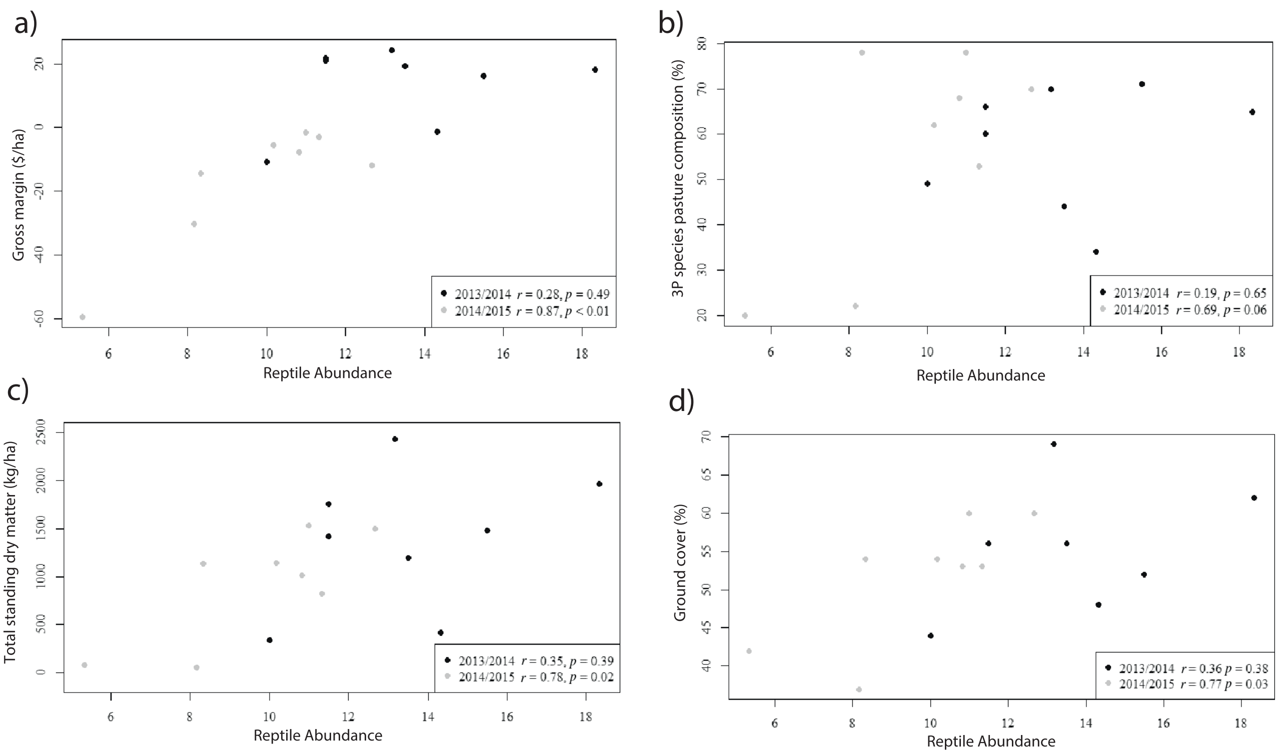

Figure 2. Pearson's correlation coefficients and significance tests of paired samples in the yr July 2013–June 2014 and July 2014–June 2015, to measure the association between reptile abundance and (**a**) profitability, (**b**) 3P species pasture composition, (**c**) total standing dry matter, and (**d**) groundcover. The *r* values range from −1 to 1 with 0 indicating no association.

to be realistic and representative of actual cattle grazing properties in the region.

The key to this outcome is that the better-managed strategies (M, V, and R) largely maintained land condition, which is the essential foundation for long-term profitability. In contrast to the H strategy, these treatments promoted a high proportion of deep-rooted productive, perennial grasses. These are far more drought tolerant and ensured there was adequate forage for the cattle through a whole range of seasons, maximizing individual animal performance (O'Reagain et al., 2009). Although total animal production ($kg \cdot ha^{-1}$) was higher in

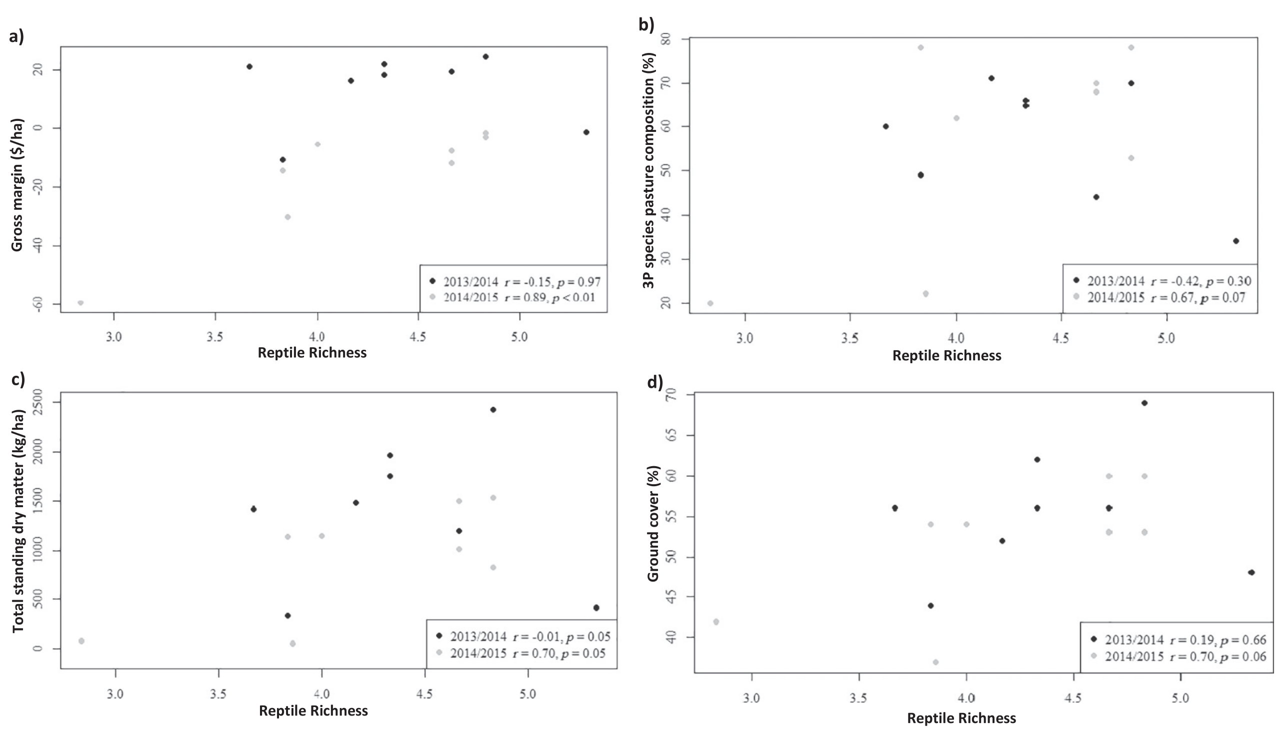

Figure 3. Pearson's correlation coefficients and significance tests of paired samples in the yr July 2013–June 2014 and July 2014–June 2015, to measure the association between reptile richness and (**a**) profitability; (**b**) 3P species pasture composition, (**c**) total standing dry matter and, (**d**) groundcover. The *r* values range from −1 to 1 with 0 indicating no association.

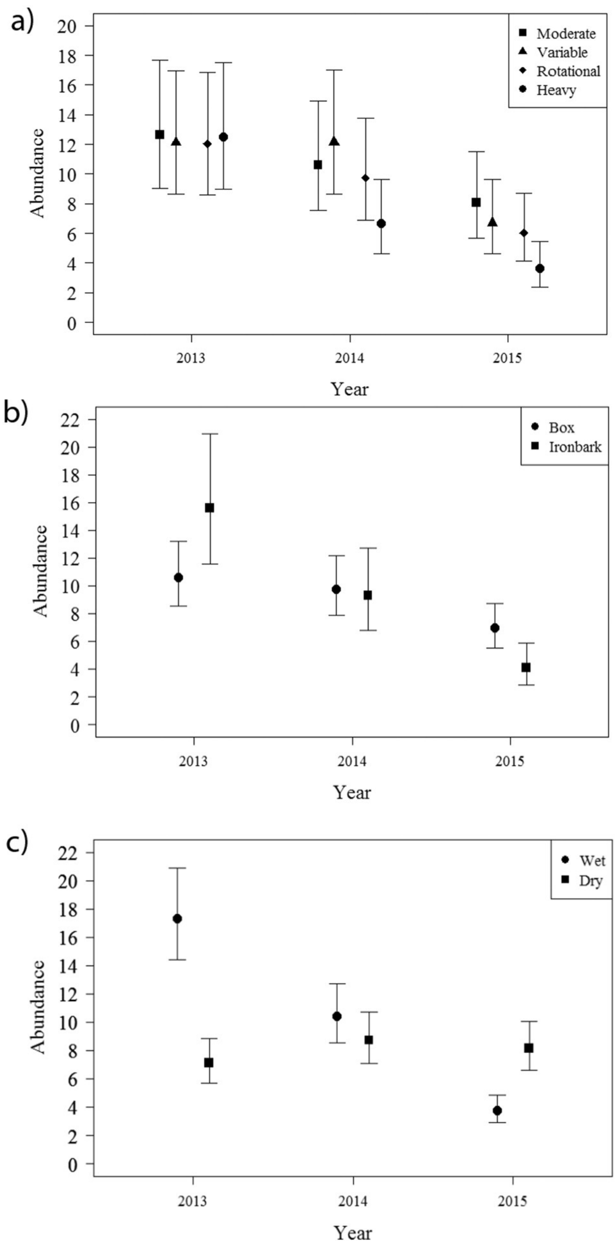

Figure 4. The fitted values with 95% confidence intervals for the fixed terms in the optimal negative binomial GLMM, reptile abundance ~ Grazing · Yr + Vegetation · Yr + Season · Yr + (1|Site): (**a**) Grazing · Yr, (**b**) Vegetation · Yr, and (**c**) Season · Yr.

the H strategy, profitability was severely eroded by lower prices caused by poorer animal condition, the expense of drought feeding in poor years, and the higher interest costs associated with greater investment in livestock capital (O'Reagain et al., 2011). Although these findings are derived from steers grazing paddocks that are relatively small (100 ha) by most commercial standards (1 000 − 6 000 ha), detailed bioeconomic modeling confirms that moderate stocking rates also optimize profitability and land condition with breeders (cows and calves) at the whole enterprise level (Scanlan et al., 2013).

Reptile abundance and richness in 2015 were lower in the H relative to the other strategies, presumably because the poorer land condition was detrimental to a reptile assemblage dominated by ground-dwelling leaf litter skinks. Terrestrial reptiles, particularly those associated with leaf litter and ground cover, are widespread and typical of savanna fauna and are negatively impacted by the effects of heavy grazing (Kutt and Woinarski, 2007; Kutt and Fisher, 2011; Frank et al., 2013). However, other reptile groups, such as agamids, may benefit from the more open ground layer that heavy grazing tends to promote (Read and Cunningham, 2010; Germano et al., 2012). Likewise, arboreal reptile species can often thrive in heavily grazed environments (Knox et al., 2012; Neilly et al., 2017). At our study site, the reptile community was dominated by terrestrial litter skinks with few agamids and our ground-based trapping methodology is likely to have been biased against arboreal herpetofauna that use the ground infrequently (Nordberg and Schwarzkopf, 2015). Other work at the site, however, has shown that the terrestrial reptile abundance is driven by habitat structure changes at ground level (Neilly et al., 2017). Although it has not been tested for this system, changes in habitat structure may indirectly influence the ability of reptile species to avoid predation, find suitable prey, and effectively thermoregulate (Valentine et al., 2006; Hacking et al., 2014; Abom et al., 2015).

In addition to the effects of grazing management, reptiles responded to climatic, seasonal, and vegetation differences. In the latter case, the less productive ironbark vegetation community may be relatively more sensitive to the negative impacts of drought and overgrazing, possibly due to its inherent lower fertility (O'Reagain personal observation; unpublished data). Management strategies, particularly stocking rates, thus should be adapted to land types and regions (Smith et al., 2012). Grazing pressure in larger, spatially variable paddocks with different land types is also seldom uniform. Accordingly, it is also important to manage for the vulnerable land types within the paddock, and not just for the paddock as a whole.

Over the 3 yr of this study, the grazing trial experienced a year with average rainfall, followed by 2 drought yr. The strong correlation between reptile abundance and richness with profitability and land condition in 2014/2015 was likely caused by the dry conditions at the time. Although reptile abundance and richness declined in all treatments in 2015, this decline was greatly exacerbated by the heavy grazing pressure in the H treatment and its impacts on habitat availability (Neilly et al., 2017). In contrast, the M, V, and R strategies buffered the effects of the drought to various degrees, likely due to the greater proportion of 3P grasses. A similar effect has been noted with cattle production (O'Reagain et al., 2009) with drought effects emerging far sooner in heavily stocked treatments. The amplification of drought impacts under less sustainable grazing management is likely to become even more important as climate variability becomes increasingly pronounced with predicted climate change (Lohmann et al., 2012).

The relatively subtle differences among M, V, and R treatments for all of the variables considered are expected. On most rangelands, stocking rate is a more important determinant of management outcomes than either grazing system or the application of pasture resting or spelling (O'Reagain et al., 2014). In the present study, the two conservatively stocked, fixed stocking strategies (M and R) performed slightly better, in terms of reptile abundance and land condition, than did the variable stocking strategy. Although relatively light stocking rates were applied in the V treatment in more recent years, the tendency for slightly reduced reptile abundance in the V stocking paddocks likely reflects the high stocking rates applied 12 yr earlier, immediately preceding the 2002–2007 drought (O'Reagain and Bushell, 2011). It is surprising that the R treatment did not perform better in terms of land condition and biodiversity relative to the M strategy, as wet season spelling has a marked beneficial effect on land condition (Ash et al., 2011; Scanlan et al., 2014). However, relatively muted responses to spelling on these land types has also been reported by Jones (2016), and it is possible that the benefits of spelling were partially negated by the higher stocking rates applied to the nonspelled parts of the system during the wet season (O'Reagain and Bushell, 2011).

The applicability of the present results to other rangeland systems will likely depend on the rainfall, edaphic properties and evolutionary history of ungulate herbivores at other locations. Australia lacks large native grazing ungulates, so Australian rangelands are likely to be more vulnerable to the impacts of livestock grazing, compared with rangelands on other continents. Given the documented episodes of historical overgrazing in Australia (McKeon et al., 2009), the modern-day reptile community may be impoverished and dominated by species with some level of grazing tolerance, while grazing-sensitive species have already decreased in abundance or become locally extinct (James et al., 1999; Fensham and Fairfax, 2008; Dorrough et al., 2012; Kay et al., 2016). Aside from the impacts of grazing per se, other management practices often associated with grazing enterprises can also have major landscape impacts (Price et al., 2010). Our data come from a tropical savanna rangeland that is relatively “intact” (i.e., with little weed encroachment, with no tree clearance, little or no pasture improvement, and no fertilization). Furthermore, while fire is commonly used as a management tool in conjunction with grazing and has an important impact on vertebrate communities (e.g., Fuhlendorf et al., 2006; Kutt and Gordon, 2012), the interaction between fire and grazing was not explicitly addressed in this study. Where grazing regimes include other disturbances such as these, the cumulative impact on the landscape or indeed the impact of these other elements on their own may be more important than the differences among stocking rates (Brennan and Kuvlesky, 2005). While this study was conducted in a controlled experimental setting, other rangeland systems may be subject to a more complex set of confounding management practices, which would need to be considered holistically.

The extent of an agriculture-biodiversity trade-off in any rangeland system will depend on what is meant by “biodiversity” in a particular case. As we have shown here, if our conservation goals at this site included maximizing reptile abundance and richness, we could recommend that heavy grazing be avoided and a conservative or flexible approach to grazing be applied. However, reptiles are unlikely to be representative of all vertebrate fauna. Indeed, birds and mammals have shown varied responses to different grazing strategies (Neilly et al., 2016). Therefore, rangeland management for the purpose of off-reserve conservation should be tailored to the specific conservation goals at that location. An accurate understanding of the “opportunity cost” to landowners of adopting a specific conservation-friendly practice would be particularly useful when devising rangeland management incentive schemes and guiding government policy.

Implications

Rangeland scientists have long asserted that the key to sustainable pastoralism and animal production is to maintain the soil, vegetation, and perennial forage, which are also essential elements for supporting native wildlife (Curry and Hacker, 1990). Our findings, that there was no trade-off between reptile abundance or richness and profitability or land condition, support this assertion. These results go further, providing possibly the first direct empirical data demonstrating that there is a considerable economic benefit to be gained by managers by adopting grazing strategies that maintain land condition and, by implication, maintain biodiversity. This kind of multidisciplinary research is the key to challenging the belief that rangeland management and conservation are intrinsically opposing goals, allowing us to explore the potential for “off-reserve” conservation on rangelands.

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References

Abom, R., Vogler, W., Schwarzkopf, L., 2015. Mechanisms of the impact of a weed (grader grass, *Themeda quadrivalvis*) on reptile assemblage structure in a tropical savannah. Biological Conservation 191, 75–82.

Ash, A.J., McIvor, J., Corfield, J., Ksiksi, T., 2011. Grazing management in tropical savannas: utilization and rest strategies to manipulate rangeland condition. Rangeland Ecology & Management 64, 223–239.

Asner, G.P., Elmore, A.J., Olander, L.P., Martin, R.E., Harris, A.T., 2004. Grazing systems, ecosystem responses, and global change. Annual Review Environmental Resources 29, 261–299.

Brennan, L.A., Kuvlesky, W.P., 2005. North American grassland birds: an unfolding conservation crisis? Journal of Wildlife Management 69, 1–13.

Bylo, L.N., Koper, N., Molloy, K.A., 2014. Grazing intensity influences Ground Squirrel and American Badger habitat use in mixed-grass prairies. Rangeland Ecology & Management 67, 247–254.

Cingolani, A.M., Noy-Meir, I., Díaz, S., 2005. Grazing effects on rangeland diversity: a synthesis of contemporary models. Ecology Applications 15, 757–773.

Crowley, G., 2015. Trends in natural resource management in Australia's Monsoonal North: the beef industry. The Cairns Institute, James Cook University, Cairns, Australia.

Curry, P.J., Hacker, R.B., 1990. Can pastoral grazing management satisfy endorsed conservation objectives in arid Western Australia? Journal of Environmental Management 30, 295–320.

Dorrough, J., McIntyre, S., Brown, G., Stol, J., Barrett, G., Brown, A., 2012. Differential responses of plants, reptiles and birds to grazing management, fertilizer and tree clearing: plant, reptile and bird responses to agriculture. Australian Ecology 37, 569–582.

Eldridge, D.J., Val, J., James, A.I., 2011. Abiotic effects predominate under prolonged livestock-induced disturbance: livestock-induced disturbance in woodlands. Australian Ecology 36, 367–377.

Eldridge, D.J., Poore, A.G., Ruiz-Colmenero, M., Letnic, M., Soliveres, S., 2016. Ecosystem structure, function and composition in rangelands are negatively affected by livestock grazing. Ecology Applications 26 (4), 1273–1283.

Facelli, J.M., Springbett, H., 2009. Why do some species in arid lands increase under grazing? Mechanisms that favour increased abundance of *Maireana pyramidata* in overgrazed chenopod shrublands of South Australia. Austral Ecology 34, 588–597.

Fensham, R.J., Fairfax, R.J., 2008. Water remoteness for grazing relief in Australian aridlands. Biological Conservation 141 (6), 1447–1460.

Frank, A.S.K., Dickman, C.R., Wardle, G.M., Greenville, A.C., 2013. Interactions of grazing history, cattle removal and time since rain drive divergent short-term responses by desert biota. PLoS ONE 8, e68466.

Fuhlendorf, S.D., Harrell, W.C., Engle, D.M., Hamilton, R.G., Davis, C.A., Leslie Jr., D.M., 2006. Should heterogeneity be the basis for conservation? Grassland bird response to fire and grazing. Ecology Applications 16, 1706–1716.

Germano, D.J., Rathbun, G.B., Saslaw, L.R., 2012. Effects of grazing and invasive grasses on desert vertebrates in California. Journal of Wildlife Management 76, 670–682.

Hacking, J., Abom, R., Schwarzkopf, L., 2014. Why do lizards avoid weeds? Biology Invasion 16, 935–947.

Isbell, R., National Committee on Soil and Terrain, 1996. The Australian soil classification. CSIRO Publishing, Victoria, Australia, p. 152.

James, C.D., Landsberg, J., Morton, S.R., 1999. Provision of watering points in the Australian arid zone: a review of effects on biota. Journal of Arid Environments 41, 87–121.

Kay, G.M., Mortelliti, A., Tulloch, A., Barton, P., Florance, D., Cunningham, S.A., Lindenmayer, D.B., 2016. Effects of past and present livestock grazing on herpetofauna in a landscape-scale experiment. Conservation Biology 31, 446–458.

Knox, C.D., Cree, A., Seddon, P.J., 2012. Direct and indirect effects of grazing by introduced mammals on a native, arboreal gecko *(Naultinus gemmeus)*. Journal of Herpetology 46, 145–152.

Kutt, A.S., Fisher, A., 2011. Increased grazing and dominance of an exotic pasture *(Bothriochloa pertusa)* affects vertebrate fauna species composition, abundance and habitat in savanna woodland. Rangeland Journal 33, 49–58.

Kutt, A.S., Gordon, I.J., 2012. Variation in terrestrial mammal abundance on pastoral and conservation land tenures in north-eastern Australian tropical savannas: Mammal variation on pastoral and conservation lands. Animal Conservation 15, 416–425.

Kutt, A.S., Woinarski, J.C.Z., 2007. The effects of grazing and fire on vegetation and the vertebrate assemblage in a tropical savanna woodland in north-eastern Australia. Journal of Tropical Ecology 23, 95–106.

Kutt, A.S., Vanderduys, E.P., O'Reagain, P., 2012. Spatial and temporal effects of grazing management and rainfall on the vertebrate fauna of a tropical savanna. Rangeland Journal 34, 173–182.

Landsberg, J., James, C.D., Morton, S.R., Müller, W.J., Stol, J., 2003. Abundance and composition of plant species along grazing gradients in Australian rangelands. Journal of Applied Ecology 40, 1008–1024.

Lohmann, D., Tietjen, B., Blaum, N., Joubert, D.F., Jeltsch, F., 2012. Shifting thresholds and changing degradation patterns: climate change effects on the simulated long-term response of a semi-arid savanna to grazing: climate change and land use in savannas. Journal of Applied Ecology 49, 814–823.

Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 405, 243–253.

McIntyre, S., Hobbs, R., 1999. A framework for conceptualizing human effects on landscapes and its relevance to management and research models. Conservation Biology 13, 1282–1292.

McIvor, J.G., Ash, A.J., Cook, G.D., 1995. Land condition in the tropical tallgrass pasture lands. 1. Effects on herbage production. Rangeland Journal 17, 69–85.

McKeon, G.M., Stone, G.S., Syktus, J.I., Carter, J.O., Flood, N.R., Ahrens, D.G., Bruget, D.N., Chilcott, C.R., Cobon, D.H., Cowley, R.A., Crimp, S.J., Fraser, G.W., Howden, S.M., Johnston, P.W., Ryan, J.G., Stokes, C.J., Day, K.A., 2009. Climate change impacts on northern Australian rangeland livestock carrying capacity: a review of issues. Rangeland Journal 31, 1–29.

McLean, I., Holmes, P., Counsell, D., Ltd., B. A. P., Co., H., 2014. The northern beef report (2013 beef situation analysis) Final Report B. Com 0348. North Sydney, NSW, Australia, Meat and Livestock Australia, p. 154.

Milchunas, D.G., Sala, O.E., Lauenroth, W.K., 1988. A generalized model of the effects of grazing by large herbivores on grassland community structure. American Nature 132, 87–106.

Neilly, H., Vanderwal, J., Schwarzkopf, L., 2016. Balancing biodiversity and food production: a better understanding of wildlife response to grazing will inform off-reserve conservation on rangelands. Rangeland Ecology & Management 69, 430–436.

Neilly, H., Nordberg, E., Vanderwal, J., Schwarzkopf, L., 2017. Arboreality increases reptile community resilience to disturbance from livestock grazing. Journal of Applied Ecology Advance online publication.

Niamir-Fuller, M., Kerven, C., Reid, R., Milner-Gulland, E., 2012. Co-existence of wildlife and pastoralism on extensive rangelands: competition or compatability? Pastoralism: Research, Policy and Practice 2, 8.

Nordberg, E.J., Schwarzkopf, L., 2015. Arboreal cover boards: using artificial bark to sample cryptic arboreal lizards. Herpetologica 71, 268–273.

O'Reagain, P.J., Bushell, J.J., 2011. The wambiana grazing trial. Key learnings for sustainable and profitable management in a variable environment. Queensland Government Brisbane, Queensland, Australia 51 pp. Available at: https://futurebeef.com.au/wp-content/uploads/2012/04/5332_Wambiana-grazing-trial_update_v13.pdf. Accessed 20th May 2016.

O'Reagain, P.J., Scanlan, J.C., 2012. Sustainable management for rangelands in a variable climate: evidence and insights from northern Australia. Animal 7 (s1), 68–78.

O'Reagain, P., Bushell, J., Holloway, C., Reid, A., 2009. Managing for rainfall variability: effect of grazing strategy on cattle production in a dry tropical savanna. Animal Production Science 49, 85–99.

O'Reagain, P., Bushell, J., Holmes, B., 2011. Managing for rainfall variability: long-term profitability of different grazing strategies in a northern Australian tropical savanna. Animal Production Science 51, 210–224.

O'Reagain, P., Scanlan, J., Hunt, L., Cowley, R., Walsh, D., 2014. Sustainable grazing management for temporal and spatial variability in north Australian rangelands—a synthesis of the latest evidence and recommendations. Rangeland Journal 36, 223–232.

Orr, D.M., O'Reagain, P.J., 2011. Managing for rainfall variability: impacts of grazing strategies on perennial grass dynamics in a dry tropical savanna. Rangeland Journal 33, 209.

Price, B., Kutt, A.S., McAlpine, C.A., 2010. The importance of fine-scale savanna heterogeneity for reptiles and small mammals. Biological Conservation 143, 2504–2513.

Read, J.L., Cunningham, R., 2010. Relative impacts of cattle grazing and feral animals on an Australian arid zone reptile and small mammal assemblage. Australian Ecology 35, 314–324.

Scanlan, J.C., MacLeod, N., O'Reagain, P.J., 2013. Scaling grazing trial results upwards to a whole property level—a case study using the Wambiana grazing trial. Rangeland Journal 36, 223–232.

Scanlan, J.C., McIvor, J.G., Bray, S.G., Cowley, R.A., Hunt, L.P., Pahl, L.I., MacLeod, N.D., Whish, G.L., 2014. Resting pastures to improve land condition in northern Australia: guidelines based on the literature and simulation modelling. Rangeland Journal 36, 429–443.

Smith, F.P., Gorddard, R., House, A.P.N., McIntyre, S., Prober, S.M., 2012. Biodiversity and agriculture: production frontiers as a framework for exploring trade-offs and evaluating policy. Environmental Science Policy 23, 85–94.

t'Mannetje, L., Haydock, K.P., 1963. The dry-weight-rank method for the botanical analysis of pasture. Grass Forage Science 18, 268–275.

Tothill, J., Hargreaves, J., Jones, R., McDonald, C., 1992. BOTANAL—a comprehensive sampling and computing procedure for estimating pasture yield and composition. Tropical Agronomy Technical Memorandum, CSIRO Australia, Division Tropical Crops and Pastures, p. 88.

Valentine, L.E., Roberts, B., Schwarzkopf, L., 2006. Mechanisms driving avoidance of non-native plants by lizards: lizards avoid an introduced weed. Journal of Applied Ecology 44, 228–237.

Villar, N., Cornulier, T., Evans, D., Pakeman, R., Redpath, S., Lambin, X., 2014. Experimental evidence that livestock grazing intensity affects cyclic vole population regulation processes. Population Ecology 56, 55–61.

Woinarski, J.C.Z., Ash, A.J., 2002. Responses of vertebrates to pastoralism, military land use and landscape position in an Australian tropical savanna. Australian Ecology 27, 311–323.

Appendix 4: Bob Shepherd's Carrying Capacity Ready Reckoner

(DRAFT ONLY) Long-term Carrying Capacity (ha/AE) - Ready Reckoner (DRAFT ONLY)

(minimum average residual pasture = 800kg/ha)

by Bob Shepherd DAF Charters Towers Qld

Upper Burdekin Catchment (Charters Towers Region)

Low Rainfall Year (470mm - 30 percentile rainfall)					Median Rainfall Year (660mm - 50 percentile rainfall)					High Rainfall Year (800mm - 70 percentile rainfall)				
‡ Land Condition	Soil Fertility				‡ Land Condition	Soil Fertility				‡ Land Condition	Soil Fertility			
	Low	Moderate	High	High & Cleared		Low	Moderate	High	High & Cleared		Low	Moderate	High	High & Cleared
A	15ha/AE	10ha/AE	6ha/AE	4ha/AE	A	12ha/AE	6ha/AE	4ha/AE	2.5ha/AE	A	10ha/AE	5ha/AE	3ha/AE	2ha/AE
B	DS	13	8	5.5	B	16	8	5	3.5	B	13	7	3.5	2.5
C	DS	DS	37	7	C	DS	13	8	6	C	DS	11	6	4.5
D	DS	DS	DS	DS	D	DS	DS	DS	37	D	DS	DS	26	9
* DS = destock	Tree basal areas used:- 4m²/ha normal density for HM&L fertility; 1m²/ha for high fertility & cleared													

High fertility land types (150kg/hd/yr) cleared or treeless:-
1. Black basalt country (naturally treeless)
2. Brigalow & gidgee scrubs (cleared with minor regrowth)
3. Downs (bluegrass &/or Mitchell grass)

High fertility land types (150kg/hd/yr) with trees:-
4. Basalt country (red, brown or black with trees)
5. Black goldfields country
6. Clayey alluvials

Moderate fertility land types (120kg/hd/yr) with trees:-
7. Blackwood scrubs on structured clays (cleared with minor regrowth)
8. Box country
9. Loamy alluvials
10. Narrow-leaved ironbark on deeper soils
11. Red goldfields country
12. Softwood scrubs (cleared with minor regrowth)

Low fertility land types (90kg/hd/yr) with trees:-
13. Blackwood scrubs on massive soils (cleared with minor regrowth)
14. Narrow-leaved ironbark on shallower soils
15. Ranges
16. Silver-leaved ironbark
17. Yellowjack & other eucalypts

Land types not included due to limited distribution:-
18. Box & napunyah
19. Lancewood bendee rosewood country

Adult Equivalents (AEs):- 1.0AE = 450 kg L Wt dry & empty animal
Example 1 - 180kg weaner = 0.5AEs
Example 2 - 450kg PTIC cow = 1.35AEs

Some definitions

Long-term carrying capacity - is the average rate (ha/AE) at which livestock can be sustainably grazed over a 10 year period. This is the data shown for the Median Rainfall Year in the table above. It assumes a minimum average residual of 800kg/ha of pasture at the end of the dry season.

Short-term carrying capacity - the rate (ha/AE) at which livestock can be grazed for a calendar year. This can be obtained from the table above by selecting the type of year (based on rainfall) being experienced ie **Low**, **Median** or **High** rainfall year.

Stocking rate - the number of cattle that can be run in a paddock for a nominated period such that adequate pasture cover is retained to maximise the infiltration of rainfall during the next wet season. This can only be obtained by doing a forage budget at a paddock scale. **Figures in the table above are carrying capacities, not stocking rates.**

Note:- carrying capacity and stocking rates are expressed in ha/AE (adult equivalent), therefore as carrying capacity increases, the number of hectares required to support each AE decreases ie the numbers get smaller.

‡ ABCD Land Condition Framework

"A" - good coverage of 3P pasture species; high ground cover; few weeds; good soil surface condition with no evidence of soil movement.

"B" - some decline in 3P pasture species; increase in undesirable species or weeds; signs of previous erosion or susceptibility to erosion.

"C" - general decline in 3P species; dominated by undesirable pasture species, annual grasses or weeds; obvious signs of erosion and significant areas with low pasture cover.

"D" - general lack of perennial pasture species; may be dominated by annual species; severe erosion or scalding resulting in a hostile environment for plant establishment and growth.

Bonuses & discounts

Bonus - well established legume pastures will increase carrying capacity by 50% eg 10ha/AE becomes 6.5ha/AE (LTCC x 0.65)

Discount - moderate woodland thickening (including woody weeds) will decrease carrying capacity by 25% eg 10ha/AE becomes 13.5ha/AE(LTCC x1.35)

Discount - heavy woodland thickening (including woody weeds) will decrease carrying capacity by 50% eg 10ha/AE becomes 20ha/AE (LTCC x 2)

Some GLM recommendations

1. Set sensible upper limits to stocking rates in good seasons; the sky is not the limit!
2. Reduce cattle numbers quickly and rebuild numbers slowly. Delay bringing cattle home from agistment until pasture is well "ahead of the cattle."
3. Stock conservatively to allow flexibility for the adoption of a wet season spelling program across the property.

Fundamentals first

1. Understand what determines pasture growth - rainfall, land type & land condition
2. Land condition is the only one that can be managed
3. Adequate water distribution
4. Paddocks fenced to land types where feasible
5. Stocking rates matched to carrying capacity
6. Targeted wet season spelling
7. Burn to suppress woodies & change pasture composition (pre-fire plan & post-fire manage)
8. Control weeds early
9. Over-sow pastures with legumes

Fine tuning

1. Evaluate your grazing system - but be realistic about the degree of improvement.
2. Move supplementary feeding points around the paddock
3. Monitor land condition (use Forage & VegMachine packages)
4. Visit other properties & regions for new ideas
5. Seek out quality training

Disentangling the effects of management and climate on perennial grass pastures and the degradation that follows multi-year droughts

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Abstract: Measured data from a long-term grazing trial and insights gained from modelling show that degradation processes following multi-year droughts are not easily reversed, and perennial pastures don't always recover. The combination of drought and overstocking has led to a significant decline in land and pasture condition, with the death of perennial grasses, loss of surface soil protection from ground cover and delayed recovery from drought. Tied up to the loss of desirable perennial grasses is the increase in non-desirable grasses and shrubs, which puts further pressure on the pasture resource available for grazing.

The aim of this study is to use a long-term, high-quality dataset to separate the effects of grazing management and climate on pastures using the biophysical model GRASP. The model captures the effects of both climate and grazing management on the pasture resource and pasture attributes. This involves gaining insights and detecting shifts in vegetation species composition after multi-year wet and dry periods, as well as how the grass species composition changes with the interaction of drought and high stocking rates. The loss of perennial, palatable and productive grass species is important for the grazing industry as it impacts pasture quality, quantity and resilience. When these grass species have been grazed out of the system, animal production can be impacted. The shifts in vegetation composition could also be driving changes in hydrology through reduced infiltration, increased runoff and changed water use patterns by vegetation.

The Wambiana grazing trial is regarded as one of the most important field experiments in grazing science because it addresses the major issue of long-term livestock grazing of Queensland's native pastures in a highly variable climate. The trial provides an excellent opportunity to evaluate the effects of climatic (i.e. multi-year wet and dry periods) and grazing management (i.e. fire and stocking rate) on pasture production and resource degradation for a savanna ecosystem (open woodland with perennial native pastures). The simulation study used the GRASP model to represent various processes affected by: a) rainfall variability at multi-year timescales with periods of above average rainfall (Wet Periods 1 and 2) and below average rainfall (Dry Periods 1 and 2); and b) variation in grazing pressure by comparing moderate and heavy continuous stocking rates.

Combining data on stocking rates, field measurements of runoff, pasture growth, biomass, grass basal area, species composition and satellite remote sensed green and dry fractional cover with the GRASP model provides the opportunity for high quality model parameterisation where many of the model parameters are strongly constrained by observational data and previous modelling experience. A well calibrated model is a starting point to investigate the development of new model functions and analyses. We detail how the model calibration was developed, and to what extent we could explain the observed changes in pasture biomass. This work revealed emerging processes in the landscape that we do not currently model, some of which are caused by prolonged droughts and high stocking rates. These processes include the increase in introduced grass species *Bothriochloa pertusa* and an increase in the native shrub currant bush (of up to 30% of the land surface area). This work also revealed the need to model the effects of degradation of soils (surface sealing and reduced infiltration) that followed multi-year drought and high utilisation rates. The parameters and insights derived from this study will help inform the modelling of degradation and recovery in grazing landscapes. This study is important for the grazing industry and policy as it impacts on calculations of long-term carrying capacities, pasture biomass and ground cover for sustainable grazing. This study contributes to current applications of GRASP addressing long-term carrying capacity in areas with woody vegetation.

Keywords: *drought, recovery, woody vegetation, savanna ecosystems, parameter estimation*

1. INTRODUCTION

An issue commonly raised in the sustainable management of land and pastures in a drought prone climate is how to separate the effects of climate and management. Drought combined with overstocking has led to a significant decline in land and pasture condition in north Queensland in terms of reduced ground cover and a decline in perennial grass species (Tothill and Gillies 1992, O'Reagain et al. 2014). Managing pasture condition and in particular, perennial grass composition, is critical for the long-term sustainability of grazing lands. However, the high year-to-year and multi-year rainfall variability that is a feature of Queensland's climate poses major challenges for land managers, especially in multi-year droughts. Understanding the relative roles of both climate and management is thus critical in improving sustainable management of our land and pasture resources.

The purpose of this study is to separate climate and management effects on pastures using long-term measured data and simulation modelling. One of the main indicators of the impact of grazing is pasture biomass or total standing dry matter. Other indicators are pasture species composition, grass basal area and ground cover. The changes in vegetation species composition after long dry periods and overgrazing are important indicators of pasture degradation and recovery. These shifts in vegetation composition could also drive changes in hydrology through reduced infiltration, increased runoff and soil evaporation and changed water use patterns by vegetation.

Over the last 70 years, field trials (lasting approximately 10-15 years) have provided recommendations on sustainable grazing management. Simulation models have been developed to extrapolate the findings over longer periods using historical climate data and to other locations. The Wambiana grazing trial was set up near Charters Towers in Queensland in 1997 to compare different stocking strategies over time in a highly variable climate (O'Reagain et al. 2018). Measured data from the experiment over the last 23 years provided us with information and insights to model processes such as pasture degradation and recovery. This paper describes the modelling and optimisation approach using field measured pasture biomass and species composition data, complemented with satellite remote sensing data for ground cover. The insights and systems analysis from this study are important for the grazing industry and policy as it impacts on calculations of long-term carrying capacities and pasture biomass available for sustainable grazing.

2. STUDY AREA AND DATA

This study uses measured data from one of the longest running field trials in Queensland – the Wambiana grazing trial (Figure 1). The experiment was established in 1997 as a large grazing trial with the specific objective of quantifying the relative effects of different grazing strategies on animal production, economic performance and resource condition. The trial is located in an open woodland 70 km south-west of Charters Towers in north Queensland (20° 34'S, 146° 07'E) (O'Reagain et al. 2018). Long-term average annual rainfall is 627 mm (calender year, 1890 to 2020), with 80% of rainfall occurring from October to March. Rainfall is highly variable, ranging from 109 to 1410 mm/yr. Most of the rainfall occurs in the 3 months of summer (56% of the long-term annual average).

The trial site is in the *Aristida–Bothriochloa* pasture community (Tothill and Gillies 1992) and is an open *Eucalyptus-Acacia* woodland overlying C4 tropical native grasses. The trial site has three vegetation-soil associations, but this study focuses on data and modelling from the dominant (55% by area) association referred to as Box. The Box landtype is characterised as brown Sodosols and Chromosols and is dominated by Reid River

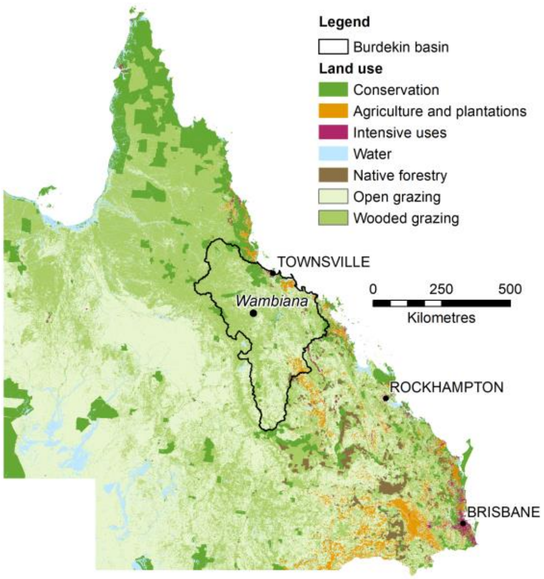


Figure 1. Wambiana Grazing Trial and the Burdekin catchment overlain on the distribution of major land use types in Queensland. The Queensland Land Use Mapping Program (QLUMP) is the best currently available, published in 2019. The wooded vs open grazing is from the woody vegetation extent product from the Remote Sensing Centre based on 2014 imagery. (https://qldspatial.information.qld.gov.au)

box (*Eucalyptus brownii*). An understorey of currant bush (*Carissa ovata*) also covers up to 30% of the area and is steadily increasing. Pastures on the Box landtype are dominated by native perennial grasses and annual grass species. The exotic, stoloniferous perennial grass, Indian couch (*Bothriochloa pertusa*), has increased since 2010 in all treatments, particularly in the heavily grazed treatments. The trial has five grazing strategies replicated twice, in paddocks from 93 to 117 ha in size (O'Reagain et al. 2018). Here we focus on two treatments with the greatest contrast:

1. Moderate stocking rate (MSR) - continuously stocked at the estimated long-term carrying capacity of the site to achieve an average of 20-25% utilisation of expected pasture growth (8 - 10 ha/AE).
2. Heavy stocking rate (HSR) - continuously stocked at about twice the long-term carrying capacity to achieve an average of 40-50% utilisation of expected pasture growth (4 -5 ha/AE). Stocking rates had to be significantly reduced in a number of years due to drought and the lack of available forage.

Daily interpolated climate data was obtained from SILO (Jeffrey et al. 2001) for Charters Towers weather station 34084. Rainfall data measured at the trial site using pluviometers was used in the simulation study. A rainfall anomaly time series was used to identify drought periods, following the method of Saft et al. (2015), shown in Figure 2, where bars indicate annual rainfall anomalies, and the smoothed line indicates three-year rolling average rainfall anomaly. There were 2 distinct dry and wet periods identified during the study; wet periods 1998 to 2001 and 2007 to 2012; dry periods 2002 to 2006 and 2013 to 2020.

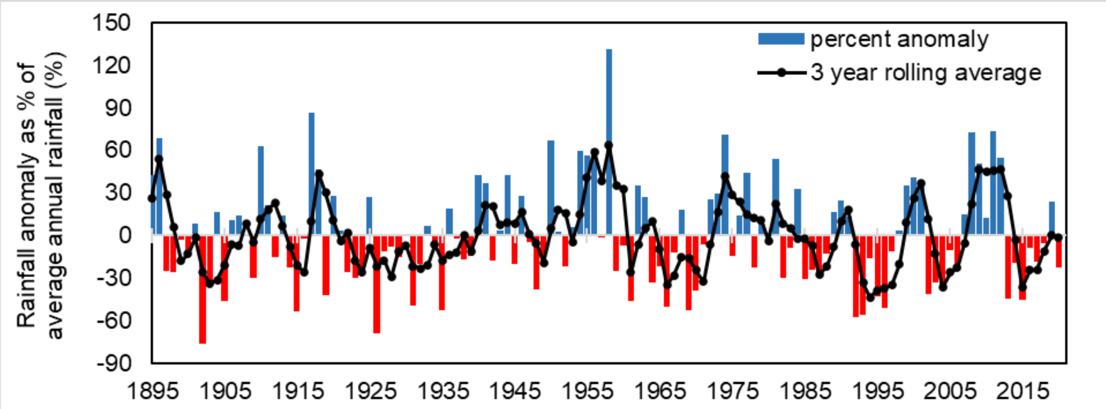
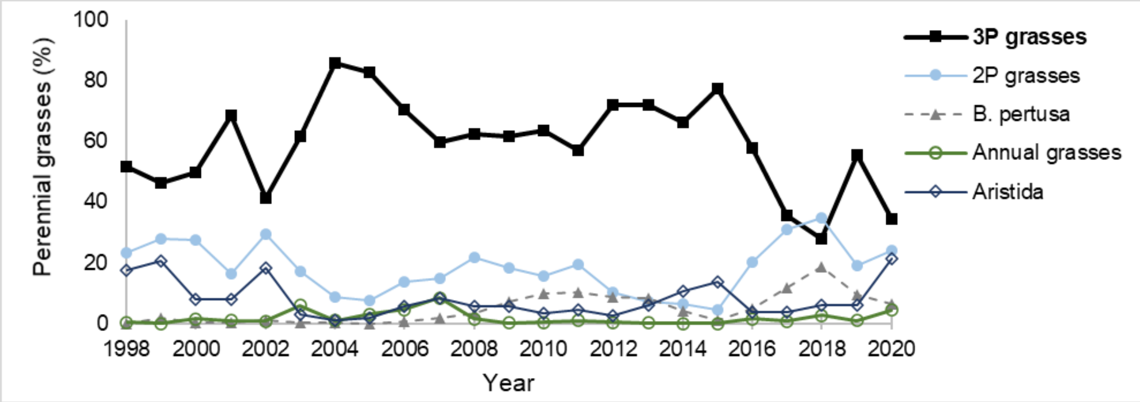


Figure 2. Rainfall anomaly as a % of average annual rainfall for the water year (30 Sep to 1 Oct) for Charters Tower climate station 34084. Bars indicate annual rainfall anomalies and black line indicates three-year rolling average rainfall. Red bars indicate years falling in identified drought period; blue bars indicate the remainder of the historical period.

Pasture biomass (i.e. total standing dry matter) and species composition was measured annually at the end of the wet season (May) and in the late dry season (October) using the Botanal methodology (Figure 3). Species data was grouped into major functional groups (3P grasses, 2P grasses, *Bothriochloa pertusa*, annual grasses, and *Aristida* species). The P's represent grasses that are perennial, productive and palatable and are desirable species in the grazing system and are an important indicator of pasture condition. Pasture composition data guided parameterisation, particularly for minimum nitrogen concentration during the wet and dry periods.

Satellite data for deriving cover was extracted from the United States Geological Survey's Landsat dataset for all single date, cloud free, Landsat based estimates. These data were extracted from Landsat images from 1994 to 2020 from the QLD Government Remote Sensing Centre data store on (26/02/2021). The satellite-derived data used for modelling were fractional green cover, total ground cover and persistent green. The persistent green cover data was used in the model as an indicator of change in foliage projected cover.

