



final report

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Wambiana Grazing Trial Phase 3: Stocking Strategies for Improving Carrying Capacity, Land Condition and Biodiversity Outcomes

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Abstract

This third phase (2014-2017) of the long-term Wambiana grazing trial continued testing the ability of different stocking strategies to cope with rainfall variability. Results over 20 years showed 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. Nevertheless, experience in the current drought has highlighted the advantages of flexible over fixed-stocking.

Detailed bio-economic modelling comparing the performance of different stocking strategies showed that enterprise profitability and sustainability were maximised when stocking rates were aligned with available forage. This could be either through fixed moderate stocking or risk averse, flexible stocking. The general agreement between modelling and trial results indicates that the Wambiana trial outcomes are also likely to apply at the enterprise level.

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.

Executive summary

The Wambiana grazing trial was established near Charters Towers in 1997 to test the ability of different stocking strategies to cope with climate variability. This third project phase (2014 – 2017) continued the testing of these strategies but focused in particular on whether flexible stocking (+/- spelling) could outperform constant moderate stocking with or without wet season spelling. These results, coupled with property scale bio-economic modelling, were used to identify grazing strategies to manage sustainably and profitably in a variable climate. Consultation with producers and extension staff was also conducted to develop extension messages, identify barriers to adoption and suggest extension processes and products to promote the adoption of better grazing management strategies.

With extended drought over the last five years, including the fourth driest year on record, conditions were extremely challenging, requiring ongoing adaptive management. This included drought feeding in some years as well as the complete withdrawal of stock due to welfare reasons from heavy stocking rate (HSR) paddocks in late 2014. Stocking rates in the HSR were also substantially reduced in subsequent years due to the shortage of forage.

Although total precipitation in 2016/17 was also below average, cattle weight gains were exceptional due to the well distributed rainfall. Nevertheless, by December 2017 pasture yields were extremely low (<370 kg/ha) necessitating the partial destocking of the HSR for welfare reasons. In January 2018 the two fixed, moderately stocked treatments (+/- spelling) were completely destocked to avoid irreversible pasture degradation. This is the first time in 20 years that these moderate stocking treatments have needed destocking. In contrast, the two 'flexible' stocking strategies are still stocked, albeit very lightly, as stocking rates had been progressively reduced through the recent drought years. While challenging, these climate conditions have been critical in testing the long term sustainability of fixed versus flexible stocking and in refining the adaptive management guidelines being developed in this project.

Analysis of the 20 years of trial data shows the following: Individual live weight gains (LWG) and carcass values were greatest under constant moderate stocking (MSR) and rotational wet season spelling (R/Spell), both run at long term carrying capacity (LTCC). Conversely, individual LWGs and carcass values were lowest in the HSR stocked at twice LTCC. Individual LWGs in the two 'Flexible' strategies varied with stocking rate, but were far better than those in the HSR.

In contrast, total LWG/ha was highest in the HSR. However, this required expensive drought feeding in six of the 20 years of the trial, with HSR stocking rates also having to be cut in a number of years. In comparison, partial drought feeding was only required once in 20 years in the other strategies.

Average gross margin (GM) in the HSR was by far the lowest (\$5/ha/yr) and barely half that in the other strategies (\$10-13/ha/yr). This is a direct result of the higher costs due to drought feeding, interest on livestock capital and reduced product value in the HSR. Variability of annual income was also by far the greatest in the HSR with negative GMs in nine of the 20 years. Over 20 years, accumulated GM (\$106/ha) in the HSR was thus less than half that in the other strategies (\$250-260/ha). Scaled up to a 25 000 ha property, this approximates to a \$3 million advantage to these latter strategies.

Constant moderate stocking with spelling (R/Spell) and moderate stocking without spelling (MSR), were both sustainable, maintaining a high proportion of 3P grasses. In contrast, the HSR was not sustainable with the proportion of 3P grasses declining and the proportion of 2P species increasing significantly with time. The exotic grass *Bothriochloa pertusa* increased in all treatments but this increase was also by far the greatest in the HSR. Pasture condition in the 'flexible' strategies was acceptable but somewhat poorer than in the MSR and R/Spell, due to the ongoing lag effects of a period of overgrazing leading into the 2002-2007 drought.

The progressive loss of 3P grasses in the HSR reduced yields and sharply increased the inter-annual variability in forage availability. This significantly amplified the effects of inherent rainfall variability making management more difficult and increasing vulnerability to drought. The decline in pasture condition also reduced resilience in the HSR as shown by the need to implement drought feeding significantly earlier in the recent drought compared to the earlier 2002-2007 drought.