The satellite-derived observations were also used to compare the ground cover of the grazing trial to the surrounding region (25km radius) as shown in Figure 4 and available for any property in Queensland from the LongPaddock website (https://www.longpaddock.qld.gov.au/forage). The plot shows narrow bands of high ground cover during the 2 wet periods: 1998 to 2001 and 2007 to 2012 and highlights ground cover was similar to other properties in the region during the wet years. The plots also clearly show the separation of ground cover that occurs during the dry periods: 2002 to 2006 and 2013 to 2020. It also illustrates how ground cover at the Wambiana grazing trial (for all treatments and paddocks) compares to the region. The plot illustrates the effects of climate during the wet and dry periods, with narrow bands during the wet periods and a wider range of ground cover during the dry periods. It is in this wider range of ground covers during the dry periods where the effects of management can be investigated.



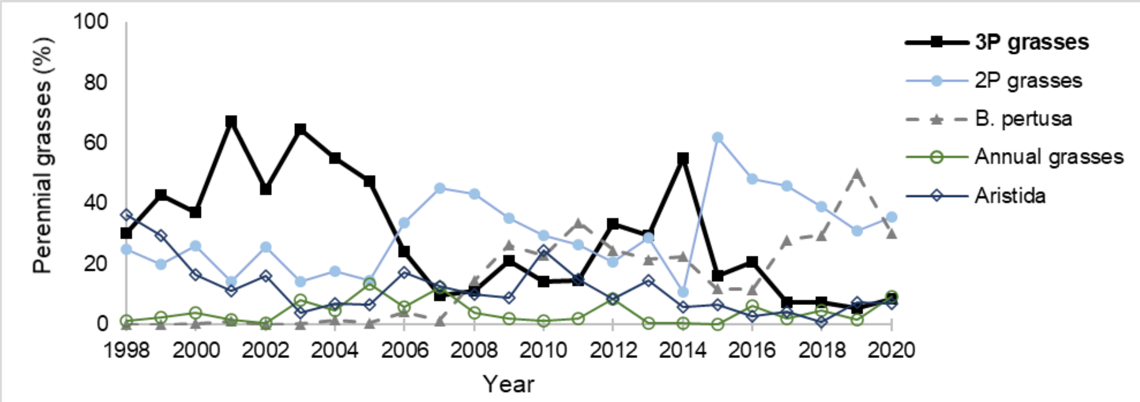


Figure 3. Measured pasture composition of grasses at the end of the wet season in May for (a) moderate and (b) heavy stocking rate paddocks for the Box landtype at the Wambiana grazing trial. The proportion of 3P grasses is an important indicator of pasture condition and the moderately stocked treatment has a higher proportion of 3P grasses compared to the heavily stocked treatment. The introduced grass, *Bothriochloa pertusa* is increasing in both treatments, and is higher in the heavy stocked treatment.

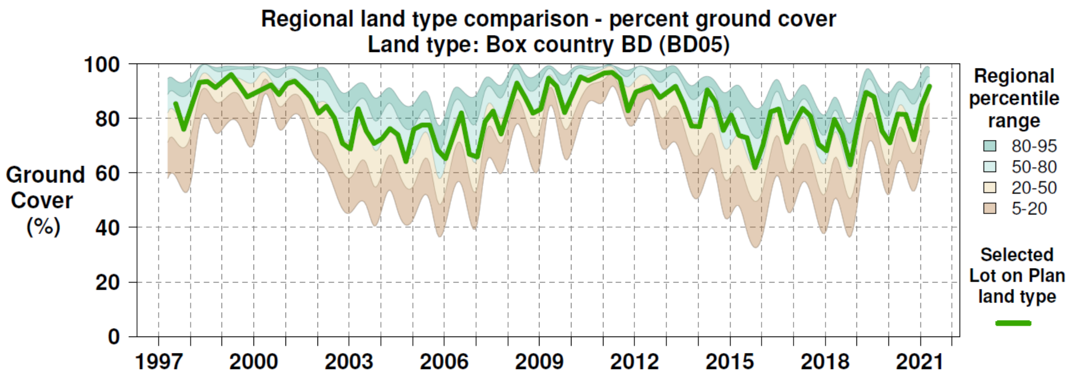


Figure 4. Regional land type comparison of percent ground cover for the Box landtype at Wambiana, compared to the region. The green line represents the average of all treatments in the grazing trial.

3. MODEL DESCRIPTION

GRASP is a biophysical model of soil water balance, pasture growth and animal production developed for northern Australian grasses in wooded and non-wooded systems (Day et al. 1997, Zhang et al. 2021). The Cedar version of GRASP (version 1.2) was used for all model simulation and is the Linux version that underpins the core model used on other platforms such as the Windows version and other operational versions, such as FORAGE (Zhang et al. 2021). Practical applications for the model include the calculation of long-term livestock carrying capacity for grazing properties in Queensland using GRASP and its parameter sets to combine knowledge from field experimentation, land resource surveys, remote sensing of vegetation and grazier estimates of carrying capacity (Zhang et al. 2021).

Driving data such as climate, stock numbers, stock live weight, and fire incidence were assembled for each treatment and entered into the GRASP management records data format. In addition, field observations of pasture biomass, composition, grass basal area and satellite cover were entered into the GRASP management record format and checked for errors. These measured datasets are invaluable in calibrating, testing and model improvement as well as ground truthing remote sensing data.

The starting point for growth related model parameters was the analysis of measurements from exclosure plots established at the grazing trial. Pasture growth, soil moisture and nitrogen were measured through the growing season using the GUNSYNpD methodology which was designed to collect a minimum dataset for estimating key pasture growth and soil parameters (Day et al. 1997). Runoff measurements from small catchments within the grazing trial were used to ensure that modelled runoff was within the range of observations. We estimated parameters using a Differential Evolution method (Storn and Price 1997), which is a simple and efficient method for global optimisation. The objective function was the root mean square error of daily pasture biomass predictions. Parameters were optimised to minimize the objective function, with parameters constrained within sensible limits based on prior knowledge from a wider network of grazing trials and grass production sites to calibrate the model using 23 years of measured pasture biomass data. The two parameters optimised were the *potential pasture regrowth* (parameter 6) and the *soil moisture threshold for the cessation of pasture growth* (parameter 149). We used the moderate stocking rate treatment for calibration and applied the calibrated model to the high stocking rate treatment to reveal degradation signals once the effects of climate and livestock consumption were accounted for.

4. RESULTS AND DISCUSSION

Improvement in pasture biomass simulated by GRASP was obtained through optimisation of two parameters with measured data for the moderate stocking rate treatment. Optimised parameters were then run for the heavy stocking rate treatment, with reasonable predictions of pasture biomass, showing that grazing management effects could be explained by consumption of pasture dry matter (Figure 5). Changes in foliage projected cover used in the simulation explained some of the variation in pasture biomass. This was particularly important after pasture burning, when foliage projected cover was greatly reduced.

The model calibration of the moderate stocking rate treatment was reasonable but did not capture all aspects of the measured data (Figure 5a). Simulations of standing dry matter were consistently higher than measured values for the last 5-7 years of the trial for both treatments, even after stocking rate was reduced in the high stocking rate treatment during the drought when severe degradation occurred (Figure 5b). The low pasture biomass in both treatments indicates that degradation processes of both the pasture and soil resource were not being captured after the last drought. Trial data shows that pasture composition had changed before this effect became apparent in the simulations, indicating that the degradation processes, in addition to composition change (Figure 3) were already in progress.

The likely causes of the over-prediction of pasture biomass in Figure 5 are: (1) reduced tussock densities as a result of low rainfall and associated higher grazing pressure; (2) surface sealing and reduced infiltration capacity (Fraser and Stone 2016); and (3) increasing density of shrub cover (currant bush) resulting in greater competition for soil water and nutrients impacting pasture growth. The mathematical representation of these processes is the subject of current research. In addition, we are aware of other factors affecting pasture biomass such as increased detachment rates, errors in accurately measuring biomass in the prostrate form of *Bothriochloa pertusa*, and livestock consuming an increased forb/annual grass component prior to field measurements in May.

The differences in pasture biomass between moderate and heavy stocking rate treatments allow some assessment of climate and management effects. The simulations of pasture biomass with constant parameters over the 23 years for the moderate stocking rate explain the ‘potential’ effects of variable rainfall on biomass. The biomass differences between stocking rate treatments in both wet periods and most of the first dry period are simulated/explained by the increased consumption (and trampling) from higher stocking rates.

In contrast, the lower pasture biomass at the end of dry period 1 and most of dry period 2 (compared to the ‘potential’) demonstrated the decrease (‘degradation’) in pasture production caused by the heavy grazing pressure, particularly in the prolonged dry periods. For both moderate and heavy stocked treatments, the lower pasture biomass (compared to the potential production) at the end of dry period 2 indicate that recovery of pasture production back to potential did not occur. In particular, there was a lack of recovery in the heavy stocking rate treatment even though the grazing pressure had been greatly reduced, suggesting longer lasting effects on the resource with heavy utilisation.

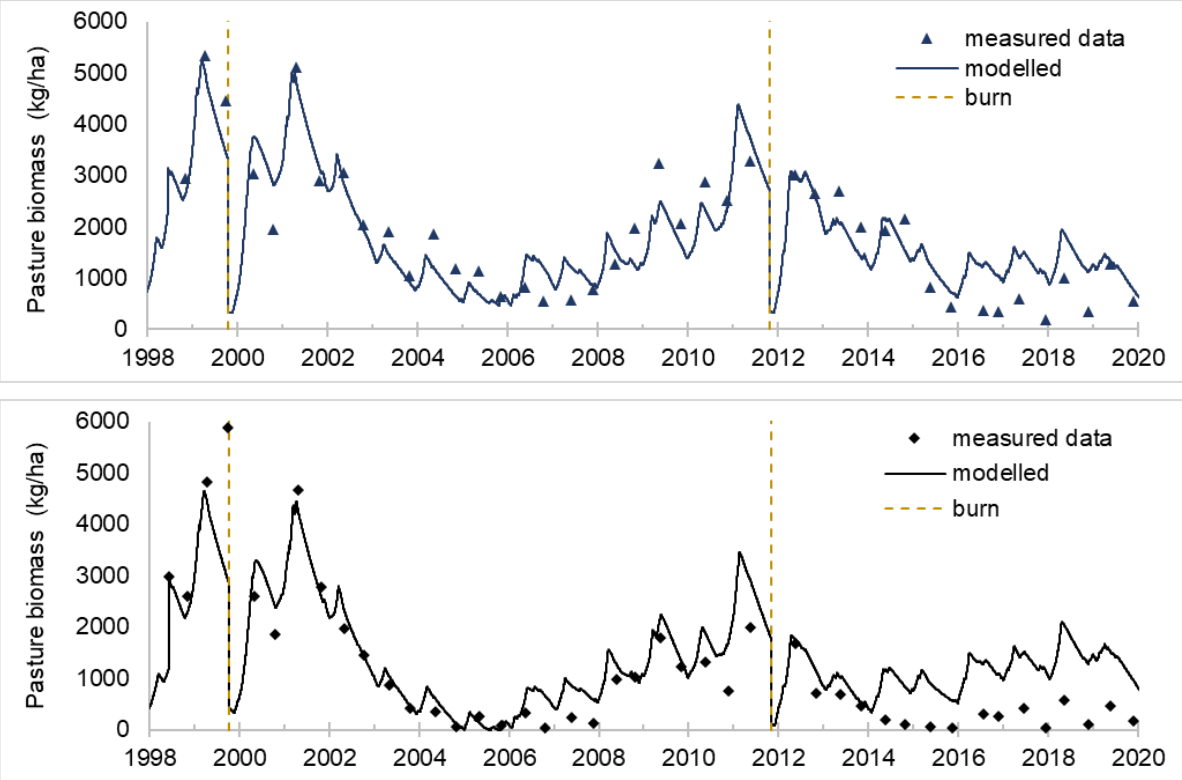


Figure 5. Predicted and measured pasture biomass for two treatments, (a) moderate stocking rate (top) and (b) high stocking rate (bottom). The site was burnt in October 1999 and 2011 to manage woody vegetation.

Comparison of simulated green cover and the satellite-derived green cover were in general agreement (Figure 6). The annual seasonal wet and dry cycle of green cover was well simulated by the modelled processes of pasture growth and senescence which are strongly linked to soil moisture. Peak observed and simulated green cover were similar in the two wet periods and at the start of the two dry periods with some under prediction consistent with under prediction of pasture biomass. However, in the later years of the two dry periods, peak green cover was under predicted in contrast to the over prediction of pasture biomass. Possible causes could be changes in the relationship of green cover to green biomass as a consequence of changes in pasture sward structure and/or changes in pasture species composition associated with heavier grazing pressure.

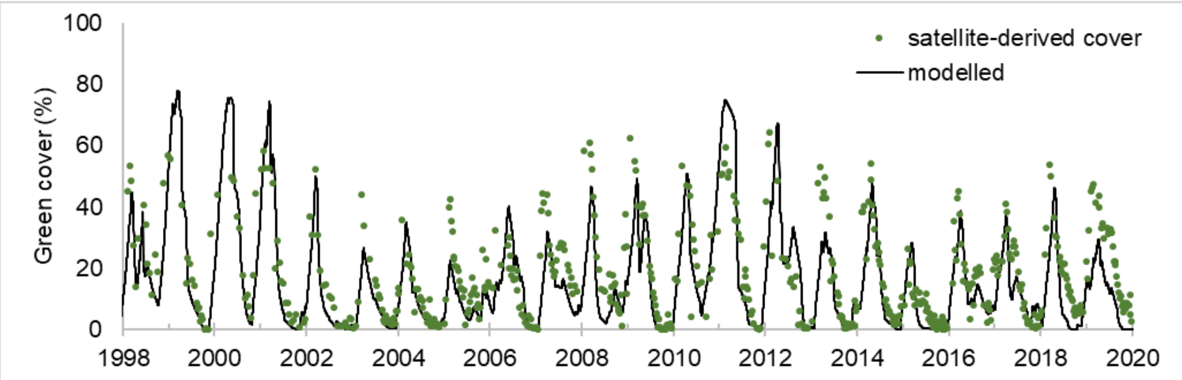


Figure 6. Predicted green cover for the moderate stocking rates treatment plotted with observed satellite-derived green cover.

A scoping study was carried out using a systems analysis approach to investigate the biophysical processes operating that were not currently captured by the dynamic model. The wet and dry periods were separated during the simulation with separate sets of parameters and model resets. This approach provided insights on the processes driving pasture growth during the wet and dry periods. The study revealed that 4 major parameters could be used to simulate pasture biomass reasonably well compared to measured data, particularly in the last dry period (2014 to 2020) which was overpredicted by the dynamic model. The 4 parameters were *potential* *nitrogen uptake*; *minimum nitrogen concentration in pasture dry matter*; *potential pasture regrowth*; and *soil moisture threshold for the cessation of pasture growth*.

For the optimisation used in Figure 5, we calibrated only two of these parameters for the full 23 years of the trial without any separation of wet and dry periods (*potential pasture regrowth* and *soil moisture threshold* parameters). The next steps are the construction of sub-models in GRASP dynamically linking variation in these parameters with pasture composition and perennial tussock density reflecting the effects of multi-year rainfall sequences and grazing management (stocking rates and fire).

5. CONCLUSION

This study provides parameterisation for improving the modelling of pastures in savanna ecosystems, especially during prolonged droughts. The findings of our study will contribute to current applications of GRASP addressing the issue of long-term carrying capacity and pasture biomass available for sustainable grazing. We demonstrate how satellite-derived vegetation cover data can be used to evaluate and support modelling of ground cover in grazing systems. Modelled and measured pasture biomass agreed well after model optimisation and provided insights on missing processes, giving us more confidence in identifying degradation and recovery signals. This study revealed several known but unrepresented processes in the GRASP model, which is the subject of current research. However, the long-term datasets and modelling can help diagnose the patterns of degradation and provide a platform for the generation and testing of algorithms that more accurately describe aspects of the degradation process.

ACKNOWLEDGEMENTS

This work would not have been possible without the long-term dataset from the Wambiana grazing trial co-funded by DAF and Meat and Livestock Australia. We are deeply grateful to the Lyons family, Wambiana, for hosting the trial site, and to John Bushell and technical staff at DAF for data collection. We are grateful to Mathew Pringle for python scripts to estimate fractional cover from Landsat, Robert Denham for the Ground Cover Regional Comparison Report, and to Tessa Chamberlain from the Paddock to Reef Team for the Queensland Land Use Mapping and woody vegetation extent. We acknowledge funding from the Queensland Drought and Climate Adaptation Program (DCAP) and the Queensland Reef Water Quality Program.

REFERENCES

Day, K.A., McKeon, G.M. and Carter, J.O. (1997). Evaluating the risk of pasture and land degradation in native pastures in Queensland, Final Report on DAQ124A to RIRDC (six volumes).

Fraser, G.W. and Stone G.S. (2016) The effect of soil and pasture attributes on rangeland infiltration rates in northern Australia. The Rangeland Journal 38, 245-259.

Jeffrey, S.J., Carter, J.O., Moodie, K.B. and Beswick, A.R. (2001) Using spatial interpolation to construct a comprehensive archive of Australian climate data. Environmental Modelling & Software 16(4), 309-330.

O'Reagain, P.J., Scanlan, J., Cowley, R., Hunt, L. and Walsh, D. (2014). Sustainable grazing management for temporal and spatial variability in north Australian rangelands – a synthesis of the latest evidence and recommendations. The Rangelands Journal 36: 223-232.

O'Reagain, P., Bushell, J., Pahl, L., and Scanlan, J. (2018). Wambiana Grazing Trial Phase 3: Stocking Strategies for Improving Carrying Capacity, Land Condition and Biodiversity Outcomes. Meat and Livestock Australia Final Report to Project B.ERM.0107 (Meat and Livestock Australia: North Sydney, NSW.); 149pp.

Saft, M., Western, A.W., Zhang L., Peel, M.C. and Potter N.J. (2015). The influence of multiyear drought on the annual rainfall-runoff relationship: An Australian perspective. Water Resources Research. 51, 2444–2463. https://doi.org/10.1002/2014WR015348

Storn, R. and Price, K. (1997). Differential evolution – a simple and efficient heuristic for global optimization over continuous spaces. Journal of Global Optimization, 11, 341–359.

Tothill J.C. and Gillies C. (1992) 'The pasture lands of northern Australia. Their condition, productivity and sustainability.' (Tropical Grassland Society of Australia: Brisbane)

Zhang B., Fraser G., Carter J., Stone G., McKeon G., Whish G., Wilcock J. (2021). An online system for assessing long-term carrying capacity for Queensland grazing properties: Part 2 modelling and outputs (accepted: The Rangelands Journal).

Appendix 8: Case studies- Northern Grazing Demonstration project

Executive Summary

Producers associated with the Wambiana Grazing Trial (WGT) identified that inspiring land managers to adopt better grazing management by on-property demonstrations of what can be achieved with good, conservative grazing management practices should be a priority.

This Northern Grazing Demonstration (NGD) project was established on four commercial properties, one each in the priority areas of Upper Herbert, Upper Burdekin, Bowen Broken Bogie (BBB) and Fitzroy regions within the Great Barrier Reef catchment. Each property had an associated local producer group of between four to eight members. This project did not intend to compare different management strategies in a research framework, rather, its intent was to demonstrate and extend current research knowledge, and best practice, in grazing land management by on-property demonstrations using collaborators that are recognised as managing their land well.

The network of demonstration sites successfully provided an essential platform for the Wambiana Grazing Trial to discuss and extend its findings and recommendations. It is difficult to predict how many groups will continue after this project, but it is likely that Ametdale, Leichhardt Creek and Goshen groups will continue in the short term. Both sites will be supported through the DAF Reef Water Quality Activities Grazing Extension Support project.

Without exception, all producers involved in the communication events rated them highly. The demonstration sites provided an ideal forum to show that graziers can, and are, managing their land well, while remaining productive and viable. Some simple land management messaging came out of the project. The top producers do the following:

1. Recognise that their pasture resource is the key profit driver in their business.
2. Combine common sense, experience and visual feed assessments to manage cattle numbers in a variable rainfall climate.
3. Use systematic wet season spelling every year to maintain/improve land condition and provide a pasture/feed buffer during the lean low rainfall years.
4. Use selling and destocking trigger points to balance cattle and feed supplies. '*We place value on a core group of breeders, normally our younger heifers, everything else is expendable'.*
5. Maintain some stubble and good ground cover at the break of season to maximise pasture response and minimise erosion.

Although this type of awareness project will contribute to increasing adoption, it is a slow process. It is also becoming increasingly apparent that many producers do not recognise that they have a grazing land management issue and is therefore not a priority to them. However, there are new and accessible tools such as FORAGE, StockTake and Ready Reckoner that are making inroads for improving understanding of 'my property' GLM issues. Unfortunately, many still show little understanding of how poor grazing land management (including low ground cover at the break of season) links to, and impacts, both cattle production and downstream ecosystems. Realistically, the NGD was only planting the seed for practice change; however, this project will leave a legacy of practical messaging and improving management tools for those producers ready for change.

Recommendations

- Monitor the progress of the new Northern Breeding Business (NB2) model as this could provide a new adoption framework

- Land condition and grazing management projects need to be over a longer time frame than three years to achieve higher success in adoption.
- Continue monitoring progress at Ametdale to determine the length of time required for the on-ground changes to occur and calculate cost-benefit over a length of time. Leichhardt Creek group site will continue to operate in this region.

Grazing and business management in the Bowen, Broken, Bogie Region

Property: **Leichardt creek**

Date: **December 2020**

Background

Leichhardt Creek is a 16,900 hectare property approximately 130 km south of Townsville, near Gumlu. The property is a breeding and backgrounding operation that generally carries around 2400 Adult Equivalents (AE), and receives average annual rainfall of around 600 mm. Over the last 20 years however, this has varied between 300 and1700 mm. The managers like those of many beef cattle operations, treat the property as they would their own. They have been working on Leichhardt creek for over 17 years and this has given them a good understanding of its capacity from a grazing land management perspective. Soil types, grazing values and safe stocking rates are shown in Table 1.

Table 1: Leichhardt Creek soil types, stocking rates and grazing values

Soil type	Grazing value*	Carrying capacity in A condition & 100% access to water
River alluvial	10	1 AE: 4.0 ha
Ironbark on Deep Clays	8	1 AE: 5.0 ha
Red Goldfields Soils	7	1 AE: 5.0 ha
Black Goldfields soils	7	1 AE: 5.0 ha
Rangelands	4	1 AE: 10 ha
Tea Tree Forest	2	1 AE:12.0 ha

* Land types recognised across the Bowen Broken Bogies region and grazing value of each type in good condition. The highest value land is rated 10 and the lowest rated 1.

The predominant land types on Leichhardt Creek are almost uniformly comprised of Black (Figure 1) and red goldfield soils. This type of country is typically on a well-structured red clay-loam soil and is common to that area of the Burdekin. Although it is not premium beef production country it is generally considered to be very good breeder country. The east and south-east parts of the property are rangelands with some areas of Tea Tree Forest which is heavily timbered. There are some narrow strips of alluvial soils directly adjacent to watercourses and some interspersed areas of Ironbark on deep soils.

Figure 1: Black Goldfields land type

Figure 2: Ironbark on Deeper Clays

In terms of pasture, most of the property is dominated by Indian couch with a healthy mix of native pastures such as black spear grass, desert blue Grass and Aristida spp. There is also a good population of Shrubby and Caribbean Stylos which are a significant contributor to the diet composition of cattle.

Figure 3: Red Goldfields land type

Production System

Leichhardt Creek is a breeding and growing operation that has the flexibility to market growing animal to feedlots as backgrounders (340-420 kg liveweight) or in leaner years as live exports cattle (270-340 kg liveweight) although with good management employed this has not been a required market for some years. They only sell a small number of young females prior to mating, these animal are identified and spayed so that they can be held onto without fear of unwanted pregnancies. All empty females are allowed one chance to miss a calf and are identified by a button earmark. If the cow misses two calves she is then offloaded as a cull cow to the meatworks (generally at 450-550 kg liveweight).

Control mating has been conducted at Leichhardt Creek for some years now. Bulls are put out with females from the second week of January until the end of May (18 weeks). Maiden heifers are mated for a shorter time from second week of January till end of April. Females are then managed as separate mating groups until their second calf. Table 2 outlines Leichhardt Creek's herd economic performance for 2019-20.

The manager plans to implement an intensive grazing system that includes leucaena next year. He intends to utilise leucaena to improve weight gain and allow steers to be turned off earlier in May, spell the leucaena for 6-8 weeks, and then if the season allows, graze it again with cull cows so that they can be turned off before the wet season. This will reduce the stocking rate of other retained breeders and allow a greater wet season response.

This sort of thinking moves hand in hand with their desires to move the business further towards conservative grazing whilst also improving cattle performance to maintain or increase the kg/ha produced. They are also keen to improve the genetic potential of their cattle through improved selection of females in order to retain a core breeding nucleus. As the manager says, *"we place value on a core group of breeders, normally our younger heifers, everything else is expendable".* They are also looking to identify Brangus sires with better objective measurements.

Table 2: Herd dynamics and gross margin/AE for Leichhardt Creek

	Herd Figures 2020
Total adult equivalents	**2,600**
Total cattle carried	**2,779**
Weaner heifers retained	**387**
Total breeders mated	**1,452**
Total breeders mated & kept	**1,184**
Total calves weaned	**825**
Weaners/total cows mated	**56.85%**
Wnrs/cows mated and kept	**69.73%**
Overall breeder deaths	**5.20%**
Female sales/total sales %	**43.94%**
Total cows and heifers sold	**317**
Maximum cow culling age	**13**
Heifer joining age	**2**
Total steers & breeders sold	**402**
Average female price	**$1,222.91**
Average steer/bullock price	**$1,374.02**
Capital value of herd	**$2,935,994.43**
Net cattle sales	**$944,034.73**
Direct costs excluding bulls	**$60,402.25**
Bull replacement	**$28,902.86**
Gross margin for herd	**$854,729.61**
GM per adult equivalent	**$328.74**
GM/AE after interest *	**$272.28**

*NB: These figures utilise current prices (October 2020).

Land Management

Leichhardt Creek has quite variable land types that are based primarily on topography; the low-lying areas are Clayey Alluvials and Red Goldfields, with some Tea Tree Plains on the eastern side which transition to better ironbark country on deeper soils and then into rangelands country. One of the primary issues is the steady increase of chinee apple, particularly in areas where slope and thick native vegetation prevent effective management. The manager has implemented a management plan that aims to reduce chinee apple as much as possible in paddocks that are open and manageable, and to monitor and restrict cattle traffic from paddocks that have higher infestation rates. Spot spraying and a tree saw are combined to manage infestations based on the density of trees in the paddock.

The manager has a passion for what he does. Here are some simple statements he has made in the past that shows how management has been to meet the challenges of variable rainfall and grass growth.

'I think there's not enough monetary value placed on grass. Six to seven years ago, this place ran around 3200 head. The onus was on supplying 1000 weaners a year. Since we came here that number has come back to around 2400. We still wean around 800 a year, we get more calves from those cows we have. Overall, those animals leaving the place are better. So, our kg/ha overall has increased. I think that's largely due to having a mindset of producing grass for cattle to eat.'

'During the year we run paddocks together. But when the season comes, we rotate between them to get some rest on the grass. Nonperformers get shifted as early as possible'

'If the money's good we will sell our steers two months early (early March) and forgo the extra weight gain in order to get a spell the paddocks at the end of the wet season (March/April).'

'Some years back (2011) we held onto our steers for an extra year due to the live trade ban. Our numbers rose to 4000 head. It was a bad idea, even though it was a good year and we thought we had the grass, we are only now recovering.'

It is interesting to note that this can be confirmed by Forage data. The manager talked about the cattle they were running in 2010/2011 (3200 head) and how this was placing pressure on the operation, which was further compounded in 2011 with excess steers from the live trade disruption. It is clear from the timelines, in Figure 4, that this pressure of grazing had a greater effect on the more palatable creek country where for four to five years ground cover was below average. These areas have been identified within the BBB as key contributors to degradation and sediment to the Great Barrier Reef. Good visual assessments by the managers and adjustments to long term stocking rates have increase ground cover back to regional averages on the Blue Gum land type in Bottom paddock.

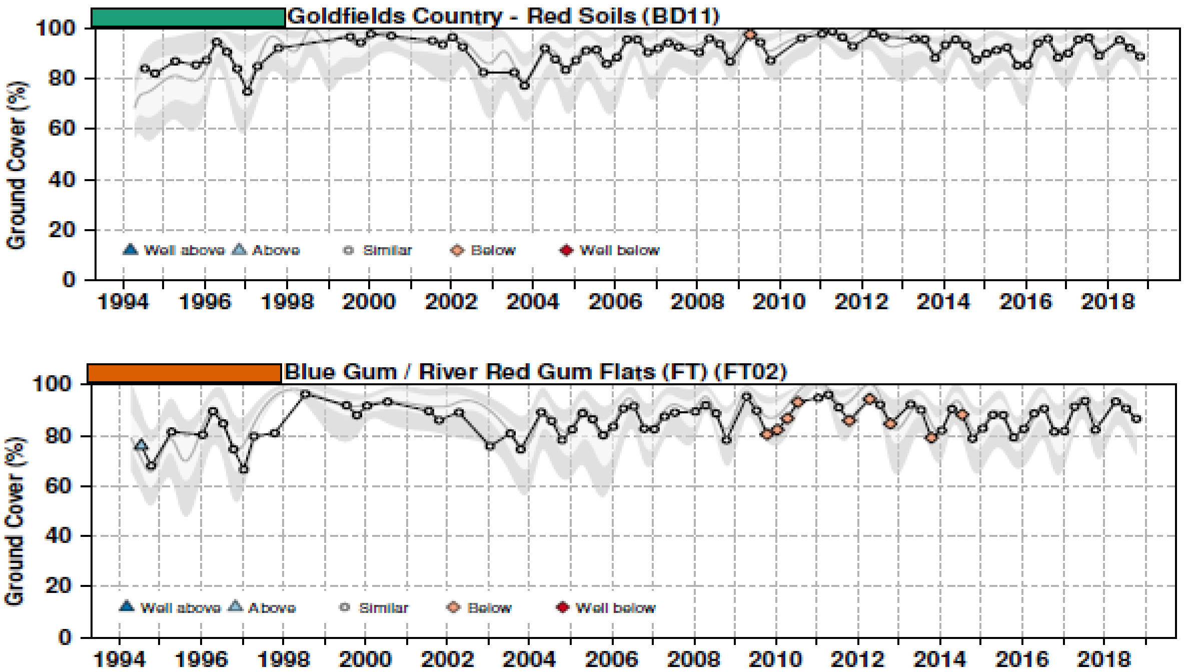


Figure 4 - Forage reports for Top Dam Paddock. Note Indian couch pastures show higher ground cover compared with most 3P tussock grasses

Future Direction

The managers are well supported by the owners of the property with their primary goals, which are:

- Improve the overall land condition of the property by managing stocking rates and ensuring adequate end of dry season residual on the ground.
- Manage a strong, heathy pasture to compete with chinee apple and reduce its impact on productivity.
- Continue to improve overall market access and increase the amount of turn-off options to provide greater flexibility during variable seasons.
- Improve the fencing and water infrastructure to take full advantage of the grazing area, prevent over utilisation of preferred creek frontage and implement wet season spelling.
- Improve the genetic potential of their herd, particularly in terms of fertility traits.

Grazing and business management in the Mount Garnet region

Goshen and Wyoming stations

Owners: Theresa and Brett Blennerhassett

Total grazing area: 27,200 hectares

December 2020

Background

Goshen Station is situated on the Herbert River, 90 km south of Mt. Garnet on the Gunnawarra Road. The property has been in the Blennerhassett owners since 1997. Brett and Theresa Blennerhassett have managed the station for many years and in 2015 purchased the property from the owner's company and are new owner-managers. Wyoming station (8,100 ha), 20 km to the west, was also purchased in 2018.

Goshen has a 26 km river frontage on to the Herbert Riverland (Figure 1). It is the last grazing property on the river before the Herbert drops from the southern Tableland through a spectacular gorge down into the coastal plains west of Ingham.

Figure 1: The Herbert River at Goshen Station

Goshen Station is 19,100 ha and is typical of the district, with a mixture of soils covered by native grasses (mainly black spear and Kangaroo grass). Soil types, grazing values and safe stocking rates are shown in Table 1.

Table 1: Goshen and Wyoming soil types, stocking rates and grazing values

Soil type	Grazing value*	Carrying capacity in A condition & 100% access to water
River alluvial	10	1 AE:4.0 ha
Red basalt Black basalt Black soil	9	1 AE:4.9 ha
Red earth	5	1 AE:8.0 ha
Yellow earth Grey clay Grey slate	3	1 AE:10.0 ha
White-grey sandy country	1	1 AE:14.0 ha

* Land types recognised across the Upper Herbert region and grazing value of each type in good condition. The highest value land is rated 10 and the lowest rated 1.

Both properties are naturally timbered with a range of species depending in soil types. Box, bloodwood and ironbark dominate. Both properties have large treeless black soil plains (Figure 2) covered with thick stands of Angleton grass (*Dichanthium sp.*).

Figure 2: Black soil plains typical of Goshen and Wyoming station

Indian couch is also spreading into the pastures after being spread down roadways by local government equipment. A total of 1,620 ha of red earth country has been cleared on Goshen and planted to improved pastures. Best performing species include legumes Seca and Verano and grasses Bissett, Rhodes, Keppell and Buffel. Cunningham (250 ha) and Redlands (182 ha) leucaena has also been planted in 10 metre rows (Figure 3). Seasons allowing, the remaining cleared area will all be planted to Redlands leucaena and improved pastures to boost weight for age of all steers and cull heifers.

Figure 3: Redlands leucaena and improved pasture planted on Goshen Station.

Production System

Goshen and Wyoming stations are breeding, growing and supplying store cattle for fattening into the owner's meat wholesale business, Bingil Bay Beef (Figure 4). Improved weight for age and higher price/kg will be achieved through conservative stocking rates and improved pastures. The aim is to have all sale male cattle on improved pastures to reach sale weights in excess of 400kg. The herd genetics are a mixture of Brahman and Santa Gertrudis breeds with a small Santa stud herd of 60 cows kept on Goshen.

Figure 4: Goshen steers nearly ready for sale

Weaner cattle are removed from their main breeder herd grazing at approximately six months of age and range from 140–220 kg live weight. They are grown out on native and improved pastures on Goshen/Wyoming and are 350-400 kg live weight when sold. Cull cows average 400–550 kg live weight at sale. Table 2 outlines Goshen/Wyoming Stations' herd economic performance for 2019-20.

Brett is starting to use controlled mating on both properties to tighten the calving window and improve overall breeder performance. First and second calf heifers are now segregated to allow targeted management and the identification of superior fertility and genetics.

Table 2: Herd gross margin figures, 2019-20

	Herd figures 2020
Total cattle carried	3,390
Total calves per year weaned	1064
Total cows and heifers sold	450
Average female price	$882
Total steers and bullocks sold	520
Average steer/bullock price	$994
Net cattle sales	$913,848
Dips, drench, vaccines and supplements	$225,800
Bull replacement	$56,582
Gross margin for herd	$490,527
Gross margin per AE*	$169

Note: * The long-term average gross margin per AE for the district is $120-140. 2020 has seen the highest prices ever for fat and store cattle in Australia due to the shortage of cattle and booming export prices.

The improved pasture area of 1,620 ha is carefully managed with sustainable stocking rates, fertiliser applications and rotational grazing to maximise animal performance and maintain a good grass/legume balance (Figure 5).

Figure 5: Improved pasture leucaena mix at Goshen

The soil is tested every two years to determine exact fertiliser requirements for improved pasture paddocks on Goshen (Table 3).

Table 3: Soil test results from four improved pasture paddocks, Goshen Station (2020)

	Leucaena paddock 1	Leucaena paddock 2	Leucaena paddock 3	Top Sheoak improved pasture paddock
pH levels (water)	6.6	6.3	6.6	6.4
Phosphorus (Colwell mg/kg)	10	14	25	13
Sulphur (mg/kg)	9	8	12	7
Calcium (amm-acet) cmol/kg	5.8	3.8	6.3	5.5
Magnesium cmol/kg	1.3	1.20	1.2	1.30
Potassium cmol/kg	0.57	0.38	0.83	0.40
Zinc mg/kg	0.26	0.33	0.27	0.90
Copper mg/kg	0.69	0.59	0.68	1.20

Guided by the soil test results the most cost-effective fertiliser combinations are determined and applied. Phosphorous, sulphur and sometimes nitrogen are the usual deficient nutrient. The 1,620 ha of improved pasture and leucaena is split into eight paddocks for rotational grazing. At present a mob of sale cattle are grazing through this system before sale in mid-year and live weight gains are being recorded. Table 4 lists the production benefits of this pasture development and compares this to native pasture systems. This growing season DAPS is the most cost-effective fertiliser available and will be applied at 180kg/ha.

Table 4: Production and economic comparisons on cleared red earths between fertilised improved pastures (with Redlands), improved pasture (no fertiliser) and native pastures on Goshen Station

	Improved pasture + Redlands	**Improved pasture**	**Native pasture-trees**
Species	Bisset, Seca, Rhodes, Verano, Buffel, Keppel, Redlands	Bisset, Seca, Rhodes, Verano, Buffel, Keppel	Kangaroo/speargrass
Area	69	69	69
Stocking rates (ha/AE)	0.6	2	6
Cattle numbers	120	34	11
Daily LWG (kg)	0.6	0.35	0.27
Annual LWG (kg)	219	128	99
Total LW/year (kg)	26,280	4,352	1,089
LWG value at $3.00/kg	$78,840	$13,056	$3,267
LWG value/ha	$1,142	$189	$47
Supplements costs/head/year	$2.00	$10-25	$15-30

Land Management

Most of Goshen is covered in native pastures with 40% of the property regarded as good country, frontage, black and basalt soils while 60% of the property has poorer red earth, yellow and granite soils. Wyoming consists of red and black basalt soils, including many treeless black soil flats. The major issues with the native pasture country in the poorer soil areas is weed invasion (mainly Lantana, Figure 6) and timber thickening. To combat these issues Brett annually spells country over the wet season to regenerate native species and to accumulate fuel loads for burning after the first storms. Brett has a 2-3 year systematic wet season spelling and burning program on Goshen and Wyoming. Stocking rates across both properties are conservative to cater for rainfall and seasonal variability (Figure 7; Goshen wet season spelling and fire plan for next 2-3 years)

Figure 6: Lantana is the main weed issue on Goshen Station

Over 35 km of fencing and 15 off-stream waters have been installed over the last few years. The new fencing and waters allow improved grazing flexibility in riparian areas with wet season spelling, rotational grazing and monitoring for evaluating pasture yields and ground cover.

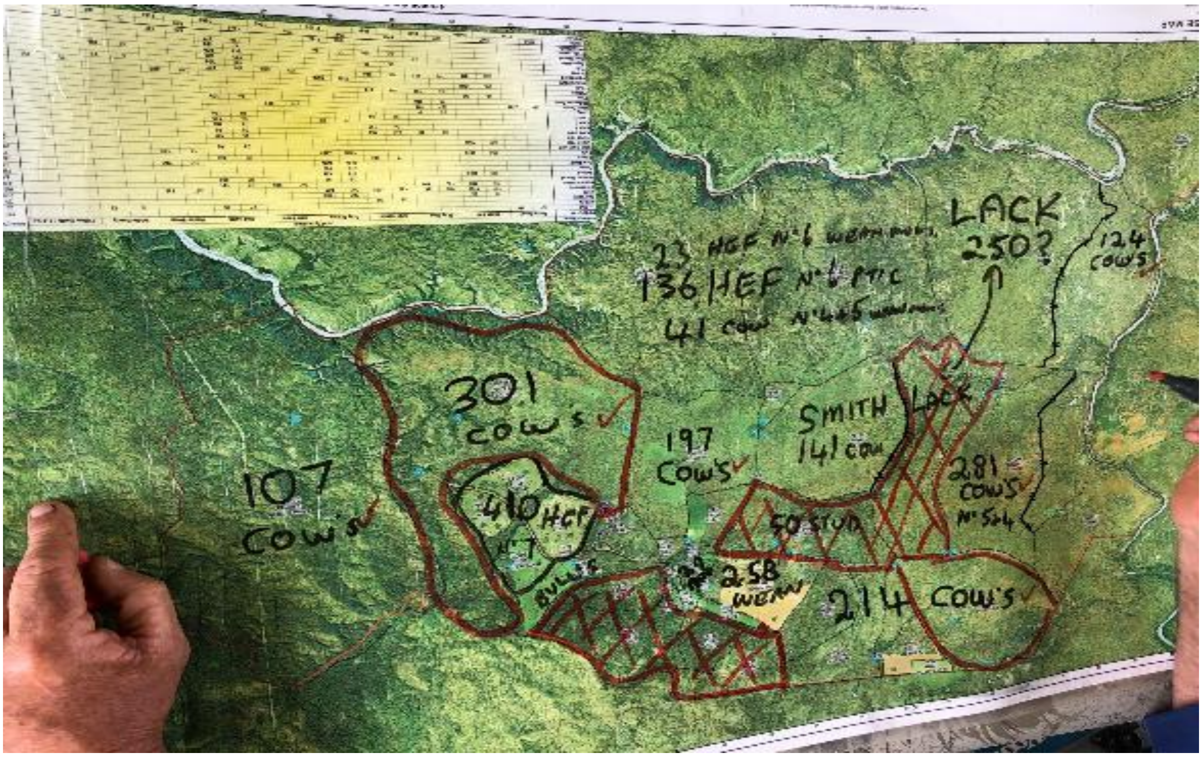


Figure 7: Using a property map to plan ahead for the wet season spelling and/or burning

A small demonstration was conducted on Goshen over two wet seasons to measure soil movement, comparing well-managed improved pastures and native pasture/timbered country (see box below).

Improved Pastures Minimise Sediment Loss

Well-managed improved pastures that maintains over 90% ground cover results in minimal soil movement (see Figure 8) compared to an adjacent native pasture site under tree cover (see Figure 9).

Research done on Goshen Station south of Mt Garnet over two wet seasons reveal native pastures under trees (see Figure 10) have three times the soil movement during the wet season than the nearby cleared, improved pasture site (see Table 5).

The key to minimising soil movement is maintaining over 50% effective attached ground cover especially at the break of the season when we receive heavy storms (see Figure 11).

The Upper Herbert River region has been used for cattle grazing since the early 1900s and has seen a rapid timber thickening problem develop in that time.

Very little native grass can grow under the thick tree canopy leaving a soil surface covered by little grass and a lot of unattached dead leaves, which doesn’t prevent soil movement during heavy rain.

The improved pasture site was dominated by Keppel pertusa and Rhodes grass with some Seca and Verano stylo that provided over 90% ground cover.

Table 5: Sediment Loss Results

	Cleared improved pasture	**Native pasture in trees**
Year 1 Soil Movement	680 g	2,236 g
Year 2 Soil Movement	720 g	2,376 g

Note: Research sites are within 100 metres of each other and have the same rainfall, slope and soil type.

Figure 8: Showing sediment trap in improved pasture site

Figure 9: Showing sediment trap nearby in thickly timbered country with mostly unattached dead leaves as ground cover

Figure 10: Showing the timber thickening problem that seriously reduces grass production

Figure 11: Showing good balance of trees and grass

Numerous long-term monitoring points have been installed over the years to allow land condition changes to be monitored. (Figure 12).

Figure 12: Long-term monitoring point showing good pasture condition and ground cover late in the season

Future Direction

The next major management change on Goshen/Wyoming is to run cows in larger mobs to increase rotational grazing and wet season spelling options for native pasture recovery and resilience. This will be carried out in combination with first round preg-testing and segregation (by calving groups) to reduce supplement and mustering costs across both properties.

Grazing and business management in the Upper Burdekin region

Case study 3

Total grazing area: 41,277 hectares

December 2020

Background

Case study 3 is situated in the Dalrymple shire, north of Charters Towers. The property is a family run breeding enterprise, which they have owned for the past 10 years.

The property has approximately 33kms of frontage country. The property is 41,277 ha with a mixture of land types and native pasture species. Table 1 shows the main land types on the property and an indicator of carrying capacity if the land type is in A condition and fully watered.

Table 1: Main land types of Case study 3 and long-term carrying capacity estimation for land in A condition and 100% access to water. Data sourced from FORAGE reports, available at www.longpaddock.qld.gov.au

Land types	Estimated Area (ha)	Long Term Carrying Capacity in A condition & 100% access to water (ha/AE) *
Silver-leaved Ironbark	14,125	9.8
Box and napunyah	10,238	18.4
Ranges	5,685	53.2
Narrow-leaved ironbark on shallower soils	5,423	13.6
Loamy alluvials	3,036	5.6
Lancewood-bendee-rosewood	1,932	81.6

*Please note: The Long-term carrying capacity report is still in prototype stage with ongoing refinements being made. The report is designed as a starting point for discussion on the number of livestock a property can carry in the long-term without reducing land condition.

There is a good mix of perennial pastures on Case study 3, including Urochloa, Black Speargrass, Kangaroo grass and Buffel grass. Some sections of the property have been heavily sown with Seca and Verano (stylo varieties). Indian couch is also encroaching onto areas of the property.

Figure 1: Narrow-leaved ironbark on shallower soils land type on Case study 3

Case study 3's long-term annual median rainfall is 648mm (Figure 2), with most of the rainfall falling between the months of December and March.

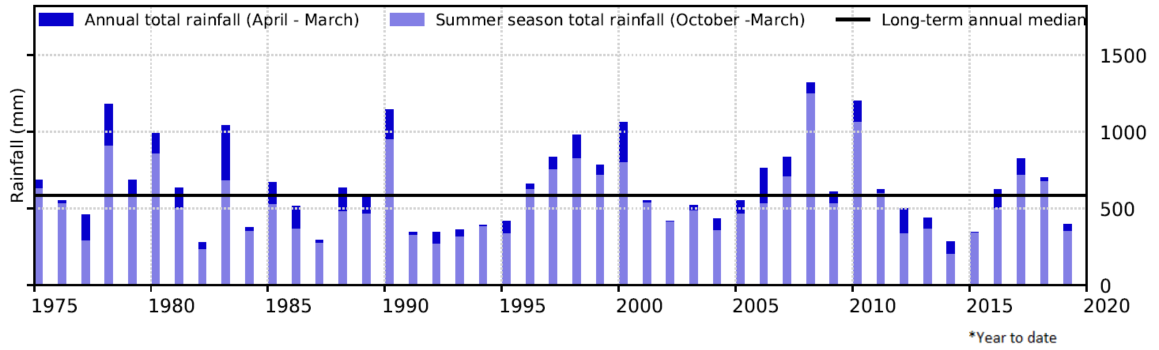


Figure 2: Historical annual and summer season rainfall. Data sourced from FORAGE reports, available at ww.longpaddock.qld.gov.au

Production System

Case study 3 is one property within the owner's beef cattle business. The property is a breeding block focusing on the supply of weaners which are transferred off at 200kg. The aim is to keep all breeders in body condition score 2.5 or better which is achieved by conservatively stocking at an average of one adult equivalent to 10 hectares and destocking early when required. The herd genetics are 78 per cent Bos Indicus with a mixture of Brahman, Droughtmaster and Santa Gertrudis breeds. A Brahman and Santa Gertrudis stud herd are also run on the property supplying commercial bulls into the Case study 3 herd.

Weaner cattle are removed from the main breeder herd in late September to early October at approximately nine months of age and averaging 200kg live weight. Weaners are held, fed, and educated for two weeks before being transferred out, cull cows are sold at 10 years of age, if dry, averaging 580 kg live weight at sale. Table 2 outlines the expected economic performance using these management practices at Case study 3 over the long-term using average prices received at Charters Towers saleyards over the past 12 months.

Control mating is used to tighten the calving window and improve overall breeder performance. Weaner heifers retained as replacements, are segregated to allow targeted yearling joining of those that have reached puberty at approximately 18 months or 325kg live weight. Foetal aging is regularly used to help segregate breeders based on foetal age for supplement requirements.

Loose lick rations are used flexibly on the property based on the season and condition of the cows. Dry season licks start with a 30% urea loose lick reducing to 22-24% urea pre calving and phosphorus is increased. This strategy is used to prepare cows for calving and lactation. Wet season licks are not routinely used.

Table 2: Herd gross margin figures

	Case study 3
Total cattle carried	3402
Total calves per year weaned	1502
Total cows and heifers sold	607
Average female price	$1,112
Total steers and bullocks sold	751
Average steer/bullock price	$557
Net cattle sales	$1,093,884
Dips, drench, vaccines and supplements	$156,032
Bull replacement	N/A
Gross margin for herd	$742,201
Gross margin per AE*	$176

Note: * 2020 has seen the highest prices ever for fat and store cattle in Australia due to the shortage of cattle and booming export prices.

Land Management

Since acquiring the property 10 years ago, the owners have noticed an improvement in grass species, through a change in management strategies of the property. Management has focused on implementing wet season spelling, managing grazing pressure, conservative stocking, additional water points, pregnancy testing and managing supplement programs.

A serious concern on Case study 3 is woodland thickening, with a reported thickening rate of 1.5% in the Dalrymple area. Fires are not used to control woodland thickening, however, have occasionally been used on the property to encourage new growth and manage undesirable grass species.

The property is routinely wet season spelled, especially in high traffic areas. Waters are shut off and supplement feeding troughs are moved regularly to help manage grazing pressure. The owners aim to leave 1500kg dry matter at the end of the year to help manage land condition and ground cover, this is usually the case every eight out of 10 years. Figure 4 shows the percent ground cover for all dominant land types compared to region around Case study 3 (25-50km radius). The red line on

Figure 4 indicates a high ground cover percentage for the property. The owners believe in making early decisions to destock rather than wait out the season.

Figure 3: Good quantity of feed in the dry season (December 2019).

Destocking is also a routine occurrence, with the pastures and seasons regularly 'eyeballed' and cattle moved or sold as required.

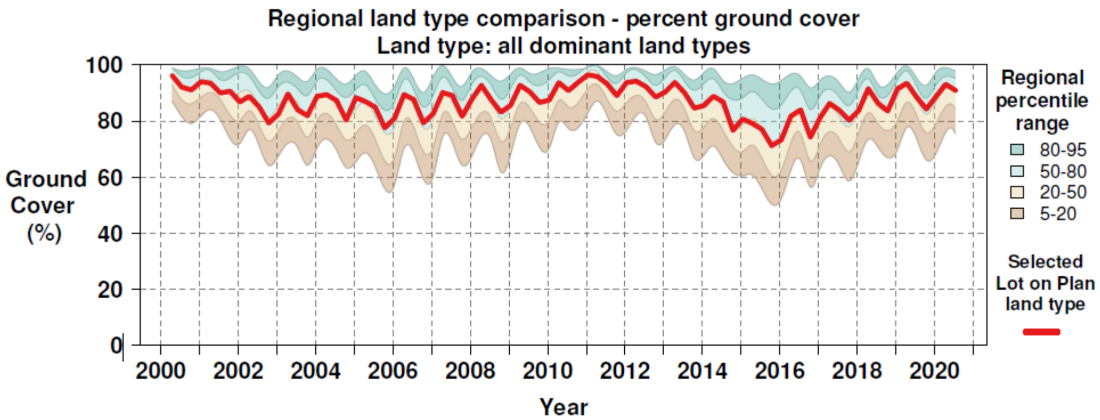


Figure 4: Regional land type comparison – percent ground cover for all dominant land types. Data sourced from FORAGE reports, available at www.longpaddock.qld.gov.au

Case study 3 also has several long-term monitoring points which are actively used and monitored on the property.

The property has had an increase of infrastructure since ownership, including new dams/watering points and fences. Eleven new watering points have been developed on the property allowing cattle to use previously unutilised areas. Dam squares are locked up during the wet season and opened back up in March/April.

Future Direction

The owners aim to work on turning off a younger product, to be able to aim for more markets, whilst increasing the genetics of the cattle – improving the stature and saleability of their cattle. They also aim to refine new techniques that have recently been introduced into the management strategy of their property.

Grazing and business management in the Fitzroy region

Ametdale, St. Lawrence

Managers: Ian and Penny MacGibbon

December 2020

Background

Ian and Penny MacGibbon of Ametdale Station, St. Lawrence joined the Northern Grazing Demonstration Project to help address land condition and productivity issues. Ametdale is a breeding block with predominantly native pastures and moderately shallow soils (Figure 1) resulting in pasture management and nutrition being key business priorities. While running to best management practice standards, they still needed to further subdivide 1200 ha paddocks to address patch grazing. A consultative group of graziers addressing similar issues was established. The group was informed on the latest findings from the Wambiana grazing trial and applied these learnings to two case study paddocks. The paddocks were sub-divided and pasture monitoring sites established. Well below average rainfall was experienced, particularly for 2017-18 and 2018-19, and as a result, cattle numbers had to be reduced. However, the 2019-20 summer generated a good pasture response and the start of an improvement in land condition.

Ian and Penny manage for good ground cover to ensure that most rainfall events result in an effective growth response in the perennial grasses (Figure 1 and 2).

Figure 1: Pasture monitoring site W5 in Well paddock. Black spear and Desert bluegrass are abundant and there is a small amount of Indian couch (<10%).

The cattle are mostly high content Brahman for low cost management. Molasses and urea supplementation are important for using the dry grass after winter and strategic burning is used from November to December if the season allows. The landtypes in the demonstration paddocks are locally described as 'Ironbark country' and the flats are subject to Indian couch invasion and some gullying (Figure 3).

Figure 2: Black speargrass seedlings and the native legume Birdsville Indigo, Top9 paddock February 2019.

Grazing Land Management Issues

A significant problem on Ametdale are areas of poor land condition on the flats in the Ironbark country. These degraded areas are historical problems caused by poor grazing distribution and unevenness of utilization. Patch grazing is a continuing challenge and has contributed to the change in pasture composition from dominance by 3P (productive, perennial, palatable) grasses to Indian couch. Areas of bare soil have also developed where the soil surface is eroded (Figure 3).

Figure 3: Pasture monitoring site W2 in Well paddock. Pasture yields are usually very low and dominated by Indian couch.

To address these issues, Ian and Penny focussed on two 1200 ha paddocks (Well and Top9). Sub-division fencing was installed to create five sub-paddocks allowing adaptive management in both the area and length of time spelled in the two demonstration paddocks. The sub-division fencing allowed eight weeks rest and 20 days grazing over the wet season with usually two grazes from May to December and two from December to April. If there was an extended wet season then the number of grazes was increased.

Adaptive Management and Pasture Monitoring

In April 2018 Ian and Penny reduced numbers aggressively in both paddocks due to the poor season and their concerns for the condition of the pasture at the end of the dry season (Table 1). Top9 numbers were kept low in 2019-20 and ground cover and pasture yields been maintained at good levels. A return to good seasonal conditions in the 2019-20 summer resulted in high pasture yields and ground cover with Top9 recording an improvement in the proportion of 3P species in the pasture.

Table 1: Stocktake pasture monitoring for Well and Top9 paddocks at Ametdale.

Paddock/Date	Dec 2017	Feb 2018	May 2018	Nov 2018	May 2019	Dec 2019	Jun 2020	Nov 2020
Well								
Pasture yield (kg/ha)	1400	-	1500	900	2400	1100	2600	1300
3P %	46	-	46	45	47	49	47	46
Ground cover %	80	-	80	75	85	75	95	80
% of LTCC			71			108		~60
Top9								
Pasture yield (kg/ha)	-	1300	1300	1000	2800	1600	4000	2900
3P %	-	23	24	24	34	33	42	41
Ground cover %	-	75	75	65	80	70	85	75
% of LTCC			49			73		~80

Managing For The Long Term

Maintaining and improving land condition requires a long term approach. A realistic estimate of the rate of improvement with the actions implemented would be a 10% increase in LTCC over 10 years for the demonstration paddocks The time required to improve land condition and the cost of infrastructure are thus challenges to implementing improved grazing management, hence the importance of looking after land that is in good condition.

Conclusions

Despite drought conditions for most of this project, the wet season spelling implemented, improved grazing distribution and prompt action by Ian and Penny to reduce numbers has enabled a good pasture growth response despite below average summer rainfall. Land condition in Top 9 paddock has started to improve due to lower grazing pressure and good summer rainfall in 2019-20. The case study has highlighted the importance of:

- Stocking to LTCC.
- Adjusting numbers to the amount of feed available.
- Wet season spelling.
- Improving grazing distribution.

Paul Jones: Technical note – Recovering C condition land :

Wet season spelling and recovery of C condition land

Key points

- Large areas of C condition country exist with much reduced productivity due to the loss of productive, perennial and palatable 3P grasses
- The loss of 3P grasses is usually caused by overgrazing or persistent selective grazing.
- Drought also stresses 3P grasses, but the effect is amplified by heavy stocking but reduced under moderate stocking rates.
- Wet season spelling can be used to regenerate C condition pastures, but only works under moderate stocking rates
- Wet season spelling needs to be applied adaptively i.e. adjust the area spelled and the length of the spell depending on rainfall – in good seasons spell more country for longer.
- Spelling has an immediate benefit in terms of improved cover and yield, but actual improvements in species composition are more gradual.
- Land condition improvement with spelling will occur but must include stocking around LTCC, adjusting stock numbers to the amount of feed available, and avoiding high grazing pressure on non-spelled paddocks

The issue

In all northern Australia pasture communities 3P (**P**alatable, **P**erennial and **P**roductive) grasses like Mitchell grass, bluegrass and black speargrass are the cornerstone of profitable and sustainable beef production

Unfortunately, there have been significant declines in these grasses which, coupled with poor soil condition, have led to large areas of C condition land. As soil condition deteriorates, rainfall infiltration and nutrient cycling decline and the risk of soil erosion increases (Figure 1). This, coupled with the reduced density and vigour of 3P grasses substantially reduces the capacity of land to respond to rainfall and produce useful FORAGE. Carrying capacity is thus significantly lower on C condition land and often less than 50 % of that on A condition country.

In C condition pastures, 3P grasses are often selectively grazed leading to a further reduction in plant size, reduced seed production and minimal seedling recruitment Areas between remaining 3P grasses are usually dominated by low yielding annuals or less preferred perennials like hairy panic (2P – short-lived **P**erennial and **P**alatable) .

These often provide high quality feed for short periods after rain, but this does not last, and feed shortages develop quickly in dry periods. Indian couch may also dominate in some areas and while it provides ground cover, it is often less productive than the native grasses they have displaced.

Figure 1: "*C" condition land with a high density of wiregrasses, increasing bare areas between the tussocks and many dead crowns of 2P grasses which died during the mid-2010s drought*

C condition areas should thus be targeted for land condition improvement through wet season spelling because:

- There is potential to change from a low to a moderate density of 3P grasses and increase carrying capacity.
- Soil surface condition is generally good enough to enable improvement as ground cover, infiltration and nutrient cycling improve.
- There is a significant production benefit when progressing from C to B, or A condition.
- Most properties have adequate infrastructure and management capacity to trial wet season spelling.

What causes C condition land?

Historical issues, patch grazing and fragile soils

C condition land develops through overgrazing of preferred 3P grasses, often in conjunction with drought. The overgrazing may result from poor water distribution with heavy grazing pressure around isolated waterpoints. It also results from overstocking and/or when stock numbers are not adjusted downwards in drought. Continuous and heavy grazing pressure on the 3P grasses causes a reduction in vigour and eventual death.

Generally, perennial grasses with a large bulk above ground have a large and vigorous root system. In contrast short, overgrazed plants lack the photosynthetic ability to support vigorous root growth. Seed production also declines with heavy grazing and the lack of a viable seedbank restricts the ability to recover. While this is happening, the soil surface is losing ground cover, rainfall infiltration and nutrient cycling decline and erosion increases. The surface of duplex soils often becomes hard-setting under these conditions which contributes to the poor habitat for plant growth and recruitment. Gully heads on duplex soils can also become active under these conditions.

Even at moderate stocking rates, patch grazing (areas preferentially grazed by cattle) can also contribute to a slide in land condition if not managed due to the relentless high grazing pressure. These areas are often grazed even more heavily on C condition land because of the palatable annual grasses and forbs which respond readily to small falls of rain.

Ingress of Indian couch

A further contributing factor to reduced carrying capacity and declining land condition is the ingress of Indian couch which is not as productive as the original 3P grasses present before the decline to C condition. Indian couch dies out in dry conditions with only scattered, remnant parent plants surviving so the contribution to carrying capacity in drought is negligible. Several good wet seasons may be required to re-establish Indian couch from seed and runners post drought. Indian couch also has a relatively small, shallow root system which further reduces soil condition and rainfall infiltration. It also has poor quality standing feed during the dry season. If management is aimed at utilizing this feed before it lignifies it may result in a spring feed shortage, low ground cover and compromises land condition improvement.

While Indian couch provides ground cover it significantly reduces the resilience of 3P grasses in C condition land and can prevent their recovery. Indian couch is tolerant of high grazing pressure and responds well to small falls of rain. It also produces far more seed than 3P grasses and together with the ability to spread by runners, it has a competitive advantage over many better species. This is shown by the fact that it has spread regardless of grazing pressure in many regions and has even invaded some ungrazed areas.

Historical impact of drought

Long term, detailed studies on perennial grass dynamics near Charters Towers and Julia Creek in the early 2000's gave valuable insights into how that drought stressed pastures. In both Mitchell grass and desert bluegrass, basal cover i.e. the total area of rooted plant bases, declined significantly from 2002 to 2003, falling from 2.5 per cent to 0.5 per cent over the twelve months period This drought-induced decline in crown cover occurred regardless of stocking rate or whether spelling was applied. However, stocking rate strongly affected the rate of recovery over the next seven years with crown cover recovering to 1.5 per cent under moderate stocking compared to only 0.5 per cent under heavy stocking. A similar trial conducted near Calliope showed the same response to drought with black spear and forest bluegrass.

More recent research on wet season spelling within the Wambiana Grazing Trial found that desert bluegrass suffered major mortality over the driest years (2014-16) under both moderate and heavy stocking. However, far more tussocks (75 %) died under heavy than under moderate stocking (35 %). Tussocks also started dying much earlier in the drought under the heavy stocking as these plants were smaller with shallower roots and hence far more vulnerable to drought.

This suggests that much of the damage was caused by heavy stocking before the drought actually commenced. Heavy stocking thus amplified the negative impact of droughts while moderate stocking rates tended to reduce its effects. As a result, total basal cover i.e. the total area of rooted plant bases which determines pasture production, declined the most under heavy stocking (Figure 2).

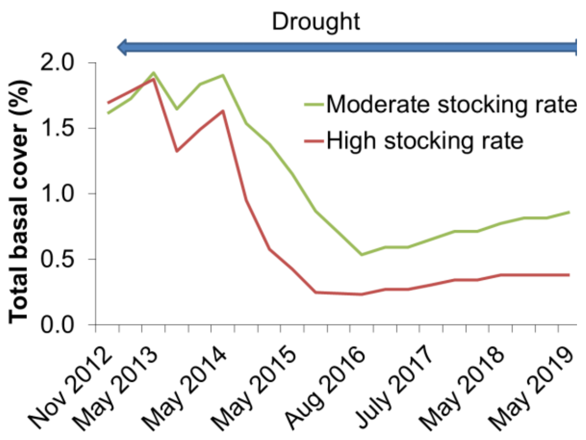


Figure 2: *Drought impact on basal cover of perennial grasses is buffered with a moderate stocking rate*

Wet season spelling did little to buffer drought effects, with similar levels of tussock death in both spelled and unspelled plots. This indicates that wet season spelling is of limited value in buffering drought effects unless coupled with moderate stocking rates.

How does C condition land recover?

Ground cover is critical for the health of 3P grasses regardless of pasture condition. Broadleaved forbs, Indian couch and other 2P and increaser grasses often make an important contribution to ground cover and begin the process of improving soil surface condition, infiltration and nutrient cycling. However, 3P grasses need gaps to establish into a pasture where they are not dominant. This may occur through drought/fire/disturbance resulting in death or weakening of these other species and even the tree layer. If a viable seedbank of 3Ps is present, and good growing conditions ensue, then a change in composition can favour the 3Ps.

The Ecograze study near Charters Towers showed what appeared to be full recovery of pasture yield and composition after eight years of moderate grazing and wet season spelling. However, the paddocks still had numerous bare areas 5–20 m across. These areas were patch grazed by cattle and had higher levels of runoff and nutrient movement. Ground cover from annual grasses, forbs and litter helped these patches recover and 3P grasses established at the downslope edge of the patch where soil moisture and nutrient levels were better and more conducive for seedling establishment. This supports other research showing that pastures usually need a sequence of favourable seasons to fully recover.

Strategies to recover C condition land

1. *Reduce stocking rates to match land condition*

Because the LTCC for C condition land has been considerably reduced, it is essential that stocking rates be lowered to reduce the pressure on the remaining 3P grasses and allow them to start recovery. Lower stocking rates will also minimise periods of feed shortage and low ground cover and so improve soil health.

> The focus is on recovering the 3P grasses through allowing new plants to germinate and establish, existing plants to recover or reducing competition from undesirable plants.

2. *Implement wet season spelling*

Wet season spelling is essential for recovering 3P grasses through allowing new plants to germinate and establish, existing plants to recover and set seed and reducing competition from undesirable plants. It is important to note that spelling does not buffer the effects of heavier stocking rates i.e. regardless of spelling overall stocking rates still need to be within LTCC.

Prioritise paddocks for spelling based on their current overall condition, the proportion in poor condition, the likelihood of success and the ease of implementation. Ideally spell for the whole growing season but a minimum length of time should be 8 weeks. Commence spelling when there has been sufficient summer rain to start new growth (50mm over 2 - 3 days).

Spelling must be managed adaptively and other non-spelled areas closely monitored to avoid overgrazing. During dry conditions the area and length of the spell should be minimized to avoid excess grazing pressure on the stocked areas.

Spelling management should be planned and integrated for example by removing cattle at the last mustering round of the dry season or spelling weaner and holding paddocks. If prescribed burning is important then spelling will be needed to build adequate fuel loads and also for pasture recovery following burning.

In some cases an intensification of management through installing extra infrastructure and stock movements may be needed. This will be useful to keep stock away from patch grazed areas or to enable wet season spelling. Whatever system is used a realistic stocking rate is necessary.

3. *Use FORAGE budgeting to adjust stocking rate to seasonal conditions*

Adjustment of stocking rate around the long-term carrying capacity is essential to ensure good pasture condition and to improve profits. This is particularly so on C condition land. FORAGE budgeting is usually conducted at the end of the wet season. This is when the amount of FORAGE available for grazing until the beginning of the next wet season can be assessed and stocking rates calculated. C condition land is generally suited to shorter grazing periods because of the high proportion of less productive grasses and patch grazing problems. There may not be adequate FORAGE to graze for the whole dry season and also achieve ground cover and pasture yield targets for the beginning of summer growth.

In setting stocking rates, targets should be set to achieve desired residual yields (800-1000+ kg/ha) at the end of the dry season to ensure good ground cover and resilience for future years. StockTake is a useful tool to help in developing a FORAGE budget.

4. Fire

In certain cases, the use of fire in conjunction with wet season spelling may help in the recovery of C condition land, particularly to control weeds or reduce competition from woody species. Fire also stimulates black speargrass but tends to set back some wiregrasses, provided there is adequate rest after the fire. Fire and spelling may also be used to even out patch grazing by moving animals off over grazed areas and encouraging them to utilise patches that have become rank and unpalatable.

In summary the best management to increase the percentage of 3P grasses is the use of regular wet season spelling and moderate stocking rates.

Case study – 'Addressing land condition'

Improve land condition by the use of regular wet season spelling and moderate stocking rates.

Reduce stocking rates to match land condition

Monitor non-spelled paddocks for overgrazing

Minimize the length and area of the spell during dry conditions

Set stocking rate targets to achieve 800-1000

Issues at Ametdale, St Lawrence Qld

Ian and Penny MacGibbon own and run Ametdale Station, a breeding block in central Queensland with predominantly native pastures and moderately shallow soils. Pasture management and cattle nutrition are key business priorities. While most of the property has good land condition, there are areas of bare soil and erosion on the flats in the ironbark country. These degraded areas are historical problems caused by poor grazing distribution. Patch grazing is a continuing challenge and has contributed to the change in pasture composition from 3P dominant to Indian couch. Ian and Penny want to improve pasture condition and diet quality by increasing the proportion of the better grasses (3P%) in the pasture yield (Figure 3).

To address these issues, in 2018, Ian and Penny subdivided two 1,200 hectare paddocks to create five sub-paddocks allowing better control of grazing pressure and pasture spelling. Rainfall was well below average for 2017-18 and 2018-19. However, the 2019-20 summer generated a good pasture response and the start of an improvement in land condition.

In April 2018, cattle numbers were reduced in both paddocks to around half of the long-term carrying capacity (LTCC) in line with the low rainfall and poor wet season pasture growth. Cattle numbers were kept low in 2019-20 and this, combined with better seasonal conditions has resulted in high pasture yields, good ground cover and an increase in the contribution of 3P% grasses to yield from 23% in February 2018 to 42% in June 2020.

Maintaining and improving land condition requires a long-term approach. While the rate of improvement might be expected to accelerate with time, a realistic estimate would be a 10% increase in LTCC over 10 years for these demonstration paddocks. The time required to improve land condition and the cost of infrastructure are challenges, hence the importance of looking after land that is already in good condition.

The case study has highlighted the importance of:

- Stocking to LTCC
- Adjusting numbers to the amount of feed available
- Wet season spelling.

Figure 3: *Black speargrass seedlings and Birdsville Indigo, Ametdale February 2019*

The effect of fire on the long-term dynamics of *Carissa ovata* (Currant bush)

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Abstract

Carissa ovata (Currant bush) is a major native woody weed widespread in the Burdekin and Fitzroy catchments that significantly reduces carrying capacity**.** Fire suppresses *Carissa* however there is no **l**ong-term data on its efficacy**.** We monitored the effect of two fires on *Carissa* cover on three soil types between 1999 and 2020 near Charters Towers. Fire caused significant reductions in *Carissa* cover, but cover returned to, and then exceeded pre-fire levels within six to seven years. Over the 22-year period *Carissa* canopy cover thus increased 1.8-fold on heavy clay soils but more than doubled on texture contrast soils. Drought had little effect on *Carissa* except on better drained or shallower soils where cover declined slightly. *Carissa* canopy cover also increased irrespective of the grazing strategy. These results highlight that more regular fire is required to suppress *Carissa* and the need for further research in understanding and controlling this significant native weed.

Keywords

Woody weeds, fire frequency

Introduction and Methods

Carissa ovata (Currant bush) is a major native woody weed widespread in the Burdekin and Fitzroy catchments that significantly reduces pasture production through competition. Good grazing management therefore requires a reduction in carrying capacity to mitigate further pasture condition decline. Fire suppresses *Carissa* (Back et al. 2005) however there is no long-term data on its efficacy as a control mechanism. The study was conducted on the Wambiana Grazing Trial located 70km SW of Charters Towers. Long term (111 year) mean annual rainfall is 640mm (C.V. = 40%). The site is in the *Aristida Bothriochloa* community with a range of soils including kandasols, sodosols, chromosols and vertosols (Isbell 1996). There are three soil-vegetation associations on the site: *Eucalyptus melanophloia* (silver leaf ironbark) on yellow/red kandasol, *Acacia harpophylla* – *Eucalyptus brownii* (brigalow-Reid River box on grey vertosols/grey earths and a *E. brownii* community (Reid River box) on brown sodosols and chromosols. The trial has five grazing strategies including heavy stocking rate (HSR), moderate stocking (MSR) and rotational spelling (R/Spell) all replicated twice (see O'Reagain and Bushell (2011) for more detail.

To investigate the change in *Carissa* cover, over 8km of permanent monitoring transects were surveyed on the box, brigalow and ironbark soil types in each of these three strategies. Cover was measured along a 100m tape stretched between steel pickets at each monitoring site. Percent cover was calculated by measuring the distance of the tape intersected by *Carissa* canopy cover between the pickets.

The site was burnt in the late dry season in October 1999 and again in October 2011 with hot fires. *Carissa* canopy cover was measured pre- and post-fire, as well as in 2015, 2016, 2018 and 2020. Rainfall was above average before and after both fires, but near or well below average between 2001-2007 and 2014-2020.

Results and Discussion

Both the 1999 and 2011 fires resulted in a large reduction in canopy cover of *Carissa*. However, plants re-sprouted and grew rapidly post-fire, as shown by the increases in canopy cover in later years. The increase in canopy cover continued to occur despite less than average rainfall. This is evident in Fig.1 where the percent canopy cover increased by 10.4% between 2015 and 2018 whilst rainfall ranged from 246mm in 2014/15 to 446mm in 2017/18.

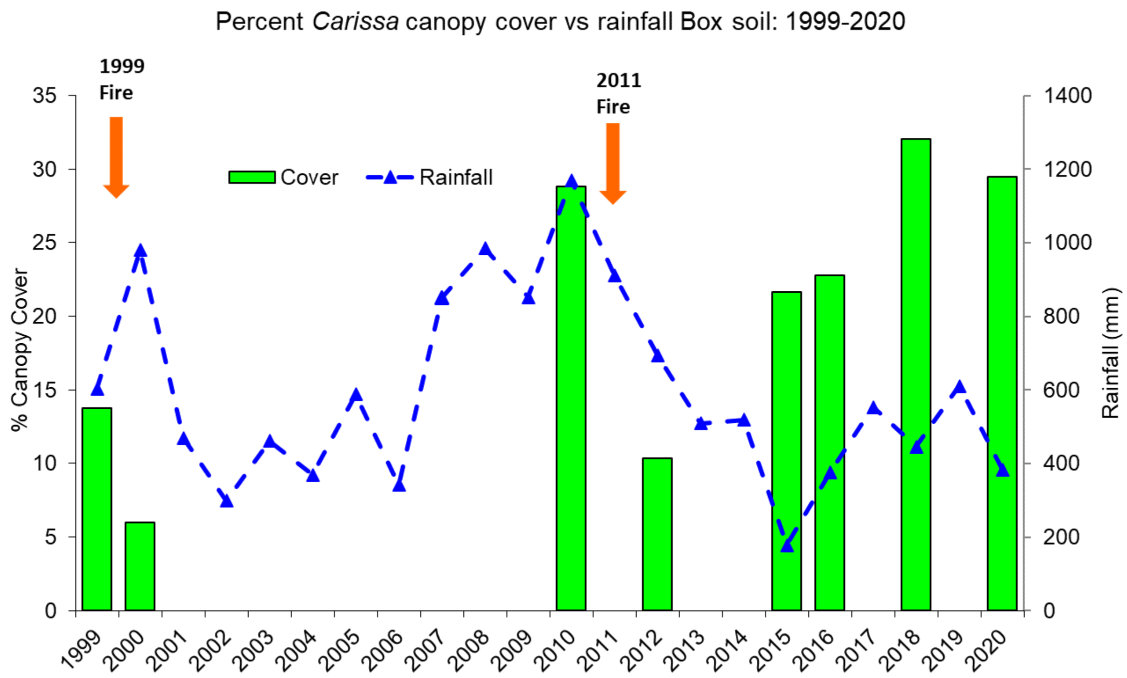

Fig.1. *Percent canopy cover versus rainfall on the box land type (data averaged across all treatments). The reduction in percent canopy cover is clear following fires in 1999 and 2011.*

Between 1999 and 2020 percent *Carissa* canopy cover has also increased from 9.7% to 13% on brigalow land types but declined on the lighter soils associated with the ironbark land type (Fig.2)

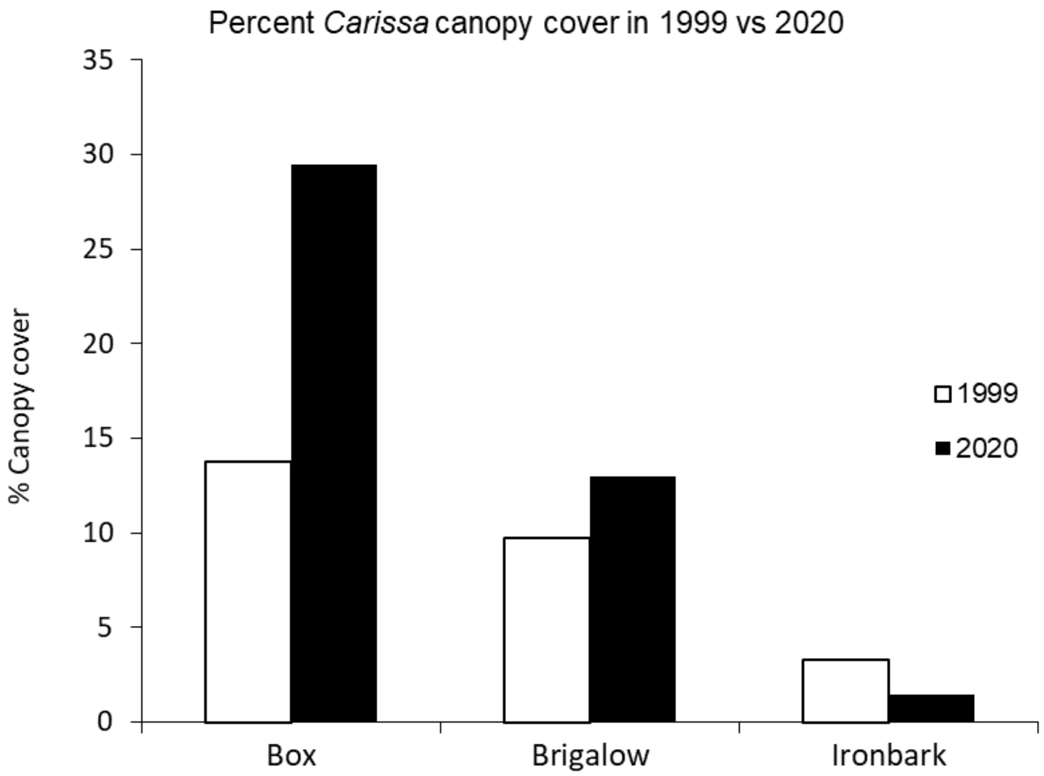

Fig.2 *Percent Carissa canopy cover at Wambiana on three land types in 1999 and 2020*

The canopy cover of *Carissa* has also increased irrespective of grazing strategy. Although canopy cover on the box land type increased most under the heavy stocking rate following the 2011 fire, canopy cover still more than doubled in paddocks which were conservatively stocked and incorporated a wet season spell.

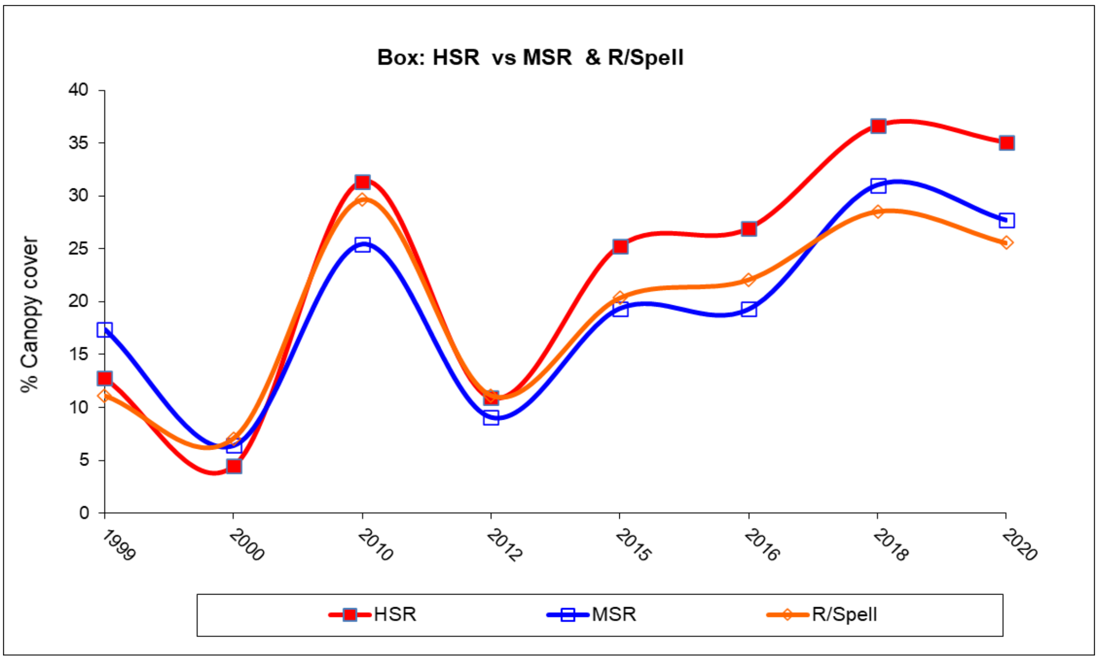

Fig.3. *Comparison of percent Carissa canopy cover on box land type in three different grazing strategies. HSR – heavy stocking rate; MSR – medium stocking rate; R/Spell – rotational spelling.*

Conclusions

These results suggest that a more frequent fire regime is required to suppress *Carissa* growth. A long-term study in the Northern Territory found that late dry season fires every four years kept woody cover increase to 4% on semi-arid woodland (Cowley et.al, 2014). Despite the variability in rainfall, average yields of >1000kg/ha were recorded in 13 of 23 years of the Wambiana Grazing Trial and therefore it expected that fuel loads would be sufficient to enable more frequent effective fires.

The results also suggest the need for further research to help understand and control this significant native weed and the local interaction between fire, woody thickening and pasture condition.

References

Back P. V. (2005). The impact of fire on population density and canopy area of currant bush (*Carissa ovata*) in central Queensland and its implications for grazed woodland management. *Tropical Grasslands* **39**, 65-74.

Cowley R. A., Hearnden M. N., Joyce K. E., Tovar-Valencia M., Cowley T. M., Pettit C. L., Dyer R. M. (2014). How hot? How often? Getting the fire frequency and timing right for optimal management of woody cover and pasture composition in northern Australian grazed tropical savannas. Kidman Springs Fire Experiment 1993-2013. *The Rangeland Journal* **36,** 323-345. http://dx.doi.org/10.1071/RJ14030

Isbell R. F. (1996) 'The Australian Soil Classification.' (CSIRO Publishing: Melbourne, Australia) 143

O'Reagain P. J., Bushell, J. J. (2011). 'The Wambiana grazing trial: Key learnings for sustainable and profitable management in a variable environment.' Queensland Government Brisbane

Appendix 11: Wambiana project: Presentations and visitors to site

Table 1. Presentations on Wambiana trial results with audience breakdown between January 2018 and December 2021.

Audience	Date	Total	Agency	Graziers	COMMENTS
Dept of Science (Reef) & Office of Great Barrier Reef	12/3/2019	18	18		Brisbane: Short presentation on WGT as prelude to meeting on Northern Grazing Demonstration sites.
North Australian Beef Research Committee	27/03/2019	20	10	10	Presentation in Wambiana conference room then site tour, chairs of most RBRCs present, went well, good questions re: spelling, WOWs, BoPer & Nic Spiegel's trial, Lin Schwarzkopf also presented.
Ametdale (Marlborough) Producer Consultative Group	11/06/2019	12	1	11	Ian & Penny MacGibbon’s property - really good group involved in Northern Grazing Demo. Producers very interested in improving land condition & tree thickening.
Ametdale N Grazing Demo Field Day	7/08/2019	26	11	15	Presented main results from trial; good questions re: selection for landtypes, treatment effects on rainfall infiltration & early green up, had CC declined & potential CaOva effects
NBRUC poster presentation	21/08/2019	30	20	10	1 minute presentation; Strong support from WA WALIRC member; interest from others
PO & JJ Radio interviews Country Hour & Rural Roundup, at field day	17/10/2019				ABC Radio interviews Country Hour & Rural Roundup played over every day of following week 21-25 October 2019,
Invited presentation Society for Range Management meeting in Denver, Colorado.	18/02/2020	80	70	10	Invited paper in 'Translating stocking rate trial results to ranchers' symposium; Audience up to 120
Northern Beef Team catch up	3/08/2020	34	34		Northern Beef Catch Up - DAF staff from CT, Mareeba, Cloncurry, Richmond, Brisbane
Ametdale consultative committee N Grazing demo	20/10/2020	14	4	10	Ametdale, Marlborough. Spoke about WOWs & remote sensing. Good interest. Questions about buying/selling cattle with markets; Current bush, tree thickening.
Ametdale NGD field day	10/11/2020	25	8	17	Ametdale Northern Grazing Demo project final field day - presented again on 23 years of trial results & latest WOW data. Geoff Fordyce & Dave Smith on how WGT results link directly to breeder performance.
Goshen NGD field day	12/11/2020	25	4	21	Goshen NGD final field day- JJB presented…Bank rep noted how Wambiana results are influencing banks’ lending policies
Christmas creek NGD field day	16/12/2020	15	5	10	Christmas Creek NGD field day along with Geoff F., Dave Smith. Presented on trial with with a handout; other speakers tied results in very well with breeder performance and the need to manage stocking rates to get good individual animal performance.

Audience	Date	Total	Agency	Graziers	COMMENTS
NQ Beef Research Committee, Bowen	13/04/2021	12	6	6	Update on WGT results and possible directions for new work.
(Bunuro project) Torrens Creek information evening	6/10/2021	20	3	17	JJ presented on video due to Covid. Producers supportive & felt they had heard info. before at previous events i.e. extension of WGT has been successful and widespread
Australian Rangelands Society meeting, Longreach	7/10/2021	60	55	5	Good response & questions, also an on-line audience (but not sure how many)
NQ Beef Research Committee meeting, Hughenden	12/11/2021	17	8	9	Presented results & future MDC: Good response & questions; Why no multi-paddock system (time to do something similar ?); Similarity of outcomes for non-HSR strategies; ….Impressed with longevity of trial & effort in keeping it going;
	Total	**408**	**257**	**151**	

Table 2 Visitors to Wambiana trial site and breakdown by occupation between January 2018 and December 2021.9 (Other=agribusiness, feed reps, valuers etc)

Group	Date	No.	Agency	Grazier	Student	Other	Comments
Queensland Fire & Rescue: Rural Fire brigades	1/02/2018	22	2	4		16	Very hot day but some good comments and interests esp. from the 1 or 2 graziers present
Agribankers forum	14/03/2018	27	7	3		17	Really good day, bankers v interested, some younger staff with little experience of beef industry, good discussion re: banking policy & sustainability issues
NQDT & Office of Greta Barrier Reef	27/03/2018	11	11				6 NQDT, 3 from OGBR. Good day presentation at office then field trip, saw P4S7 and old photos; good team building and good questions from stakeholders. See DAF Intranet story
JCU Wildlife ecology students	20/04/2018	51			46	5	Really good group, good questions & students really enjoyed presentation and field visit; afterwards show and tell with snakes.
DAF, Deputy director general	5/09/2018	6	6				Acting DG Bernadette Ditchfield, Adam West (N Region Director) & 2 other mngt team members + Brigid N and Vivian Finlay new Ag Economist. Visitors appeared impressed.
Wambiana GAC	13/11/2018	16		16			Wambiana GAC: Presented latest results and viewed WOWs in operation. Demonstrated Observant cameras & water tank monitors. Good turnout & had our new member Martin Holzwart present. Good day
North Australian Beef Research Committee	27/03/2019	20	10	10			NABRC - presentation in conference room then site tour, chairs of most RBRCs present, went well, good questions re: spelling, WOWs, BoPer & JCU Biodiversity
JCU Wildlife ecology students	23/04/2019	40			35	5	As usual good group: presentation in Wambiana conference room, then field trip to P4 and P1 flume. They found a rare ornamental snake - see photos.
Queensland Fire & Rescue: Rural Fire brigades	23/05/2019	17	4			13	'Firies' very impressed that we had the 21 years' experience to back up what we were talking about ! Good group but limited knowledge of industry.
Animal Ethics Committee, Brisbane	23/05/2019	3	1			2	Annual EC inspection of site with Lex Turner - they joined tour with QFRS
Argentinian scientist	28/08/2019	1	1				Javier Sanguinetti, Argentinian biologist doing feral pig bait trial (Hog-gone) on W & Trafalgar. V interested and keen to get Argentinians out to see trail & other Australian work.
Wambiana Field day	17/10/2019	100	22	53		25	Field day went v well; paddock tour, guest speakers Geoff Fordyce, on how trial findings apply to breeders, M Lyons compounding gains with genetics, Ian McLean business management & Bunuro case study with mob grazing. Also new Forage pasture growth alert.
UQ Soil biocrust team	9/11/2020	8	6		2		Wendy Williams, Prof. Susanne Schmidt & others from UQ sampling at trial from 9-13 Nov as part of MLA funded soil biocrust project.

Group	Date	No.	Agency	Grazier	Student	Other	Comments
DAF extension team	18/11/202	4	2			2	Kate Brown & Jodie Ward (DAF), with film crew to shoot drone footage of some paddocks & interview
MLA program leaders & adoption staff	25/11/2020	4				4	Nigel Tomkins, Tim Huggins, Alana Boulton & Bridie ? from MLA visit trial & view WOW, paddock differences & cattle.
Jo Owens - DCAP modeller	23/02/2021	1	1				Jo Owens, Drought & Climate Adaptation Program & TERN, she is modelling long term pasture change under different treatments.
NQ Dry Tropics extension group	24/02/2021	20	20				NQ Dry Tropics extension staff from Burdekin & Bowen Broken Landholders Driving Change project. Good questions and feedback & relationship building. Also Rob Hassett (DAF) & LCAT
Wambiana GAC	3/03/2021	18	3	15			GAC meeting- good discussion about future projects, and key issues. Also some next generation managers with different views & questions.
JCU wildlife ecology students	8/04/2021	23			23		Presentation in the paddock; good questions about management and beef industry.
TERN team set up 6 monitoring sites on WGT	30/04/2021	6	6				TERN (Terrestrial Ecosystems Research Network) team spend 5 days at WGT setting up 6 monitoring sites & took detailed soil & plant measurements. National network.
Jason Strong, MD of MLA + Russell Lethbridge & DAF staff	4/06/2021	7	5	2			Jason Strong MD of MLA & Russel Lethbridge MLA board), John Lyons & 4 DAF staff visit trial. MD impressed with trial but WGT should stop and focus on adoption.
Ed Charmley (CSIRO) + 3 others	16/06/2021	4	4				Holland Dougherty post doc at UNE working in LPP, Ausbeef and modelling of methane emission; Greg Bishop-Hurley, Simon Hunt.
UQ Agriculture students northern tour	28/06/2021	19	2		17		Really good group of students, lots of questions and interest, included Rebecca Ash & new TO Celste Ogg; led by Karen Harper (UQ) and husband Steve.
Education Qld Distance Education Cert III Agriculture.	26/08/2021	17			17		16&17 yr old students from Charleville, Brisbane, Bundaberg, Mackay, Townsville, Dauringa, Atherton Tableland. Forage budgeting field exercise, WOWs
Wambiana Field Day 2021	15/09/2021	82	14	36		32	Field tour, producer speakers Michael Lyons, Fran Lyons & Jamie Gordon: chairman Don Heatley. Small group discussions on possible future direction of trial.
Will Edwards (JCU) & partner	20/10/2021	2	1			1	Will Edwards samples ant at trial at TERN sites with volunteer Jim.
Blackheath & Thornburgh College Agriculture and Cert 3 Ag Studies students	9/03/2022	30			27	3	27 Students and 3 teachers. Students boarders from rural areas and cattle properties throughout Qld and NT. Presentation around rainfall/pasture growth and condition followed by field activity calculating a forage budget. Demonstrated the WOW unit.
N. Gulf graziers eBeef tour + N Gulf staff	22/03/2022	29	6	23			Graziers from Mt Surprise, Georgetown & N Gulf NRM Staff. Good tour with good, interesting questions. Many younger producers.

Group	Date	No.	Agency	Grazier	Student	Other	Comments
JCU wildlife ecology & marine biology students	22/04/2022	28			24	4	JCU annual student sampling field trip to Wambiana. Conference room & then field trip - shortened due to rain. Good response from students and staff. NB as usual students sampling trial paddocks
	Total	629	141	168	191	129	

Table 3 Wambiana popular publication articles between January 2018 and May 2022.

Title	*Publication*	Year
Addressing land condition issues at Ametdale: part of the Northern Grazing Demonstration project	*FutureBeef website*	26/02/2021
TERN sampling at Wambiana, Fletcherview & Brigalow Research station	*TERN website*	30/08/2021
Twenty-four years of research on show at Wambiana Field Day	*FutureBeef website*	29/09/2021
Giving nitrogen a boost (Soil biocrusts)	*Qld. Country life, 20 August 2020*	20/08/2020
Take a long term view of stocking rates	*MLA Feedback magazine, Sept-Oct 2020, 16*	2020
Cattle performance data aids grazing decisions	*Qld. Country Life & N Qld. Register 19 October 2020*	19/10/2020
Boost pasture recovery	*North Qld Register 26 September 2019, p.11*	26/09/2019
Summer spelling vital (Jones)	*Qld. Country Life 26 September 2019, p. 26*	26/09/2019
'Recovery of perennial grasses after drought' (Paul Jones)	*Qld. Country Life 18 April 2019, p. 49:*	18/04/2019
Can we predict animal performance from space	*Northern Muster & CQ Beef, December 2018, p. 2*	2018

Survey of grazier knowledge, attitudes, skills and aspirations from the Wambiana grazing trial - Report

February 2022

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1 Snapshots

Results from phone surveys of 30 graziers familiar with Wambiana Trial results

90% of graziers gained new **KNOWLEDGE** from the WGT results

'New' for them:

"WGT illustrated there was no more money in having more cattle and there were more costs e.g. supplements etc."

'New' as reinforcing their practices:

"It reinforces what you think you might know from the experience of doing management and the Trial results put figures on it."