Surprisingly, the flexible strategies were no more profitable and indeed resulted in lower pasture condition than fixed stocking at LTCC, as applied in the MSR and R/Spell. This probably reflects the relatively short time period (2010-2017) over which the newer 'flexible' strategies have operated, as well as carryover effects from the previous 'variable' stocking strategies applied in Phase 1 of the trial. However, experience in the current drought has convincingly demonstrated the advantages of 'flexible' over fixed stocking, with both the MSR and R/Spell severely overgrazed and requiring destocking in January 2018. Nevertheless, the relative recovery and performance of these strategies post-drought will need to be assessed before any evidence based recommendation can be made on the relative advantage of fixed versus flexible stocking. These outcomes will be reported in the next stage of this project.

Bio-economic modelling was also used to compare the sustainability and economics of fixed and flexible stocking, with or without spelling, over 30 year climate windows, and assess how these were influenced by starting pasture condition, climate and stocking rate. Overall, the best sustainability and economic outcomes were achieved when either fixed or flexible stocking strategies aligned stocking rates with the amount of feed available each year.

Climate period and to a lesser extent, initial pasture condition, also affected outcomes. Under 'typical' sequences of lower rainfall years and moderate (B) to poor (C) condition pastures, lower stocking rates were more profitable and sustainable than heavy stocking. Heavy stocking only outperformed lighter stocking rates in rarer sequences of above average rainfall years and when pastures were in good (A) starting condition. Model simulations showed that spelling increasingly improved pasture condition and profitability as (i) a greater proportion of the stock from spelled paddocks were agisted off-property, (ii) starting pasture condition declined, and (iii) stocking rates increased. Simulations nevertheless indicated that stocking rate was the major driver of sustainability and economic performance with spelling having a relatively minor effect i.e. spelling does not compensate for the deleterious consequences of heavy stocking.

There was broad general agreement between the trial results presented above and modelling outcomes. This shows that whatever their limitations, the trial outcomes are also likely to apply at the enterprise level under a range of rainfall scenarios. Profitability and land condition will thus be maximised with flexible stocking around long term carrying capacity with stocking rates adjusted in a risk-averse manner, coupled with wet season spelling.

A workshop was held with DAF extension staff in October 2015 to identify strategies to improve adoption of grazing management guidelines. A consultative workshop was also held with producers in March 2016 to inform the design of an extension plan. Producers identified poor motivation, lack of business planning, ignorance and time management issues as key adoption barriers in the grazing industry. Importantly, people needed to be *inspired* to change. Suggested solutions included demonstrating the benefits of sustainable management via case studies and research trials, training and on-going extension and peer support. These workshop outcomes were used to formulate a draft design brief and a plan for extension activities and extension products.

The Wambiana 'futuring' workshop to determine the trial's future was held in June 2016 with key producers, senior DAF management and collaborators from CSIRO, James Cook University and the Department of Science, Information Technology and Innovation (DSITI). The workshop acknowledged the achievements of the project in developing evidence-based guidelines for

sustainable and profitable grazing management. The central importance of the project in addressing key questions as to how different management strategies affect productivity and issues such as water quality, faunal diversity, carbon sequestration and green-house gas emissions was also highlighted. Its significant role in providing long term, high quality data for ground truthing and further developing new remote sensing products was also emphasised. The workshop strongly supported continuation of the project with some changes. These included installing precision pastoral equipment like walk-over weighing, remote monitoring of water tanks and troughs, collaborative projects testing and developing remote sensing tools to aid stocking decisions and the establishment of on-property demonstration sites in other areas. These suggestions were included in the successful project application to MLA and are currently being implemented.

Acknowledgments

We are deeply grateful to the Lyons family of 'Wambiana' and in particular Michael and Michelle Lyons for their support, hospitality and encouragement over the last 21 years in running the trial. There were many occasions when their timely assistance made the difference between disaster and success. Without their enthusiastic co-operation and hospitality the trial could simply never have happened and this research could not have occurred.

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
8 April 2018

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
CP	Crude protein
db_RDA	Distance based redundancy analysis
EOD	End of Dry season (November)
EOW	End of Wet season (May)
Flex	Flexible stocking strategy
Flex+S	Flexible stocking with wet season spelling
GAC	Grazier advisory committee
GM	Gross margin
GRASP	GRASs Production pasture growth model
ha	Hectare
hd	Head
HSR	Heavy stocking rate
IVD	<i>In vitro</i> digestibility
LWG	Live Weight Gain
MSR	Moderate stocking rate
M8U	Molasses and urea (8%)
MVA	Multivariate analysis
N	Nitrogen
NMS	Non metric multidimensional scaling
NPV	Net present value
R/Spell	Rotational spell strategy
SOI	Southern Oscillation Index – Variable strategy
spp	Species
SR	Stocking rate
TSDM	Total standing dry matter
VAR	Variable Stocking strategy
WS	Wet Season
WGT	Wambiana grazing trial
YLD	Yield