NEW knowledge gained:

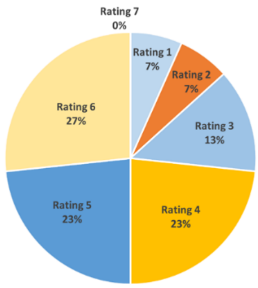
23/30	Profitability
19/30	Stock numbers & feed supply
18/30	Stock numbers drive performance/land condition
16/30	Wet season spelling
11/30	Ecology of native grasses

"Good to have profitability results in black and white as my parents said don't overstock but couldn't explain their reasons."

"I have been working to understand how we can incorporate wet season spelling without damaging the paddocks where extra stock are held during the wet season."

"I got new knowledge that they probably didn't expect us to get and it is that moderate continuous stocking doesn't maintain land condition."

73% *identified their change in **ATTITUDE** at rating of 4 or above*



"I used to be thinking about cattle and their production and I now look at pasture and how it is going."

"Mostly we have refined what we do from WGT results and we use the results when making decisions."

63% gained new **SKILLS**

For five (5) options offered by WGT team,
'Yes' response = **5 or less** for any option.

As well, **30%** chose 'Other Skills.'

Most said their skill came from SEEING the paddock at the trial site and learning what TO DO or NOT TO DO.

"Being in a paddock where a particular stocking strategy has been used, to see what's happening."
"To increase ground cover for water penetration."

70% of graziers **ASPIRING** to make change

Frequent mentions:

Wet season spelling - *"To put wet season spelling in place."*

More observation of pasture - "(Because)Now we understand you need to have grass left at end of year to get water into the soil."

Varying stocking rate - *"We considered using forage budgets more for stocking rate decisions rather than doing it on an ad hoc basis."*

60% report **MAKING A PRACTICE CHANGE**

"I started wet season spelling and also control stock numbers to not overstock."

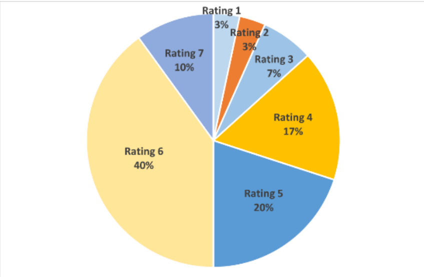
"Vary the stocking rate through trading cattle as different seasons require."

"Using pasture budgeting to match our stocking rate to carrying capacity."

Not all can change yet

"No (change) because I don't yet understand how."

87% Acknowledge **RELEVANCE** of results to own property (Rating >4 out of 7)



Reasons

"They are relatable and apply to here as we know that if we flog country we lose grass and we don't want that."

" Certainly, the flexible stocking rate aligns with what we are doing and we do pasture budgeting."

53% (16 of 30) rate **VALUE TO BUSINESS** as greater than 4 out of 7

16 **as a proportion of** 18 **graziers who made a change** is 89% who find their change of greater than average value to their business.

"Very valuable as it means we make decisions before our backs are to wall and look for other options to reduce stocking rates."

"Valuable as WGT gave us the figures for costs and the impact on pasture and income so (now) we do not overstock."

"Rated lower at the present as for these changes it is too early to tell."

100% rate **USEFULNESS** of WGT results to industry at 4 or more out of 7

60% rate USEFULNESS of WGT results to industry it at 6 or 7

"It is the best thing ever and if people would look at it they could see that. For example, we sell bullocks at 3.5 years, at 360 to 400kg, our neighbour sells at 4.5 years and 340kg and neighbour stocks more heavily than we do."

"I don't think type of country matters as the principles apply to all types."

"Quite high as there have not been too many trials that have run over long times and that makes the results more powerful."

The most important message from WGT

Five (5) initial categories:

- To not overstock
- Longer-term perspectives
- Profitability impacts
- Management of pasture, and
- Whole grazing system perspectives.

Sixth category here of **contrasting views**

"Unfortunately, WGT is out of date with what is needed and even GAG members are convinced to stick to science only and not explore other things such as improved pastures or treating berry bushes to give mulch even though it takes machinery."

Current level of use in the industry

23% rated **USE BY INDUSTRY** at highest 5 or 6 on the 7-point scale

Ratings suggests that a large proportion of grazing business are yet to fully utilise the results from WGT.

Thoughtful first, then qualifying their rating,

"There are a lot of principles and maybe in terms of 'how widely' it is a Yes and a No situation i.e. some are, some aren't, and they may do one of many practices."

Optimism – "Probably in the last 20 years people are looking differently at how they manage and that's due to things like Wambiana Grazing Trial and RCS."

How to increase use of results

*"WGT need to keep thinking how to present to wider industry as it is difficult to present that we are bad in our management when we don't have a viable alternative to offer in its place. That is, we need to have an alternative that shows **gain** otherwise graziers will continue with business as usual."*

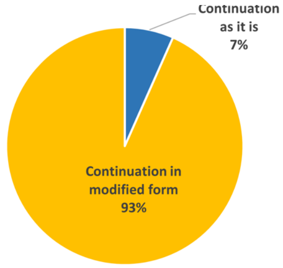
One approach may be a 'value proposition' or a 'business benefit'.

That's reported in the extension literature. The term there is **'relative advantage'.** It is reported in the meta-review of adoption literature by Pannell et al (2006) and in other adoption literature (Kuehne et at 2017).

Relative advantage is described as an **important factor in gaining adoption** of a different management practice in agriculture.

Continue 'As it is' or 'A modified form'

All 30 supported it **continuing** and 28 of those do so **with modifications**



"The longer the current trial goes in years the more relevant it becomes, and the reason is variation in seasons."

"At Wambiana there is the opportunity to do other things…need work on more ground-breaking modifications."

What to investigate at WGT

21 say **RECOVERY** strategies for land degraded by Trial.

Most frequently said: *"Use cattle to improve the overgrazed paddocks so it is profitable while it is being improved."*

"Need a few things like different grazing strategies, to become fully regenerative and look at recovery."

6 say **CARBON**. *"Carbon research to keep the industry informed of what the actual figures are for beef production."*

4 say **CONTROL** the spread of currant/berry bush.

"The more woodland thickening the higher is the stocking rate on the paddock, so how much is stocking rate down at WGT due to woodland increase."

Individual topic examples:

"How to show the feedback loop of declining feed quality (pasture condition) and poor pasture response at the next rain."

'If they could incorporate consideration of debt in the financials, they calculate for stocking rates because that is the reality (for many graziers)."

Reservations about scientific only method

"They (WGT results) do apply however I don't think they are necessarily the best way forward for the industry as they (those running WGT) are still sticking to scientific method rather than look at production as a focus.'

Their reservation - WGT may not trial strategies that:

- Deliver on animal production
- By using larger mobs
- In rotational strategies that increase rest periods
- To promote improvement in pasture condition (including the presence of desirable species).

For the future, multiple graziers gave recovery suggestions that match this concept of improvements to pasture through grazing strategies that allow for animal production. The 'thinking concept' is that both can be improved at the same time.

Value of long-term industry research – grazier ratings

93% rating 4 or more out of 7 83% rate it 6 or 7 out of 7

"Long-term research gives strength behind the data from its consistency which increases the certainty that graziers can get the same result."

"Without trials for long periods we won't know the long-term effects."

2 Introduction

The Wambiana Grazing Trial (WGT) started in 1997 to test and develop sustainable and profitable strategies to manage for rainfall variability in extensive grazing lands. The trial is located on the property Wambiana near Charters Towers, Queensland, and consists of 10 paddocks each 100 hectares in size.

The Wambiana Phase 3, 2018 Report[1] with results over 20 years reports that fixed moderate stocking at long term carrying capacity, with or without spelling, maintained pasture condition and maximised individual animal production. It was also twice as profitable as fixed, heavy stocking. Pasture condition declined significantly under heavy stocking, directly reducing drought resilience. Surprisingly, flexible stocking was no more profitable than fixed moderate stocking and resulted in slightly poorer pasture condition. The report states that, Nevertheless, experience in the current drought has highlighted the advantages of flexible over fixed-stocking.

The 2018 report states that in consultation with producers and extension staff, key messages were identified and an extension design brief formulated. In summary, enterprise profitability and land condition will be maximised with risk-averse, flexible stocking around long term carrying capacity, coupled with wet season spelling.

A funding agreement between the Queensland Department of Agriculture and Fisheries (DAF) and Meat and Livestock Australia (MLA) enabled the continuation of the research project with Wambiana Phase 4, and that phase is currently concluding. As part of the Phase 4 contract the WGT team commissioned a supplementary survey of KASA (Knowledge, Attitudes, Skills and Aspirations) on practice change resulting from the WGT project and its associated activities.

This surveying involved interviewing 30 beef producers independently selected from more than 40. The beef producers were interviewed by phone in November/December 2021 and their responses uploaded to the YourData site provided by DAF. This report was prepared using that data.

3 Methodology

3.1 Qualitative research surveying

The qualitative surveying method used in this research required a methodology which allowed the interviewees to provide their information in an in-depth[2] way. This

[1] URL http://era.daf.qld.gov.au/id/eprint/6338/1/B.ERM.0107_Final_Report.pdf Accessed Jan 2022

[2] Minichielleo, V., Aroni, R., Timewell, E. & Alexander, L. (1990). In-depth Interviewing: Researching People. Melbourne: Longman, Cheshire.

approach is to enable them to talk of their reasoning and motivations when rating and commenting in responses.

Because it is data of each person's experiences, it is a less structured approach that was taken to allow for the differences and similarities to be made apparent by the respondent. Semi-structured interviewing allows for individuality of grazier response, and it is the approach used with topics in the Wambiana Grazing Trial survey of 2021, where they were introduced as open-ended questions to initiate topic relevant responses.

The semi-structured process allows the interviewer to use probe questions to expand on any topic. An interview guide was prepared from the research questions and sent to graziers before the interview if they wanted it.

This surveying methodology enabled the researcher to develop a deeper understanding of the role the Wambiana Grazing Trial (WGT) results filled for each respondent. It did so through hearing from respondents on the level of change in their knowledge, attitude, skills, and aspirations to change, as well as the trial's level of impact on any grazing management practice change made.

3.2 Data analysis and interpretation

Grounded theory provides a method for collecting and analysing qualitative data in social research. In this project, it was used to create understanding of how graziers are experiencing the phenomena of the Wambiana Grazing Trial and the level of influence of the results in their management.

The grounded theory methodology, when applied systematically, enables a fuller understanding of the situation through the construction of theories that explain what those in the situation of grazing management practice change are experiencing. It does so in a form that is then readily accessible to others. Because the research questions require the collection and analysis of qualitative data of graziers' experience, grounded theory presents itself as a suitable methodology for data analysis and interpretation.

The open-ended questions used provided qualitative data which was reviewed by the researcher for repeated items, ideas, concepts or elements and their ratings or their relative frequency. As the interviews progressed these were clustered into like topics. Where the topics are sustained in frequency of mention, they became categories. These categories are the basis for the results presented in this report and it is grounded in graziers' experience of the Wambiana Grazing Trial.

Overall a constructivist approach[3] was used in the collection of the data in this project. It recognises that those in the situation are more able to describe their experiences and that data collection cannot be totally objective for qualitative data i.e. it is influenced by the questions asked and the presence of the interviewer. For that reason, the process benefits from creating a climate of non-judgement and supportive listening as referred later in this section as 'data collection principles'. Creating such a climate also increases the confidence that conclusions identified are realistic when drawn from the accumulated data.

3.3 Respondents

WGT staff provided the names and contact details of graziers who had participated in the trial activities previously in one or other of three (3) ways. They also provided WGT events or activities graziers attended as part of the extension work of the Trial. Staff also made the initial contact seeking agreement to be interviewed. These two pieces of information were used by the interviewer to make connection to the landholders.

Confidentiality of survey information has been assured because the project team agreed to anonymity through separation of landholder details and survey responses.

3.4 Response numbers

All surveys were arranged via phone and conducted by phone at a time chosen by the grazier respondent.

Responses were collected from 30 graziers. Staff provided the names of 43 graziers and from these the researcher selected potential respondents. These were based on the type of connection to WGT, their location by district/region and a range of known experiences with the trial and its activities so they were as representative as possible of the group on offer. Some were selected on the basis of the researcher's knowledge of grazing management from having previously surveyed some in the districts/regions.

Of the potential contacts one (1) chose not to be involved and another responded to a text that they'd make contact however they had not done so in the time available for surveying. About a third of graziers needed to make a change to the time due to their working commitments and this was accommodated by the researcher.

3.5 Data collection principles

During the phone data collection, the interviewer:

- reminded respondents of the survey purpose

[3] Mills, J., Bonner, A., & Francis, K. (2006). Adopting a Constructivist Approach to Grounded Theory: Implications for Research Design. International Journal of Nursing Practice,12(1),8-13.

- demonstrated non-judgement of responses through acceptance and supportive listening
- matched the speed of interviewing with the respondent's delivery
- matter-of-factly reminded them that their own knowledge and experience should be taken into account when responding to questions about new knowledge, skill, change in thinking (attitude) and aspiration to change as well as actual practice change
- used a process of seeking disconfirming information particularly in relation to impacts that may or may not be attributable to WGT results
- regularly checked for understanding with the respondents
- posed probing questions based on each grazier's responses to assist in explaining the responses.

3.6 Collection and upload

The process used for collection and upload was:

- An initial phone contact by the researcher to check interest, availability and date for phone collection of responses. As this was a first connection by the interviewer with each grazier, it included a brief conversation on current situations on their property often related to seasonal conditions.
- The graziers were offered the interview questions by email for their information before the interview. All but one asked to have the questions sent to them beforehand.
- Call as agreed to conduct the interview and collect the information, reorganising the time when needed.
- At the interview the responses were noted as keywords, phrases and direct quotes, directly into the YourData site provided.
- As soon as possible after each interview the notes were expanded more fully from keywords and phrases so that it portrayed, as authentically as possible, all data relevant to the research questions.

All 30 data sets were used to prepare the research report as described in the grounded theory methodology process earlier.

3.7 Reporting

Qualitative data is the foundational information used for reporting this research. In the report it provides understanding of how graziers are experiencing the phenomena of the Wambiana Grazing Trial through attention to repeated items, ideas, concepts or elements and their ratings or relative frequency. Examples of these Items are shown in *italics* which are the direct quotes graziers made when interviewed and are examples of the qualitative data on which interpretations were made.

4 Context for the survey

4.1 Familiarity with WGT results

All of the 30 graziers had connections with Wambiana Grazing Trial (WGT) in one or more of three ways:

- Attended field days at WGT site
- A member of the Grazier Advisory Committee (GAC)
- Being in a group attending activities on one (1) of three (3) properties demonstrating WGT principles.

For those interviewed the majority had attended field days on the WGT site, and attendees at only one (1) demonstration property were made available for interview. A few were, or had been, members of the Grazier Advisory Committee.

Some commented about their connection in this way:

- *Have attended three (3) field days and am on GAC…and it's the relevance that keeps me going back!*
- *Have been to field days and was on GAG at the start where we said we know how to manage using conservative stocking rates. Since then however, the trial went on and we have valued the figures that had been shown to explain the link to profitability from conservative stocking and the better pasture results.*
- *I was involved at a demonstration property and read other WGT information from Paul Jones.*
- *Went once quite a while ago.*
- *I've been twice in the last 10 years.*
- *Went to Wambiana 10 or 12 years ago and recently went to our discussion group where we talked about it.*

All said they were familiar with the results at some level and their ratings of familiarity on a 7-point scale are shown in Table 1, where 1=Not familiar; 7=Very familiar.

Table 1. Familiarity with the grazing trial principles

Rating	Percent	Responses
Not familiar 1	0.0%	-
2	0.0%	-
3	3.3%	1
4	10.0%	3
5	36.7%	11
6	40.0%	12
7 Very familiar	10.0%	3

Table 1 shows that 29 graziers rated familiarity with results at 4 or higher and with 23 rating their familiarity at a 5 or a 6 and a further three (3) rating their familiarity at 7. Some took the opportunity to make a comment, for example:

- *Big take home is more cattle doesn't mean more profit so run less cattle and get more money and keep the grass. I now watch ground cover more because if I have too many mouths on then all cattle suffer and lick costs go up and we feed lick.*
- *Six (6) as I am fairly familiar. I find it very interesting from GLM point of view as it is relevant and unique in the length of time it's been running. And the longer it's gone on, the more relevant it's become and the findings are becoming more dramatic!*
- *I'm reasonably confident with the results. The secret was to do it over the long term because when it started there were better seasons and the researchers realised they hit the country too hard early.*
- *Am familiar with the general principles. What stuck out for me at the trial was some of the things my company was trying to do with forage budgeting…at WGT it was good to see it laid out in a practical application in the north.*
- *WGT is great thing and top marks to Peter O'Reagain and John Bushell. Shame is everyone can't do it and those who need to see it don't see it.*
- *Have had an interest in WGT for a long time so have been getting Trial info plus we did GLM where there was talk on grazing strategies from WGT. However, industry has moved past those first grazing strategies now.*

Some commented on not always being able to use their WGT knowledge:

- *Fairly familiar however sometimes when things are tough, we aren't able to stick to the principles e.g. when export ban hit.*

- *Reasonably familiar and we try to not overstock but we can't do that every year. When we can we wet season spell.*

Others were familiar with the WGT principles, had attended multiple times however were able to identify other sources from which they gained the principles first:

- *Been there four (4) or five (5) times and main principles are wet season rest and conservative grazing, however we got our ideas in 2000 at an RCS (Resource Consulting Services) Grazing for Profit School and have developed our management from there.*
- *I was involved early and the results are pretty much now known on-rote for me. Of course, anyone who knows anything would know the more grass you give cattle the faster they grow, so that's not new!*
- *I know of their variable stocking rates which is something I have always done, and I knew it from my own understanding of how to manage country.*

4.1.1 Summary

All 30 graziers were familiar with the Wambiana Grazing Trial. For some it was their first source of information on the grazing strategies they now use even when they could say they aren't able to apply the principles every year. For others the trial was not their first source of the information.

5 Change in Knowledge, Attitude, Skills and Aspiration to change

5.1 Awareness, new knowledge/information from WGT results

In this section the first aspects of Bennett's Hierarchy's stages involving change were canvassed with the 30 graziers i.e. those of awareness and new knowledge.

Awareness of four (4) of six (6) aspects of WGT results were evident and a considerable majority of these graziers reported getting new knowledge.

Awareness of WGT results

Graziers were also asked of their awareness of six (6) statements summarising aspects of the results from WGT. They were asked to respond with one of a 'Yes', a 'No', or a 'Not sure'. Their responses are shown in Table 2 where 19 to 25 were aware of each of four (4) results through their contact with the Trial.

Table 2. Awareness from the Wambiana Grazing Trial

Awareness of results	Responses
The value in adjusting stocking rates as seasons change even if stocked at your LTCC	25
Potential benefits to production through matching stocking rates to forage supply and wet season spelling	25
How management can affect the severity of drought and its impact on land condition	20
How to minimise pasture degradation and improve recovery post drought on your property	19
That there are decision support tools e.g. FORAGE, VegMachine, the Ready Reckoner to assist in managing stocking rates.	13
The value in managing woody plants using fire	6

For the other two (2) listed aspects in result summary statements the level of awareness decreased:

- Thirteen (13) were aware from WGT of decision support tools like FORAGE being available for pasture management, and
- Just six (6) reported being aware of the value of managing woody plants using fire.

That only six (6) said they were aware of fire as valuable for woody plant control is not a surprise as comments made elsewhere were that at WGT fire hadn't controlled currant bush, for example, '*Currant bush is a problem and the data for fire shows it is not an effective tool.*'

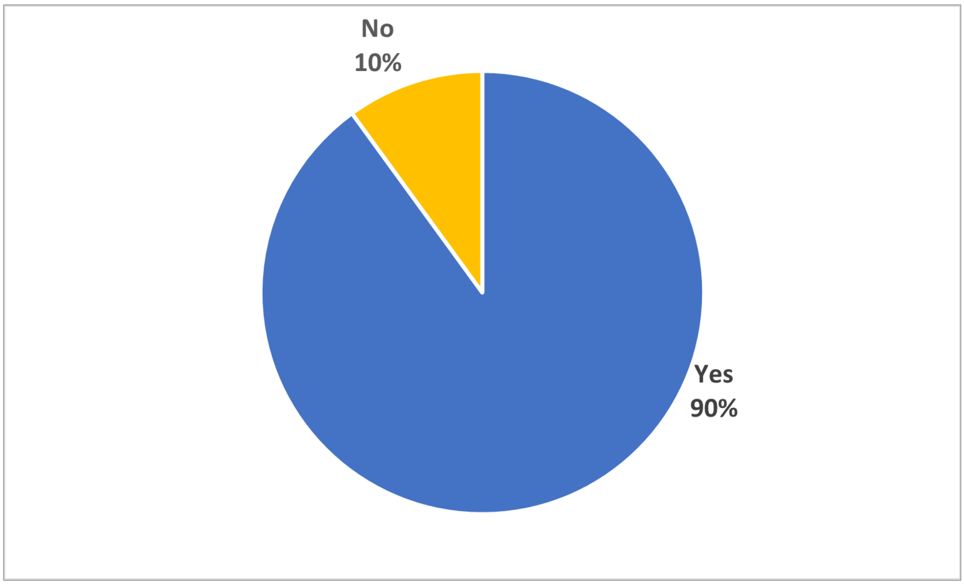
Examples of some other comments of interest were:

- *I am aware of these things however that is only knowing it and I'm not able to act on that awareness.*
- *I don't think Long Term Carrying Capacity (LTCC) is a useful term to be using and needs to be removed.*
- *It's not that complex to judge the amount of feed and having extra is better than having less.*
- *We are lightly stocked however our business model includes agistment which is set stocked. It is a tricky thing to shift people's agistment cattle around, even when we know they'd do better elsewhere (other paddocks).*
- *Some of these came from general experience and other sources and not just WGT.*

5.2 New knowledge/information

Figure 1 shows that for these 30 graziers, 90% report gaining new knowledge or information from the Wambiana Grazing Trial results.

Figure 1. Gaining new knowledge



Their responses most often describe the new knowledge in one or other of two ways. The first is that the knowledge was 'new' for them, for example, '*New information on rotational grazing and its results and the grazier speakers at 2021 field day told us more of their use of rotational grazing and resting.*'

The second was that the while the knowledge wasn't new to them, what was 'new' was the reinforcement it offered of a previously held management idea. For example, '*It reinforced what I knew from my father that when droughts come lighten off. Now I keep Wambiana results in mind as I move forward and make management decisions.*'

In a follow-on question graziers were offered the topics of new knowledge identified by the researchers as coming from the WGT work. The topics graziers reported is shown in Table 3.

Table 3. New information/knowledge

New information/knowledge	Responses
Profitability of different stocking strategies	23
How stocking rates drive animal performance and land condition	19
Matching stocking rates to feed supply	18
Wet season spelling	16
Understanding of the ecology of key grasses like desert bluegrass and what's needed for their survival in pastures	11

The impacts of the different stocking strategies are the standout in the acquisition of 'new knowledge' for graziers. This is possibly not unexpected as many respondents referenced seeing the evidence in the higher stocked paddocks of the loss of pasture.

It also may be expected given that grazing industry business success depends on profit, and WGT results showed figures for increased costs and lower returns in the high stocking rate strategies.

Some stocking rate comments were:

- *Yes, new knowledge because some principles were confirmed e.g. for stocking rate. I was aware overstocking has a poor long-term result and this is confirmed as now we know the heavy stocking rate hasn't been successful.*
- *Good to have profitability results in black and white as my parents said don't overstock but couldn't explain their reasons. I also learnt from the owner where I worked for a few years to not overstock and to sell so stock are off the grass and with no costs to buy feed.*
- *It is the longevity of the trial that is important and what's happened to different paddocks over the years is the new information.*
- *The more important thing for me was that light grazing worked for nearly 20 years but come 2015 that failed too.*
- *WGT illustrated there was no more money in having more cattle and there were more costs e.g. supplements etc. WGT has never been more relevant as supplements have become more expensive.*
- *Use a variable stocking rate, was the message I got from Wambiana.*
- *The new information was that there is a sweet spot between moderate stocking and having too few cattle where you are not profitable. That WGT put figures to that strengthens the knowledge of what is sustainable.*
- *It reinforces what you think you might know from the experience of doing management and the Trial results put figures on it.*

Sixteen graziers (16) reported new knowledge about wet season spelling. Some wet season spelling comments were:

- *At the Wambiana demonstration site in our area there was a paddock where cattle had been continuously stocked. We had seen how bare it was around water points, which we often take as 'that's how it is.' It was locked up for a wet and we got to see the result after and the change was impressive!*
- *We used to wet season only spell and now in last 3 years have moved that on to rotational grazing as pastures were tired and rotations has seen pastures rejuvenated.*
- *I have been working at trying to understand how we can incorporate wet season spelling without damaging the paddocks where extra stock are held during the wet season.*

A third, that is 10 graziers, identified other topics on which they got new information other than five (5) on offer. Here they are clustered to new knowledge specific to loss of pasture/land condition, software packages, fire, waters for rotational grazing and walk over weighing infrastructure.

i) Land condition in relation to just how quickly country can be degraded with poor grazing strategies, and the value of paying attention to pasture rather than cattle, for example, *'Our new is knowledge of plant health. It's that what we can see above ground and what we do to the top can cause shrinking of root base and with that the ability of the plant to handle dry conditions.'* Also, *'I got new knowledge that they probably didn't expect us to get and it is that moderate continuous stocking doesn't maintain land condition'*.

ii) Software packages and websites for pasture assessment, said as, *'Software packages are great research tools and it is good to know about them, however I don't use them.'*

iii) That fire didn't reduce Currant bush, for example, *'It was not new knowledge for me but one thing I did take away is that no matter what fire they used it didn't make the amount of berry bush any less and they kept getting more.'*

iv) Waters for rotational grazing, for example *'The need for more waters to allow stock to be rotationally grazed'*.

v) Walk over weighing, said as *'How useful walk over weighing technology might be for us'*.

vi) Other notable responses for new knowledge were:

- *I always took something away from the WGT, however it doesn't cover the influence of debt and other costs such as education, ill health, succession etc. Or that banks demand payment and they expect us to have numbers which limits what we can do to use the grazing principles from WGT.*
- *The grass species monitored showed how fragile native blue grasses can be in a pasture. If they are overgrazed not much comes back from seed and they are not getting thicker in the Trial pasture even after rain.*
- *At WGT there is still lot for the team to learn about resting. In general there is the idea that three (3) months rest followed by nine (9) months stocking is all that's needed, however the gains made in the wet season spelling are difficult to maintain when continuously grazed after only one spell.*
- *I already do some of these things which I learnt from my experiences while agisting cattle before I took over managing this place.*

5.2.1 Summary and discussion

Nineteen (19) to 25 of these 30 graziers reported being **aware** of four (4) of six (6) statements on aspects of WGT results related to pasture management. As well some graziers said they were aware of these as findings from WGT however they were also aware of them from other sources. For some of these the other source was where they gained it first.

With 90% of these graziers gaining **new knowledge** from WGT it is evident that the results for production, pasture and profit are generally well known particularly by those in the surveyed group particularly for the original stocking rate treatments.

By the scarcity of comment on awareness or new knowledge gained about variable stocking rates it seems fewer respondents are aware of the most recent use of variable stocking rates in the Trial work. This apparent lower awareness may mean the WGT team could consider how they might portray the progressive role WGT has taken in interpreting and applying the research results. In a related topic the value of having field days show WGT's progress over time as a learning mechanism for attendees, is a topic raised by a grazier when responding about future directions for the Trial (See Section 7).

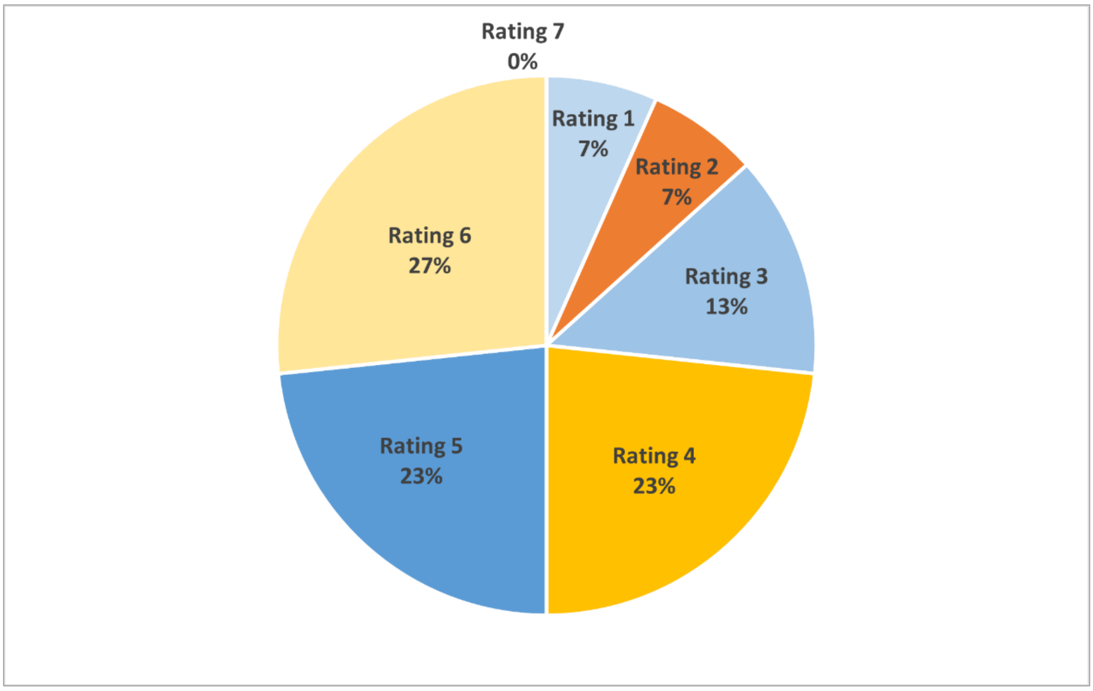
5.3 Attitude change in management thinking from WGT results

In this section graziers were asked to rate the level of change in their thinking from what they knew of the WGT results. In this survey a change in thinking about management change prompted by the Trial results, represents a shift in attitude about their management. Bennett's Hierarchy[4] acknowledges this as a stage in moving to practice change.

All 30 graziers rated the change in their thinking from knowledge of WGT results on a scale of 1 to 7 where 1=Not at all, and 7=Quite a bit. The proportions of their ratings are shown in Figure 2 where eight (8) rated it 3 or less and 22 rated the change prompted by WGT results higher at either 4, 5 or 6.

[4] Rockwell, Kay and Bennett, Claude, "Targeting Outcomes of Programs: A Hierarchy for Targeting Outcomes and Evaluating Their Achievement" (2004). Faculty Publications: Agricultural Leadership, Education & Communication Department. 48.

Figure 2. Level of change in graziers' thinking



That no one rated it 7 is understandable for this group when considering:

- Managers in agriculture use multiple sources of information in decisions, as shown in the Pannell et al[5] (2006) review of adoption and Kuehne et al[6] (2017).
- These graziers were encouraged throughout the survey to consider the breadth of experiences they'd had that influenced their management decision making, as the methodology in this surveying included having respondents know they were being asked to provide what better represented their situation.

Some described the explicit use of WGT results for example like this, *'I use the WGT principles here where I manage on this property. I use them in our family grazing business as well. I used to be thinking about cattle and their production and I now look at pasture and how it is going.'*

For others the impact on their thinking was to refine their management, describing it as, *'Mostly we have refined what we do from WRT results and we use the results when making decisions.'*

It is valuable to note that even where WGT results changed a grazier's thinking there are reasons it doesn't follow through to use in their management. For example, one

[5] D J Pannell, G R Marshall, N Barr, A Curtis, F Vanclay and R Wilkinson, (2006) Understanding and promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental Agriculture, 46, 1407–1424*

[6] Kuehne, G. et al (2017) Predicting farmer uptake of new agricultural practices: A tool for research, extension and policy. Agricultural Systems 156 (2017) 115–12

grazier said, '*Has changed my thinking however I'm limited in what I can do because of the debt I have to service.'*

The range in others' ratings is, of course, reflective of how much their thinking has been influenced by the results. For some graziers, the WGT results represented how they have always managed their properties and their thinking hasn't changed e.g. '*It has been the way we manage for a long time.'*

For others the results have reinforced principles learnt much earlier again without change to thinking, '*Not so much changed my thinking but WGT results have reinforced how I manage as I learnt the main principles before WGT began.'*

And for another group of graziers the results are a reminder rather than a change and still led on to use in decisions, '*Rather than changed my thinking the results serve as a reminder of where the pastures have gone under the different regimes at Wambiana and I use that knowledge in making decisions.'*

Some other comments included:

- *It has changed our thinking a lot because of it we have made a statement that we will start fencing our country to do rotations and better manage pasture spelling and recovery. Our current five (5) breeder paddocks will each be fenced into 3 or 4 smaller paddocks.*
- *Totally reinforced my thinking and it added measurements which gave strength of conviction to me.*
- *The last 10 years have been very dry here and we may have to get used to that…recently I looked at photos from WGT 2021 when we started a grazing group in our (district). WGT underlines what most of us do around here. I have questioned the WGT moderate stocking rate as I think it is probable still too high.*
- *They showed some things about complete wet season spelling versus set stocking versus moderate stocking and that showed how complete rest made a real difference whereas we thought we were doing rest when we were partially reducing stock numbers in a paddock. The lesson was to not just lighten off but to give a complete rest to paddocks as part of a rotation.*
- *Not a great deal if at all but I do think about their…I look of ways to improve my soil, pasture and production and I and a mate bounce ideas off each other. I do know WGT is doing it with pasture in its natural state but that doesn't work for a lot for country such as mine that has the potential for improved production.*
- *Because agriculture is fragile decisions need to be thought about before putting in place, so we talk and talk to others doing it and decide how to make things work, so some change in my thinking has come from WGT.*

- *I had guessed that the results maybe what they are, but it is vital to me that the guess is now confirmed.*

5.3.1 Summary and discussion

In summary, 22 of the 30 (73%) of surveyed graziers reported their attitude to management changed from the new knowledge they gained from WGT results. It is represented here as changes made to their thinking about management.

Some reported:

- An explicit change in thinking to now focus on what's happening for the pasture and to knowing how to wet season spell.
- That Trial results have refined their overall management thinking.
- What they saw happen to pastures in the WGT paddocks is in mind when decision making.
- The results, including the figures on costs, have reinforced what they do in management.

Not everyone who changed their attitude as a result of WGT has been able to act as they wish and the example here is that debt prevented them doing so. Later in the report we will see the proportion of the 30 graziers who went on to change a management practice.

The figure of 73% changing their thinking represents a cascade down from the 90% who gained new knowledge. That this happens is understandable in terms of knowledge being something known at an awareness or cognitive level. Thus, new knowledge can represent only an addition to what is known. Change in attitude requires some level of cognitive dissonance to prompt the shift to a different state, one in which, for these graziers, there is recognition of a need to do something in their management.

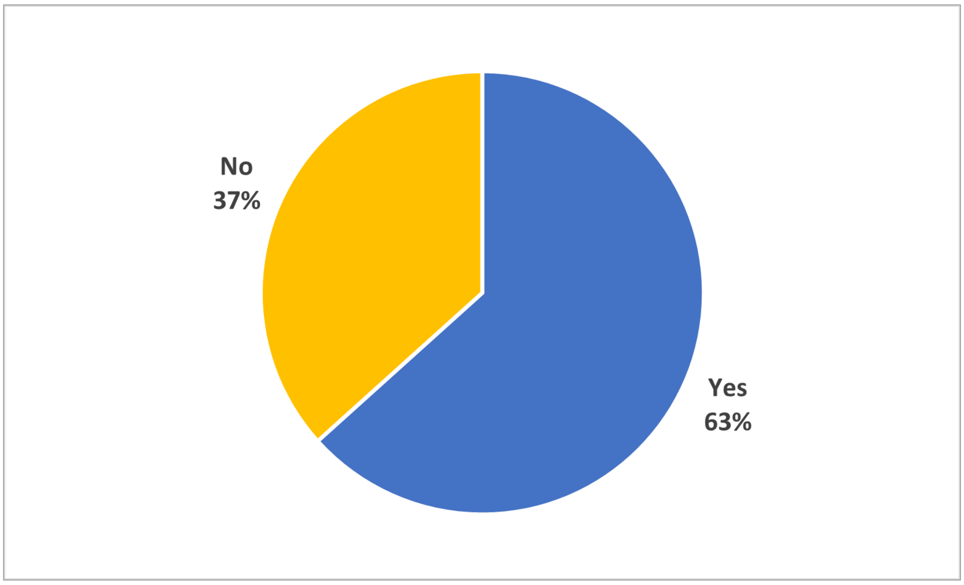
Attitude change is actual change, and it is an important prerequisite step for 'doing' something different. It does however remain a thinking process only and as such need not lead on to practice change. Later in the report we will see the proportion of the 30 graziers who went on to change a management practice.

Section 5.4 will examine whether or not the graziers gained new skills from the Wambiana Grazing Trial.

5.4 Graziers learning new skills from WGT results

Graziers were asked whether or not they learned a new skill from Wambiana Grazing Trial. 'Yes' responses came from 63% of these graziers. (See Figure 3)

Figure 3. Learning new skills from Wambiana Grazing Trial results



Secondly, graziers also responded to options for particular skills they gained, and their responses are shown in Table 4.

Table 4. Particular skills gained

Particular skill	Responses
Pasture yield photo standards	5
FORAGE reports on the Long Paddock website to estimate pasture availability and manage stocking rates.	4
VegMachine (to assess paddock level changes in ground cover in response to drought and management.)	3
Technology (e.g. Walk over weighing or remote cameras on water points)	3
The 'Ready reckoner' simple tool to set and adjust stocking rates	2

The WGT project team offered five (5) particular options they wanted graziers to respond on. For the particular options the 'Yes' responses numbered five (5) or less for any one option.

It is of interest to note that all graziers replied readily when asked if they had learnt about the options offered. That they could choose readily, plus the low incidence of replying 'Yes' to the options on offer suggests only a few graziers learnt about any one of those particular options from WGT.

In the category 'Other skills' where graziers could nominate a different skill learnt, 10 graziers nominated another skill. When describing the skill most said it was the experience of seeing the paddock situation at the trial site and learning from that what to do or not do. Examples are:

- *Being in a paddock where a particular stocking strategy has been used to see what's happening.*
- *To not overgraze to avoid woody weed increase in over-grazed paddocks.*
- *To increase ground cover for water penetration.*
- *Maintaining ground cover to stop topsoil soil loss from bare paddocks.*
- *To vary stocking rate in our system.*

That each of these descriptions was given as a skill suggests the graziers made the 'observation' of the paddock and converted their observation into the skill of doing what they believed necessary to achieve their wanted outcome.

Also, in the 'Other skills' category some graziers did describe more usually skill related practices such as pasture budgeting and identifying grass species. For example, '*Main one is forage budgeting as I knew little about it before. Now I do it visually paying attention to pasture species present. I began with using photo standards to practice*'.

5.4.1 Summary and discussion

The proportion of graziers reporting learning new skills is 63% and that is readily interpretable in the overall Knowledge Attitude Skills Aspirations (KASA) model. That figure is less easy to interpret for the particular skills the WGT team thought graziers could have learned as the proportions learning skills on the options offered is low.

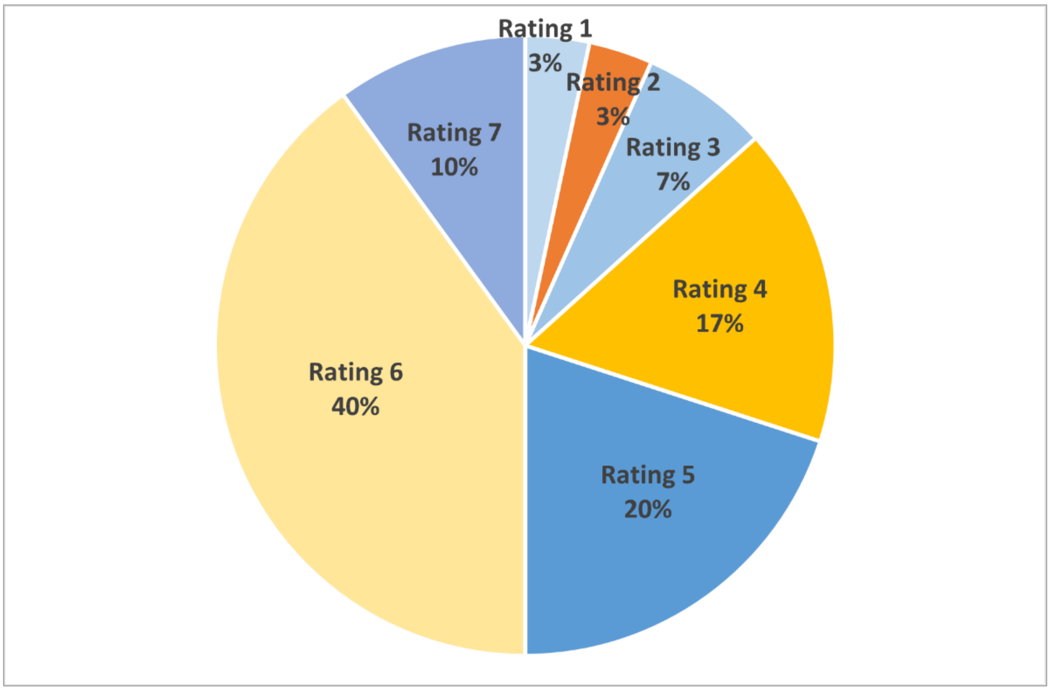
It may be of value for the WGT team to reconsider whether graziers want such skills and/or what to change in how they delivery on them at the Trial, to improve the rate uptake of those skills.

It is notable that a third of the graziers nominated other skills learned and that the predominating skill reported was that of seeing what happened in the different treatment paddocks as a lesson in what to do or not do, for their management. This aligns with a number of other comments collected in the surveying where being on the Trial site is reported as providing the evidence graziers needed to change their management. The power of the visual message at WGT may warrant consideration for how to capitalise further to connect more graziers to the Trial site.

5.5 Relevance of WGT results on graziers own properties

When asked to rate what the Wambiana Grazing Trial results have shown for their own property 50% of these graziers rate the relevance at 6 or 7 on the 7-point scale, where 1=Very little and 7=Very much. The proportion rose to 70% for 5 or more and to 87% for 4 or more. (See Figure 4)

Figure 4. Distribution of own property relevance ratings



Interpreting those figures show graziers broadly acknowledge the on-property relevance of results from Trial work done to date. That acknowledgement does not imply that all graziers are referring to the same set of results. Further, it cannot be concluded that they are using those results in their management.

What can be made of the ratings is that they are referring to what they noted in the full set of WGT results and these are what enables them to rate the relevance to their own property as they have done. The interpretations made here are based on the reasons given for ratings some examples of which are shown here.

Graziers were asked to provide a reason for their rating and their reasons can be grouped as:

- Maintaining ground cover/land condition
- Adjusting stocking rate
- Having measured results
- Seeing general relevance to their property.

Ground cover/land condition examples:

- *That stocking conservatively to maintain ground cover is profitable and looks after the country.*
- *My father did things different to how I do them as I'm now using WGT principles as we know you do not gain much by taking country too short in the dry season.*

- *They have reinforced what I knew, that overstocking can damage your paddock and it can take a lot of years to come back because rain water runs off rather than going into soil.*
- *They are relatable and apply to here as we know that if we flog country we lose grass and we don't want that.*
- *WGT is in a different climate area to us e.g. different rain, different soil type, however the principles work in any country. We have also noted the flow-on effects that happen at WGT such as increase in berry bush which is a woody weed. So WGT has provided validation of our strategies with rotations to improve land condition.*

Adjusting stocking rate examples:

- *Adjusting stocking rate on yearly pasture following rainfall and do not keep the same numbers in paddocks and Wambiana has shown importance of forage budgeting annually to choose the stocking rate.*
- *(Relevant) Because I've been able to improve the quality of pasture on a property that had been very overgrazed when I first took over its management. I improved available forage by reducing stock numbers by 40% and still get the same branding percent.*
- *In general they apply for example I do vary my stocking rate seasonally; however I have always done that.*
- *Certainly, the flexible stocking rate aligns with what we are doing, and we do pasture budgeting at end of the wet and adjust stocking rate according to what we assess for the pastures.*

Measured figures examples:

- *The results back up with figures what we were already doing.*
- *The results have reinforced what we do by the figures WGT showed.*
- *At (the demonstration property) there is more record keeping than we would do but the principles align with what we do.*

General relevance examples:

- *The results align very well with what we do now as I tend not to push the country too hard as I want to look after it and improve it.*
- *Principles work very well.*
- *The results do work on our property and align with what we are already trying to do.*
- *They do work on average but just don't get used because of what we can and can't do in our business.*

Not everyone however can or does apply the results, for example:

- *I think that they generally do, however we choose to do other strategies.*
- *They would work well and I do agree we should do more of what they say, and we are progressing that way.*
- *They are very applicable to our property however we are limited by debt and need to service the payments and also we've been in drought and lost access to agistment and had to bring them home.*

5.5.1 Summary and discussion

At 70% of graziers rating relevance to their property of WGT results at 5 or more out of 7, that is a significant proportion seeing the general relevance of the findings. In giving reasons for their rating it is possible to interpret that even with that level of acknowledged relevance it doesn't mean all are noting the same management aspects as shown by the content of their reasons.

There are four (4) categories of management into which graziers' examples of relevance could be grouped. They were ground cover/land condition, adjusting stocking rate, the having measured figures from WGT and general management.

As well, there are some graziers who can't or don't use the results they know of from WGT. From comments made here and elsewhere in this report, that appears to be from constraints related to circumstances or being a yet to take-action stance. Other research with graziers in the Desert Uplands[7] and the Burdekin[8] however suggests it may also be that they are yet to see **how to do it** on their property and in their circumstances. If that interpretation proves reasonable, then it may be an extension delivery opportunity for the WGT team to progress.

5.6 Graziers Aspiring/considering a change prompted by WGT results

In using the Bennett's Hierarchy framework and its KASA elements to assess progress towards practice change the final pre-change element is Aspiration, i.e. personal recognition of wanting or desiring to make a change.

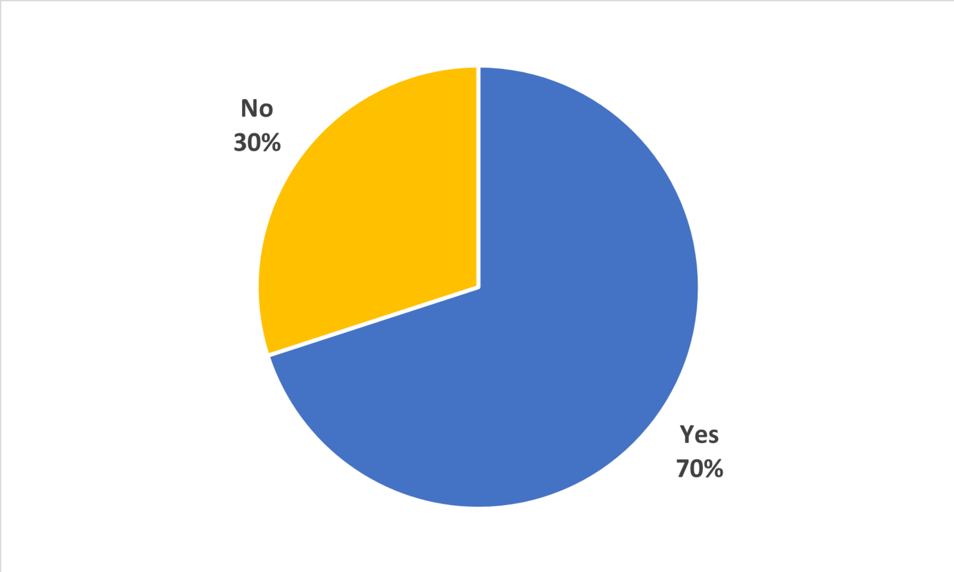
In this survey, Aspiration to make a change was assessed through asking whether or not a grazier has considered making a change based on WGT results, for example, '*To pay more attention to pasture, as for much of the other WGT information I have been doing the management already*.'

Responses here show that 70% of these graziers report considering making a change based on what they knew of WGT results. All responses are shown in Figure 5.

[7] Paterson, E & Roberts, G M O (2006) Report *"Desert Uplands Social Research for understanding and integrating local and technical knowledge for natural resource management (Stage 2)"* Desert Uplands Build-Up & Development Strategy Committee Inc. Collaborative Research.

[8] Roberts, G M O (2019), DAF Practice Change Research Surveys in the Burdekin Catchment, Report, December, Prepared by GR Consulting.

Figure 5. Proportion of graziers considering a change



It is of practical interest to note here that for some their aspiration to make a change could be situated some years ago. The reason is that these 30 graziers were, in part chosen, to represent those attending field days etc throughout from time of the WGT and the first field day was held in 2007.

Graziers' aspirations for change using WGT information can be grouped into three (3) categories, those of incorporating wet season spelling, making more observation of the pasture and varying stocking rate to suit the season.

Wet season spelling – examples:

- *The amount of spelling we do.*
- *Grazing in rotations to provide rest and recovery.*
- *To put wet season spelling in place.*
- *Wet season spelling. And knowing the WGT results I know not to use pasture for short term gain - because the figures have been done and have proven it does not work over the longer term.*

Observing pasture more – examples:

- *How we are managing our central Queensland blue grasses.*
- *My father said if you had grass at end of year you weren't utilising what you had available. Now we understand you need to have grass at left at end of year to get water into the soil.*
- *From WGT we are alert to issues like timber thickening and that raised our awareness so we know to look at our pasture situation so it doesn't happen here.*

Varying stocking rate – examples:

- *We considered using forage budgets more for stocking rate decisions rather than doing it on an ad hoc basis.*
- *Because I was thinking similar things about stocking rates etc, the results have morphed into general practice for us and we do it naturally now as part of our management.*
- *Varying stocking rates to maintain or improve land condition.*
- *Do forage budgets with an estimate of what stock can go into a paddock and then watch the pasture.*

Again, like it was for the relevance of WGT result on-property, there is evidence for aspiring to change however not being able to make it happen as a regular part of management:

- *At first, we couldn't use it as we didn't make the decisions.*
- *Doing spelling when I can.*

The responses here also show it remains a reality that like new knowledge, graziers get their aspiration to change from multiple sources. For example, '*In last 12 years we have changed to grazing and rotating in part from DAF scientists, WGT, graziers, RCS and Dick Richardson.*' And, '*I first started rotating to spell country to eliminate cattle tick which can be done if do the right type of rotation. While doing that I saw the benefits of wet season spelling and used it. We used to be close to continuous grazing.*'

5.6.1 Summary and discussion

Attendance at WGT events and access to the information in other ways has enabled 70% of these graziers to report aspiring to make a change. It is a substantial proportion considering the progression is through acquiring new knowledge and a shift in attitude which are, in the Bennett's Hierarchy model, considered foundational to changing behaviour.

Graziers' aspirations for change using WGT information can be grouped into three (3) categories, which are those of incorporating wet season spelling, making more observation of the pasture and varying stocking rate to suit the seasonal conditions. Some comments show that even with the aspiration to change circumstances can prevent changes being made.

It is of interest to note in this section and elsewhere that it is increasingly common to hear graziers speak of 'rest and recovery' rather than wet season spelling, and this has been particularly so with the data collection for this report. It leads to the idea of what is the concept behind wet season spelling and how might it be expressed to have the fullest meaning for graziers of what the practice is meant to delivery for the pasture.

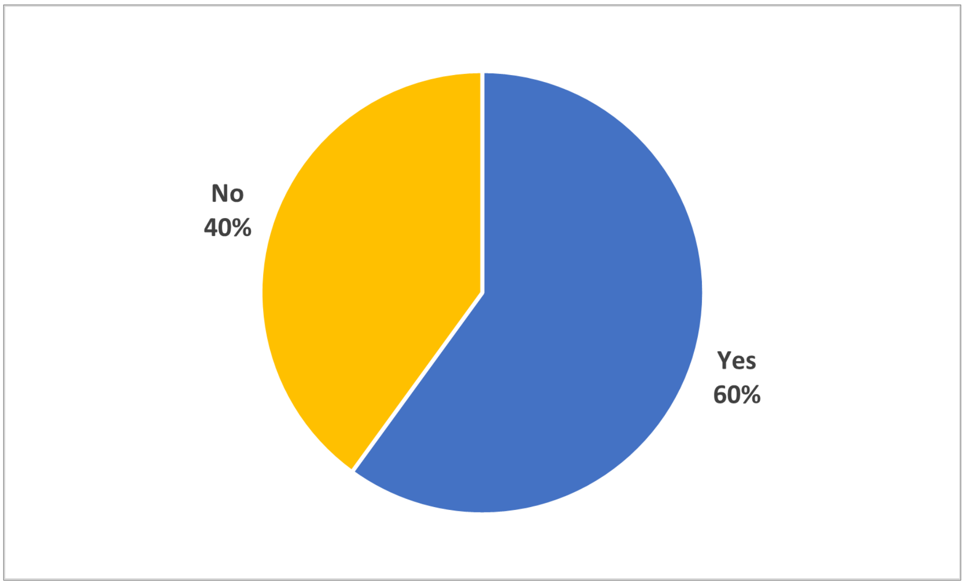
It is also interesting to note that, as elsewhere in the data collection, graziers get their aspiration to change from multiple sources including the WGT.

5.7 Graziers making a practice change prompted by WGT results

This section reports that 60% of the graziers in this group regarding the influence of WGT on their management practices, were able to identify changes they'd made. See Figure 5. One grazier said, '*Variable stocking rate (was our change) and with me it was seeing the results at WGT as well as wanting to reduce the variation in our cashflow and wanting to keep it steady rather than up and down.*'

Others were equally clear their management changes had come from another source rather than the results at WGT. For some who report change from other sources, they report that WGT results reinforce that their management is 'on the right track', for example '*Because it has only reinforced that what we do is on the right track.*'

Figure 5. Making a management change



Of the graziers reporting making a management change most describe at least one change, for example, '*We have gone to running only dry stock for the flexibility it offers to change stocking rates.*'

Others describe making more than one change for example, '*I started wet season spelling and also control stock numbers to not overstock.*' Similarly, another grazier said, '*For our own cattle we vary the stocking rate and watch the land condition.*'

Examples of individual changes made:

- *Managing stocking so we have pasture left in paddocks at the end of the dry season.*
- *Using pasture budgeting to match our stocking rate to carrying capacity.*

- *More attention to pasture and as well, the other WGT results continue to reinforce the value of the strategies we use.*
- *Vary the stocking rate through trading cattle as different seasons require.*
- *I was opposed to use fire before, but I have made a start in the direction of using it now.*
- *In paddocks where we have native blue grasses we have chosen to not do the development to improved pastures as we have with other species in paddocks with no native blue grasses.*
- *We spell more now and could do more fencing so can spell so some more country gets a blow (rest) in wet. We do spell weaner paddock each year.*

Examples of integrated changes made:

- *More fencing so we can rotationally graze. Wet season spelling is also in use as are annual forage budgeting for stocking decisions.*
- *Changed to rotational grazing to vary stocking rate and provide spelling for paddocks.*
- *We fenced to manage country better and to do wet season spelling when we can.*

Two others explained wanting to change but being unable to do so yet saying:

- *No (change) because I don't yet understand how to not damage our soil, which is yellow, when extra cattle are in other paddocks while their paddocks are wet season spelled.*
- *Not yet, but we have committed to it (fencing for rest and rotation) and I'm working on how to do it. We have bought some fence materials.*

5.7.1 Summary and discussion

That 60% of graziers surveyed made one or more management practice changes based on their experience of WGT is significant. Importantly the changes reported relate to aspects of better managing pasture or land condition through:

- Assessing pasture to decide on the stocking rate
- Varying stocking rate to maintain pasture
- Resting (spelling) pasture in the wet season
- Keeping residual pasture at the end of the dry season.

Given the explicit attention to pasture management as their chosen practice change suggests these graziers have recognised, at some higher level than previously, the importance of pasture in their business of grazing for animal production. Practical pasture management is foundational to success in a grazing business and this was recognised in the establishment of the WGT to provide information and results that graziers could use in decision making for pasture management. The changes reported here demonstrate that the trial is delivering on its purpose and is supporting graziers to make positive management changes.

When considering the proportion of this group of graziers making a change it is of interest to note that in the surveying a third of graziers said, at some stage in the discussion, that the WGT results reinforced the relevance of what they already did. One said it as, '*They (WGT) have reinforced what I knew that overstocking can damage your paddock.*' Another said, '*It has been good to go and see and have our ideas reinforced and know we are on right track. And that brings home things not to do like overstocking, because it takes a long time to come back.*'

While it is difficult to be definitive the fact that a third said the result reinforced what they already did, plus others having first contact with WGT results some years ago, brings into perspective the significance of 60% of the surveyed graziers changing. The perspective is that this is more than likely a minimum level of practice change in the grazier grouping.

As well a number of graziers in the surveying said they got their first WGT experiences earlier in the life of the project. One grazier said when asked if they'd made a change based on WGT results, that they couldn't be sure. They said it like this, '*While I think probably not I do know that when you go to something and learn new (things) then think about how to use them, then over time you don't know directly where you got them from.*' Such a comment is readily understood when it is noted that WGT has already celebrated 25 years of research and graziers acknowledge the continuing revelations from the Trial.

5.8 Value of changes made to grazing businesses

Graziers making change were readily able to assess the value to their business when they were asked to do so on a 7-point rating scale, where 1=Of little value; 7=Very valuable. Their ratings are shown in Table 5.

The ratings are across all 7 options. For some it was too soon to assess the value of their change for example, '*Rated lower at the present as for these changes it is too early to tell i.e. is not measurable at this stage.*'

For others they already know it is highly valuable with one grazier reporting, '*Very valuable because we are not walking such a tight rope each year and have more pasture and better pasture!*'

And a second said, '*Invaluable to be alerted to what has happened with berry bush. WGT is not the be-all and end-all but is building block with data we can use.*'

Table 5. Value of the change to the grazing business

Rating	Percent	Responses
Of little value 1	0.0%	0
2	3.33%	1
3	3.33%	1
4	10.0%	3
5	10.0%	3
6	23.33%	7
7 Very valuable	10.0%	3
N/A	40.0%	12

Ten (10) graziers rated it 6 or 7, and 16 rated it 4 or more, which represents 53% of the total surveyed group. It suggests they have already identified real value for themselves in making the change.

Interestingly for the 16 rating the value of the change at 4 or more, when taken as a proportion of those making the change i.e. 18 graziers, it represents 89% of those making a change and who find it of greater than average value to their business.

One grazier, who did not make a change made this comment highlighting the value of the WGT results for them, '*As we didn't change anything we can't rate value to the business, but having the figures from WGT does keep us managing our stock numbers and keeping our eyes on the pasture so we don't overstock.*' They make it clear that the results have real meaning that applies even for those who were already doing what WGT results show is valuable.

It seems that having access to WGT results can further explain the reinforcement talked of by graziers when they say the results keep them committed to managing using principles which WGT demonstrated are valuable grazing business management practices.

Examples of some other reasons given for the rating put on the value of the change to their business were, Impact on profitability, Influence on thinking/decisions and Focus on pastures.

Impact on profitability examples:

- *It helps grow my knowledge to run a profitable show by looking after pasture.*

- *Valuable as WGT gave us the figures for costs and the impact on pasture and income so we do not overstock.*
- *Valuable because I don't get to the pinch at the end of the dry each year. For example, it was really dry 3 years ago and other graziers told me they spent $200k to $500k on hay. I did not have to feed hay at all. The value is that it reduces stress and workload.*
- *Trading cattle has given added value, more so lately with cattle prices, and we are not overgrazing our paddocks.*
- *Very valuable as it means we make decisions before our backs are to wall and look for other options to reduce stocking rates. For example last year with a shorter wet season our option was to purchase land in April as by March our forage (assessment) showed our cash flow would be affected.*

Influence on thinking and decision-making examples:

- *Significant value as it changes our way of thinking about stocking rate as we can sell when we need to.*
- *Yes, on account of when our management team of two can't make the decision about stock numbers then if have something that gives a generally good decision that is useful as the worst decision is not to make one. The WGT results help us make those decisions about numbers.*

The value of focusing on pasture management examples:

- *It is valuable in that spelling adds certainty to the country and the amount of grass it will grow as less water goes in with less grass coverage and rain is lost. That's important as you can do supplementing when you have dry feed but the moment you have to bring in roughage you have to ask yourself about how that happened, as it costs a lot.*
- *It is significant as we can manage our pasture in a better way*
- *It hasn't been of great value however we feel we will have better quality pastures and we are waiting to see what is happening with the die-back in buffel and native species.*
- *The fences and spelling were not a lightbulb moment for us but they have had an average improvement from doing them.*

5.8.1 Summary and discussion

Graziers making changes were readily able to rate the value of the change to their business. Ten (10) graziers rated it 6 or 7 on the 7-point scale, and 16 rated it 4 or more. Their ratings suggest they have already identified real value for themselves in making the change.

Interestingly for the 16 rating the value of the change at 4 or more, when taken as a proportion of those reporting making a change i.e. 18 graziers, it represents 89% who find it of greater than average value to their business.

The reasons for their value ratings could be classified into three (3) broad headings namely 'Impact on profitability', 'Influence on thinking and decision making' and 'The value of focusing on pasture management'.

As well in this section, an additional interpretation could be made of the meaning when 10 of the 30 graziers said that WGT results reinforced their use of their current practices. The additional information was given by a grazier who didn't make a change and it is that the figures from WGT keep them focussed on control of stock numbers and having their eyes on the pasture.

This suggests the WGT results have meaning not only for those making a change but also for those using strategies like those shown by the trial and which they got from some other source. That knowledge further suggests the WGT impact is broader than just those who make a change because it serves as a continuing reminder to other graziers too.

5.9 Usefulness of WGT results to the northern beef industry

All 30 graziers rated their estimate of the usefulness of WGT results to the northern beef industry as a whole. All 30 (100%) rated it 4 or greater out of 7, and 60% rated it at a 6 or a 7, as shown in Table 6.

Table 6. Level of usefulness to the northern beef industry

Rating	Percent	Responses
Not useful 1	0.0%	-
2	0.0%	-
3	0.0%	-
4 Average	10.00%	3
5	30.00%	9
6	33.30%	10
7 Very useful	26.70%	8

One (1) grazier hesitated before doing so to say, '*Hard for me to answer as others have right to their own decisions*'. They went on to say that with that in mind they rated it at the average point of 4.

When giving reasons of their rating on usefulness to the northern industry most could be clustered into the five (5) categories of Applicability, Constraints on use, The value in length of the Trial, Observations of non-use and Future trial possibilities.

5.9.1 Applicability

- *It is the best thing ever and if people would look at it they could see that. For example, we sell bullocks at 3.5 years, at 360 to 400kg, our neighbour sells at 4.5 years and 340kg and neighbour stocks more heavily than we do.*
- *There are some people who say the country would be better off if locked-up and not grazed, however WGT principles show there is a profitable way to use the country to make a living and to keep the country in good order.*
- *WGT results are extremely important to the industry because if we do get questioned on what we do as managers we can refer to the treatments and the figures…any info that gives the true picture is important for industry.*
- *Enormously useful as the principles apply generally.*
- *I don't think type of country matters as the principles apply to all types and at (the demonstration property), people could see the results on the trial sites.*
- *Totally relevant in two (2) ways, one is for the environment/pasture benefit and the second is the economics in terms of returns.*
- *Principles would completely change the beef industry because the more we look at 30cm above ground to 1m below the better. If a trial of this type and length had been done in 1890 then the industry would be in a hugely better place now.*

5.9.2 Constraints on use

- *I think it would apply to most of northern beef industry with the exception the big areas in the Gulf.*
- *Reality is not everyone is in a perfect world of being able to do what the results show - it is determined by debt level. Also, the management you can do is only as good as the rain you get.*

5.9.3 The value in the length of the trial

- *Very useful as you can just do a trial for a few years but if we half suspecting climate change then need long trials to give the facts. One such fact is that the continuous moderate stocking is good as in the longer term but in droughts it showed that pasture was still being degraded.*
- *There is huge potential in the WGT work to show feedback loop (from overgrazing) of declining feed quality and poor pasture response at the next rain. In the MLA*

report that shows 20% of producers are the only ones making a real profit, shows how much potential there is for getting this happening.

- *Quite high as there have not been too many trials that have run over long times and that makes the results more powerful.*

5.9.4 Observations of non-users

- *There are ample numbers graziers who operate on par with moderate and heavy grazing and need to do it differently for the good of the country.*
- *All of us have different pressures so within those boundaries the results are useful for the industry.*
- *Some graziers don't do variable stocking where they could do it.*
- *I rate 5/7 because there is still a large percentage who set-stock. It is a double-edged question because it's alright to do trials however the problem is the lack of uptake - most times extension is preaching to converted.*

5.9.5 Future trial activity

- *Forage budgeting is critical and it is a simple concept but with large paddocks and diverse land types it is not that simple. WGT could be used to teach how to better pasture budget.*
- *The trial can show how to step into a rotational system in stages so graziers are seeing the benefits. For example, begin with wet season spelling to show how grass responds which is beginning the move it and it shows how wet season spelling grows more grass.*
- *Grazing people need to see what has happened at WGT in the rundown of the country.*

5.9.6 Summary and discussion

The majority of these graziers were confident that the WGT results would be useful to the northern beef industry. This is shown by 100% rating usefulness at 4 or more on the 7-point scale and 60% rating it at 6 or 7. It is informative to note only three (3) rated it at 4/7. That 27/30 rate usefulness to industry at the higher end of the rating is of practical value for the Trial operators to know because it highlights the relevance of their work.

Graziers' higher ratings is also of significance as it suggest they see real applicability of the results to date and collectively the 30 graziers in this survey group represent a cross-section of graziers who:

- Know the WGT results at some level, with some being involved from the setting-up
- Represent a spread geographically across the northern beef industry in Queensland, and

- Gave reasons for their rating which reflect observations and experience of the industry in their region and so their reasons came through the lens of interpreting the results in the context of the industry.

Taken together these points suggest the group is competent (i.e. well placed) to assess usefulness to industry and that provides and increased level of confidence in their 'usefulness' ratings.

When giving reasons of their rating on usefulness to the northern industry most could be clustered into the five (5) categories of Applicability, Constraints on use, The value in length of the trail, Observations of non-use and Future trial possibilities. Most reasons were about the applicability of results to the northern industry.

As well, three (3) examples were given of how the trial could work to prepare graziers to pasture budget to find their path into resting or spelling country and to see the damaging long-term effects of continued overgrazing. These too are topics the WGT team may find useful to focus their extension effort towards.

5.10 Level of use in the industry

These graziers were less optimistic when asked to rate use by the industry, unlike when rating 'usefulness to industry'. The range of their ratings is shown in Table 7.

Table 7. Level of use in industry

Rating	Percent	Responses
Not used 1	0.0%	-
2	10.00%	3
3	16.70%	5
4 Average	50.00%	15
5	13.30%	4
6	10.00%	3
7 Highly used	0.0%	-

Only 23% rated use by industry at even 5 or 6 on the 7-point scale, and none rated it at 7 (1=Not used; 7=Highly used). At 23% for ratings 5 or 6, that is significantly lower than 90% rating for 5 or more on the level of usefulness to the industry. Based on their previously assessed substantial competence to assess usefulness to industry, they can also be considered competent to assess level of use. Their overall ratings suggests that a large proportion of grazing business are yet to fully utilise the results from WGT. It is something the trial can usefully address in its work in the future.

Most graziers also took somewhat longer to arrive at their rating often qualifying their rating with statements like, '*There are a lot of principles and maybe in terms of 'how widely' it is a Yes and a No situation i.e. some are, some aren't and they may do one of many practices.'* Or, '*Hard for me to say, however in our local area my experience tells me more do use the WGT principles.'*

Few were as optimistic as this grazier who said, '*It is pretty widespread I think as It's been available for years and people go around and talk and you'd have to be a big hermit not to have heard of it.'*

More were like these graziers who said:

- *Not as many as should be.*
- *More and more are doing it but still 80% are not.*
- *Many still set-stock.*

Some could see a trend taking place over the last 10 or 20 years towards better management of pastures prompted by the type of seasons and access to activities on managing pasture. For example:

- *Probably in the last 20 years people are looking differently at how they manage and that's due to things like Wambiana Grazing Trial and RCS.*
- *The recent light seasons have people looking more at their stock numbers and they are not getting on with just an attitude to build numbers up.*

There were other optimistic assessments too, most often when limiting the area over which they rated the use of WGT results and considering recent dry seasons. For example, '*Widely used! For example, if I think of the immediate area in an 80k radius they are widely known and adopted in last 10 years which have been dry ones mostly. Wambiana is a significant part of the reason for that change.'* And, '*Not a lot yet, however the Trial is now becoming more acknowledged especially with the dry years. Next phase could include targeted extension for the Trial and its results.'*

5.10.1 Summary and discussion

Many of these graziers said they may not know enough about the whole northern beef industry to rate use by industry of WGT results. A case previously made was suggested to support their competence to do so.

With only 23% rating use by industry at even 5 or 6 on the 7-point scale, that is significantly lower than 89% rating of 5 or more on the level of usefulness to the industry.

Their overall ratings suggests that a large proportion of grazing business are yet to fully utilise the results from WGT. This appears as something the trial can usefully address in its work in the future.

One reservation was expressed here on the level of use of WGT result by industry proposing that it wasn't influencing as many graziers as it could because current work didn't include more than a record of production output. The suggestion was that attention to strategies that incorporate production as a part of the strategy will result in increased uptake.

There were few with reservations about the WGT approach going forward however one expressed theirs in this way, '*They (results) do apply however I don't think they are necessarily the best way forward for the industry as they (those running WGT) are still sticking to scientific method rather than look at production as a focus.'*

They were referring to strict adherence to conventional science constraining future WGT work. Their reservation was that at WGT it may not be possible to trial strategies that:

- Deliver animal production returns
- By using larger mobs
- In rotational strategies that increase rest periods
- To promote improvement in pasture condition (including the presence of desirable species).

That this reservation was expressed here in relation to the level of use of WGT result by industry is of practical interest to note for the future, because later in the survey graziers were asked what work could the trial continue with in future. At that stage multiple graziers gave suggestions that match this concept of pasture recovery through strategies that involve animal production and profitable returns. It can be suggested graziers are asking the WGT team to consider applying the thinking model of 'both this and that' i.e. both improving land condition and continuing profitable animal production, can be done at the same time.

6 Next steps

6.1 The most important message from WGT

The majority of these graziers gave a shortlist of at least two (2) messages when asked for the most important message coming out of the Wambiana results for industry. For example, '*Moderation in stocking rates is sustainable, and know you can't overstock continuously.'*

An example that integrated more messages is, '*Most important is we can do harm by overstocking and taking things (pasture recovery) for granted as has been done in past. A shining light is that if spell and treat well we can recover pasture over time*'.

That these graziers gave more than one message may testify to their increased breadth of knowledge of the WGT results. Within that breadth of knowledge there is sufficient consistency across replies to bring them together under five (5) initial categories. The categories, in no particular order are, **To not overstock, Longer-term perspectives, Profitability impacts, Management of pasture,** and **Whole grazing system perspectives**.

As well, three (3) respondents offered responses that can be grouped to make a sixth category here of **Contrasting views**. That is, they are in contrast to the general theme of 'management strategies of importance' which other graziers presented. That they took the opportunity to offer contrasting ideas is ideal and it provides the WGT team additional material as they consider the overall survey responses.

6.1.1 To not overstock – examples:

- *It is that overstocking country isn't sustainability and that's important because grazing is a long-term industry as shown by the successful families that are generational.*
- *While moderate stocking is good, variable is the way to operate and that was what gave the most consistent beneficial outcome.*
- *Conservative (stocking pays) off for the country and financially too. Also, there are times when you can run a few more but you must be very ready to reduce numbers quickly with poor seasons for rain.*

6.1.2 Longer-term perspectives – examples:

- *We need to change what we are doing. There is lot to learn about to balance landscape and production in a healthy way.*
- *Longevity that's what WGT has got, and because we get patches of good seasons and poor seasons that is important. For example, early in WGT heavy stocking in a series of good years looked ok, now even moderate continuous stocking has been shown to damage pasture.*
- *Keep an eye on the long-term goal of what you do because what you do this year affects next year and the next year so think that what you are doing is for every future year.*

6.1.3 Profitability impacts – examples:

- *Profitability of lower stocking rate.*
- *If I have to choose one thing then land condition is the massive factor in where you make your profit. There are lots of things that go in land condition and it is 80% or*

more of where profit comes from. Also, any damage (to land condition) affects next 3 seasons, e.g. eaten bare means less water penetration which means less pasture grows.

- *Moderate stocking is more profitable and I also think there are some opportunities to push country a bit harder but you need to be able to pull back off the extra stocking quickly and must have an 'out' plan.*

6.1.4 Management of pasture – examples:

- *We need ground cover to get rain to penetrate the soil so we need to understand feed residuals. We need to be managing the pasture to include complete rest for paddocks.*
- *Stocking rate needs to be managed so pasture doesn't degrade.*
- *I came home with a set against rotation as a young man and have changed now. Wet season spelling is an important message but where the removed cattle go needs to be taken into account because they are not just 'not in the paddock' they are 'somewhere'. Also, because they (WGT) spell different paddocks each year the paddocks don't get the spelling often whereas in our system they do.*

6.1.5 Whole grazing system perspectives – examples:

- *The most important message is variable stocking rates with wet season spelling because continuous is not applicable in the north. That's because we are never in control of seasons but are in control of the amount of feed we use, the amount rest we give the pasture and in control of the way we graze it.*
- *Wambiana has shown if we look at soil and grass and not just the economics, that shows what's important in the long term. It also applies when buying a place so forget the figures they say (advertise) it carries and look at what are the edible grasses and what condition are they in.*
- *Match stocking rate to carrying capacity at any one point in time and don't use LTCC (Long Term Carrying Capacity) and base any decisions on what's really there. Also, it is important to have some rest and do some mobbing up so you can free up country to be spelled for recovery.*

6.1.6 Contrasting views – examples:

- *Unfortunately, WGT is out of date with what is needed and even GAG members are convinced to stick to science only and not explore other things such as improved pastures or treating berry bushes to give mulch even though it takes machinery.*
- *There is a whole plan there if you want to use it but we all know running minimal cattle means you do get good cattle however that's not possible in a business.*

- *High stocking rates are less profitable in the long term but flexible stocking rate is a much riskier strategy without a compensating benefit over a moderate stocking rate because you are always trying to buy and sell when others are too and that is risky.*

6.1.7 Summary and discussion

In responding with their most important message from WGT there was sufficient consistency across grazier responses to bring them together under five (5) initial categories, with a sixth being Contrasting perspectives. The categories were, To not over-stock, Longer-term perspectives, Profitability impacts, Management of pasture, and Whole grazing system perspectives**.** This represents graziers' summarised view of what WGT has shown are management strategies important for industry to use.

Taken together the responses can be considered from a number of perspectives one of which is how well they align with what project staff identify as the most important messages. Any differences between the two may present as a means of further focussing attention on WGT results. As well, differences may show where current main messages need to be emphasised as replacing earlier results.

It is of interest to note that responses in the categories of, To not overstock, Pasture management, Longer-term perspectives and Profitability, may be considered the more likely overall responses about WGT. As such they present as ones that others in the industry will be more likely to relate to and can therefore usefully find a place in any future industry extension work WGT undertakes.

Of note is the category of Longer-term industry perspectives. Having the category may indicate some graziers are suggesting future WGT work integrate all results as practices in a grazing system approach. Such a system could include a move towards holistic approaches founded on the science findings from the Trial. An holistic approach is something which some graziers in this survey group suggest is currently not in the research or in the presentation of Wambiana Grazing Trial findings.

In the Contrasting views category there are other points of note for the WGT team. From the three (3) different views offered:

- The first suggests the project potential is being constrained by a too strict adherence to only practices already supported by science as suitable.
- The second presents the view that a grazing business can't run as few cattle as WGT results say to do.
- The third presents the view that acting to vary stocking rate is a risk as it involves trading cattle in competition with other graziers.

The first is one for the project team to examine to assess their level of 'cutting' edge grazing science for the northern beef industry. The second and third present extension opportunities for the project team once they have assessed the extent of such views are present across the industry in the north.

6.2 Increasing industry's use of WGT results

Asking these graziers to give ideas for how to increase industry's use of the results prompted quite a few saying they didn't have ideas to make that happen. Two (2) typical comments were of the type, *'Nothing comes to mind'* and, *'That's a hard one and I can't think of anything that will change that.'*

Some explained further on their not knowing, '*I can't think of any way to get uptake. Society is on about immediate gratification whereas land management requires thinking long-term.'*

One grazier recognised the WGT team had done all they could by presenting long term results consistently. They said, '*At WGT they have covered it all and they have done an excellent job with all the variants of the paddock stocking rates and have had consistent messages year in and year out.'*

6.2.1 Suggestions from graziers

Others gave suggestions and one which contextualised what could be done was, '*WGT need to keep thinking how to present to wider industry as it is difficult to present that we are bad in our management when we don't have a viable alternative to offer in its place. That is, we need to have an alternative that shows gain otherwise graziers will continue with business as usual.*'

Other suggestions, which could be presented within the context of a viable alternative, were focussed on activities like:

- Having graziers using the WGT principles share their information.
- Engaging with grazier groups in their local area.
- Showing the paddocks to practical graziers who need to see the impacts.
- Using one's neighbour's curiosity about another's level of production.
- Local demonstration sites.

Examples of how these were said are:

- *From an extension perspective the extra graziers speaking (at the 2021 field day) about how they use WGT results is valuable as they are investing their own money.*
- *Also take the results to local community groups that already talk e.g. road groups, Landcare groups etc and take it to them in short sessions.*

- *Producer based research demo sites of WGT results are good to get learning out to industry as our industry will believe more of other grazier rather than researchers.*
- *Maybe if neighbour sees next door is turning off heavier steers than they do, they would want to know how to do it.*
- *I do know that field days at Wambiana are good for practical managers like me to get me to see the results and see the impact of the different strategies for themselves.*
- *Maybe use WGT as a training ground for things like getting from set stocking into to rotations, beginning with wet season spelling which can show recovery of country to people.*

Some were more pessimistic about getting change saying for example, '*Nothing I can think of because most of those who aren't using the results are stuck in that mindset and that's what they do and aren't going to change. You can give the data but they will still do what they've always done*.'

This grazier is making a point about adoption that is particularly relevant to this report. It is that giving information alone is not the way to engage most graziers in considering change. Knowing this the WGT team can work to make their extension activities, including field days, go beyond giving information to deliver activities that provide a pathway to practice change.

One producer referenced Facebook as a means of connecting WGT more fully with a wider group of graziers in the industry. They said, '*WGT doesn't get bad publicity and I would like to get my boys there but we have been busy expanding. I think use things like Facebook to get the message out*.' That using social media to gain adoption is possible is shown in the proposed model FutureBeef is developing in its online only DAF service delivery, to provide a pathway to adoption. (Sallur, pers. com.)

A step that can be included on the pathway to adoption is suggested by another grazier whose ideas was, '*Demonstrate improvements in production approaches that benefit the resources of soil and pasture and which then flow on to the producer.'* This suggestion of 'demonstrating' will be of value when considering the earlier mentioned activity of making the relative advantage of the results known to graziers.

Another grazier spoke of the concept of relative advantage saying that for any practice change to be self-sustaining it requires the economic benefit to be known. They said it like this, '*With the wet season spelling message there has to be economic benefit and that will make it self-sustaining for financial and environmental reasons.*'

6.2.2 Summary and discussion

The theme of most graziers' suggestions is to use other graziers in the process of engaging those yet to use WGT principles. That idea, like the concepts of value propositions and relative advantage, are also to be found in the Pannell et al[9] (2006) review and in the Roberts[10] (2019) report of research with Burdekin graziers.

One way that concept may usefully be interpreted is through a business lens where providing a 'value proposition' or 'business benefit' encourages custom from a potential 'buyer'. In the case of WGT the buyers are graziers yet to use the management principles arising in the research.

What also makes the concept of providing a value proposition of a viable alternative of interest as a way forward is that it is also reported in the extension literature. The term there is 'relative advantage'. It is reported in the meta-review of adoption literature by Pannell et al[11] (2006) and in other adoption literature (Kuehne et at[12] 2017). Relative advantage is described as one of the important factors in gaining adoption of a different management practice in agriculture.

As well the same concept is in the service delivery principles found to be relevant to Burdekin graziers (Roberts 2019[13]). In that applied research graziers reported that they'd benefit from receiving concrete evidence of the advantage of a change over their current practice. They suggested it is one of the services that will increase their willingness to adopt a change in management.

The inclusion of a question on how to have more graziers use the results, suggests the team are intending to engage more graziers in adopting their researched management strategies. Given that assumption then in whatever the team does to increase adoption, a positive way to do that is in the context of presenting a 'viable alternative' to what those graziers are doing now. For that reason, another topic for the team to examine can be that of creating a value proposition for change in a way that will have meaning for graziers. Most likely it will be multi-layered because even as this survey shows, that is how the industry is made up with graziers at different stages in their production practices.

6.3 Next for the Wambiana Grazing Trial

In this section of the survey graziers were asked whether or not they supported the continuation of the trial either 'As it is' or in 'A modified form'. All 30 supported it

[9] D J Pannell, G R Marshall, N Barr, A Curtis, F Vanclay and R Wilkinson, (2006) Understanding and promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental Agriculture, 46, 1407–1424*

[10] Roberts, G M O (2019), DAF Practice Change Research Surveys in the Burdekin Catchment, Report, December, Prepared by GR Consulting.

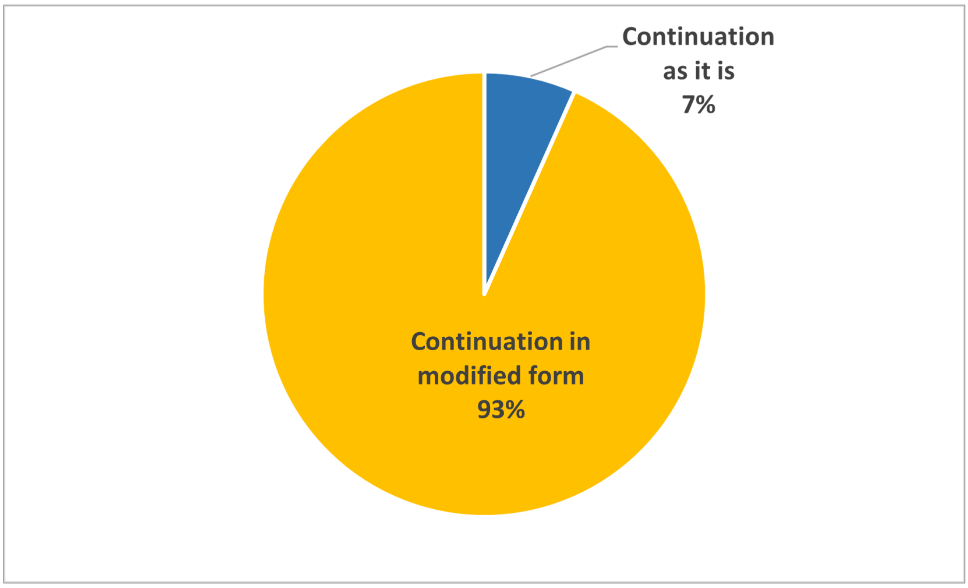
[11] D J Pannell, G R Marshall, N Barr, A Curtis, F Vanclay and R Wilkinson, (2006) Understanding and promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental Agriculture, 46, 1407–1424*

[12] Kuehne, G. et al (2017) Predicting farmer uptake of new agricultural practices: A tool for research, extension and policy. Agricultural Systems 156 (2017) 115–12

[13]

continuing and 28 of those proposed it do so with modifications made to the work it does. (See Figure 7)

Figure 7. Support for continuation of Wambiana Grazing Trial



While not asked for comment with their response, some graziers did so. Examples of the range of comments are:

- *Keep one paddock of each as control strategies and modify the other paddock.*
- *It needs to go for a long time and do variations that can improve recovery.*
- *I think it is important for next generation coming through to see the results for themselves, both graziers and DAF staff.*
- *Need to keep going with what started at least as part of the future. At the moment it may have been changed too much.*
- *Modified to what we want to know about next and that's carbon.*
- *The longer the current trial goes in years the more relevant it becomes and the reason is variation in seasons.*
- *At Wambiana there is the opportunity to do other things e.g. don't continue with heavy because of results, but now do need work on more ground-breaking modifications.*

One (1) of the two (2) graziers supporting continuation but not giving modifications disqualified themselves from offering ideas as they were unsure of all that the trial had done. The said it like this, '*I don't know enough to know about modifying however I am impressed with what can be seen over time to understand the impacts of stocking rate decisions.*'

The second said, *'I don't really know as there are other people testing walk-over weighing and drafting, and also lick mixes and it is important WGT don't replicate what others are already doing.'*

6.3.1 Summary and discussion

It clear that these 30 graziers support WGT to be continued and 28 of those suggest it be done with modifications. The consistency with which the 30 in the sample group want it to continue strongly suggests they see value in doing so. It is notable that at the time of discussing this question no graziers needed time to deliberate with themselves on their answer and all responded immediately.

Taking these points together and having heard of the role of WGT results with this group of graziers, an interpretation that can be made is that:

- 90% of these graziers report gaining new information from WGT
- 60% have changed one or more practices using WGT results, and
- Even for graziers who gained their current management elsewhere, and
- Even for those who don't use the results themselves as suggested,
- They value the results.

Previously made comments suggest the value to them could be in one or more forms of direct benefit to their own management, reinforcement of their current practices or the value they perceive the results offer to others in the industry.

Of these 30 graziers 28 want modification and graziers' suggestions for modifications to the work of WGT will be the topic in the following section.

6.4 What graziers would like to see investigated at WGT

In total 21 of these graziers suggest WGT now investigate recovery strategies for land in the trial that has been degraded by grazing. The next most frequently mentioned topic for investigation is carbon with six (6) graziers referring to it. After that is the topic of strategies to control the spread of currant/berry bush, mentioned four (4) times and there are three (3) individual topics.

6.4.1 Recovery of degraded country

In general, the content of the 21 mentions of recovery align with the 'preliminary idea' the WGT team put up as the approach in the immediate future. That idea is to continue some treatments but focus on remediation options like spelling and/or mob grazing for the paddocks in poor condition. Graziers did provide information that extended beyond the WGT team's description and offers detail of how recovery may be achieved.

There were four (4) sub-themes within the comments on recovery. They were Profitability, Rotational grazing, Mechanical intervention and Other.

6.4.2 *Profitability*

Ten (10) graziers included the theme of ‘to make a profit’ when making their recovery suggestions:

- *This (recovery) would be especially for degraded country to learn how to have it recover and be able to make a profit while that is happening.*
- *Use cattle to improve the overgrazed paddocks so it is profitable while it is being improved.*
- *I don't know if it’s possible to register a business outcome as well as an environmental outcome. Maybe pick a couple of ways that it is economically viable to do the recovery of pasture i.e. keep doing what WGT are doing and report whether or not it is possible and profitable to recover pasture.*

6.4.3 *Rotational grazing strategies*

Rotational grazing strategies were suggested or implied by numbers of graziers when speaking of recovery and the use of rotations further implies doing so with larger mobs of cattle. For example:

- *I'd like to see the type of strategy where cattle are mobbed up more and moved around paddocks…and country is given a spell through the year as well as during the wet season.*
- *As it's already fenced they could use electric fencing to get bigger mobs and move them every week to 10 days through 6 paddocks.*

Some included with their rotational grazing strategy, ways to apply rotational strategies with bigger mobs and reasons to do it. Most also suggest more rotations throughout the year as important in the process of recovery. They said for example:

- *Stop three (3) months spell and nine (9) months continuous grazing and change to something like 2 weeks graze twice a year in larger mobs for smaller periods, while not over doing the rate of utilisation i.e. keep it at 20-30%. Leave (pasture) residue to give strength of pasture that regrows after rain.*
- *Use larger mobs for short times as that will minimise selectivity of certain species and also reduce preferentially grazing in part of a paddock and that (is what) causes grazing damage.*
- *Spell in wet and other times in year.*
- *Include wet season spelling to show the level of economic successfulness and environmental benefit.*

Most graziers wanting rotational grazing included in future say to keep current strategies going and use the 'replicate paddocks' differently, '*I think modify it a little, e.g. still need control strategies of moderate and heavy stocking. There are two (2) paddocks of each so I guess they could put one (1) paddock of each strategy to keep going.*'

6.4.4 Mechanical intervention

Mechanical intervention was suggested as possibly being needed in recovery work by three (3) graziers. They said where that's done future work can provide details of the cost of recovery:

- *Struck me at the time the next thing to do is find out what's the cheapest and most useful way to regenerate it to A condition while also keeping production happening. To still run stock while getting back to full recovery. Some paddocks may need machine intervention.*
- *Rotations could be used as part of recovering the degraded country and it could include mechanical means as well as collect details of the economics of it all.*

While mechanical intervention may not be a first-choice tool in a grazing system, these 10% of surveyed graziers do think it may have a place based on their experience.

6.4.5 Graziers' other recovery ideas

i) Suggestions were made to involve graziers successful in recovering land in degraded condition, for example, '(*There's) More call to use holistic grazing management strategies as there are people doing it and they claim, and have, the data to match.*'

There was a suggestion of who could be involved in designing the future recovery strategies, with one grazier saying, '*Need a few things like different grazing strategies, to become fully regenerative and look at recovery. People who could contribute ideas for the future are Dr Christine Jones, Fran Lyons for her work on property and Michael Lyons for his work with RCS.*'

These suggestions support the WGT to continue their use of grazier input into design of grazing strategies, through making a shift to using ideas from graziers already demonstrating success with grazing strategies to recovery land condition.

ii) WGT 'costings' or 'figures' were regularly mentioned by some graziers in the surveying as giving them reinforcement for what they did and/or gave increased confidence in the results. When taken in the context of future work it suggests graziers want WGT to continue to deliver 'figures/costs' detail in the recovery phase. For example, '*WGT could next be investigating repairing pastures that have been damaged by overstocking in the dry and record the cost to do it for the heavy and moderate* *stocking rates.* And, '*Would be good to know how long it takes to get country to come back (recover) and what are the financial cost to get it back.'*

iii) On another recovery topic one grazier said, '*I don't have anything else to add to what's being done as they already have rotations happening with monitoring of the pasture responses.'* They were the only one saying this and it may be important to note that. Also, one other grazier acknowledged that currently there are at least some flexible stocking rates, saying to split paddocks in future work and, '*Modify each treatment to use **the** flexible stocking rates as a way to recover country that is degraded.'* The prompt to note it is if only two (2) of 30 graziers' comments say rotations or flexible stocking rates are in the WGT grazing strategies already, it raises the question of how come others did not acknowledge that WGT currently includes those. This is a topic for the WGT team to consider for future action.

iv). Social licence to graze cattle is a topic mentioned with some regularity throughout the surveying. Graziers referred to WGT research as being able to support the industry's claim to responsible land use. A specific suggestion made for future work was this, '*Increase the biodiversity work being done in the Trial by JCU. This can be done in the variable stocking rate paddocks to show the benefit to the biodiversity in this environment from grazing. If grazing can be good for the environment then it can improve our social credentials through evidence of improvement."*

6.5 Carbon and future WGT work

Carbon was the topic included by six (6) graziers in their suggestions for WGT's future work. Their theme was consistent in that they know little about what is the current status of carbon in northern grazing systems, what it means for the industry, what it offers and what its costs maybe to the industry. Examples of how it was said are:

- *Also look at carbon capture. I am completely in dark on where we are as producers and what we can do to become carbon neutral. It would be good to know where the average place fits into the carbon set-up in terms of contribution to carbon in the atmosphere.*
- *Not real sure if this could be done, however maybe carbon farming could be looked at. It is now becoming pertinent and that's what science could do to show the reality and make sense of what is happening in the grazing industry.*
- *Carbon research to keep the industry informed of what the actual figures are for beef production. I'd like to know more about carbon such as if a beast eats grass rather than it gets burnt, what's the difference in what happens to the carbon?*

Some do recognise it may not be the place of WGT to be in grazing industry carbon research saying, 'I'm *not sure WGT is the place to do it however if it is not an income stream for me I want to know what to do to keep producing cattle.'*

Some do suggest how research could be started, for example:

- *In terms of what WGT could do relating to carbon it is to begin by looking at what real data is already available elsewhere and where are the gaps and are they relevant for WGT to work on.*
- *Measuring emissions from cattle and the effects on carbon to examine is there differences between treatments. The heavy hitters in the industry believe emissions will affect future market access for beef…so it would be useful for the WGT to do work on carbon emissions.*
- *In the recovery work to also track biodiversity of nature and carbon. Start with the base line and measure is there a change with different grazing strategies. Also, how valuable a resource is it to the industry and how easy or difficult it is to achieve getting carbon levels up.*
- *Need to look is there a modern technique for grazing that puts carbon back in soil. Modern techniques are important as we've got start looking differently at what we do to 25 years ago.*

Most graziers suggesting work on carbon acknowledge they know little of the current status of carbon for the northern cattle industry. Some are unsure of the role WGT could take however others do suggest beginning by assessing where the industry has a positive or negative impact and the differences between treatments on those impacts. For them the importance of including carbon research is to do with their being able to continue grazing cattle and trading in beef.

6.6 Currant bush control

Currant bush thickening was a theme noted throughout this surveying by some graziers from both their own experience and from seeing the increase in the WGT paddocks. Each time it was said was in relation to, '*…understanding that increasing berry bush means you need to re-adjust stocking rates (down).*' For the future the suggestion is to '*Look for other ways to manage currant bush*'.