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1 Background

The Wambiana grazing trial, south-east of Charters Towers, began in 1997 with initial funding from the Federal Government's Drought Regional Initiative and the Natural Heritage Trust. Meat and Livestock Australia (MLA) has provided funding support of \$1.16m for the Wambiana trial since 2002 under three projects (NBP.318, NBP.0379, and NBP.0635). The findings from this long term trial have been critical in demonstrating the linkages between moderate stocking, good land condition, reduced runoff and erosion, reduced risk, and increased productivity and profitability in a variable climate. The findings have been communicated through a range of MLA and DAF activities. The first research phase (1997-2011) was unable to provide strong evidence that flexible stocking rate strategies or rotational wet season spelling can cost-effectively improve carrying capacity or land condition at the paddock scale. The next phase of the Wambiana trial (2012-2014) aimed to quantify the impacts and economic cost-benefits of flexible stocking rates and rotational wet season spelling strategies aimed at improving carrying capacity and land condition, but has not been running long enough to yield definitive results. Two projects have also been embedded on the Wambiana trial site - B.NBP.0555 to improve the evidence base and modelling capacity underpinning recommendations for use of wet season spelling to recover poor condition grazing land and ERM.088 determining whether a trade-off exists between economic performance, beef productivity, and land management for biodiversity.

An external review of the Wambiana grazing trial (March 2014) reported that the trial had largely achieved the original objectives but recommended its continuation to allow completion of the embedded projects and permit a full assessment of the new treatments

2 Project objectives

By 30 September 2017 the project will have:

- Maintained existing treatments in the Wambiana grazing trial and continued data collection required to support the embedded projects NBP.0555 and ERM.0088
- Analysed the Wambiana animal production and pasture data. Analysis of the pasture data will include multivariate, pattern seeking techniques that can summarise and display such complex data, possibly revealing new insights or leading to the formulation of new testable hypotheses.
- Undertaken more detailed modelling and economic analysis assessing the long term profitability and sustainability of the different stocking strategies for a range of starting land conditions over a range of climate windows.
- Outlined draft extension messages based around the primary question for a grazier - does current land condition influence the relative profitability and hence selection of different grazing strategies?
- Convened the producer advisor group and other interested landholders to develop a design brief for information, products and decision tools that include herd management options in addition to changes in grazing management (e.g. change in reproductive efficiency, management calendar) that meets business profit goals, achieves desired pasture composition and reduces soil loss.
- Conducted a workshop by 30 April 2016 with key stakeholders presenting the results of the above analyses and determining unanswered questions that create uncertainty in completion of the original objectives of the Wambiana grazing trial and make recommendations for any future work and appropriateness of use of the existing site.
- Drafted two journal manuscripts based on the modelling and economic analyses and analysis of pasture data.

3 Experimental procedure

A brief description of the Wambiana trial and treatments are given below. For more detail see (O'Regain *et al.* 2008; O'Regain and Bushell 2011).

3.1 Site description

The Wambiana trial was established in 1997 near Charters Towers (20° 34' S, 146° 07' E) in an open *Eucalypt* - savanna on relatively infertile soils. Experimental paddocks are approximately 100 ha in size and contain similar proportions of three different soil-vegetation associations (O'Regain *et al.* 2008). These are; Reid River box on sodosols and chromosols (Box), silver leaf ironbark on yellow-brown earths (Ironbark) and brigalow-box on grey earths and vertosols (Brigalow). Mean annual rainfall is 650 mm and is highly variable (C.V. = 40%) and largely (70%) concentrated in the wet season (December to April).

3.2 Grazing strategies

3.2.1 Phase 1

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 sub-section 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).

3.2.2 Phase 2

Following the technical review of the trial in November 2009 and consultation with the Wambiana grazer advisory committee (GAC), some treatments were adapted as indicated for Phase 2 (Table 3.1).

Table 3.1: 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	Phase 2 Strategy
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 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 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.

3.3 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 grazer 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.

3.4 Pasture spelling

As specified above, the grazing strategies were applied and managed adaptively based on conditions in each treatment replicate i.e. paddock. In the treatments with spelling, the sub sections were spelled based on need and time since they were last spelled and were accordingly designated 'priority' or 'secondary' sub-sections. As a consequence, sub-sections in those treatments with spelling (R/Spell and the Flex+S) were spelled from periods ranging from only three weeks (2014/15) to up to 25 weeks in a year depending upon rainfall, grazing pressure on the non-spelled sections and whether the sub-paddock was a priority or secondary area. In summary, the frequency, timing and total area spelled were managed in an adaptive, flexible manner based on the need for spelling, the timing and spatial distribution of rainfall, the rate of pasture growth and grazing pressure in non-spelled areas.