A suggestion for assessing loss of grazing area over time was the use of WGT paddock photographs through the years. It was said in this way, '*From photos showing good grass compared to the progression to not good. The more woodland thickening the higher the stocking rate on the paddock, so how much is stocking rate down at WGT due to woodland increase. That's not talked about or shown anywhere (that I know) but politically it may not be possible.*'

6.7 Other items of note

i) Two (2) graziers suggest future 'activities' which might be categorised as increasing the emphasis on learning about how stocking rate decisions impact future productivity.

Each made a suggestion with the first being, '*It would be good if graziers were to get to recognise link that because you are taking competition away at the WGT by eating the pasture so low, the currant bush can move in.*' The second was, '*How to show the feedback loop of declining feed quality (pasture condition) and poor pasture response at the next rain.*'

A 'learning' shift in emphasis from reporting data in relation to production and costs, to focus more strongly on productive capacity through decisions and over time, may be a way to move research to the reality of supporting more adoption of results.

ii) One (1) grazier asked if debt could be factored in to how grazing outcomes could be reported. They said, '*If they could incorporate consideration of debt in the financials they calculate for stocking rates because that is the reality (for many graziers)*'.

This presents as a single grazier only comment, however the recognised proportion of graziers who carry debt (MLA[14]) indicates it may be insightful. As such it presents an opportunity for the WGT team to embrace the opportunity to include consideration of debt in a new way in their work and to do so with a view to improving the case for graziers with debts to adopt the recommended practices.

It is probable that a 'standard approach' economic analysis will not meet this grazier's expressed suggestion. Inclusion of debt in future WGT work is likely to produce a more potent output when the economic assessment incorporates how graziers actually experience debt in their management.

6.7.1 Summary and discussion

Recovery of degraded paddocks was clearly foremost in graziers' minds as they thought about the future of the Trial. In general grazier suggestions for research for land condition recovery align with the 'preliminary idea' the WGT team put up as the approach in the immediate future. That idea is to continue some treatments but focus on remediation options like spelling and/or mob grazing for the paddocks in poor condition.

The question of what the Trial could do in future was asked in an open-ended way without prompts. Knowing that, it is of interest to note that even though 29 asked for the questions before the survey, and the WGT team's preliminary idea was written on the question sheet at the start of this question, no one referred to it. Rather they used words like 'recovery of degenerated paddocks' and 'improve country'. For example, '*Recovery in degenerated paddocks i.e. how to fix what has happened through*

[14] URL accessed Jan, 7 2022 https://www.mla.com.au/globalassets/mla-corporate/prices--markets/documents/trends--analysis/abares-farm-survey/abares-financial-performance-beef-farms-2013-14-to-2015-16.pdf

overgrazing.' And, '*The previous stocking rate results are all there so that much has run its race. Now they could spell it up and see what it takes to improve the country.'* Using other words may mean they didn't read the questions they asked for, or it may mean they didn't find the description given as meaningful to them as graziers. Given that only a couple said they didn't get to read the questions, it may be the latter. If so then the WGT team may want to take that into account as they plan for the future.

Graziers did provide information that extended beyond the WGT team's description. Most of these graziers had multiple ideas for WGT for future work. And in the first instance their focus was clearly on how to recover degraded land condition to a commercially productive state through grazing, making a profitable income and knowing what recovery will cost. Costings as presented in the Trial data are something graziers have acknowledged as valuable and that theme is continued here with a request to provide all costs incurred in generating recovery.

Rotations with larger mobs of cattle predominate in the suggestions for how to recover land condition. In that context more graziers suggest the rotations include longer rests between grazing periods and that resting phases continue beyond the wet season. Several responses suggest using ideas from graziers already demonstrating success in land condition recovery and one suggests three (3) names to contact for strategies they have in use.

Most of the 20% of graziers suggesting work on carbon acknowledge they know little of the current status of carbon for the northern cattle industry. Some are unsure of the role WGT could take however others do suggest beginning by assessing where the industry has a positive or negative impact and the differences between treatments on those impacts. For them the importance of including carbon research is to do with their being able to continue grazing cattle and trading in beef.

Currant or berry bush thickening was a theme noted throughout this surveying by some graziers from both their own experience and from seeing the increase in the WGT paddocks. Most frequently it was referred to as decreases in available grazing area. The message for future work was to consider other ways to manage currant bush. One grazier suggested, in another part of the survey, to find ways to demonstrate the link between having cattle eat more of the available grass in a season, with increases in the presence of berry bush. The WGT team may want to do this as a path to future prevention rather than control once berry bush has increased.

There is also recognition that mechanical intervention could play a part in the recovery of degraded land. That three (3) graziers, representing 10% of those surveyed, are on the same path brings it to notice. At no stage did the three (3) say what might be done mechanically.

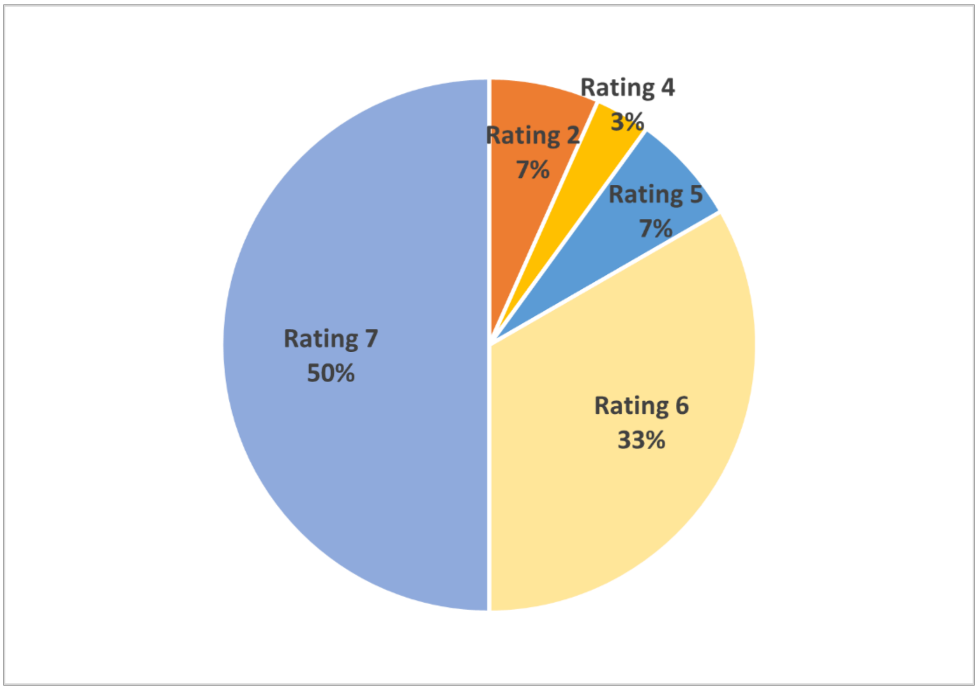
Social licence to graze cattle was a topic mentioned with some regularity throughout the surveying. Graziers referred to WGT research as being able to support the industry's claim to responsible land use. A specific suggestion made here for future work was to increase the biodiversity work being done in conjunction with JCU as a means to test, and from there to hopefully advance, the social licence credentials of grazing in the north.

There was on one suggestion to factor in debt in assessing the application of WGT findings to the northern beef industry. The suggestion's value may lie in taking a different approach to interpreting the cost to implement the Trial's findings. One way to do this may be through understanding how graziers actually experience debt in their management, and building that into the research, extension and adoption program for the Trial.

6.8 Long-term research for the beef industry – grazier ratings

The value of long-term industry research was rated by these 30 graziers and the proportions are shown in Figure 8 where 1=Of little value; 7=Very valuable]. Half, i.e. 15/30 rated it 7 with a further 10/30 rating it 6. Only two (2) rated it less than 4.

Figure 8. Value of long-term research for the beef industry



The proportions demonstrate that the majority support long-term industry research. Some commented by restating their choice of rating of 'Very valuable' rather than giving a reason.

Where reasons were given they included reference to the level of confidence provided that the results are meaningful for the industry, that long-term is necessitated by the time to show things like land management impacts, and the fact that graziers can't do long-term research themselves. For example, '*Very valuable as I'd suggest to funders that there are too many short-term research projects that give short term outcomes whereas land management and genetics take longer*.' Another said it like this, '*Long-term research gives strength behind the data from its consistency which increases the certainty that graziers can get the same result.'*

For those whose ratings were low for long-term research their reasons were, for example, '*Strict science-based research is too slow…'* and, '*There's nothing else that needs long term research that I can think of.'*

Another qualified their rating with the comment, '*As long as it doesn't just do what others are doing.'*

Reasons supporting long-term research were the more frequent and other examples of reasons given for doing so were:

- *Incredibly important! While we do our own trials to a degree, we are too busy to do the big picture stuff e.g. markets, genetics, land condition, staff retention etc.*
- *Long-term is very important. We jumped on that bandwagon when we bought this place by talking to the former owner, whose family had been here for 100 years, to understand more of how to manage it. Long time trials are very valuable.*
- *Without trials for long periods we won't know the long-term effects e.g. Northern Territory research on rotational grazing was short term and gave results without being really clear.*

6.8.1 Summary and discussion

The support for long-term beef industry research is clear from a significant majority of these 30 graziers. Some commented by some restatement of level of rating of 'Very valuable' rather than giving a reason. Where reasons were given they included reference to the level of confidence time provides that the results are meaningful for the industry, that it is necessitated by the time to show things like land management impacts, and the fact that graziers can't do long-term research themselves.

As well, in comments made elsewhere, a number of graziers mentioned that had WGT stopped prior to the very dry 2015 season (Section 2.1), they would not have known how vulnerable moderate grazing strategies were to generating adverse land condition outcomes in times of drought. They also referred to the variability of seasonal conditions as making long-term necessary (Section 2.1).

Taken together the numbers rating long-term research highly plus the reasons given, they are clear in showing that this group of graziers support beef industry long-term research.

7 A compilation of other comments that may be of note

It can be of interest to note one-off comments that pursue another theme during a survey. The WGT project team may find instructive to read these in the context of their future work.

- *One thing I did wonder about WGT was at the field day we were told that the medium stocking rate with no spelling when compared to rotations, was a better option for production and profit. My question is, were 3P grasses present in the same proportion in the medium stocking with no spelling, or were they going up or down compared to the rotational? Reason is I don't think we could sustain continuous grazing of even the medium stocking rate on our property.*
- *At a Beef Research Council meeting we asked of* (WGT representative)*, Do you think you got the stocking rates right when you started? The answer was that at start of WGT 25yrs ago local graziers looked at the paddocks and voted to set the high, moderate and light stocking rates i.e. they were chosen with local knowledge. The story needs to be told of how WGT got to the high, moderate, light stocking rates used, to show people where the chosen stocking rates came from. That however, may not be the way do it now as even now the variable is probably not variable enough and moderate is not moderate enough.*
- *At one time, in the dry, the WGT steers were going backward whereas we adjusted our supplement to maintain weight. I have talked to the WGT team and GAG about nutrition but they wouldn't change. They kept going with high 30% urea whereas I understand that above 10% is costly and is lost.*
- *There is need for a new GAG.*
- *Change GAG to introduce grazing and resting strategies to recover the country that's been degraded. If there is a need to shift paddocks regularly maybe* (WGT team) *could get Michael involved to shift cattle more quickly in wet season. Any modification needs to keep system as simple as possible.*
- *If it (WGT) doesn't get refunded there could an opportunity that Michael Lyons could keep something happening with the trial site in some form of his choice for recovery, and DAF could monitor the rate of recovery of the country.*
- *Each time we go to the paddocks or look at the results we take a way a little more each time. Our level of understanding increases. You don't get a whole lot in one visit and this needs to be considered when creating field days.*

8 Appendix 1

Wambiana Grazing Trial Phone Survey Questions - October/December 2021

Section 1. Introduction

1. I understand you've been to 1 or more Wambiana Grazing Trial (WGT) field days, have been on the Grazier Advisory Committee (or been in a demonstration group using its results). Is that correct? ***Note:*** *First WGT field day 2007*

   YES/NO
2. How familiar would you say you are with the grazing principles from the WGT? (For example, moderate stocking rates are more profitable in long-term/ need to proactively adjust stocking rates with seasons)

   Please select an overall rating

   Rating scale where 1= Not familiar 4=Average 7=Very familiar

   1 2 3 4 5 6 7

Section 2. Knowledge and awareness

3. Can you say you **gained new information/knowledge** from the results at Wambiana? YES/NO/NOT SURE

4. If YES, did the new information/knowledge relate to:

Yes/No	Profitability of different stocking strategies
Yes/No	Matching stocking rates to feed supply
Yes/No	How stocking rates drive animal performance and land condition
Yes/No	Wet season spelling
Yes/No	Understanding of the ecology of key grasses like desert bluegrass and what's needed for their survival in pastures
Other	Describe any other information/knowledge:

5. Overall **how much** would you say the results from WGT have **changed your thinking** on how you manage your grazing business? Please select an overall rating.

   Rating scale where 1=Not at all 4=Average 7=Quite a bit

   1 2 3 4 5 6 7

   Reason/s:

6. How aware are you of?

Yes/No/Not sure	The value in adjusting stocking rates as seasons change even if stocked at your LTCC

Yes/No/Not sure	How to minimise pasture degradation and improve recovery post drought on your property
Yes/No/Not sure	Potential benefits to production through matching stocking rates to forage supply and wet season spelling
Yes/No/Not sure	The value in managing woody plants using fire
Yes/No/Not sure	That there are decision support tools e.g. FORAGE, VegMachine, the Ready Reckoner to assist in managing stocking rates.
Yes/No/Not sure	How management can affect the severity of drought and its impact on land condition

Section 4. Skills

7. Can you say if you gained new skills from the results at Wambiana for use on your property? YES/NO

8. If YES, did the skills relate to:

Yes/No	*FORAGE* reports on the Long Paddock website to estimate pasture availability and manage stocking rates.
Yes/No	*VegMachine* (to assess paddock level changes in ground cover in response to drought and management.)
Yes/No	The 'Ready reckoner' simple tool to set and adjust stocking rates
Yes/No	Pasture yield photo standards
Yes/No	Technology (e.g. Walk over weighing or remote cameras on water points)
Other skills	Describe:

Section 5. Practical application of the WGT results

9. Overall what do you think the results of Wambiana have shown over time for your own property?

   Please select an overall rating.

   Rating scale where 1=Very little 4=Average 7=Very much

   1 2 3 4 5 6 7

   Reason/s:

10. Have you **considered** changing any of your management based on the results of the WGT? YES/NO

11. If YES, what management did you consider changing? (Provide prompts if needed such as items in Q5 and Q7.)

12. Based on the results of the WGT did you end up **actually making** any changes? YES/NO

13. If YES, what management change/s did you put in place? Please describe. Are there any other changes?

14. How valuable has this change/s been to your business? Please select an overall rating or is it too early to tell?

    Rating scale where 1=Of little value 4=Average 7=Very valuable

    1 2 3 4 5 6 7 Too early to tell

    Reason/s:

15. If NO, to putting the change in place, what further assistance and or training might you need to take your next step on this topic? Tick all that apply.

- ☐ Further assistance from a DAF extension officer on how this practice could work on my property
- ☐ More evidence of the benefit of this practice on my property
- ☐ Contact with a producer group and/or another producer using it
- ☐ Contact with a technical specialist
- ☐ Something else….

16. How would you rate the usefulness of the WGT and its results to the northern beef industry?

    Please select an overall rating.

    Rating scale where 1=Not useful 4=Average 7=Very useful

    1 2 3 4 5 6 7

    Reason/s:

17. How widely do you think the WGT results are being used/adopted by industry? Please select an overall rating

    Rating scale where 1=Not used 4=Average 7=Highly used

    1 2 3 4 5 6 7

    Reason/s:

Section 6: Next steps

18. What is the **most important message** coming out of the Wambiana results for industry?

19. What information is missing or what information is required to increase use of WGT results across the beef industry? e.g. decrease numbers quickly in dry times/increase slowly in good times etc?

Section 7. What can be next in the WGT

The WGT is looking for investment to continue for another 4-5 years. The preliminary idea is to continue some treatments but focus on remediation options like spelling and/or mob grazing for the paddocks in poor condition.

20. As a beef grazier yourself, do you support the continuation of the WGT as it is?
    - Continuation as it is
    - A modified form

21. What else would you like to see investigated at WGT?

22. How would you rate the importance of long-term research for the beef industry? Please select an overall rating.

    Rating scale where 1=Of little value 4=Average 7=Very valuable

    1 2 3 4 5 6 7

    Reason/s:

Section 7

This survey is anonymous – but for recording purposes could you please provide:

23. Property size (hectares): ________________
24. No. of cattle: _________
25. No. of sheep: __________

If you would like a DAF extension officer or specialist or more information:

Your name: ____________________________________ Phone number: ____

Property: ____ Postcode: ______________________

Email address: ____ PIC number__________________________

Summary notes Gerry (an unlimited box to record into)

Thank you for completing this evaluation. We will use the information to improve future events, plan future activities and to keep our funders informed.

Why use fire?

Woodland thickening is widespread throughout Queensland due to the reduced use of fire. Declining pasture condition has also reduced grass competition, allowing trees to grow faster and thicker. Prior to European settlement, Aboriginal people routinely burnt to 'open up country'. Later, graziers also used fire to remove dead grass and improve feed quality.

Over the last few decades the use of fire has drastically declined with the introduction of urea supplements allowing older, low-quality forage to be utilised. Without occasional fire, trees thicken up, reducing pasture production directly through competition.

Figure 1: Fire is a good servant but a bad master. Used properly it is very effective tool in management.

Burning is thus an important tool to maintain the tree:grass balance, suppress woody plants and reduce wildfire hazard. It can also be used to reduce patch grazing and encourage more even paddock utilisation. Fire can also obviously be used as a hazard reduction tool to reduce the severity or likelihood of wildfires.

Used correctly, fire can be used to help improve pasture composition. Some 3P species, especially black speargrass (*Heteropogon contortus*) and kangaroo grass (*Themeda triandra*), are favoured by fire. In contrast, desert bluegrass (*Bothriochloa ewartiana*) appears to be neutral in response to fire whilst some wiregrasses (*Aristida*) are clearly set back. The introduced legume *Stylosanthes* is killed by fire but recovers quickly from soil seed banks. Fire, combined with wet season spelling, can thus be used to manage stylo dominance in grass: stylo paddocks.

3P grasses are those which are *Perennial, Productive and Palatable*.

Indicators of the need to burn

Fire is an important tool when implemented correctly, and at the right time of the year when pastures are dormant. Indicators that a paddock may need a burn include:

- Woody thickening, especially shrubby native weeds like currant bush (*Carissa species*) and/or exotic weeds like rubber vine (*Cryptostegia grandiflora*).
- Patch grazing with very short areas amongst rank, ungrazed pasture.
- Stylo dominant pastures with declining grass yields.

How to use fire

Different types of fires are used to achieve different outcomes. A 'hot' fire is generally used to manage the tree: grass balance, whereas a 'cool' fire is used to control patch grazing and promote desirable 3P species. It can also be used to kill some thin barked woody weeds (including *Parkinsonia*).

Whether a fire is 'hot' or 'cool' relates more to timing and conditions of a burn, and less so the amount of fuel. However, to carry a fire you need a minimum of about 1500 kg DM/ha.

A 'cool' burn is often done immediately after the first rains (storm burn) provided the grass is dormant and has not yet started fully growing. At other times, a 'cool' fire can be achieved early in the morning or late in the evening when temperatures are cooler and relative humidity higher.

A 'hot' burn is usually applied later in the day when temperatures are high, humidity low and fuel very dry. In these burns, the more fuel in terms of dry matter per hectare, the better, as the aim is to get the flames up into the woody layer (aim for >2000 kg DM/ha).

To accumulate enough fuel for a hot fire, paddocks may need to be locked up for some months prior to burning. However, applying moderate stocking rates should naturally allow sufficient fuel to accumulate for burning in most years. Burning frequency will depend upon the rainfall and land type. For example, at the Wambiana grazing trial, silver leafed ironbark areas are less tolerant of frequent fire than box landtypes.

To manage rank grass and promote 3P species, burn with a head fire (with the wind) at the start of the wet season immediately after about 50mm of rain (cool burn). The pasture is thus burnt before it actively starts growing, but when there is sufficient soil moisture to drive the new seasons growth. However, burning too late once the grass is actively growing will severely damage the pasture and can drastically reduce production.

After burning

Paddocks need to be spelled after burning to ensure that pastures recover before being grazed (Figure 3). Ideally, grazing would not be reintroduced until after the pasture has gone to seed. Grazing too early reduces the energy in root reserves and can set 3P species back severely.

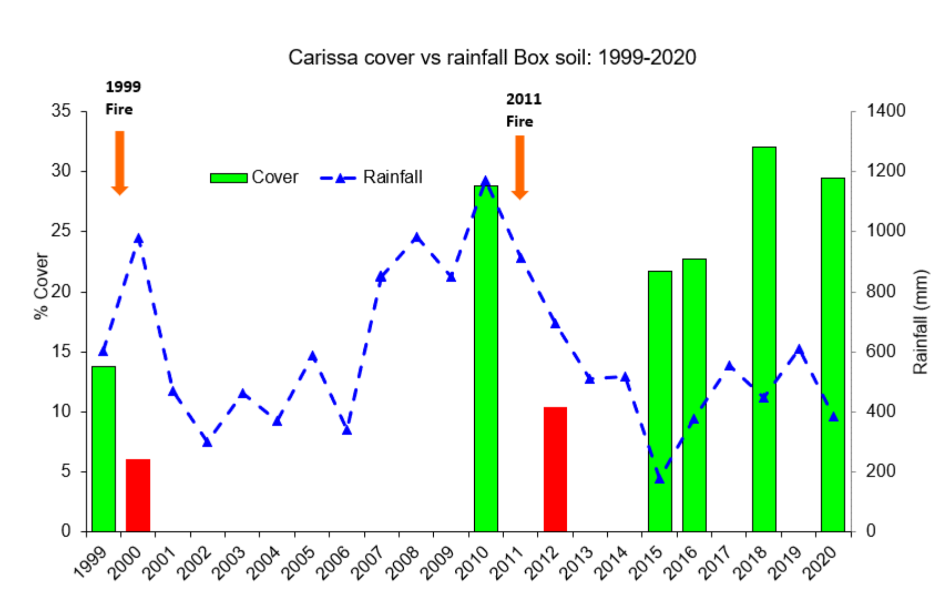


Figure 2: Fire is effective in controlling Carissa but unless it is regular, Carissa easily gets out of control reducing pasture production.

Figure 3: Burnt patches in large paddocks will be heavily grazed and decline in condition unless stock are removed.

Remember, the whole paddock needs to be spelled, even if only part was burnt (for example, following a lightning strike). If not, animals will concentrate on the burnt area and can seriously damage pasture condition.

If the wet season is poor, and recovery slow paddocks may need to be locked up for the following wet season to allow recovery*.

**See wet season spelling factsheet for how to do this.*

How often?

The optimum fire frequency will depend on the land type and rainfall but probably should not exceed once every 5 to 10 years. Burning can be applied more often in higher rainfall regions and on higher fertility land types. However as a general rule, fire can be applied:

- Every 10-25 years on less fertile, fragile country.
- Every 5-10 years on more productive country.

Findings from the Wambiana Grazing Trial

The Wambiana trial contains a mix of brigalow, box and silver leafed ironbark landtypes. Research at the site shows that fire will only kill between 4 and 16 % of woody plants with the number varying between species. Unsurprisingly, those killed were generally small trees (<1m). However, some very large old trees, often with hollows, were also killed.

The vast majority of trees resprout from their bases or along their main stem. This is not surprising considering that Australian savannas are very well adapted to fire.

Although fire does not kill many trees, top-killing the main stem and forcing them to resprout, changes the structure of the woodland, opening it out. This reduces competition and directly increases grass growth. Importantly, it suppresses woody species and keeps them short enough to control with fire (the 'fire trap'). If most trees are kept below 2-3 m they can still be top killed with fire forcing them to regrow from their bases. Above this height fire will have little or no effect. This was found at the Wambiana trial with some young Brigalow and ironbark trees rapidly growing up above fire height before they could be controlled.

While fire also caused complete top kill of the native woody weed Currant bush (*Carissa ovata*), it regrew back to its former levels within five or six years (Figure 1). More regular fire is thus needed to keep *Carissa* under control and stop it's spread.

Tips for using fire

Avoid burning when seasonal forecasts for the approaching wet season indicate below average rainfall. Consult seasonal forecasts for this information such as the Bureau of Meteorology.

Remember to contact your fire warden to get a permit to burn before starting any fire

Remember, use fire with caution, "*Burning is a good servant but a bad master".*

Burning guidelines

- Contact your local fire warden for training. qfes.qld.gov.au/about-us/frontline-services/rural-fire-service
- QFES also provides information on current fires, obtaining permits and information on preparing for a fire.
- Plan ahead to ensure enough fuel for the type of fire desired and there is sufficient forage in other paddocks so that they are not overgrazed.
- Know your weather conditions for the upcoming burn and post- burn: bom.gov.au/
- Does your property border a national park? If so, contact Queensland Parks and Wildlife Service (QPWS).

More information

For more information on using fire to manage your country contact your local extension officer. Futurebeef.com.au/contact-us/

Figure 4: The same monitoring site at the Wambiana trial over 20 years. Left- the site in 2001 after being burnt in 1999 and right, the same site in 2021. Despite a second fire in 2011 the Brigalow suckers had outgrown the fire

Why match stocking rates with available forage?

Matching stocking rates with available forage ensures animals always have sufficient feed. It thus minimises the impact of dry years and avoids the costs of drought feeding. Most importantly, it prevents overgrazing and helps maintain land condition.

Conversely, in good years stocking rates can be adjusted upwards to increase production without damaging pastures. It thus maximises animal production and maintains land condition in our variable rainfall environment.

Indicators that stocking rates are not matched with available forage

When stocking rates are not matched with available forage, overgrazing occurs and land condition declines. Indicators that this is occurring include:

- Low ground cover (<50%) at the end of the dry season.
- Ground cover consistently lower than regional averages for landtypes in question, especially in dry years (see FORAGE online tool).
- Pastures dominated by unpalatable species like wiregrass, annual grasses and/or forbs.
- High runoff with break of season storms and reduced response to rain.

Findings from the Wambiana Grazing Trial

Evidence from the Wambiana grazing trial near Charters Towers shows that failure to reduce stocking rates in dry years results in reduced animal production and pasture degradation. This can occur even if stocked around the Long Term Carrying Capacity (LTCC). These effects are even more marked if stocked above the LTCC as happened in the Heavy Stocking Rate (HSR) paddocks) at the trial.

Conversely, adjusting stocking rates to match available forage reduced the impact of dry years but also maximised the benefits of better seasons i.e., it increased drought resilience and was more profitable due to lower costs (especially by avoiding drought feeding).

Figure 1: At the Wambiana trial reducing stocking rates early gave good animal production and pasture yields despite the severe drought of 2002-2007.

The Ecograze trial near Charters Towers also showed that adjusting stocking rates to achieve the recommended pasture utilisation rate of 20-30% maintained land in good condition in drought years and allowed land in poor condition to improve.

However, the Wambiana trial also showed that overstocking in good years and/or failing to cut numbers sufficiently fast as drought approaches can result in long term damage to land condition. Stocking rates must thus always be adjusted with caution as discussed below.

When to adjust stocking rates

The *primary* stocking rate adjustment point should be around the end of the wet season, as this is when there is the greatest certainty about *how much* forage will be available for the year (i.e. little chance of further growth) and how long it has to last (i.e. the 6-8 months dry season).

Other logical *secondary* stocking rate adjustment points are in the mid and late dry season and in the early-mid wet season.

How to adjust stocking rates

Adjust stocking rates in a cautious, flexible manner as seasons vary, based on available forage, animal performance, seasonal conditions and where appropriate i.e. later in the dry season, climate forecasts.

Calculating stocking rates

Stocking rates are usually set based on a forage budget. This is done by first estimating the amount of feed in a paddock based on photo standards or some other method (see Tools). Where tree cover is low, satellite based tools can also be very helpful.

A calculation is then done to estimate the number of animals a paddock can support for a defined period of time (the dry season + a buffer) as explained at the end of this document.

The attached flow diagram (Figure 2) lays the process out in a series of easy steps.

Other useful means of adjusting stocking rates are:

- The 'Shepherd Carrying Capacity Ready Reckoner' (Upper Burdekin only) or,
- Grazing charts as used by Resource Consulting Services Australia www.rcsaustralia.com.au

Even if not running a rotational grazing system, regularly calculating grazing days per hectare in relation to rainfall is a very good way of keeping check on stocking rates relative to seasonal conditions.

Adjusting stocking rates

Whatever the method used, it is important to set upper limits on stocking rates in even the best seasons to prevent overgrazing. As an example, no more than 20 % above LTCC.

Changes in stocking rate should always minimise risk i.e. cut stocking rates sharply e.g. by 20-40%, with the approach of poor seasons but increase stocking rates gradually e.g. 10-15%, in good seasons. The degree of change will also depend on:

- Current stocking rates relative to LTCC.
- Land condition trends and the risk of degradation i.e. if pasture condition is declining or recovering post drought and/or seasonal outlooks are negative, err on the side of caution.

It is also important to:

- Constantly assess available feed and animal condition as described above,
- Set firm decision points for early-mid February and Easter in case the wet season fails, and
- Monitor on-going climate forecasts.

> Remember: stocking rates based on forage budgets estimates are only broad guides – use with caution and adjust numbers as needed.

Rules of thumb

Any increases in stocking rate at the end of the wet should obviously be done with stock that can be marketed relatively easily in the event of a poor wet season the subsequent year. Agistment is also an excellent, lower risk option to utilise excess forage.

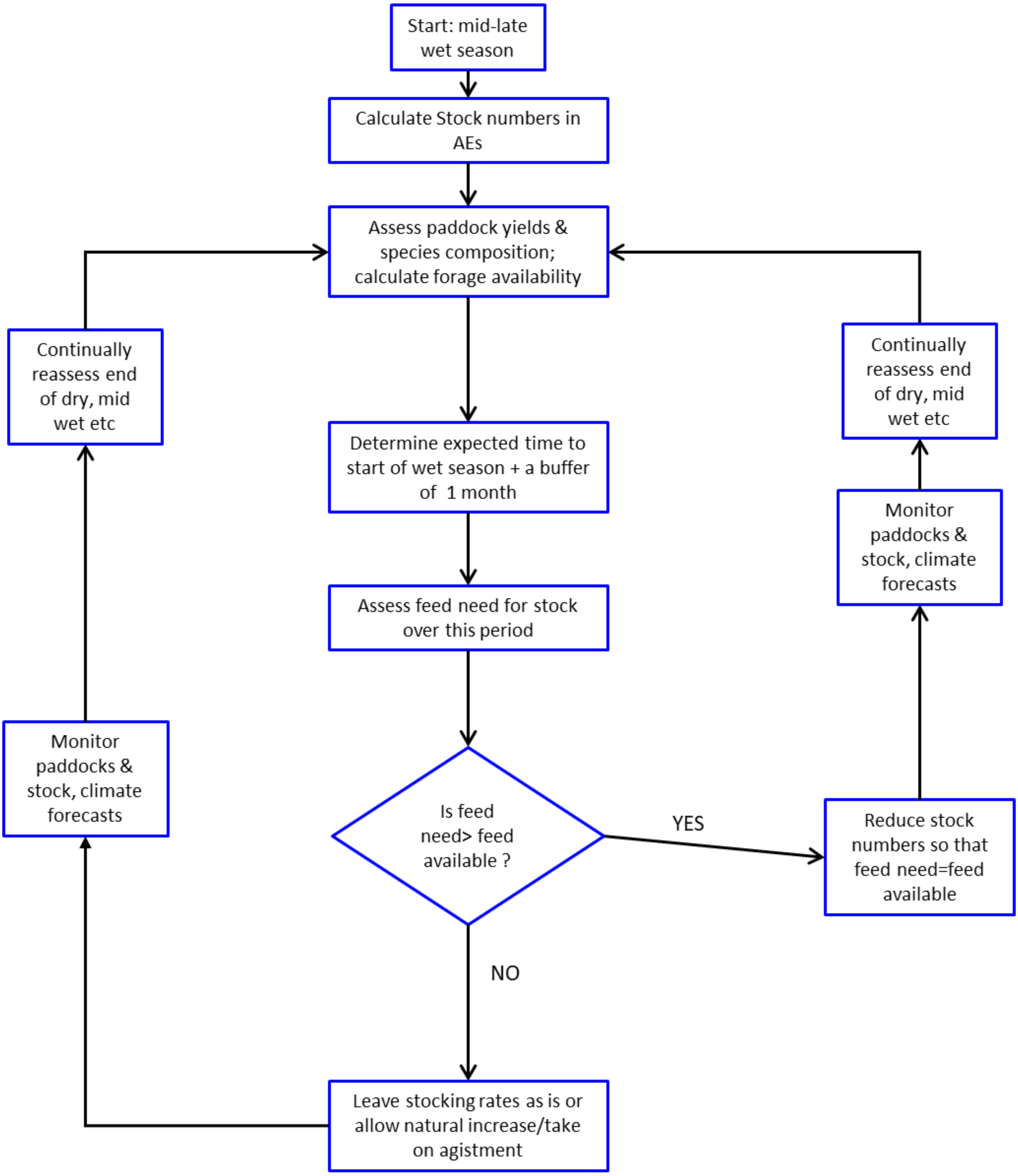


Figure 2: Flow diagram for balancing stock numbers with forage availability

Doing a forage budget

To learn how to do a forage budget attend a Stocktake Forage budgeting course and/or use the Stocktake App (see Tools) and/or see Table 1 below.

How to do a forage budget

To do a forage budget, you need to know the following:

- Paddock size
- Pasture yield
- Percent unpalatable pasture (undesirable species and/or plant parts, weeds etc.)
- Pasture utilization rate (from land type sheets in *Futurebeef*)
- Length of grazing period e.g. the dry season
- Daily consumption per Adult Equivalent (AEs)
- Usable paddock area
- Expected start of the next wet season + a buffer of 1 – 2 months.

The 'usual' start of wet season growth is taken as the date when there is >75 % probability of getting more than 50 mm of rain in two days. i.e. later than the 'green date'. Always add a buffer of at least a month in case of a late start.

Calculations are then done like as in Table 1. These take the forage available to the animal and subtract the desired residual amount after grazing to give the total useful available pasture. This figure is used to determine how many animals can run in a paddock for a certain period of time. The time can be manipulated either way e.g., more cattle for a shorter time, or a sustainable number for the whole dry season.

Calculations can be complex and will be detrimental to land condition and production if too optimistic. It is therefore recommended to seek assistance from an extension officer.

Alternatively:

- Attend a forage budgeting field day or Stocktake course.
- Attend an MLA *Edge* Grazing Land Management (GLM) workshop which will provide you with the information and training needed to do calculations yourself.

TTable 1: An example of a basic stocking rate calculator based on a forage budget

	Basic Stocking Rate Calculator		
	Property:		
	Paddock & Date:		
	Pasture type - tussock or Indian couch:		
A	Estimated total pasture yield:		Kg DM/ha
B	% unpalatable species		%
C	Yield unpalatable species (A x B %)		Kg DM/ha
D	Yield of palatable species (A -C)		Kg DM/ha
E	Utilization rate %		%
F	Pasture available for grazing (D x E%)		Kg DM/ha
G	Graze period		Days
H	Daily consumption per adult equivalent	10	Kg DM/ha
I	Stocking rate (G x H ÷ F)		ha/AE
J	* Residual of total pasture yield (A -F)		Kg DM/ha
K	Stockdays per hectare (F ÷ 10)		SD/ha
L	Usable paddock area		hectares
M	Paddock short-term carrying capacity (L ÷ I)		AEs
N	Cattle class AE rating (from AE table)		"Class"
O	Paddock cattle numbers (M ÷ N)		head
	* If residual is less than 800kg/ha for tussock pastures or 600 kg/ha for Indian couch, then subtract the residual first and do the forage budget on the balance. ** DM = Dry Matter		

More information

For more information contact your local extension officer. Futurebeef.com.au/contact-us/

Tools and resources to assist forage budgeting

- Stocktake GLM is a decision support app that allows users to do calculations of forage budgets, plus monitor land condition and stock numbers.
- FutureBeef – practical tools, scientific insights, and relevant, timely advice futurebeef.com.au/
- Pasture growth alerts www.longpaddock.qld.gov.au/forage/
- Historical rainfall data www.longpaddock.qld.gov.au/silo/
- Assessing paddock ground cover vegmachine.net/ www.longpaddock.qld.gov.au/forage/
- Grazing Land Management (GLM) EDGE course futurebeef.com.au/
- *The Ecograze project: developing guidelines to better manage grazing country*, Ash et al (2001) CSIRO, Townsville, 44 p.

What is the Long Term Carrying Capacity?

Long term carrying capacity (LTCC) is the *average* number of Adult Equivalents (AE) a paddock can be expected to carry over the long term (10-20 years) without negatively affecting land condition.

It is a stocking rate *guide* based on the *average* pasture growth that can be expected in most (70% years). It varies with your rainfall, land type, land condition and tree density. It is also based on utilising an average of 20-30 % of pasture growth in most years. This is the *average* pasture utilisation rate which has been shown to maintain land condition.

The LTCC of a paddock is an indicator of its potential stocking rate – not a guarantee of what can be carried everv vear.

Why stock to the LTCC?

Stocking *around* LTCC is essential to maintain pasture composition and carrying capacity, give good animal performance and increase profitability.

Stocking around LTCC should leave paddocks with enough residual ground cover at the end of the dry season. It should also carry stock through moderately dry years without impacting land condition. However, in more extreme droughts, reducing stocking rates is essential to avoid long term degradation.

Being able to calculate the LTCC is also handy when looking to purchase a property and estimate how many cattle the property can run sustainably.

Indicators of overstocking

Some indicators that a paddock is overstocked include:

- Ground cover at the end of the dry season consistently low (<50%), and/or lower than regional averages for the land types in question – especially in dry years as shown on the LongPaddock *Forage* tool (see Tools).
- Pastures dominated by unpalatable species like wiregrass, annual grasses and/or weeds and forbs.
- 3P grasses are less than 40% by weight of pasture.
- 3P plants are small, lack vigour, seldom produce seed and respond poorly to rain.

3P grasses are grasses which are *Perennial, Productive and Palatable*.

- Feed often in short supply in the dry season and drought feeding often required.
- Animals perform very well in some wet years due to short green feed/annual grasses but rapidly decline in condition at start of dry season as annuals die off.
- Poor response to rainfall, soils dry out quickly post rain, and runoff causes erosion removing nutrients from property.

Figure 1: Stocking around long term carrying capacity gives good animal production and maintains pasture condition

Findings from the Wambiana Grazing Trial

Long term evidence from the Wambiana trial (WGT) with steers shows that stocking around LTCC gives best individual animal production, best carcass grades and highest prices (Table 1). For breeders, stocking around LTCC will also increase conception and weaning rates, weaner weights and minimise mortality rates in drought.

Table 1: Average animal and economic performance over 24 years of moderate and heavy stocking at the Wambiana trial.

	Stocking at LTCC	Stocking at twice LTCC
Weight gain per head (kg/yr)	117	100
Weight gain per ha (kg/yr)	14	19
Years of drought feeding	1	7
Gross margin per ha ($/yr)	$13	$7
Years with a negative GM	2	11
Price per kilogram ($/kg)	$3.65	$3.48

Stocking around the LTCC also increases drought resilience i.e., far fewer 'droughts' when feeding is required, compared to heavier stocking rates. Stocking at LTCC is thus most profitable in the long term due to better prices and lower costs (especially by avoiding the costs of drought feeding).

Evidence from the WGT and trials in other areas shows that stocking *around* LTCC maintains or improves pasture composition, increases rainfall infiltration and hence reduces runoff. Conversely, heavy stocking rates result in a rapid loss of 3P grasses and a decline in land condition and carrying capacity.

Pasture and animal response to out-of-season or early wet season rainfall is often far greater with stocking rates close to LTCC than in heavily stocked paddocks.

How to calculate your LTCC

You can estimate the LTCC of a paddock using land type sheets for your area (see Tools). Obviously, the stocking rate will depend upon the following factors:

- Land condition and tree density
- Area of each landtype
- Grazing preference of landtypes
- Distribution of waters and grazing radius

It is handy to have a property map showing land types, paddock sizes and distance to water to use with your calculations.

It is important to get LTCC estimates right to obtain realistic estimates of the capability of each paddock. Unrealistic expectations of LTCC will result in degraded land condition, poor animal performance and financial losses. Therefore it is best to seek assistance from a DAF extension officer (which is free). Alternatively, attend an MLA *Edge* Grazing Land management course.

The *Long Paddock* website (See tools) also provides a prototype LTCC report for properties. These are only intended as a guide and on ground monitoring and experience is needed to verify these.

As before, the LTCC is only a guide with the actual stocking rate needing to be adjusted from year to year based on rainfall and forage availability. Figure 3 shows the difference with LTCC and forage budgeting from the Wambiana trail and how these can be different from year to year.

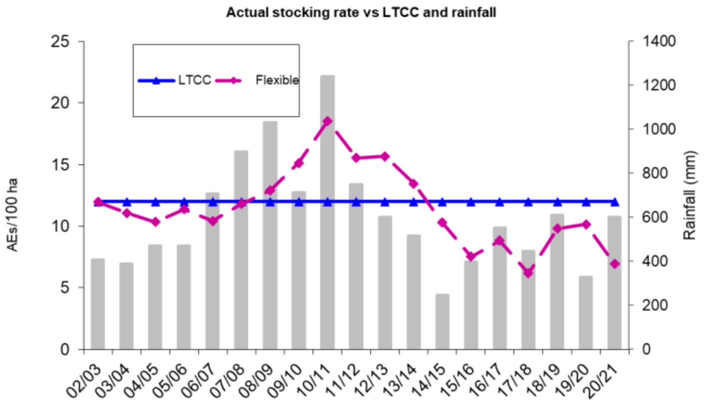


Figure 3: An example of how actual stocking rate can vary around long term carrying capacity (LTCC) based on seasonal forage availability i.e. the LTCC is a guide not the actual stocking rate that can be applied every year.

Important things to consider

- Remember, the LTCC is an *estimate* of what that paddock should be able to sustainably carry in most (not all years). Therefore it is important to do a reality check of your calculated LTCC - is it too high compared to property records?
- Compare the calculated LTCC with that applied by 'good' managers (those with

paddocks in good condition) on similar country.
- Apply adaptively: Monitor trends in pasture composition, yield and animal performance over time and adjust accordingly.

Remember: LTCC's are a guide only; it is essential to adjust and reduce stocking rates in dry years, even if stocked to LTCC.

Tools to help implement and calculate LTCC.

- Estimate long term carrying capacity for your property land types: www.longpaddock.qld.gov.au/
- Monitor pasture growth alerts for your area www.longpaddock.qld.gov.au/forage/
- Historical rainfall data www.longpaddock.qld.gov.au/silo/
- Assessing paddock ground cover vegmachine.net/ www.longpaddock.qld.gov.au/forage/
- FutureBeef – landtype sheets, practical tools, scientific insights, and relevant, timely advice futurebeef.com.au/
- Attend a Grazing Land Management (GLM) *EDGE* course futurebeef.com.au/

More information:

For more information on how to calculate or use LTCCs contact your local extension officer. Futurebeef.com.au/contact-us/

Why wet season spell?

Wet season spelling is essential to maintain and improve pasture condition. Research shows that the critical time to spell is the early wet when plants are regrowing after the long dry season. While an early wet season spell is good, a longer, full wet season spell is best, especially for pastures in poorer condition

Cattle are selective grazers, so preferred 3P grasses are often overutilised, even at light stocking rates. Without occasional rest, these 3P grasses can weaken, die and be replaced with less productive, unpalatable grasses or weeds. Wet season spelling gives 3P grasses a chance to rebuild root reserves, increase vigour and set seed. It also gives seedlings a chance to establish without being pulled out by grazing.

> 3P grasses are grasses which are *Perennial, Productive and Palatable*.

Spelling is also a good way to ensure there is a feed reserve for later in the year or for animals that need special care like weaners.

Importantly, spelling involves removing all cattle from a paddock for all or part of the wet season. Even a few head left in a paddock will still overgraze preferred areas and grasses, continuing the degradation cycle.

Indicators of the need for wet season spelling

All paddocks need occasional spelling, however indicators of the need to wet season spell are:

- 3P grasses are less than 40% of pasture with pastures dominated by unpalatable species like wiregrass and/or annual grasses and forbs.
- 3P grasses are small, weak, seldomly produce seed and respond poorly to rain.
- Paddock yields and ground cover low.

Figure 1: Wet season spelling (right) is essential to give grazed paddocks like that on the left a chance to recover.

- Preferred grasses heavily grazed, often down to their bases.
- Distinct patch grazing with tall rank grass next to heavily grazed patches.

Findings from the Wambiana Grazing Trial

The Wambiana grazing trial has shown that while recovery with wet season spelling can be slow, spelling during the growing season is still essential and allows faster recovery post drought. This can be seen from Figure 2, where the basal cover of desert blue grass, on "C" condition land, recovered a lot faster with annual spelling following a severe drought in 2014/15.

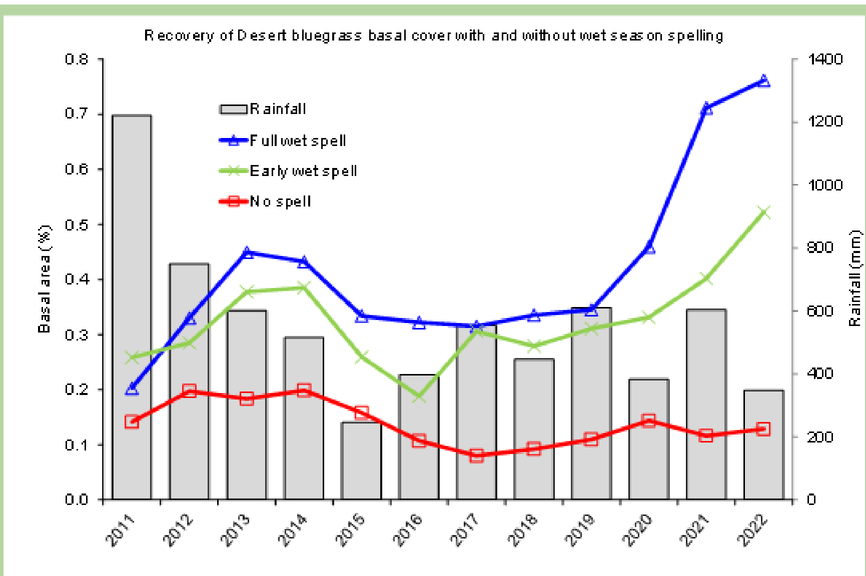


Figure 2: Under moderate stocking at Wambiana, annual wet season spelling, especially for a full wet season, led to faster recovery after the 2014/15 drought on C condition land.

Other evidence from the *Ecograze* project (2001) on goldfields and basalt landtypes in the Upper Burdekin showed rapid improvements in yield and composition with early wet season spelling were possible, provided pasture utilisation rates were conservative (25-35% utilisation rate).

> Utilisation rate is the amount of feed eaten relative to the amount grown over a growing season.

Importantly, results from the Wambiana trial and elsewhere, show that stocking rate is just as, if not more, important than spelling in determining pasture condition. This means that there will be little, if any, benefit from spelling if stocking rates are too high. It also means that higher stocking rates will still damage pasture condition even if wet season spelling is applied.

The Wambiana trial has also shown that at the same stocking rate, incorporating regular spelling increases liveweight gains in the longer term relative to not spelling.

How to implement wet season spelling

Identification of the paddock

Plan which paddocks you are going to spell well in advance of the wet season. Tips to selecting paddock(s) include:

- What is the current pasture condition?
- When was the last time it was spelled?

Removal of animals

Animals should be removed at the end of the dry season, or when is convenient with musters. Try to ensure that paddocks to be spelled have good ground cover at the end of the dry to maximise rainfall infiltration with 50% as the minimum recommended level.

Remember to consider where these animals are going to be moved to. Do not overgraze a paddock just to give another a wet season spell.

> Spelling will not buffer the effects of higher stocking rates.

Spelling

Paddocks should be locked up once conditions allow pasture growth e.g., after about 50 mm has fallen over 2 days. Check local long term rainfall data for when this might be in your region. Charters Towers, for example, usually has 50 mm fall in two days by 28 January.

How long to spell for?

At a minimum, paddocks should be spelled for the first 6 to 8 weeks of the wet season as plants are most sensitive to grazing at this stage. However, a full wet season spell will give the greatest benefit, as the late growing season is when grasses store reserves to drive growth for the next year. If paddocks are in poor condition, a full wet season spell may be required for a number of consecutive years.

> Remember, if you have had a failed wet season then the paddock has not had a wet season spell.

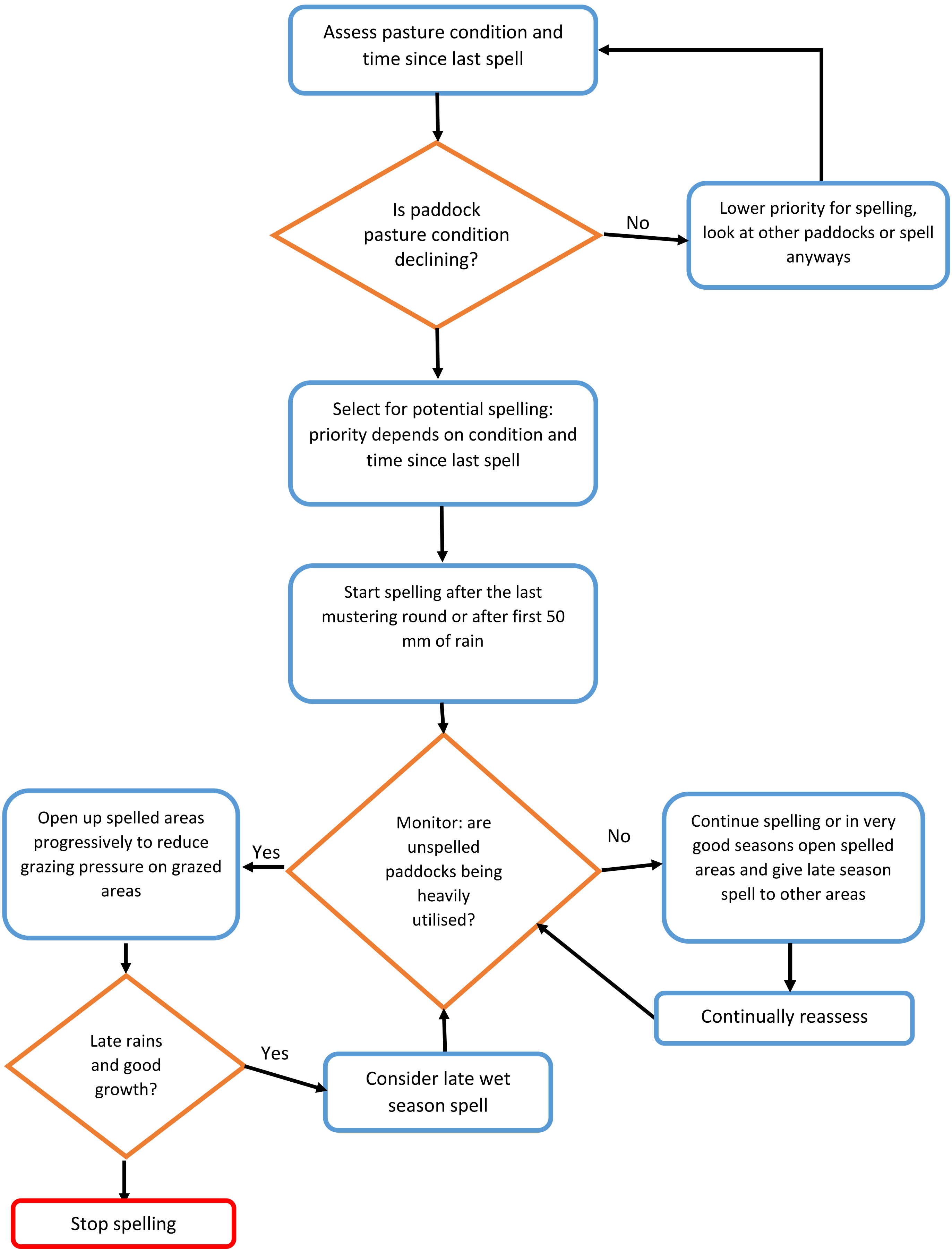
Closely monitor the other un-spelled, grazed paddocks throughout the wet season for over utilisation. If this happens it is best to start opening up spelled areas or sell cattle to reduce pressure on grazed paddocks.

In a very dry year when forage is scarce it might be best not to spell to avoid over-grazing other paddocks.

After wet season spelling

Once the desirable 3P species have set seed, cattle can be reintroduced to the paddock. However, ensure stocking rates match the amount of feed present. This can be determined using a forage budget to ensure sufficient residue remains at the end of the dry season. Importantly, stock numbers should be around or lower than the Long Term Carrying Capacity (LTCC) of the paddock, ensuring the positive effects of the spell are not lost.

Flow diagram for wet season spelling



Tools to help implement wet season spelling

- Monitor pasture growth alerts for your area www.longpaddock.qld.gov.au/forage/
- Historical rainfall data www.longpaddock.qld.gov.au/silo/
- Assessing paddock ground cover vegmachine.net/ www.longpaddock.qld.gov.au/forage/
- FutureBeef – latest practical tools, scientific insights, and relevant, timely advice futurebeef.com.au/
- Attend a Grazing Land Management (GLM) EDGE course futurebeef.com.au/
- *The Ecograze project: developing guidelines to better manage grazing country,* Ash et al (2001) CSIRO, Townsville, 44 p.

More information

For more information contact your local extension officer. Futurebeef.com.au/contact-us/ No

Demography of perennial grasses under varying resting and grazing regimes in central Queensland

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Additional keywords

Basal area, density, recruitment, mortality, survival

Abstract

Declining condition of pasture is evident in many pasture communities across northern Australia, demonstrated through a decline in density and growth of desirable perennial grasses. Resting of grazing land for maintaining or improving pasture condition is a key recommendation.

This study aimed to improve understanding of the demographics of key perennial grasses when pastures are rested to recover poor pasture condition grazing land in northern Australia. We documented the response of native pasture in priority pasture communities in northern central Queensland at two sites to different timing, durations, and frequency of pasture resting. The primary studies were on the use of growing season (or 'wet season') resting to recover the pasture condition of native pasture in poor condition. Interactions with seasonal conditions and the effect of a moderate versus a high stocking rate were examined. Detailed recordings were made on plant lifecycles, and soil seed banks each spring. The study demonstrated that pasture recovery by resting management is a

long-term process. Seasonal conditions and stocking rate were the key drivers of pasture condition. Both sites experienced dry to very dry conditions with high levels of plant mortality and low levels of recruitment and juvenile plant survival of key perennial grasses. This situation was exacerbated under high stocking rate, although *Bothriochloa ewartiana* and *Chrysopogon fallax* were able to maintain basal area under moderate stocking rate. We concluded that pasture recovery will take several years of good growing conditions to enhance seed set, recruitment and survival of key perennial grasses but this will only occur with moderate and well-managed stocking rates.

Introduction

Declining condition of pasture and soil is evident in many pasture communities across northern Australia (Queensland, Northern Territory, and Kimberley and Pilbara regions of WA), demonstrated through a decline in density and growth of desirable perennial grasses (Tothill and Gillies 1992 and McKeon *et al*. 2004). This area is of substantial importance to the Australian beef industry and economy, with usually 12 million cattle carried (ABARES 2020). Using the 'ABCD' condition ratings (Karfs *et al.* 2009), extensive areas have been estimated to be in 'C' (poor) condition: around 50% of the Northern Gulf region, 40% of the Burdekin catchment and 20% of the Fitzroy Basin. (The carrying capacity of 'C' condition pasture is reduced by 50% or more (McIvor *et al.* 1995; Ash *et al.* 1997), and these pastures are at severe risk of soil erosion and delivery of poor water quality effects downstream (Neil *et al.* 2002; Prosser *et al.* 2002). Resting of grazing land for maintaining or improving pasture condition is a key recommendation for improved grazing management across northern Australia, especially for accelerating recovery of pasture that has declined in condition Hunt *et al.* (2014).

Phelps *et al*. (2014) consulted grazing industry and rangeland technical experts across the key rangeland areas of northern Australia and found that pasture resting is a common practice and important for improving land condition under both a changing or current climate. Briske *et al.* (2008) reviewed rotational grazing on rangelands and concluded that rest periods and reduced stocking during conditions favourable to plant growth are needed for the sustainability of grazed ecosystems and recovery of degraded ones. A meta-analysis by McDonald *et al.* (2019) of global literature that compared animal production, pasture diversity and production under strategic rest versus continuous or nil grazing found that ground cover and liveweight gain per hectare were greater under strategic rest compared to continuous grazing, and concluded that more research needs to be done on the timing of rest periods relative to periods of key pasture growth.

Currently, there is little reliable and relevant information to guide cost-effective and practical resting regimes for rangeland graziers. Few data show how quickly and effectively poor pasture condition responds to variations in the timing, duration, and frequency of resting (Briske *et al.* 2008; McIvor *et al.* 2011; Scanlan *et al.* 2013). While Hunt *et al.* (2014) have made general recommendations on pasture resting, specific best management practice recommendations are lacking. Teague *et al.* (2013) have described hypotheses that need testing including that a full growing-season rest will improve pasture composition, and that greater benefits occur in drier rangelands from long rest periods rather than short grazing durations. Most rangelands experience high variability in rainfall and therefore stocking rate and weather are of more importance to plant growth than redistribution of grazing pressure in space and time (MacLeod *et al.* 2009; Briske *et al*. 2011). To add further complexity, modelling indicates that the net benefit of resting for a paddock, or group of paddocks, involves a strong interaction between both the overall stocking rate applied and the impact of any periods of heavy grazing associated with the resting strategy (Scanlan *et al*. 2011). Thus there remains a major challenge to improve knowledge on the ecological processes which drive the recovery of poor pasture condition.

The purpose of the reported study was to improve the understanding of the demographics of the major perennial grasses when resting pastures to recover poor condition grazing land in northern Australia. We documented the response of native pasture in two priority pasture communities in northern central Queensland to different timing, duration, and frequency of pasture resting. The primary studies were on the use of growing season (or ‘wet season’) resting to improve the pasture condition of paddocks of native pasture that are in poor condition. Interactions with seasonal conditions and the effect of resting and grazing regimes under a moderate versus a heavy stocking rate were also examined.

Methods

Project design

Two sites were established in northern central Queensland on grazed pastures rated to be in ‘C’ condition (Quirk and McIvor 2003). Both sites had treatments that examined the duration and frequency of resting from cattle grazing while Site 1 also examined the timing of resting and Site 2 examined the interaction of stocking rate, pre- and post-resting, on the benefits of resting.

Both sites have their main period of pasture growth from October to March when temperatures are optimal and 75 to 80% of annual rainfall usually occurs.

Site descriptions

Site 1

This site was 55 km west of Clermont, central Queensland (22º35’S, 147º12’E) in the Lennox land system (Gunn *et al*. 1967) which is described as ‘plains; loamy red earths with *Eucalyptus melanophloia* F.Muell. woodland with *Bothriochloa ewartiana* (Domin) C.E.Hubb. and *Aristida* spp.’ The main *Aristida* spp. (wiregrasses) were *A. calycina* R.Br., *A. contorta* F.Muell., *A. holathera* Domin, *A. jerichoensis* (Domin) Henrard. and *A. pruinosa* Domin. *A.longicollis* (Domin) Henrard, *A.muricata* Henrard and *Aristida psammophila* Henrard were also collected at the site. Identification of wiregrasses to a species level was problematic in the field so that *Aristida* spp. was recorded as the taxonomic unit at both sites. Botanical names in this paper are the most current listed for a plant in the Australian National Plant Index web site (ANPI 2016). The paddock is mainly box country land type under a more recent system of categorisation (Whish 2011), not cleared, with an even tree cover and predominantly native pasture with *B. ewartiana* (desert bluegrass) and *Aristida* spp. as the main perennial grasses. The site was in ‘C’ condition (Quirk and McIvor 2003) due to a general decline in the desirable perennial grass *B. ewartiana* and large amounts of the less favoured *Aristida* species. Mean annual rainfall for Blair Athol (10 kms south-east) is 619 mm with 75% occurring between October and March (Clewett *et al*. 2003). The trial here ran from October 2010 until July 2016.

Site 2

This trial was established within the Wambiana grazing trial 60 km south-west of Charters Towers, north Queensland (20º32’S, 146º7’E) (O’Reagain *et al.* 2014). It is an open eucalypt woodland with the dominant (~55%) woody vegetation being *E. brownii* Maiden & Cambage. The soils are brown sodosols, moderately fertile and support a pasture layer containing *B. ewartiana, Aristida* spp., *Chrysopogon fallax* S.T.Blake, and a variety of other perennial and annual grasses (Scanlan *et al.* 2013). The site was in ‘C’ condition (Quirk and McIvor 2003) due to a general decline in the desirable perennial grass *B. ewartiana* and large amounts of the less favoured *Aristida* species. Mean annual long-term rainfall for Trafalgar (10 kms north) is 647 mm with 79% occurring between October and March (Clewett *et al*. 2003). The main *Aristida* spp. were *A. benthamii* Henrard, *A. calycina,* and *A. queenslandica* Henrard.

Experimental design

Impacts of timing, duration and frequency of resting on pasture recovery

At Site 1, ten treatments were applied over six years to plots (20 m by 20 m) within a commercial paddock that was stocked moderately at a level that was stable around a long-term carrying capacity of about 8 ha per animal equivalent (AE: defined as a 450 kg steer). Each treatment had four replicates in a blocked design (Table 1). To account for a potential grazing pressure gradient each block was located so that all plots within the block were a similar distance (0.4, 0.6, 0.8 and 1.2kms) from a permanent water point within the paddock. The site was destocked over the 2012/13 summer following a wildfire in November 2012 and then very dry conditions.

Resting was achieved by erection of a stock-proof fence around a specific plot in October and then removing it in February (early wet season) or in May (full wet season). Along with all other treatments, the nil resting treatment (G) was rested for six months following a wildfire in November 2012.

Impact of stocking rate on the benefits of resting for pasture recovery

At Site 2 plot size and replication was the same as Site 1 and eight resting regimes were tested (Table 1). Resting was again for either the early or full wet season, but only on an annual or biennial basis. However, grazing following resting occurred at either a moderate or a high stocking rate for the remainder of each year, as opposed to only a moderate stocking year at Site 1.

(Insert Table 1)

At Site 2, equivalent sets of treatment plots were laid out in two elongated blocks about 50 metres wide in the high stocking rate paddock near a fence that separated it from the adjacent, long term moderate stocking rate paddock. The moderate stocking rate was set at 12.5 adult equivalents (AE) 100 ha^{-1} (AE = 450 kg steer) and a high stocking rate at twice that, i.e. 25 AE 100 ha^{-1} (O'Reagain *et al.* 2014). A section of that fence was then realigned so that one block, containing all treatments, was now incorporated into the adjacent moderate stocking rate paddock while the other block remained in the original paddock that had been heavy grazed for 14 years and continued under that stocking rate (Table 1). The pasture was in poor condition. The basal area of the key perennial grass *B. ewartiana* was very low due to the previous heavy stocking and drought (Orr and O'Reagain 2011).

This design provided insights into the interactions between resting regime and overall stocking rate on pastures subjected to many years of heavy grazing pressure. The grazing trial had been destocked in June 2011 and burnt in late October 2011. The whole site then received an early wet season rest before the appropriate number of cattle was reintroduced to both paddocks in February 2012 to maintain the grazing pressure differential. Data collection here ran from November 2012 to May 2019.

Population dynamics

Twelve permanently located 0.25 m^2 quadrats in each plot were recorded in detail to follow changes in plant dynamics. These quadrats were specifically chosen to contain initially a reasonable number of the key perennial pasture grasses so that their population dynamics (the perennial grass demography, basal area, density and size to be computed (Orr 1998)) could be adequately followed in detail. The fixed quadrats were stratified based on the presence or absence of *B. ewartiana* at recording 1. Six quadrats had *B. ewartiana* plant present as well as 1 to many *Aristida* spp. plants. The other six quadrats did not have *B .ewartiana* present, but did have 1 to many *Aristida* spp. present. Key perennial grasses at Site 1 included *B.ewartiana, Aristida spp* and *P. effusum*. Site 2 key perennial grasses include *B.ewartiana, Aristida spp* and *C. fallax*. All perennial grasses were recorded at both sites. Site 2 contained a small component of *Bothriochloa pertusa* (16%). The prolific stoloniferous nature of *B. pertusa* made it impossible to consistently record location and diameter of basal crowns. Being a minor pasture component, it was decided to exclude *B. pertusa* from recordings. Basal area data are presented as the total of all perennial grasses, as well as the three key grasses individually at each site (Table 2). The key perennial grasses occupied 92% and 93% of the total basal area in quadrats at Site 1 and 2 respectively.

(Insert Table 2)

The location and diameter of all individual perennial grass tussocks (including all segments making up that plant) in each quadrat were charted on gridded paper. Plant bases and segments included old degenerating plants with several segments and/or vegetative ramets rooting from stems that were in contact with the soil. Where plant bases and segments were not circular, the width was measured across the widest part and then perpendicular to that midway along the first direction. Later recordings documented the survival and change in size of these initial plants, together with the size and location of any new plants recruited subsequent to the previous recording (Orr *et al*. 2004*a*). The number of recruits at recording n+1 are those that established between recording n and recording n+1. The number of mortalities at recording n+1 is the number of existing plants that have died or disappeared between recording n and recording n+1.

All plots were recorded just before the trial started at each site and at the end of each trial. The grazed plots, and any plots which were seasonally rested in a particular wet season year, were recorded three times during that grazing year. The recording dates were September to November, February and May to July corresponding to the end of the dry season, middle of the wet season and end of the wet season, respectively. These recording times were intended to coincide with perennial grass growth Phase 4 (October), Phases 2/3 (February) and Phase 3 (May) (Quirk and McIvor 2003). No demography recordings were made on quadrats of treatments that did not require a rest that wet season, except those continuously grazed. Site 1 was recorded three times per year from October 2010 to September 2015, and then again in July 2016. Site 2 was recorded three times per year from November 2012 to May 2015, and then once annually at the end of the wet season until May 2019.

Soil seed banks

Germinable soil seed bank was measured annually for the spring of years 2011 - 2014 at Site 1, and 2012 - 2014 at Site 2. Seeds were germinated from soil samples collected adjacent to the permanent quadrats of plots rested the previous summer, and annually from the continuously grazed treatments.

Annually in spring, six soil cores each 5.3 cm diameter and 5 cm deep were bulked to form a single sample from quadrats 1-6, and equally for quadrats 7-12, giving two samples per plot/treatment replicate. Samples were stored in a dark, dry location. Early the following summer, samples were sieved through a 7mm brass sieve to remove stones and large vegetable matter, then spread as a 2 cm layer on paper towelling laid over compacted sand in 15 cm diameter, 20cm deep, drained pots in a glasshouse. The pots had been irrigated beforehand with 100ml of a strong solution of a general fertilizer. Pots were watered with town water by an overhead, hand-held sprinkler for 12 weeks, two or three times daily for the first 10 days, and then daily thereafter in the morning. Seedlings were identified, counted and removed periodically once positively named or assigned with an interim code. Where a seedling's identity was not readily determined, it or several representatives of it were allowed to grow on in their pot until flowering or fruit maturity permitted identification. If space in the plot was limiting they were pricked out as small seedlings into spare pots and allowed to grow to maturity there. Pots with plants being grown to maturity were watered from the base after the first 12 weeks to minimise surface moss, liverwort, fungal and algal growth which could interfere with development. Very slow-maturing plants had extra fertiliser periodically applied in the basal watering tray to ensure development was not jeopardised.

Statistical analysis

The various pasture parameters at each sampling date were analysed by analysis of variance in several ways. Firstly, a randomised block (RB) analysis was conducted, using the plots as experimental units. If the block variance was less than the residual variance in any RB analysis, the block effect was then incorporated into the residual term to give a more stable estimate of error, with increased degrees of freedom and thus greater precision around statistical confidence. In addition, initial values of any quadrat parameter being analysed (before treatments were applied) were used as covariates in a covariate analysis. Plots and quadrats were chosen to be as similar as possible for initial pasture condition, *B. ewartiana* and *Aristida* spp. density, and woody cover, but for other grasses the initial plot values varied considerably. For this reason, the initial mean values for treatments are included in the summary analyses tables. Covariate analyses were preferred whenever the test of significance of the covariate adjustment was significant at the 10% level. Seasonal conditions over time were also analysed using a repeated measures analysis of variance. Analyses were performed using GENSTAT (release 18.1, VSN International, Hemel Hempstead, UK).

Since some treatments had not been fully implemented before the trials ended, some treatments were identical in each block. For example, at Site 1 a wildfire burnt the whole trial in November 2012, and all plots were then rested until June 2013. Consequently, at the final recording in autumn 2015, the grazed + rest 2012-13 (G) (treatment acronyms ate defined in Table 1), and the full wet season rest in year 3 only (FY3) treatment were identical. This was duly accounted for in the interpretation of various statistical analyses.

Results

Rainfall

Mean annual and summer rainfalls are greater at Site 2 (Table 3). During the trial, Site 1 had exceptionally high annual and summer rainfall for the first two years, with the second year's non-summer rainfall also high. Thereafter this site was relatively dry for the remainder of the trial. Site 2 had high annual rainfall for the first year of the trial, with the two preceding years being exceptionally wet. Non-summer rainfall was also high for the first year at Site 2 but then the remainder of the trial period was dry, with three of the summers being very dry (Table 3). Repeated measures analysis of variance showed that there was a significant effect of seasons over time at both sites on both total basal area and key perennial grass densities.

(Insert Table 3)

Site 1

Density, recruitments and mortality

The density (plants m^{-2}) of *B. ewartiana*, *Aristida* spp. and *Panicum effusum* R.Br. varied with changing seasonal conditions. Density increased through the wet years (2010-11 and 2011-12), with a major decrease following the wildfire in November 2012 and slow recovery during the subsequent dry summers. *B. ewartiana* density increased 38%, while that of *Aristida* spp. and *P. effusum* decreased 62% and 73% respectively after approximately six years (Fig. 1). There was no significant treatment effect on *B. ewartiana* or *P. effusum* density. The density of *Aristida* spp. was significantly greater (P<0.05) under treatment G than EA, FA and FY2, and density of FA was also greater than FY2 which had only had a single rest in May 2012 (6th recording, end of second growing season), In October 2012 density of *Aristida* spp. was greater under treatment G and FY3 than under EA, EB and FB (Fig. 1b).

(Insert Fig. 1)

Overall resting treatments did not greatly affect the number of recruits or mortalities for any taxon (Supplementary Figures S1 and S2). Results are presented only for only G, EA and FA since these treatments were recorded at every recording date. Appreciable recruitment rates (7-9 plants m^{-2} over two years) and some survival of these recruits occurred for all three target species. High recruitment rates were recorded during the February 2011 to May 2012 period, and again during May to October 2014. There was an appreciable fall in recruitment during the decile 1 summer of 2012-13.

Despite relatively dry conditions (decile 4 over the 2013-14 summer), recruitment occurred in all three species (Supplementary Fig. S1), and after negligible winter rain, high recruitments for *Aristida* spp. and *P. effusum* were also recorded in October 2014. Recruitment was highest for *Aristida* spp. and least for *B. ewartiana*. However, there were significant differences in recruitments during individual time periods, but these periods were not synchronised for the three key species. *B. ewartiana* had more recruits in treatment EA compared to G and FA in May 2013, albeit of very small numbers. *Aristida* spp. had more recruits in treatment G than EA or FA in May 2012. *P. effusum* had significantly more ($P<0.05$) recruits in treatment FA than G in February 2012 (Supplementary Fig. S1). Other large, non-significant mean differences between treatments were due to localised, large recruitments in a single replicate, such as the October 2012 recording for all three species and October 2014 for *P. effusum*.

High mortalities prior to the February 2013 recording indicate most early recruits did not survive the 2012-2013 summer, probably due to the November fire and the subsequent dry conditions. Mortality of *B. ewartiana* was high among the small recruiting plants, while *Aristida* spp, and *P. effusum* had appreciable mortality among both original and recruiting plants (Supplementary Fig. S2 and S3, and Table 4 and 5). Highest mortalities were recorded at the February 2013 (after the fire), February 2015 and the July 2016 recording. *Aristida* spp. recorded a disproportionately high mortality in May 2014, while *B. ewartiana* had a significantly greater but still low mortality in treatment EA compared to G in October 2013 and in FA compared to G in May 2015 (Supplementary Fig. S2a). The mortality of *Aristida* spp. and *P. effusum* was not significantly affected by treatment nor in a consistent way at individual recording dates (Supplementary Fig. S2b and c). Proportionately, *B. ewartiana* and *Aristida* spp. had about 7% of recruits surviving to the trial's end and *P. effusum* just over 1%.

Basal area

Total basal area varied with seasonal conditions across all treatments. Treatments FA and EA had a significantly increased total basal area in May 2011 compared to G, while EA, EB and FA treatments had greater total basal area by October 2012 compared to G (Fig. 2a). This change developed during the first growing season and persisted during the second, both seasons being very wet. Basal area of *B. ewartiana* was higher in EA, EB, FA, FB and FY1 treatments compared to G in February and May 2011 (Fig. 2b). In November 2011, basal area was higher in FA than G and FY2, and in February 2012, basal area of *B. ewartiana* was higher in EA, FA and FY2 than G (Fig. 2b). Treatment had no significant effect on the basal area of *Aristida* spp. and *P. effusum* at any recording (Fig. 2c and d). Generally G had the lowest basal area in total, and for both *B. ewartiana* and *P. effusum*.

The unplanned burn and dry summer of 2012-13 most likely caused the decrease in total basal area with the majority coming from the decrease in *Aristida* spp. basal area. *B. ewartiana* basal area was relatively stable through the burn and dry summer of 2012-13, but subsequently decreased slightly with the ongoing dry conditions. The *P. effusum* basal area, although very low (<0.3%) was not affected by treatments, but had a large, persisting decrease following the burn and dry summer of 2012-13 (Fig. 2d).

There was a significant contribution from plants that recruited since trial establishment to the total basal area recorded from February 2012 (~ 10%). Conversely, original plants provided most of the total basal area (~ 90%) for all recordings. *Aristida* spp. and *B. ewartiana* each contributed about half of the total basal area until the November 2012 burn, but thereafter the basal area of *Aristida* spp declined considerably (Fig. 2c), contributing only 31% of the total for the remainder of the trial period. *P. effusum* made a very small contribution (2%) to total basal area.

(Insert Fig. 2)

Survival

B. ewartiana had the highest survival rate from the original plants, with 68% surviving six years to July 2016. *Aristida* spp. had a very low long term survival rate, being 11% after six years, and none of the original plants of *P. effusum* survived past October 2014 (Supplementary Fig. S3).

Very few recruits of any key perennial grasses survived (Table 4). The size (basal area) of dying plants was very small compared to the original plants that survived throughout the trial (Table 4). Also, the average size of surviving *B. ewartiana* plants, 55.6 cm^2, was far greater than the 8.9 cm^2 of the *Aristida* spp. survivors. The average size of the original *B. ewartiana* and *Aristida* spp. plants was similar to those surviving to July 2016.

(Insert Table 4)

Germinable seed banks

Soil sampled in the spring of 2011, 2012, 2013 and 2014 recorded very low numbers of germinable seeds of *B. ewartiana* and *P. effusum*. While the *B. ewartiana* seedbank was very low, with no germinable seeds in 2012, there was an increasing trend over time. The *Aristida* spp. seedbank had very high numbers in 2013 and 2014 with an increasing trend (Table 4). There were few treatment effects. In 2013 FA had significantly more *B. ewartiana* seeds m^{-2} compared to all other treatments except EA while EA had more *P. effusum* seeds m^{-2} compared to all other treatments (data not presented).

Site 2

Moderate stocking rate trial

Density, recruitments and mortality. The density (plants m^{-2}) of *B. ewartiana* and *Aristida* spp. under moderate stocking rate decreased over the trial period under the prevailing dry conditions, while that of *C. fallax* was reasonably stable after an early increase (Fig. 3). *B. ewartiana* density was stable until the dry conditions from 2013, thereafter recording a reduction of 44% from November 2012 to May 2019. Density began declining in October 2015 (Fig. 3a). *Aristida* spp. density was similarly stable until October 2015 but declined by 72% with the dry conditions (Fig. 3b). Mean *C. fallax* density slightly increased by 7% (Fig. 3c). There was no recorded effect of resting treatment on grass density of any grass species over the seven years.

(Insert Fig. 3)

C. fallax had appreciable, regular recruitment rates throughout the trial (Supplementary Fig. S4c), whereas *Aristida* spp. had low recruitment rates except for November 2012 (Supplementary Fig. S4b) and *B. ewartiana* had very low recruitment rates throughout the trial (Supplementary Fig. S4a). There was no measurable effect of resting treatments on *B. ewartiana*, *Aristida* spp. or *C. fallax* recruitment numbers (Supplementary Fig. S4). Long first visible leaves on *C. fallax* recruits indicated that most arose form rhizomes rather than seeds.

Mortalities occurred steadily for all key taxa with appreciably higher levels for *Aristida* spp., but significant treatment differences were only recorded for *B. ewartiana* and *Aristida* spp. (Supplementary Fig. S5). Recorded mortalities were significantly higher for *B. ewartiana* under G compared to E and FA in February 2013, and *Aristida* spp. had higher mortalities under EA compared to FA and G in February 2015. *B. ewartiana* and *Aristida* spp. had very high mortality amongst the small recruiting plants (Table 5).

Basal area. Total basal area varied with seasonal conditions under moderate stocking rate, but the dry conditions from 2012 onwards most likely caused basal area decline for two years from October 2014 before slowly rising again (Fig 4a). Across all treatments, total basal area declined from 1.6% in November 2012 to 0.9% in May 2019. Only in August 2016 did the FA rest result in a significantly greater basal area than in the EA treatment (Fig. 4a). *B. ewartiana* had lower basal area under G compared to EA, EB, FA and FB in February 2013, but was only lower compared to FA in October 2015 (Fig. 4b). *Aristida* spp. basal area was unaffected by treatment for the first five years of the trial, but in May 2018 treatment G had significantly higher basal area than FA although both were low (Fig 4c). There was no significant effect of resting treatment on the the basal area *C. fallax* (Fig 4d), although the prolonged regular FA treatment had a consistently higher basal area in later years. *Aristida* spp. initially contributed 58% of the total basal area, but thereafter decreased to only 22% of the total in May 2019. *B. ewartiana* maintained a stable basal area throughout the trial. *C. fallax* declined to a low basal area in October 2015 (0.1%), but levels recorded in May 2018 were similar to those at the beginning of the trial.

(Insert Fig. 4)

Survival. Original plants of *B. ewartiana* and *C. fallax* recorded low survival rates, with 42% and 44% respectfully surviving eight years to May 2019. Only 6% of *Aristida* spp. survived after eight years (Supplementary Fig. S6). Few recruits of *B. ewartiana* and *Aristida* spp. survived to May 2019, but survival rates were greater than that for those species at Site 1 (Table 5 versus Table 4). Conversely, over a third of *C. fallax* recruits were surviving at trial end. Individual basal area of dying plants was small (2-3 cm^2) compared to original plants that survived throughout the trial (Table 5). The *B. ewartiana* and *C. fallax* plants that survived throughout the trial increased appreciably in size, whereas those of *Aristida* spp. did not. The average calculated lifespan for *B. ewartiana* at Site 2 was 12 years under the moderate stocking rate.

(Insert Table 5)

Germinable seed banks. Soil sampled in the spring of 2012, 2013 and 2014 recorded low numbers of germinable seeds of *B. ewartiana,* and none for *C. fallax*. The *Aristida* spp. seedbank had very high seed numbers in 2013 and 2014 (Table 5). Spatial variability was substantial as suggested by the Standard Error of the means.

Site 2

High stocking rate trial

Density, recruitments and mortality. *B. ewartiana* density began declining under high stocking rate in May 2014, and resting treatments did not significantly affect density. An overall reduction of 86% was recorded from November 2012 to May 2019.

Aristida spp. density declined 79% to May 2019. Density began declining in all treatments after May 2014, and by October 2015 was consistently greater under FA compared to EA and G and significantly greater in August 2016 (Fig 5b). That difference over EA, EB, FB and G was maintained in July 2017 and May 2018. In May 2019, FA still had greater *Aristida* spp. density than EA, FB and G, but treatment EB recorded higher *Aristida* spp. density than G.

C. fallax density fluctuated around 6 plants m^{-2} through the trial (Fig 5c), and was significantly greater under FA than EA and G in October 2013, February 2014, May 2014, October 2015 and August 2016. Its density under EA, EB, FA, FB was greater than G in February 2013 and there were other individual significant differences at different sampling dates between specific treatment pairs. However, the eventual trend was for the density of *C. fallax* to be least under G and highest under FA, with other treatments intermediate (Fig. 5c).

(Insert Fig. 5)

C. fallax recorded appreciable recruitment rates throughout the trial, whereas *Aristida* spp. had low recruitment rates, except for November 2012, and *B. ewartiana* had very low recruitment rates throughout (Supplementary Fig. S7). *B. ewartiana* and *Aristida* spp. recruitment rates appeared unaffected by resting treatment, but *C. fallax* had significantly greater recruitment rates under EA & FA compared with G in February 2013. Recruitment rates were greater ($P<0.05$) under FA compared to EA and G from October 2013 to May 2015. However, in October 2015, August 2016 and May 2018 recruitment rates were greater under EA compared to G and FA (Supplementary Fig. S7).

Mortalities occurred steadily for all key taxa, with appreciably higher levels for *Aristida* spp., but treatment differences were only significant for *C. fallax*. Mortalities were significantly higher for *C. fallax* under EA when compared to FA and G in February 2014 (Supplementary Fig. S8).

Basal area. Total basal area varied with seasonal conditions across all treatments, with large reductions in *B. ewartiana*, *Aristida* spp. and *C. fallax* basal area over the trial (Fig. 6). High stocking rate and the dry conditions from 2012 onwards apparently reduced basal area in May 2013, with total basal area reduced from 1.7% in November 2012 to 0.4% in May 2019 across all treatments. Treatment G had significantly greater total basal area than EA, EB, FA and FB in February 2013 and May 2013. FA only had a significantly greater basal area than EA and G in August 2016 (Fig. 6a). *Aristida* spp. basal area was higher under FA compared to EA and G in May 2018; and EA, EB, FB and G in May 2019 (Fig 6c). There was no recorded effect of resting treatments on basal area of *B. ewartiana* (Fig. 6b), but there was a trend for FA to be greater in later years similar to *Aristida* spp. *C. fallax* had lower basal area under G compared to EA, EB, FA and FB treatments in February and May 2013. Additionally EA and EB were significantly greater ($P<0.05$) than FA and FB in May 2013. *C. fallax* had higher basal area under FB compared to G, EA and FA in February 2015, and EB was greater than EA in February 2015 (Fig 6d).

(Insert Fig. 6)

Survival. Recorded survival rates of original *B. ewartiana* and *Aristida* spp. were both very low, with 7% and 2% respectfully surviving eight years to May 2019 under high stocking rate. In contrast, *C. fallax* had a 47% survival rate after eight years (Supplementary Fig. S9). Few of the *Aristida* spp. and *B. ewartiana* recruits survived until the trial ended, but 39% of *C. fallax* recruits survived (Table 5). The average basal area of dying plants of the three key species was small compared to the original plants that survived throughout the trial (Table 5), although the latter had also decreased in size during the run of dry years. The average calculated lifespan for *B. ewartiana* at Site 2 was eight years under high stocking rate.

Germinable seed banks. Soils sampled in the spring of 2012, 2013 and 2014 contained very low numbers of germinable seeds of *C. fallax* and none for *B. ewartiana*. The *Aristida* spp. seedbank had high numbers in 2012, 2013 and 2014 (Table 5).

Discussion

Our study aimed to improve the understanding of major perennial grasses when they are rested to recover pasture condition. Numerous factors and interactions can either hinder or enhance recovery and include the magnitude and composition of existing basal area; recruitment via seed and/or vegetative means; competition from unwanted and short-lived perennial plants and the inevitable exposed soil during dry conditions; and episodic coincidences of biological and grazing management events. Despite this, recovery is not an unreasonable expectation and it is favoured where there is a presence of desirable perennial grass. It has been documented by numerous authors both in similar locations to our study (Ash *et al*. 2011; Bartley *et al*. 2014 and Koci *et al*. 2020) and also in arid regions (Noble *et al*. 1984; Griffin and Friedel 1985).

Recovery can be hindered by short-lived perennial grasses that have higher recruitment rates due to higher seed loads and ready germination. Annual and short-lived grasses commonly appear and disappear after extreme seasonal conditions. It is not easy to predict which perennial grasses will flourish due to low soil seed banks and the sensitivity of germination to temperature and temperature fluctuations (Silcock *et al*. 2005). Our study encountered such confounding interactions.

Rainfall

The exceptionally high rainfall for the first two years of the trial at Site 1 resulted in a short-term increase in density and basal area of the individual key perennial grasses and in total. The desirable perennial *B. ewartiana*, benefitted from resting during this period, but this benefit was not sustained, due to the subsequent dry conditions. The extended dry conditions, particularly at Site 2, prevented pasture recovery regardless of the resting regime or stocking rate imposed. The 2012 – 2021 period in the Site 2 area was documented as the lowest rainfall on record (Long Paddock website, 2021) using the April to March annual rainfall. McKeon *et al.* (2021) defined the 2020-2021 for Queenslands grazing lands period as dry and calculated the percentile rank for this period comparing rainfall with all sequences that have the same duration of years. It had a 1 percentile rank and clearly demonstrates the severity and extent of the dry conditions. These conditions and impact on pastures have been documented by other authors. Owens *et al.* (2021) identified a distinctly drier period than historically at Site 2 from 2002 to 2020 and documented a lack of pasture production compared to potential caused by heavy grazing pressure, reduced tussock densities, increased surface sealing and reduced infiltration, plus increased shrub cover. Cobon *et al*. (2019) documented an increase in both rainfall and pasture growth variability in this region over 50 years, indicating harsher current and future conditions for perennial grass growth and thus greater vulnerability of mis-managed pastures.

Density, recruitment and mortality

The density, recruitment and mortality of the key perennial grasses appeared most affected by changing seasonal conditions, with minimal resting treatment effects under moderate stocking rate at both sites. While *B. ewartiana* and *C. fallax* generally maintained their density, the short-lived *Aristida* spp. and *P. effusum* recorded large density decreases. Appreciable recruitment and some survival of the recruits occurred for all key species. Orr and O'Reagain (2011) previously conducted a similar study at Site 2 and found similar results for *B. ewartiana,* while *Aristida* spp. had consistently greater density under resting and *P. effusum* was unaffected by their resting treatments. McIvor (2001) found that regeneration of pasture yield and composition was not related to soil seedbanks, with basal area being a better predictor. Williams (1970) also documented long-term survival of *Chloris* *acicularis* Lindl. cohorts from infrequent and small establishment events when protected from grazing. His largest crop of seedlings recorded was 0.2 plants m^{-2} which is similar to *B. ewartiana* recruitment in our study.

High stocking rate and dry conditions at Site 2 caused the large and early reduction in density of *B. ewartiana* and *Aristida spp,* although *C. fallax* was able to maintain starting density throughout the trial. The growth form of *C. fallax* at Site 2 is strongly rhizomatous, and hence recruitment of new crowns from well-established parent plants enables easier maintenance of density than can occur via seedling establishment. Additionally, death of associated perennials leaves biological space for rhizomes to exploit. The FA treatment generally increased both *Aristida spp*. and *C. fallax* density. As at Site 1, *B. ewartiana* recruitment rates were very low at Site 2, with mortality rates probably affected most by changing seasonal conditions. The Orr and O'Reagain (2011) study recorded a similar result, with stocking rate and below average rainfall having the biggest impact on *B. ewartiana* density. They also found that *Aristida* spp. had consistently higher density under resting. However, the two studies are not totally comparable. Their study began in 1998, with all paddocks in good land condition. The current study began in 2012, with all plots subject to 14 years of high stocking rates prior that had them in poor land condition, and it also appeared to have experienced drier conditions. *C. fallax* can increase its presence during above average seasonal conditions (Watson and Novelly, 2012), and such changes led to positive improvements in pasture state at eight out of 61 sites in the Kimberley region of Western Australia over a 15 year period. Their conclusion that these changes were occurring in realistic management timeframes gives support for research reported here to continue in the realistic hope of experiencing more favourable seasonal conditions.

Basal area

The basal area of key perennial grasses, as well as total basal area was most affected by very dry conditions and the burn, with minimal resting treatment effects recorded under a moderate stocking rate. Decreases in total basal area resulted mainly from a decrease in *Aristida* spp. basal area, due to high mortalities. *B. ewartiana* basal area was stable, with a small decrease over time with the ongoing dry conditions under a moderate stocking rate. The Orr and O'Reagain (2011) study had a similar result, with stocking rate and below average rainfall having the biggest impact on *B. ewartiana* basal area. However there was a trend for increasing basal area with resting when seasonal conditions improved after 2015 at Site 2. Basal area is a key determinant of the potential for pasture growth and composition regeneration (McIvor, 2001). Hence there is potential for recovery with further improvements in seasonal conditions where some *B. ewartiana* survives. Roe (1987) also found that for *Astrebla* spp. the period between recruitment events which are sufficiently large to prevent a decline in density may be in excess of 40 years. This further highlights the importance of basal area maintenance as a major driver of pasture recovery in the absence of large recruitment events.

Under a high stocking rate, key perennial grass basal area, as well as the total basal area, were affected more strongly by changing seasonal conditions than resting regime, with a larger decrease over time, compared to a moderate stocking rate. Measured basal area of *B. ewartiana* decreased from 0.2% in November 2012 to zero in May 2019. While basal area fluctuates between years, high stocking rates will increase the speed of decrease and also decreases the germinable seed bank. Similarly *C. fallax* basal area decreased from 0.4 to 0.2% under high stocking rate (averaged across G, EA and FA). The Orr and O'Reagain (2011) study had a similar effect from stocking rate and below average rainfall, with the biggest impact on *B. ewartiana* basal area. However, they reported *C. fallax* basal area declined in the resting treatment compared with the high stocking rate. That result contrasts with this study, and is likely a consequence of the greater severity and extent of dry conditions experienced here. *C. fallax* is considered palatable, and to have a high resistance to grazing (Milson, 2000). Results here have shown that its basal area can be reduced when subject to prolonged high stocking under extended dry conditions.

Survival

Stocking rate associated with the significant effect of below average rainfall had the biggest impact on survival of *B. ewartiana* and the loss of all original plants of *P. effusum* after five years is consistent with Orr and O'Reagain (2011). It is critical to grazing management guidelines to emphasize the importance of the ability of well-established *B. ewartiana* plants to withstand fire and poor summer rains if grazing pressure remains moderate or lower.

Under moderate stocking rate, dry conditions likely caused low survival rates of the original *B. ewartiana* and *C. fallax*, and very low survival for *Aristida* spp. but a high stocking rate caused extremely low survival rates of the original plants of all key grasses. The average calculated lifespan for *B. ewartiana* (12 years under moderate stocking rate and 8 years under high stocking rate) was considerably lower than those identified by other authors. Jones *et al*. (2009) and Orr and O'Reagain (2011) calculated a 25- and 28-year lifespan respectively for *B. ewartiana* under moderate stocking rate. The 12 year study of Orr and O'Reagain (2011) experienced dry conditions with decile 2-3 annual rainfall for five years, whereas our study had consecutive annual decile 1 and 2 rainfall with corresponding decile 1 and 3 summer rainfall within just seven years. The study of Jones *et al*. (2009) over six years did not have severe drought for extended periods.

Very few recruits of any taxon survived under either moderate or high stocking rate. McIvor (2007) has shown the poor colonising ability of *B. ewartiana* compared with other perennial grasses makes it vulnerable to loss under overgrazing. He also showed that, for 80% survival of *B. ewartiana* plants, they need to be 7-9 years old and greater than 6 cm^2 plant size (basal area) which is consistent with our study. O'Connor (1994) found that size may be an appropriate descriptor of an individual's survival capability, during drought and overgrazing, as well as their reproductive output and growth. He also found that palatable seed-reproducing species can almost be eliminated under drought plus heavy grazing because of mortality of mature plants and low availability of seed.

Germinable seed banks

B. ewartiana, *P. effusum* and *C. fallax* seed banks were very low for all four years of sampling, while the *Aristida* spp. seedbank was very high in 2013 and 2014. This was reflected in the numbers of seedling recruits recorded from seed. For both sites, the very low *B. ewartiana* soil seedbank resulted in low recruitment rates during the prevailing dry conditions. During good seasonal conditions, a large seed rain could well be a source of major germination numbers provided ergot in the flowers does not inhibit seedset (Silcock *et al*. 2015). Bean *et al.* (2016), in a study in semiarid western NSW found that seed rain, in combination with a micro-environment conducive to germination such as piles of branches in contact with the soil surface, is probably the major source of germination of perennial grasses such as *Monachather paradoxus* Steud, *Digitaria ammophila*, and *Aristida jerichoensis*. However, McIvor (2001) found that the perennial grass seed bank size was not related to pasture recovery, so the low soil seed bank in our study may not hinder eventual recovery when seasonal rainfall improves.