3.5 Fire management

The trial site was first burnt on 11–12 October 1999. After the fire, the site was spelled for three months to allow pastures to recover before animals were reintroduced to the site on the 12 January 2000. The entire site was burnt for a second time in late October 2011 to control woodland thickening, particularly *Carissa ovata*, and to reset the pasture for the imposition of the new treatments. To ensure sufficient fuel for a hot fire, all animals were sent to the meatworks and the site was not grazed for six months (June to November) prior to burning. During this period, the replacement steers were kept on agistment at Spyglass Beef Research Facility, 100 km north of Charters Towers. The site was then spelled post-burn for 12 weeks post-fire until 1 February 2012 when sufficient pasture growth had occurred to allow 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 and Bushell 2011).

4 Seasonal conditions and site history

4.1 Rainfall

Rainfall varied markedly over the 20 year trial period with marked wet periods at the start of the trial and from 2007/8 to 2011/12, with 2011/12 being the wettest year in 50 years (Fig. 4.1). There were also significant periods of below average rainfall from 2001/02 to 2006/07 and from 2013/14 to 2016/17. The 2014/15 year was particularly severe (246 mm) and was the fourth driest year in 112 years (based on rainfall records at Trafalgar, 17 km NW of the trial site). The severity of the drought was highlighted by the extensive death of mature Ironbark trees observed across parts of the trial in late 2015.

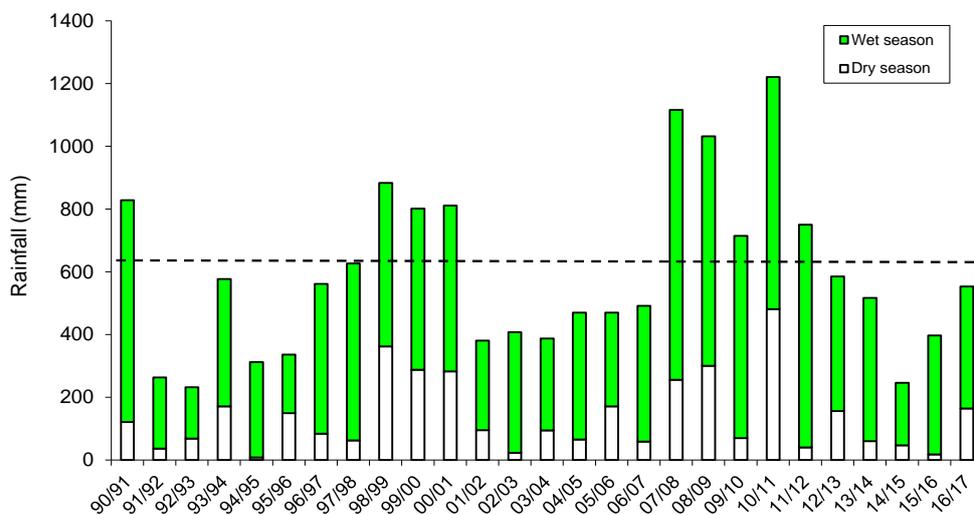


Fig. 4.1 Annual rainfall (July-June) from 1997/98 to 2016/17 at the Wambiana grazing trial (Dotted line=long term average).

4.2 Drought periods

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

$$DI = \frac{\sum \text{previous 24 months rainfall from month } x - \sum \text{long term average rainfall for these 24 months}}{\text{long term average annual rainfall}}$$

The drought index is presented in Fig. 4.2. This shows two distinct periods of drought with the first from June 2002 to about December 2008 with a second drought from late 2013 continuing until January 2018. These droughts were interspersed with two wet periods from about 1999 to 2001 and a second, longer, wetter period from late 2007 to late 2013 (Fig. 4.2).

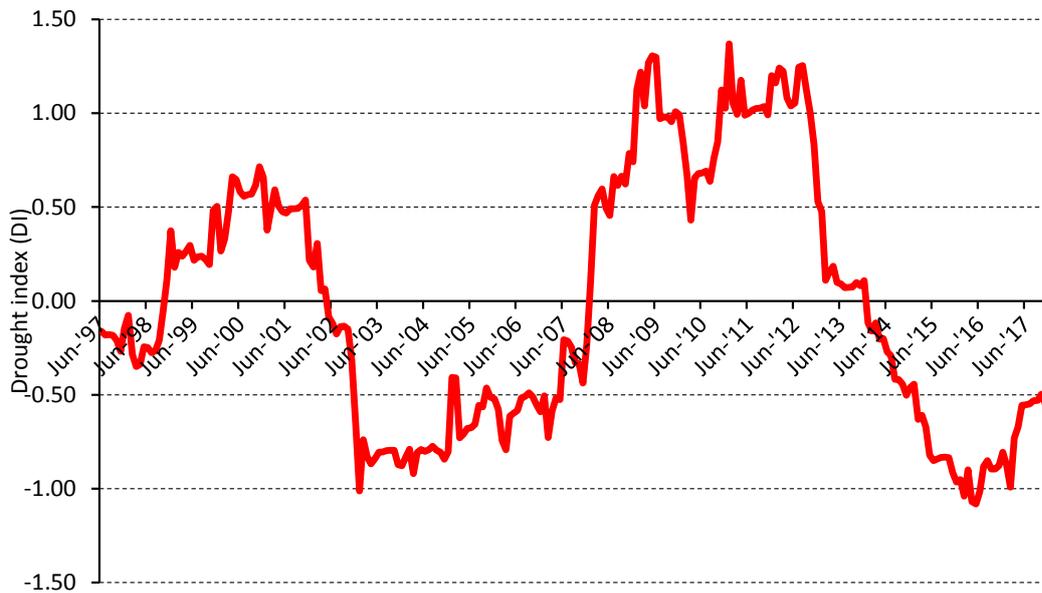


Fig. 4.2 Two year moving drought index at the Wambiana trial site from June 1997 to December 2017.

4.3 Stocking rates

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 & Bushell 2011). However, stocking rates were cut sharply thereafter in both strategies and subsequently managed in a more risk averse fashion (

Fig. 4.3). This risk averse philosophy was emphasised even more strongly when these treatments were adjusted to become the Flex and Flex+S treatments from 2010 onwards.

In the HSR, stocking rates had to be reduced by one-third between 2005 and 2009 (O'Reagain & Bushell 2011). Stocking rates also had to be cut in the 2014/15 season due to drought (

Fig. 4.3). 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.

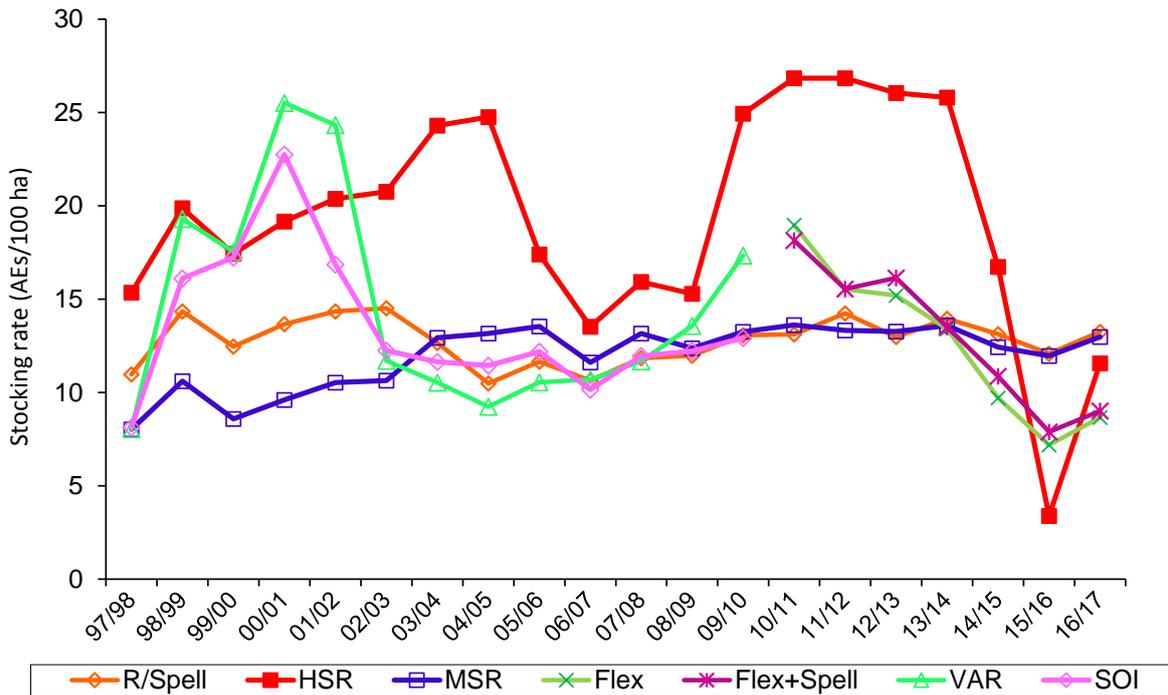


Fig. 4.3 Change in stocking rate (expressed as animal equivalents (AEs) per 100 ha) in different strategies over time at the trial. Note treatment changes post 2009/10.