Overall pasture condition changes

Several authors have documented the recovery of poor land condition at similar locations to our study. Koci *et al*. (2020) stated that the exclusion of cattle over 17 years may have restored hydrological processes through improved vegetative cover and reduced runoff and erosion. Meanwhile, Bartley *et al*. (2014) recorded a significant improvement in land condition by the increased composition of desirable perennial grasses over nine years of conservative grazing and wet season resting. Ash *et al*. (2011) demonstrated that conservative stocking with regular wet season resting will help transition to a more desirable ecological state with dominance of desirable perennial tussock grasses. Other authors have documented the recovery of poor land condition in central and semi-arid Australia. Griffin and Friedel (1985) has shown that the vegetation in central Australia, under a semi-arid climate, is well adapted to sequences of extreme wet and dry periods. Large scale periodic regeneration was associated with rare high rainfall events but the control of grazing during the ensuing recovery period was critical. Conversely, Noble *et al*. (1984) reported that in the Kimberley region of Western Australia resting pasture for only two years usually rehabilitates heavily grazed Mitchell grass pastures.

These studies have shown that pasture recovery is possible with appropriate rest, stocking rate and rainfall but the driving biological mechanisms that produced the overall improvement were often not well documented.

In our study the extended dry conditions prevented significant pasture recovery regardless of the resting regime or stocking rate imposed. This demonstrates the importance of long-lived perennial grasses and a moderate stocking rate to maintain pasture condition and productivity during extended dry conditions. A return to more favourable seasonal conditions is then expected to yield more encouraging results about the pasture recovery possible using growing season rest and moderate stocking rate.

Short-lived perennial *Aristida* spp. and *P. effusum* can recruit from seed with *C. fallax* recruiting from rhizomes and all occupy the space between the more sparse tussocks of the desired long-lived grasses. These are lower producing grasses and not favoured for recovery of pasture condition. While *C. fallax* is a long-lived perennial providing soil stability through droughts, *Aristida* spp. and *P. effusum* soon disappear and leave exposed soil. *Aristida* spp. are largely unpalatable and unwanted. The rhizomatous *C. fallax* form in the Burdekin basin compared to the large-tussocked form in monsoonal regions, has high recruitment levels with almost all coming from rhizomes (Silcock and Hall, 1996). This is a resilient source of potential improvement in basal area which is being expressed at Site 2.

B. pertusa was almost absent at both sites through this study due to the dry conditions however it has a large potential to occupy space between tussocks due to large soil seed banks and a stoloniferous growth habit. *B. ewartiana* was found to recruit from rooted culms however these are generally not persistent and none of these survived the dry conditions at site 2. At Site 1 the fire and dry summer conditions caused high mortalities of these recruits and was detrimental to pasture recovery. While *B. ewartiana* has low germinable seed banks there is a trend for increasing density by the end of the trial with increasing recruits and decreasing mortalities.

Conclusion

Demographics data over greatly contrasting years has given a better understanding of the perennial grass ecological processes when resting pastures during the summer growing season under a moderate or high stocking rate. The presence of the desirable perennial grass *B. ewartiana* was improved when rested during wet years under a moderate stocking rate. However, subsequent dry conditions for five years likely did not allow the improvement in C condition pastures to be sustained, and that condition did not change in that time. There were portents of recovery under moderate stocking rate with improving seasonal conditions. Ash *et al*. (2011) have shown the potential for recovery in this region when better seasonal conditions prevail. *B. ewartiana* has shown its value as a cornerstone species through maintenance of basal area through extended dry conditions but only under moderate stocking rate. Under high stocking rate and extended dry conditions, *B. ewartiana* was almost eliminated regardless of a growing season resting regime. Resting pastures will not improve pasture condition when combined with a high stocking rate and/or extended dry conditions.

The short-lived perennial grasses *Aristida spp*. and *P. effusum* were almost eliminated by extended dry conditions, but could repopulate from seed if adequate summer rains return. The long-lived perennial grass *C. fallax* was able to maintain basal area under extended dry conditions with moderate stocking rate but that was considerably reduced under a high stocking rate. Extended dry conditions prevented pasture recovery regardless of the resting regime or stocking rate imposed. These results demonstrate the importance of long-lived perennial grasses and a moderate stocking rate to maintain pasture condition and productivity during extended dry conditions. A return to more favourable seasonal conditions is then expected to yield more encouraging results about the pasture recovery possible using growing season rest and moderate stocking rate.

Conflicts of interest

The authors declare no conflicts of interest.

"Paul Jones is a Guest Associate Editor of the Rangeland Journal, but was blinded from the peer-review process for this paper".

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Data availability statement

The data that support this study will be shared upon reasonable request to the corresponding author.

References

ABARES (2020). Beef farms. Industry overview. Available at: https://www.agriculture.gov.au/abares/research-topics/surveys/beef#productivity (accessed 9 April 2020).

ANPI (2016). Australian Plant Name Index. IBIS database, Centre for Australian National Biodiversity Research, Australian Government, Canberra. Available at: http://www.anbg.gov.au/apni (accessed 9 April 2020).

Ash, AJ, McIvor, JG, Mott, JJ, and Andrew, MH (1997). Building Grass Castles: Integrating Ecology and Management of Australia's Tropical Tallgrass Rangelands. *The Rangeland Journal* **19**, 123–144.

Ash, AJ, Corfield, JP, McIvor, JG, and Ksiksi, TS (2011). Grazing management in tropical savannas: utilization and rest strategies to manipulate rangeland condition. *Rangeland Ecology and Management* **64**, 223–239.

Bartley, R, Corfield JP., Hawdon, AA., Kinsey- Henderson, AE., Abbott, BN., Wilkinson, SN. and Keen, RJ. (2014) Can changes to pasture management reduce runoff and sediment loss to the Great Barrier Reef? The results of a 10-year study in the Burdekin catchment, Australia. *The Rangeland Journal* **36**, 67–84.

Bean, JM, Melville, GJ, Hacker, RB, Anderson, S, Whittington, A, and Clipperton, SP (2016). Effects of fenced seed production areas and restoration treatments on the size and composition of the native grass seedbanks in moderately degraded rangelands in semiarid Australia. *The Rangeland Journal* **38**, 47–56.

Briske, DD, Derner, JD, Brown, JR, Fuhlendorf, SD, Teague, WR, Havstad, KM, Gillen, RL, Ash, AJ, and Willms, WD (2008). Rotational grazing on rangelands: reconciliation of perception and experimental evidence. *Rangeland Ecology and Management* **61**, 3–17.

Briske, DD, Derner, JD, Milchunas, DG, and Tate, KW (2011). An evidence-based assessment of prescribed grazing practices. In 'Conservation benefits of rangeland practices: Assessment, recommendations, and knowledge gaps.' (ed. DD Briske) pp. 22–74. (United States Department of Agriculture, Natural Resource Conservation Service. Washington, DC. USA.)

Clewett, JF, Clarkson, NM, George, DA, Ooi, SH, Owens, DT, Partridge, IJ, and Simpson, GB (2003). Rainman Streamflow, ver. 4.3: a comprehensive climate and streamflow analysis package on CD to assess seasonal forecasts and manage climate risk. QI03040, Dept Primary Industries, Qld.

Cobon, DH, Kouadio, L, Mushtaq, S, Jarvis, C, Carter, J, Stone, G, and Davis, P (2019). Evaluating the shifts in rainfall and pasture-growth variabilities across the pastoral zone of Australia during 1910–2010. *Crop & Pasture Science* **70**, 634–647.

Griffin, GF, and Friedel, MH (1985). Discontinuous change in central Australia: some implications of major ecological events for land management. *Journal of Arid Environments* **9**, 63–80.

Gunn, RH, Galloway, RW, Pedley, L, and Fitzpatrick, EA (1967). Lands of the Nogoa-Belyando Area, Queensland, Land Research Series No.18, CSIRO, Australia.

Hunt, LP, McIvor, JG, Grice, AC, and Bray, SG (2014). Principles and guidelines for managing cattle grazing in the grazing lands of northern Australia: stocking rates, pasture resting, prescribed fire, paddock size and water points – a review. *The Rangeland Journal* **36**, 105–119.

Jones, P., Filet, P., and Orr, D. M. (2009). Demography of three perennial grasses in a central Queensland eucalypt woodland. *The Rangeland Journal*, **31**, 427–437.

Karfs, RA, Abbott, BN, Scarth, PF, and Wallace, JF (2009). Land condition monitoring information for reef catchments: a new era. *The Rangeland Journal* **31**, 69–86.

Koci J, Sidle RC, Kinsey-Henderson AE, Bartley R, Wilkinson SN, Hawdon AA, Jarihani B, Roth CH, Hogarth L (2020) Effect of reduced grazing pressure on sediment and nutrient yields in savanna rangeland streams draining to the Great Barrier Reef. *Journal of Hydrology* **582**, 124520.

MacLeod, ND, Nelson, BS, McIvor, JG, and Corfield, JP (2009). Wet season resting – economic insights from scenario modelling. *The Rangeland Journal* **31**, 143–150.

McDonald, SE., Lawrence, R, Kendall, L, and Rader, R (2019). Ecological, biophysical and production effects of incorporating rest into grazing regimes: A global meta-analysis. *Journal of Applied Ecology* **56**, 2723–2731.

McIvor, JG, Ash, AJ, and Cook, GD (1995). Land condition in the tropical tallgrass pasture lands: 1. Effects on herbage production. *The Rangeland Journal* **17**, 69–85.

McIvor, JG (2001). Pasture management in semi-arid tropical woodlands: regeneration of degraded pastures protected from grazing. *Australian Journal of Experimental Agriculture* **41**, 487–496.

McIvor, J (2007). Pasture management in semi-arid tropical woodlands: dynamics of perennial grasses. *The Rangeland Journal* **29**, 87–100.

McIvor, J, Bray, S, Grice, T, Hunt L, and Scanlan, J (2011) Grazing management options for improving profitability and sustainability. 1. New insights from experiments. Proceedings of the Northern Beef Research Update Conference, Darwin NT. Pp. 41–47.

McKeon, GM, Hall, WB, Henry, BK, Stone, GS, and Watson, IW (2004). Pasture degradation and recovery in Australia's rangelands: Learning from History. Queensland Department of Natural Resources, Mines and Energy.

McKeon, G, Stone, G, Ahrens, D, Carter, J, Cobon, D, Irvine, S and Syktus, J (2021) Queensland's multi-year Wet and Dry periods: implications for grazing enterprises and pasture resources. *The Rangeland Journal* **43**, 121–142.

Milson, J (2000). Pasture plants of north-west Queensland. Queensland Department of Primary Industries, Brisbane.

Neil, DT, Orpin, AR, Ridd, PV, and Yu, B (2002). Sediment yield and impacts from river catchments to the Great Barrier Reef Lagoon. *Marine and Freshwater Research* **53**,733–752.

Noble, J, Cunningham, GM and Mulham, WE (1984). Rehabilitation of Degraded Land. In 'Management of Australia's Rangelands.' (Eds GN Harrington, AD Wilson, MD Young). pp. 171–186. (CSIRO Publications : Melbourne, Australia)

O'Connor, TG (1994). Composition and Population Responses of an African Savanna Grassland to Rainfall and Grazing. *Journal of Applied Ecology* **31**, 155–171.

O'Reagain, P, Scanlan, J, Hunt, L, Cowley, R, and Walsh, D (2014). Sustainable grazing management for temporal and spatial variability in north Australian rangelands – a synthesis of the latest evidence and recommendations. *The Rangeland Journal* **36**, 223–232.

Orr, DM (1998). A life cycle approach to population ecology of two tropical grasses in Queensland, Australia. In ‘Population Biology of Grasses’. (Ed. G Cheplick) pp. 366–389. (Cambridge University Press: New York, USA.)

Orr, DM, Paton, CJ, and Reid, DJ (2004a). Dynamics of plant populations in *Heteropogon contortus* (black speargrass) pastures on a granite landscape in southern Queensland. 1. Dynamics of *H. contortus* populations. *Tropical Grasslands* **38**, 17–30.

Orr, DM., and O’Reagain, PJ (2011). Managing for rainfall variability: impacts of grazing strategies on perennial grass dynamics in a dry tropical savanna. *The Rangeland Journal* **33**, 209–220.

Owens, J, McKeon, G, O’Reagain, P, Carter, J, Fraser, G, Nelson, B, and J. Scanlan, J (2021). Disentangling the effects of management and climate on perennial grass pastures and the degradation that follows multi-year droughts. In ‘MODSIM2021, 24th International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand’ (Eds RW Vervoort, AA Voinov, JP Evans, L Marshall) December 2021, pp. 106-112. ISBN: 978-0-9872143-8-6. https://doi.org/10.36334/modsim.2021.B1.owens

Phelps, D, Broad, K, Cowley, R, Emery, T, English, B, Gunther, R, Jones, P, Karfs, R, MacLeod, N, Pahl, L, Paton, C, Pryor, J, Rolfe, J, Scanlan, J, Stockdale, M, Walsh, D, and Whish, G (2014). Climate savvy grazing. (Developing improved grazing and related practices to assist beef production enterprises across northern Australia to adapt to a changing and more variable climate). Final Report Project B.NBP.0616. (Meat and Livestock Australia: North Sydney, NSW.)

Prosser, IP, Moran, CJ, Lu, H, Scott, A, Rustomji, P, Stevenson, J, Priestly, G, Roth, CH, and Post, D (2002). Regional patterns of erosion and sediment transport in the Burdekin River Catchment. CSIRO Land and Water Technical Report 5/02, Canberra.

Quirk, M, and McIvor, J (2003). ‘Grazing Land Management: Technical Manual.’ (Meat and Livestock Australia: North Sydney, NSW.)

Roe, R (1987). Technical note. Recruitment of *Astrebla* spp. in the Warrego region of south-western Queensland. *Tropical Grasslands* **21**, 91-92.

Scanlan, JC, Whish, GL, Pahl, LI, Cowley, RA, and MacLeod, ND (2011). Assessing the impact of pasture resting on pasture condition in the extensive grazing lands of northern Australia. In 'MODSIM2011, 19th International Congress on Modelling and Simulation'. (Eds F Chan, D Marinova, RS Anderssen) pp. 877–883. (Modelling and Simulation Society of Australia and New Zealand: Canberra, ACT.)

Scanlan, JC, MacLeod, ND, and O'Reagain, PJ (2013). Scaling results up from a plot and paddock scale to a property – a case study from a long-term grazing experiment in northern Australia. *The Rangeland Journal* **35**, 193–200.

Silcock, RG and Hall, TJ (1996). Tactical Pasture Management: Enhancing Profits from Poplar Box Country. Final Research Project Report DAQ076. (Department of Primary Industries: Brisbane, QLD).

Silcock, RG, Jones, P, Hall, TJ, and Waters, DK (2005). Enhancing pasture stability and profitability for producers in Poplar Box and Silverleaved Ironbark woodlands. Final report of project NAP3.208. Meat and Livestock Australia, North Sydney, NSW.

Silcock, RG, Finlay, CH, Loch, DS, and Harvey, GL (2015). Perennial pastures for marginal farming country in southern Queensland. 2. Potential new grass cultivar evaluation. *Tropical Grasslands – Forrajes Tropicales* **3**, 15–26.

Teague, R, Provenza, F, Kreuter, U, Steffens, T, and Barnes, M (2013). Multi-paddock grazing on rangelands: why the perceptual dichotomy between research results and rancher experience? *Journal of Environmental Management* **128**, 699–717.

The Long Paddock (2021). Climate risk information for rural Queensland. Available at: https://data.longpaddock.qld.gov.au/static/posters/WetDryDroughtPoster.pdf (accessed 17 Dec 2021).

Tothill, JC, and Gillies, C (1992). 'The Pasture Lands of Northern Australia.' Tropical Grassland Society of Australia Occasional Publication No. 5, St. Lucia, Qld.

Watson, IW, and Novelly, PE (2012). Transitions across thresholds of vegetation states in the grazed rangelands of Western Australia. *The Rangeland Journal* **34,** 231–238.

Whish, G (Ed.) (2011). 'Land Types of Queensland.' Version 2.0. Prepared by the Grazing Land Management Workshop Team, Department of Employment, Economic Development and Innovation, Brisbane. PR07–3212. (Department of Employment, Economic Development and Innovation: Brisbane.)

Williams, OB (1970). Population dynamics of two perennial grasses in Australian semi-arid grassland. *Journal of Ecology* **58**, 869-875.

Fig. 1. Changes over time in the density of a) *B. ewartiana*, b) *Aristida* spp. and c) *P. effusum* at Site 1. Note the Y axes have different scales.

Fig. 2. Changes over time in the basal area of a) All perennial grasses, b) *B. ewartiana*, c) *Aristida* spp. and d) *P. effusum* at Site 1. Note the Y axes have different scales.

Fig. 3. Changes over time in the density of a) *B. ewartiana*, b) *Aristida* spp. and c) *C. fallax* under moderate stocking rate at Site 2. Note that Y axes have different scales.

Fig. 4. Changes over time in the basal area of a) All perennial grasses, b) *B. ewartiana*, c) *Aristida* spp. and d) *C. fallax* under moderate stocking rate at Site 2. Note that Y axes have different scales.

Fig. 5. Changes over time in the density of a) *B. ewartiana*, b) *Aristida* spp. and c) *C. fallax* under high stocking rate at Site 2. Note the Y axes have different scales.

Fig. 6. Changes over time in the basal area of a) All perennial grasses, b) *B. ewartiana*, c) *Aristida* spp. and d) *C. fallax* under high stocking rate at Site 2. Note the Y axes have different scales.

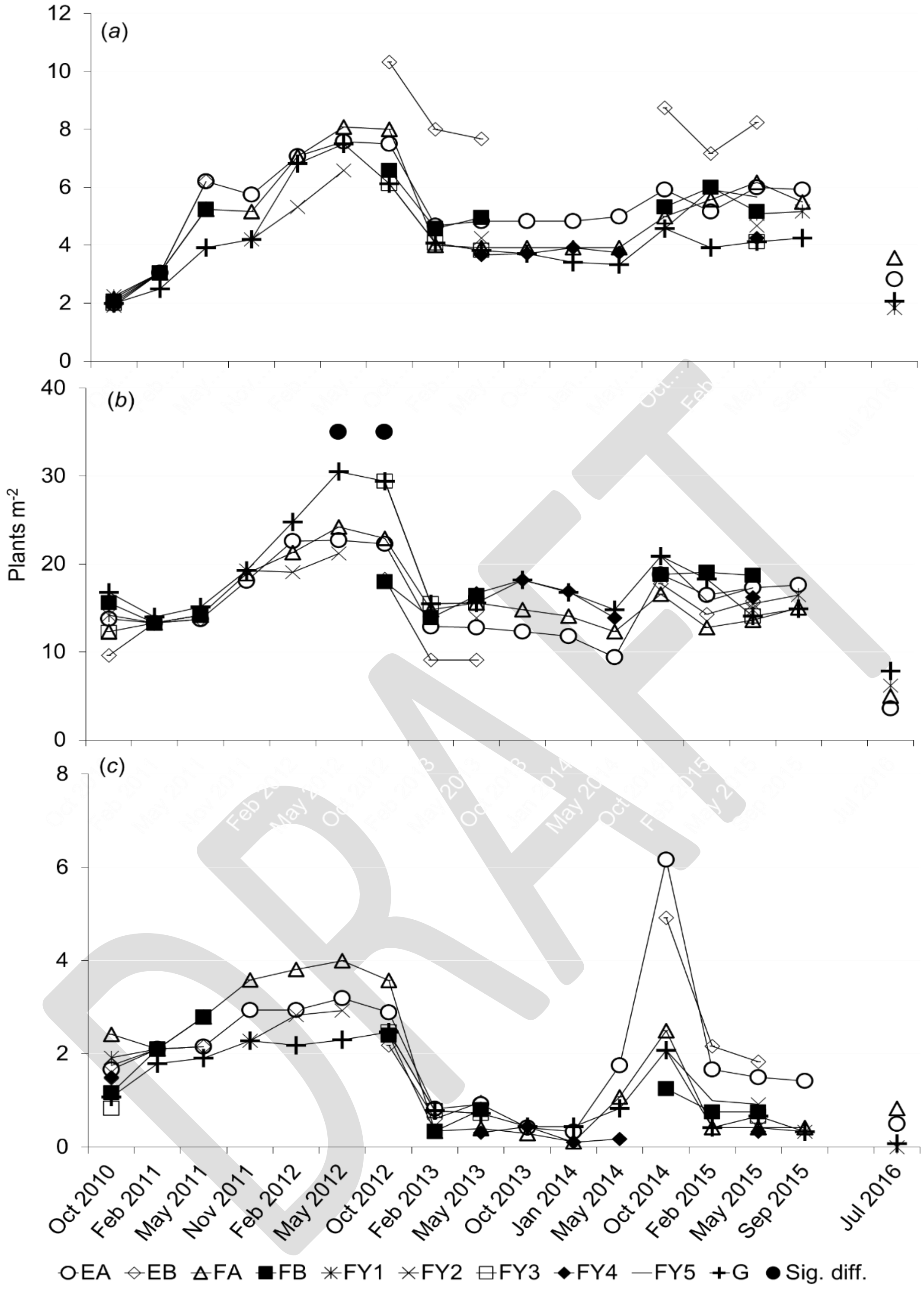
Table 1. Treatments at Site 1 and 2

Table 2. Perennial grasses at Site 1 and 2

Table 3. Annual (July–June) and summer (October–March) rainfall (mm) and decile values at each site during both the trial period and the preceding year for Site 1 and 2.

Table 4. Survival of recruits, size of surviving and dying plants and germinable seeds of key perennial grasses at Site 1.

Table 5. Survival of recruits, size of surviving and dying plants and germinable seeds of key perennial grasses under moderate and high stocking rate at Site 2.



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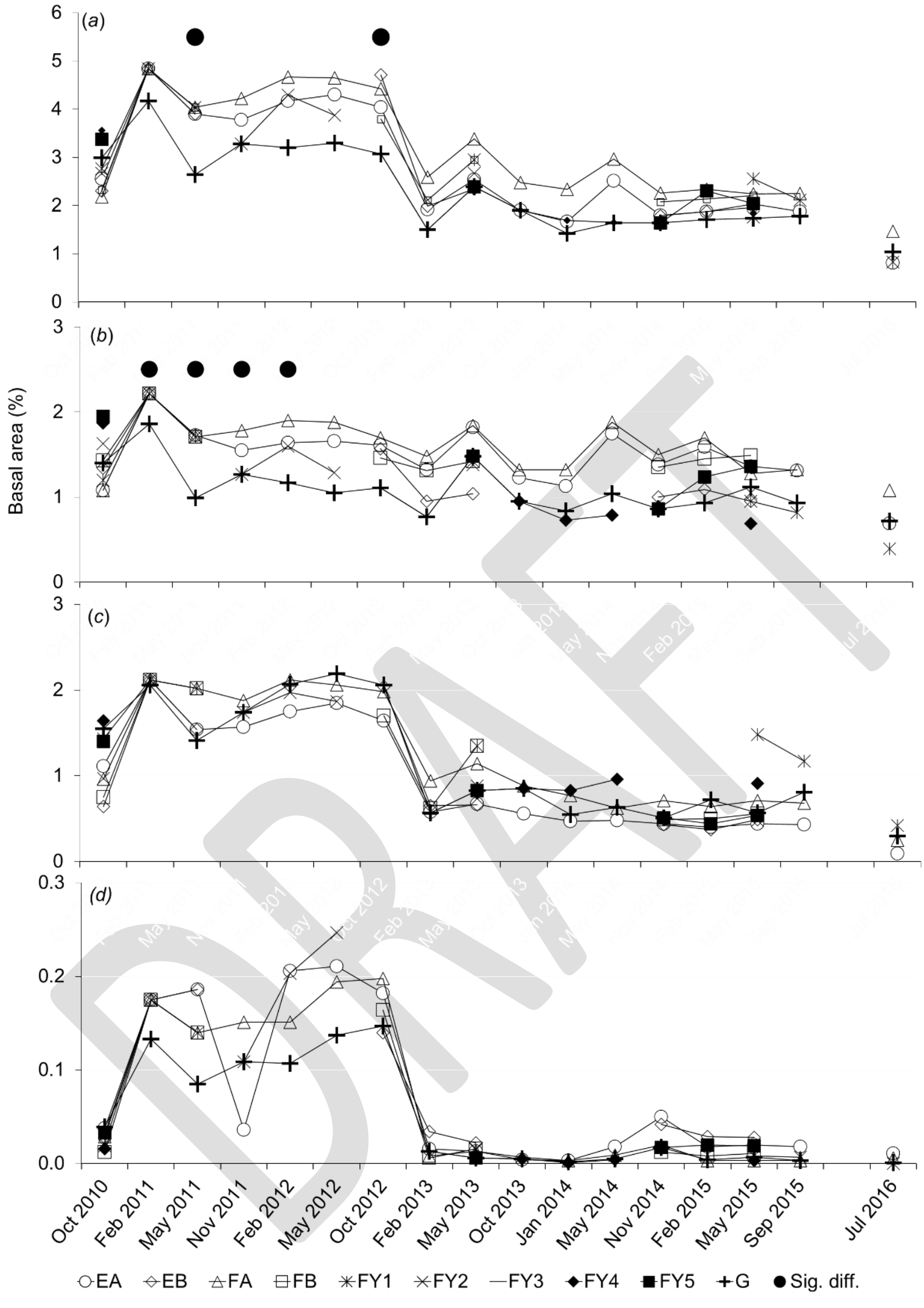


Fig. 2. Changes over time in the basal area of a) All perennial grasses, b) *B. ewartiana*, c) *Aristida* spp. and d) *P. effusum* at Site 1. Note the Y axes have different scales.

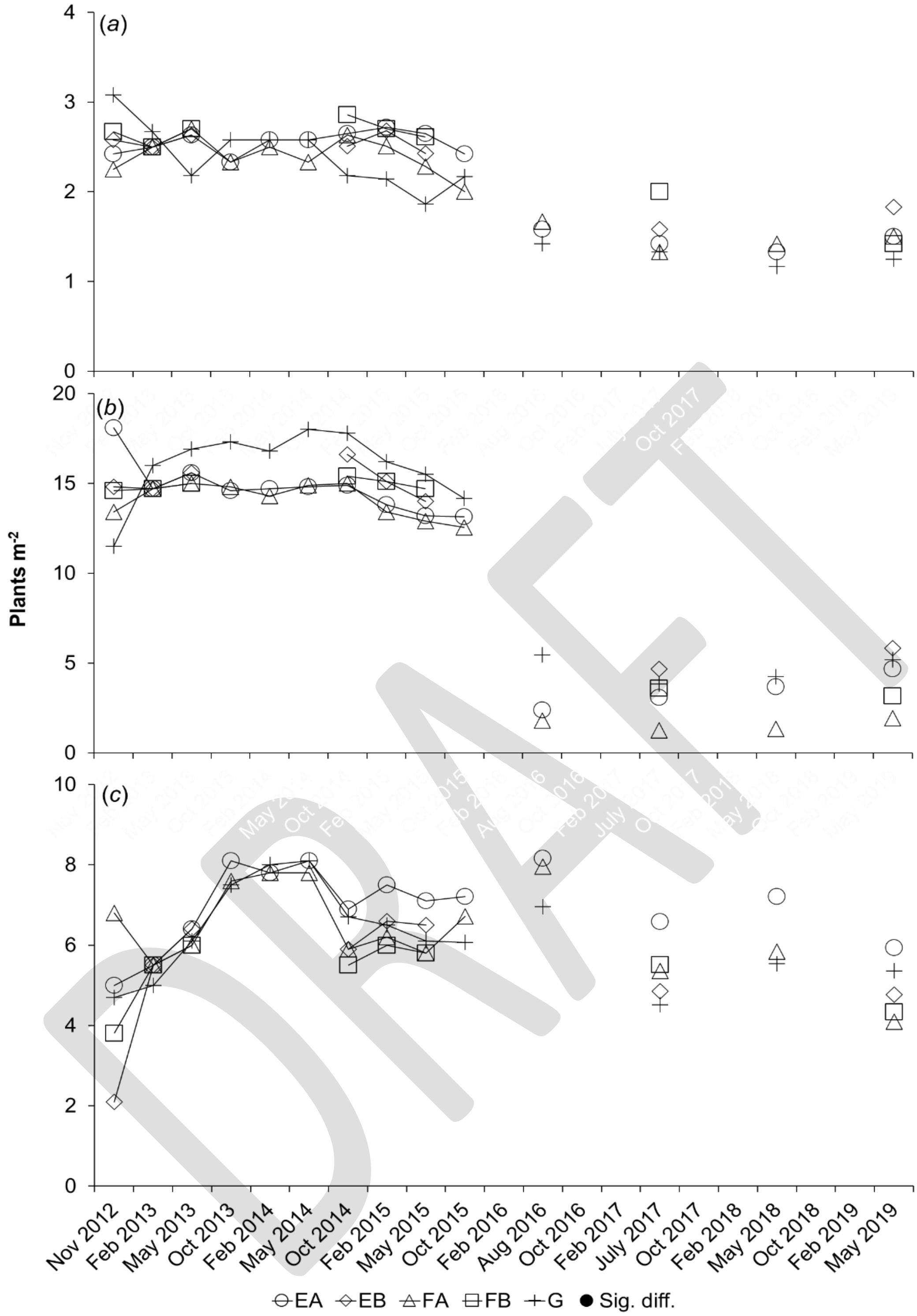
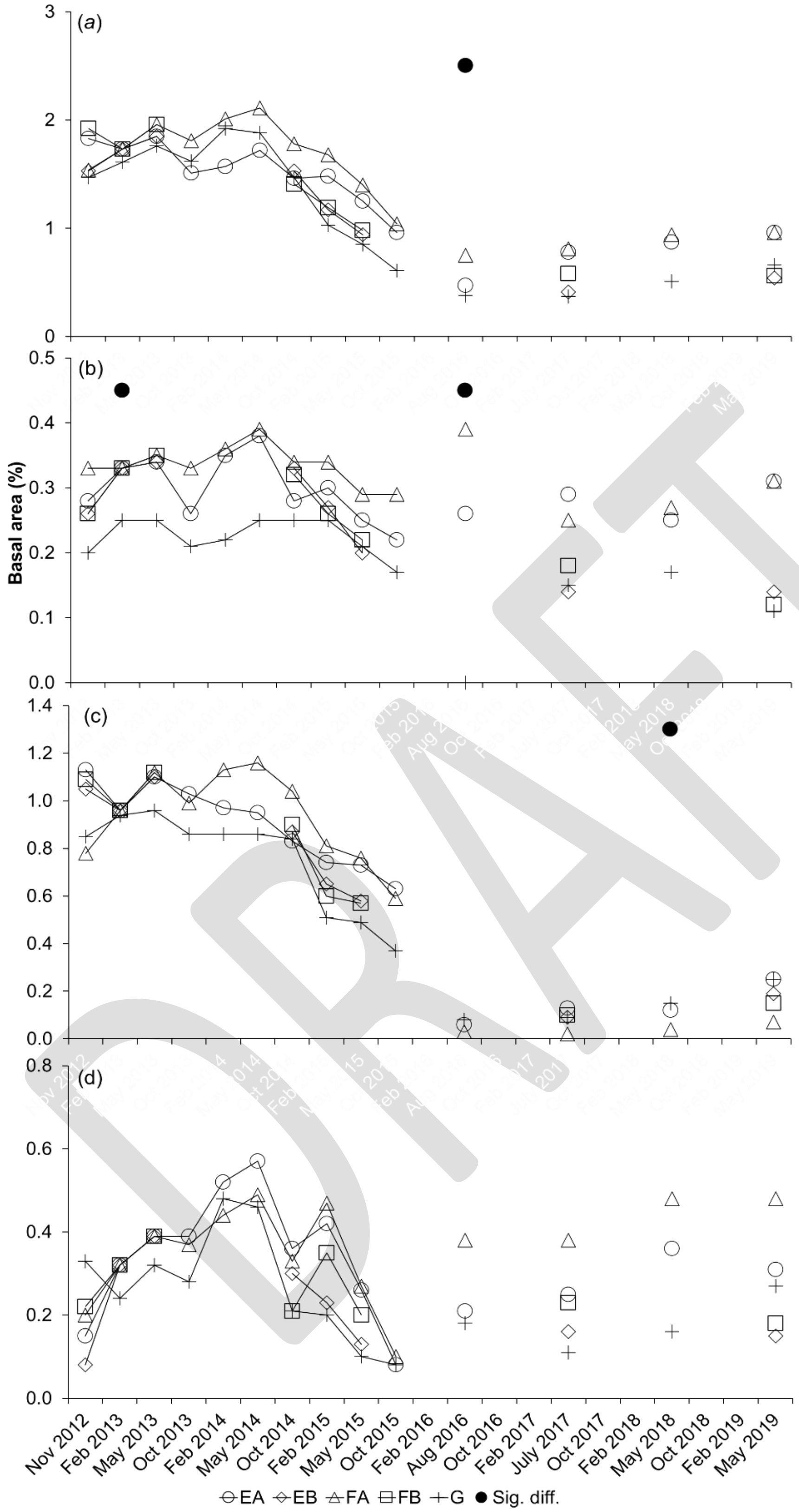


Fig. 3. Changes over time in the density of a) *B. ewartiana*, b) *Aristida* spp. and c) *C. fallax* under moderate stocking rate at Site 2. Note that Y axes have different scales.



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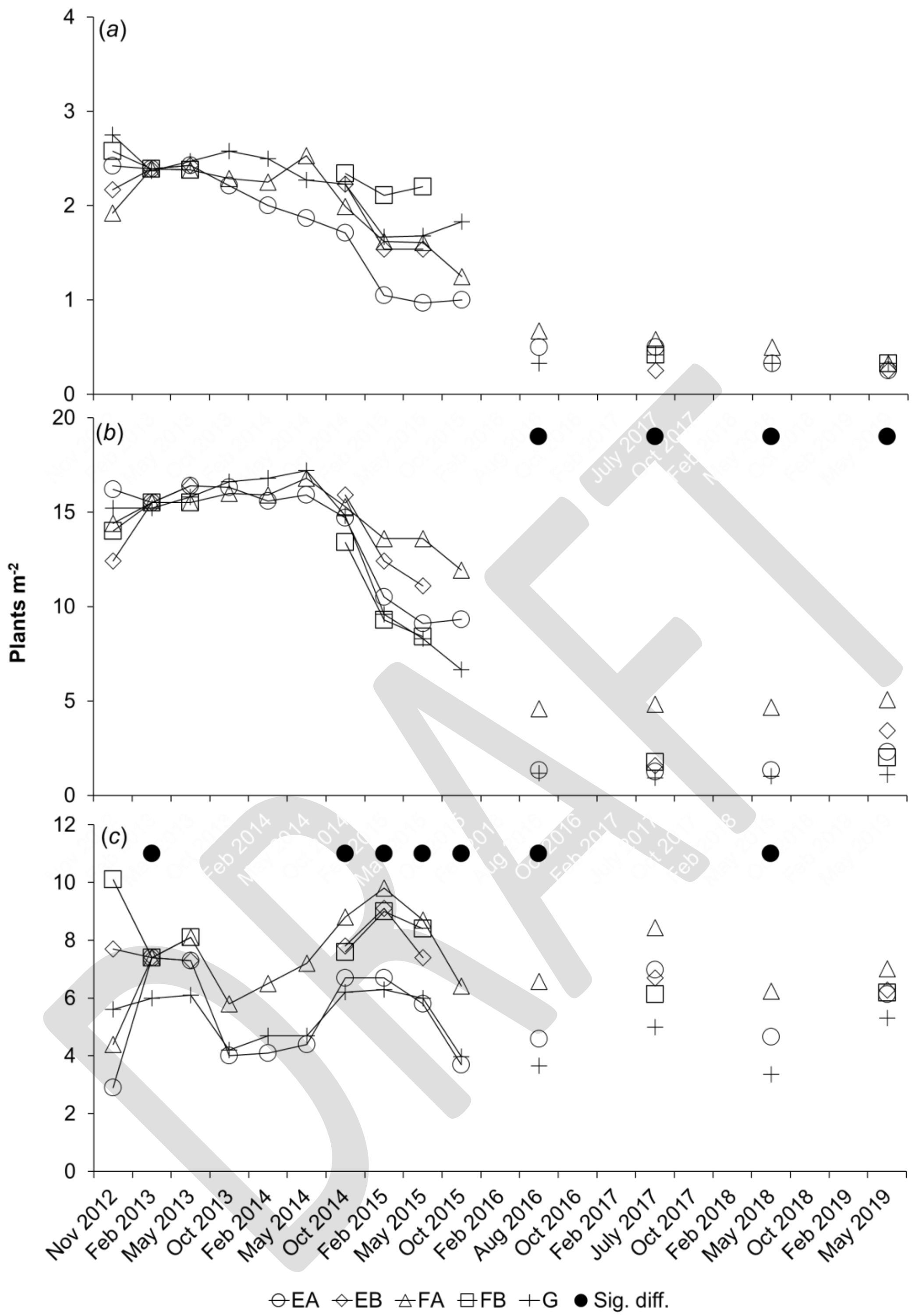

Fig. 5. Changes over time in the density of a) *B. ewartiana*, b) *Aristida* spp. and c) *C. fallax* under high stocking rate at Site 2. Note the Y axes have different scales.

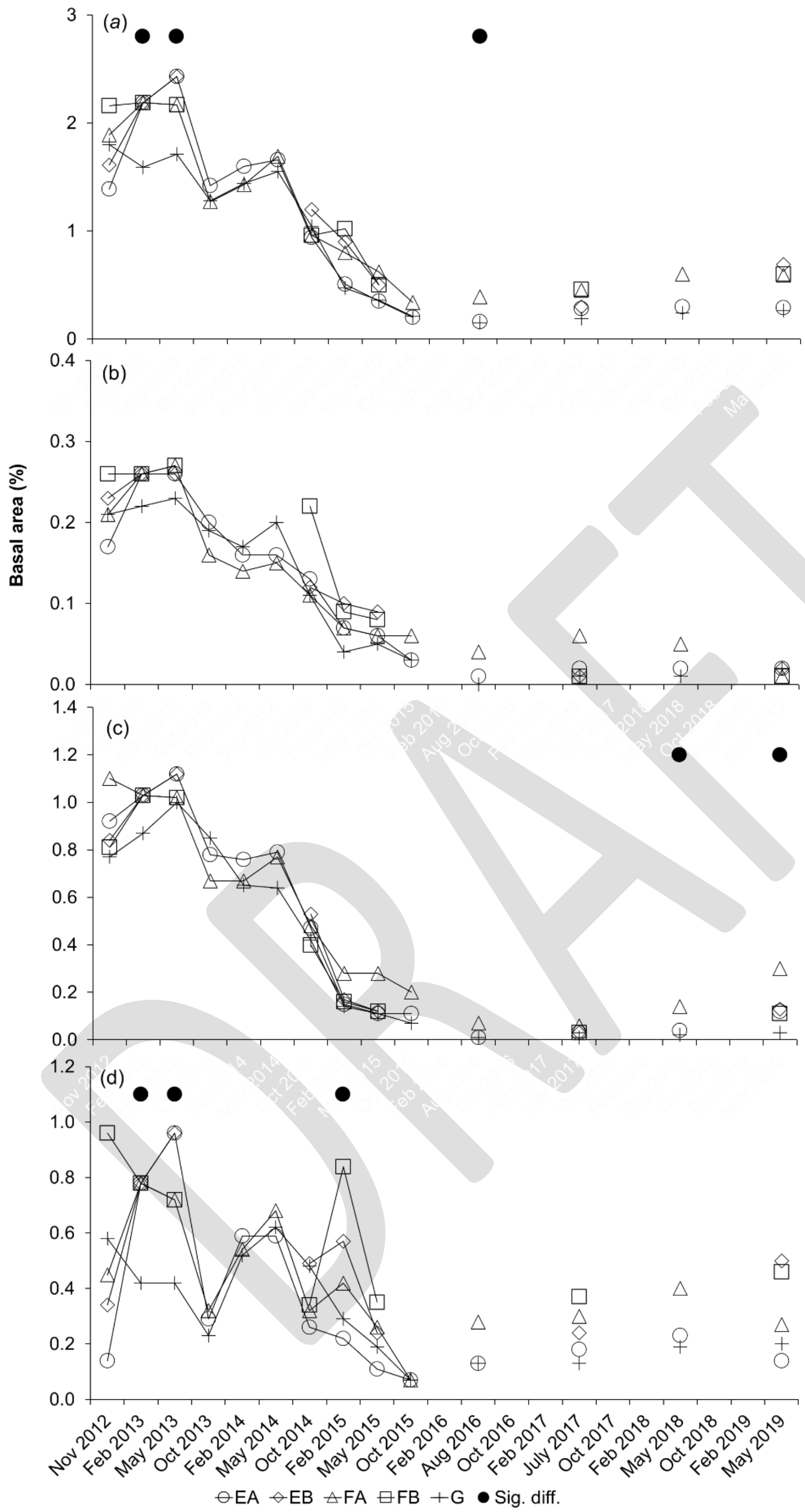

Fig. 6. Changes over time in the basal area of a) All perennial grasses, b) *B. ewartiana*, c) *Aristida* spp. and d) *C. fallax* under high stocking rate at Site 2. Note the Y axes have different scales.

Table 1. Grazing management treatments imposed at Sites 1 and 2

Project duration for Site 1 was Oct 2010 to July 2016 and Site 2 was November 2012 to May 2019. The years 1 to 5 refer to the period between July and next June and incorporates a complete summer wet season when native pasture growth and seeding recruitment predominately occurs.

Site	Treatment	Stocking rate	Abbreviation
1	Grazed continually + rest 2012-13	Moderate	G
1	Early wet season annual resting	Moderate	EA
1	Full wet season annual resting	Moderate	FA
1	Early wet season biennial resting	Moderate	EB
1	Full wet season biennial resting	Moderate	FB
1	Full wet season rest in year 1 only	Moderate	FY1
1	Full wet season rest in year 2 only	Moderate	FY2
1	Full wet season rest in year 3 only	Moderate	FY3
1	Full wet season rest in year 4 only	Moderate	FY4
1	Full wet season rest in year 5 only	Moderate	FY5
2	Grazed continually	Moderate	MG
2	Early wet season annual resting	Moderate	MEA
2	Full wet season annual resting	Moderate	MFA
2	Early wet season biennial resting	Moderate	MEB
2	Full wet season biennial resting	Moderate	MFB
2	Grazed continually	High	HG
2	Early wet season annual resting	High	HEA
2	Full wet season annual resting	High	HFA
2	Early wet season biennial resting	High	HEB
2	Full wet season biennial resting	High	HFB

Table 2. Perennial grasses at Site 1 and 2

Site	Key perennial grasses	Other perennial grasses (in order of abundance)
1	*B. ewartiana*, *Aristida* spp. and *P. effusum*	*Eriachne mucronata* R. Br., *Digitaria ammophila* (Benth.) Hughes, *Digitaria brownii* (Roem. & Schult.) Hughes, *Chrysopogon fallax* J.M.Black, *Enteropogon acicularis* (Lindl.) Lazarides, *Themeda triandra* Forssk, *Melinis repens* (Willd.) Zizka, *Austrochloris dichanthioides* (Everist) Lazarides, *Heteropogon contortus* (L.) P.Beauv. ex Roem. & Schult., *Dichanthium sericeum* (R.Br.) A.Camus and *Cenchris ciliaris* L.
2	*B. ewartiana*, *Aristida* spp. and *C. fallax*	*Panicum effusum* R.Br., *C. ciliaris, Dichanthium fecundum* S.T.Blake, *Digitaria ammophila* (Benth.) Hughes, *Digitaria brownii* (Roem. & Schult.) Hughes, *Eriachne mucronata* R.Br., *Eriochloa crebra* S.T.Blake, *Heteropogon contortus* (L.) P.Beauv. ex Roem. & Schult., *Paspalidium caespitosum* C.E.Hubb., *Themeda triandra* Forssk., *Eriochloa pseudoachrotrycha* (Stapf ex Thell.) J.M.Black, *Urochloa mosambicensis* (Hack.) Dandy and *Erichloa procera* (Retz.) C.E.Hubb.

Table 3. Annual (July–June) and summer (October–March) rainfall (mm) and decile values for each site during both the trial period and for the preceding year for Site 1 and 2.

Project duration for Site 1 was Oct 2010 to July 2016 and Site 2 was November 2012 to May 2019

Year	Site 1				Site 2			
	Annual		Summer		Annual		Summer	
	(Jul–Jun)	Decile	(Oct–Mar)	Decile	(Jul–Jun)	Decile	(Oct–Mar)	Decile
2009–10	487	4	481	6	715	7	605	8
2010–11	1052	10	572	8	1240	10	950	10
2011–12	995	10	827	10	750	8	657	8
2012–13	302	1	174	1	601	6	340	3
2013–14	399	3	379	4	517	4	482	5
2014–15	472	4	386	4	246	1	212	1
2015–16	387	2	279	2	397	2	353	3
2016–17					554	5	383	4
2017–18					446	3	423	4
2018–19					606	6	457	5
Long-term mean	545		410		635		509	

Table 4. Survival of recruits, size of surviving and dying plants and germinable seeds of key perennial grasses at Site 1.

Taxonomic unit		*B. ewartiana*	*Aristida* spp.	*P. effusum*
Survival of recruits Feb 2011 – Jul 2016 (%)		8	7	1
Size of original plants (cm^2) *		57.6 (6.2)	8.5 (0.9)	2.1 (0.3)
Size of original plants surviving to Jul 2016 (cm^2) *,1		55.6 (8.3)	8.9 (1.5)	-
Size of dying plants (cm^2) *		2.7 (0.5)	2.3 (0.1)	3.0 (0.3)
Germinable seeds (seeds m^{-2}) *	Year			
	2011	0 (0)	18 (8.2)	0 (0)
	2012	0 (0)	14 (8)	4 (3.5)
	2013	25 (9.7)	42 (28.1)	28 (21.1)
	2014	21 (8.3)	149 (29.3)	4 (3.5)

* Standard error in brackets

[1] All *P. effusum* plants from Oct 2010 had died by Oct 2014.

Table 5. Survival of recruits, size of surviving and dying plants and germinable seeds of key perennial grasses under moderate and high stocking rate at Site 2.

Taxonomic unit	*B. ewartiana*		*Aristida* spp.		*C. fallax*	
Stocking rate	Moderate	High	Moderate	High	Moderate	High
Survival of recruits Nov 2012 – May 2019 (%)	10	6	16	15	38	39
Size of original plants (cm^2) *	8.5 (1.3)	8.5 (1.2)	5.2 (0.5)	6.8 (0.6)	2.0 (0.6)	6.7 (1.5)
Size of original plants surviving to May 2019 (cm^2) *	18.0 (3.4)	4.7 (0.9)	4.8 (0.5)	4.8 (0.5)	6.1 (0.7)	4.6 (0.7)
Size of dying plants (cm^2) *	2.8 (0.6)	3.1 (0.5)	3.1 (0.2)	1.6 (0.1)	1.9 (0.1)	2.2 (0.3)
Germinable seeds (seeds m^{-2}) * Year						
2012	0 (0)	0 (0)	28 (12.1)	21 (6.4)	0 (0)	4 (3.5)
2013	7 (4.8)	0 (0)	99 (28.8)	32 (11.8)	0 (0)	4 (3.5)
2014	7 (4.8)	0 (0)	53 (13.9)	35 (10.2)	0 (0)	0 (0)

* Standard error in brackets