In contrast to the HSR, stocking rates in the MSR were easily sustained in all years without drought feeding or destocking being required (Fig. 4.3). Despite the severity of the drought, stocking rates were maintained at their normal levels (12.5 AEs/100 ha) in the moderate stocking rate (MSR) and rotational spell (R/Spell) treatments (

Fig. 4.3). However, stocking rates were progressively reduced in the flexible stocking (Flex) and the flexible stocking with spelling (Flex+S) treatments in line with declining forage availability. Note that by December 2017 the stocking rates in the MSR and R/Spell were the heaviest on the trial.

5 Effects of different grazing strategies on animal weight gains

5.1 Introduction

In this chapter data is presented on the effects of different grazing strategies on animal liveweight gain. The data on carcass characteristics and the economic performance of different strategies are presented in the chapters that follow.

5.2 Procedure

5.2.1 Experimental animals and husbandry

Experimental animals were 3/4 Brahman-cross steers between 1998 and 2004 inclusive, with a change to 7/8 Brahmans from 2004 onwards. Paddocks were 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 animals, with the older cohort being replaced by new, younger animals each year. Animals thus spent two years on the trial giving ample time for treatments to affect animal production (O'Reagain *et al.* 2009).

Animal husbandry was based on the advice of the trial grazer advisory committee (GAC) and followed industry practice. Cattle were initially not supplemented (1998-2002) but a commercial dry-season urea lick (32% urea) was provided from May 2003 and wet season P supplementation (14.76% P, 21.87% urea) from December 2004 onwards. Cattle were also implanted annually with 400 day Compudose (Dow-Elanco, Australia) hormone growth promotants (HGP) from May 2003 onwards.

5.2.2 Drought feeding

Drought feeding, usually in the mid-late dry season, had to be provided to steers in one or both HSR paddocks in six out of the 20 years of the trial. This was in the form of molasses and 8% urea (M8U) or M8U with copra meal. Steers also had to be withdrawn for various periods from one or both HSR paddocks in 2004/5, 2014/15 and 2015/16 due to the extreme shortage of forage and animal welfare considerations. Withdrawn cattle were kept in a nearby laneway and fed hay and a M8U-copra mix to improve body condition. In 2004/05 most withdrawn steers were returned to their treatment paddocks when it rained in January 2005. However, in 2014/15 most HSR steers were sold early (25 March 2015) when it became clear that the wet season had failed.

In the remaining treatments, M8U and copra drought feeding was only required in one year (2015/16). Some poor condition steers in these paddocks were also withdrawn for eight weeks late in the dry season and fed due to animal welfare considerations. All these steers were returned to their paddocks late in January 2016.

5.2.3 Animal measurements

On entering the trial at the end of May each year animals were weighed after being fasted on water overnight (see O'Reagain *et al.* (2009) for more detail). They were then weighed following the same procedure at the end of the dry season (early December) and at the end of the wet season (end of May). Change in animal height i.e. skeletal growth, was also measured but the data is not presented here.

Total liveweight gain was calculated as the difference in animal liveweight at the start and end of the grazing year (1 June to 31 May). Dry season liveweight change was calculated as the difference in liveweight between the end of May and late November/early December.

5.2.4 Statistical analysis

Total live weight gain per hectare (LWG/ha) and paddock (Pdk.) average LWG per head (LWG/hd) data were analysed using residual maximum likelihood (REML) in Genstat (v18). The fixed term was Trt * Year (Trt + Year + Trt.Year) and the (maximum) random model was Rep/Pdk + Pdk/Year (= Rep + Rep.Pdk + Pdk + Pdk.Year). Various covariance models were trialled, including: Identity, Unstructured, AR1, AR2 and allowing for heterogeneity across time and additional uniform correlation within subject. The most appropriate random model was chosen through comparing the change in deviance and change in degrees of freedom to a chi square distribution. As two of the treatments changed in 2011, two data groups were analysed i.e. Phase 1 treatments: 1998 – 2010 (old treatments) and Phase 2 treatments: 2011 – 2017 (old + 'new' treatments).

Note (a) that there is 18 years of dry season weight change data; there is no 1997/98 data as the trial only started in December 1997. There is also no 2011/12 dry season data as all steers were on agistment over that dry season to conserve fuel for the planned burn of the site 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 19 of the 20 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 (Fig. 4.3)

5.3 Results

5.3.1 Individual animal production

5.3.1.1 Dry season liveweight change per animal

Animal performance over the dry season varied markedly between years (Fig. 5.1) Substantial dry season weight loss occurred in nine of the 18 years, with declines (averaged over all treatments) of as much as -40 kg/hd in 2006/07 to as much as -69 kg/hd in 2015/16 being recorded. Conversely, appreciable dry season weight gain occurred in eight of the 18 years with steers gaining as much as +71 kg/hd in both the 2005/6 and 2016/17 seasons. These patterns were obviously driven by rainfall with weight gain in years with good 'dry season' rainfall such as 2010/11 (Fig. 5.1). Good gains were however also observed in years with relatively low 'dry season' precipitation such as 2005/6 and 2016/17 where the rainfall was well distributed. Such years followed a succession of very dry years as happened in 2005/06. The good dry season LWGs in 2016/17 following the dry years are particularly noteworthy.

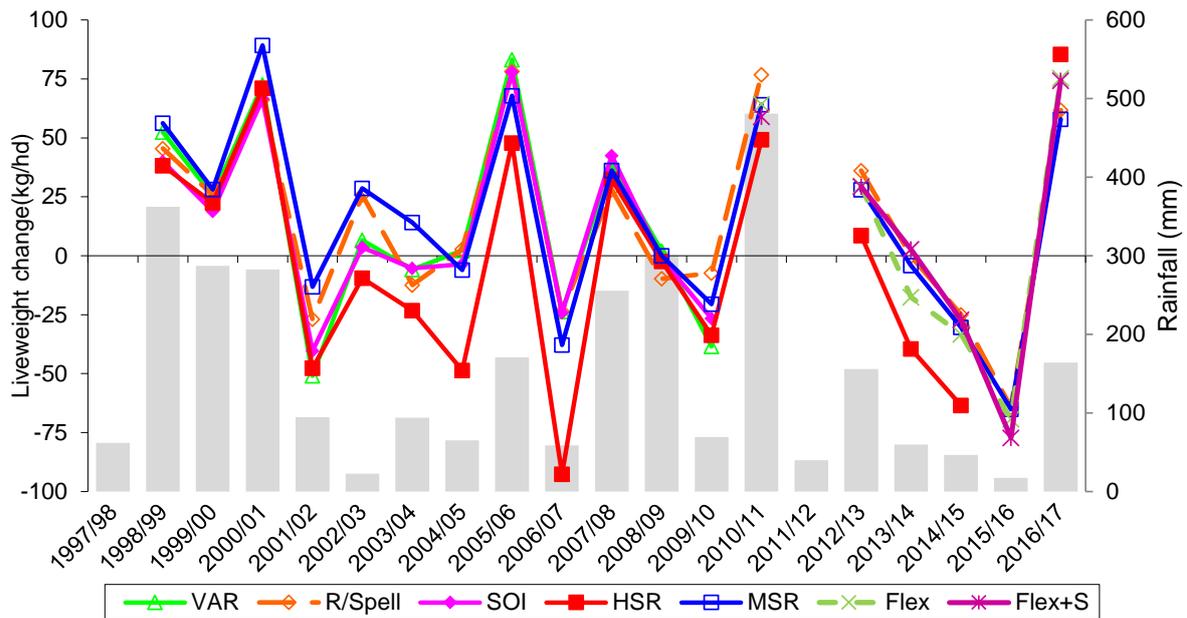


Fig. 5.1 Dry season liveweight gain/change per head for steers in different grazing strategies across Phases 1 and 2 and rainfall (in bars) from 1998/99 to 2016/17. Note treatment changes in 2010/11.

There was a significant treatment by year interaction for Phase 1 ($P < 0.001$) and Phase 2 ($P < 0.011$) indicating that treatment effects on dry season weight change were dependent upon year (Table 5.1). Overall however, dry season LWG was generally highest in the MSR (Phase 1) or in the R/Spell (Phase 2) both of which were stocked at a similar, moderate stocking rate. The relative DS animal performance in the VAR/Flex strategies varied between years depending upon the stocking rate applied that year. Dry season LWG was generally lowest in the HSR with this treatment having the lowest LWG in 10 out of the 17 years where direct comparisons can be made (Table 5.2). This was particularly noticeable in drought years with the HSR losing by far the most weight of all strategies. For example, in 2006/07 the HSR treatment lost from 55 to 69 kg/hd more over the dry season than the other treatments. An obvious anomaly was the fact that dry season LWG in the HSR was significantly ($P < 0.05$) higher than in the MSR in 2016/17 (Table 5.2). This can be attributed to the extremely light stocking rate in the HSR that year; the even lighter stocking the previous year (2015/16) would also have ensured that forage availability was far higher than might have been expected in the HSR had it been fully stocked.

Table 5.1 Significance of model terms for total live weight gain per head (LWG/hd) and LWG (change) per head over the dry season (DS) for Phase 1 and Phase 2 treatments.

Variable	Year	Treatment	Treat*year
<u>LWG/hd: Total</u>			
Phase 1: 1997-2010	<0.001	0.189	0.049
Phase 2: 2011-2017	<0.001	<0.001	<0.001
<u>LWG/hd: DS</u>			
Phase 1: 1997-2010	<0.001	0.009	<0.001
Phase 2: 2011-2017	<0.001	0.493	0.011

Table 5.2 Mean dry season liveweight change per head for (a) Phase 1 treatments from 1997/98 to 2009/10 and (b) Phase 2 treatments from 2010/11 to 2016/17. Data are REML estimated means. Treatment abbreviations as before. Means with different letters within the same columns differ significantly ($P < 0.05$).

(a) Phase 1

	Liveweight change (kg/hd)												
	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 a	22	71	-48 a	-9 a	-23 a	-49 a	48 a	-93 a	32	-2	-34 a
MSR	-	56 b	28	89	-13 c	29 b	14 c	-6 b	68 b	-38 b	36	0	-21 ab
R/SPELL	-	45 ab	26	66	-27 bc	26 b	-13 ab	3 b	78 b	-24 bc	28	-10	-7 b
SOI	-	37 a	22	67	-49 a	7 a	0 bc	-6 b	79 b	-29 bc	38	1	-30 a
VAR	-	55 b	23	72	-41 ab	2 a	-12 ab	4 b	82 b	-19 c	42	-1	-34 a

^A No dry season LW data available for 1997/98.

(b) Phase 2

	Liveweight change (kg/hd)						
	2010/11	2011/12 ^A	2012/13	2013/14	2014/15	2015/16 ^B	2016/17
Flex	64	-	30	-17 ab	-34 b	-69	75 ab
Flex+S	59	-	30	2 b	-27 b	-77	74 ab
HSR	49	-	8	-40 a	-72 a	-	86 b
MSR	65	-	28	-4 b	-30 b	-65	58 a
R/SPELL	77	-	36	-0.5 b	-25 b	-65	61 ab

^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.

5.3.1.2 Total Liveweight gain per animal

There was also a large variation in total LWG between years ($P < 0.001$) in both Phases 1 and 2 (Table 5.1) with average weight gains varying from 43 to 168 kg per annum, depending upon rainfall (Fig. 5.2). In drought years like 2005/6 and 2014/15 however, animals barely maintained weight and, in the HSR, actually lost weight over the year.

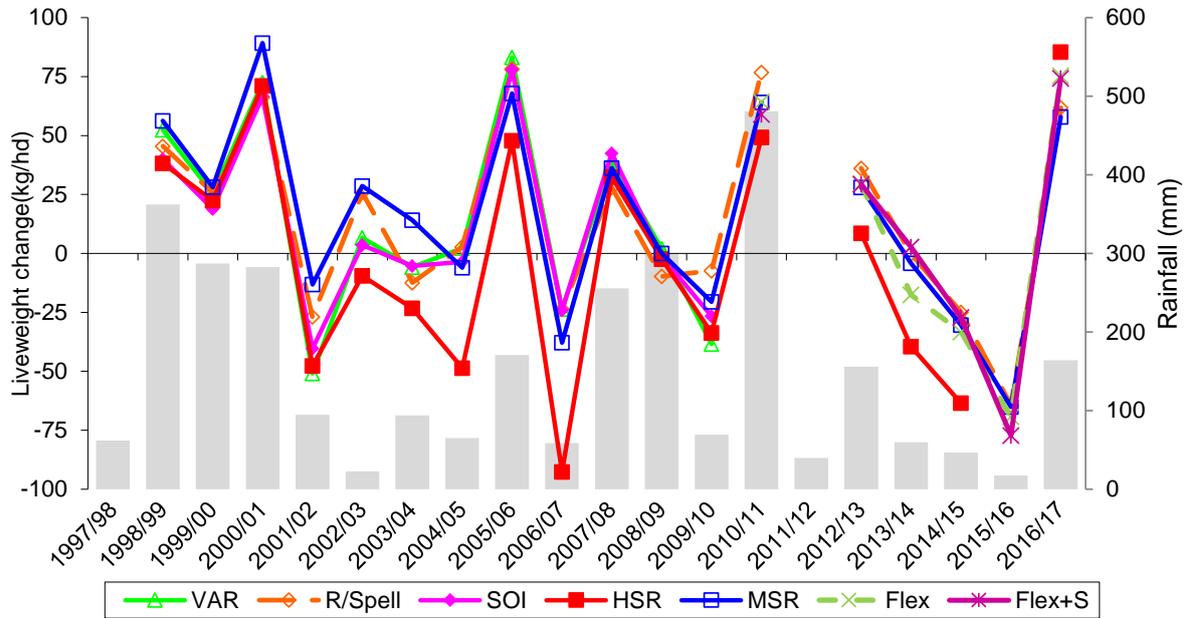


Fig. 5.1 Dry season liveweight gain/change per head for steers in different grazing strategies across Phases 1 and 2 and rainfall (in bars) from 1998/99 to 2016/17. Note treatment changes in 2010/11.

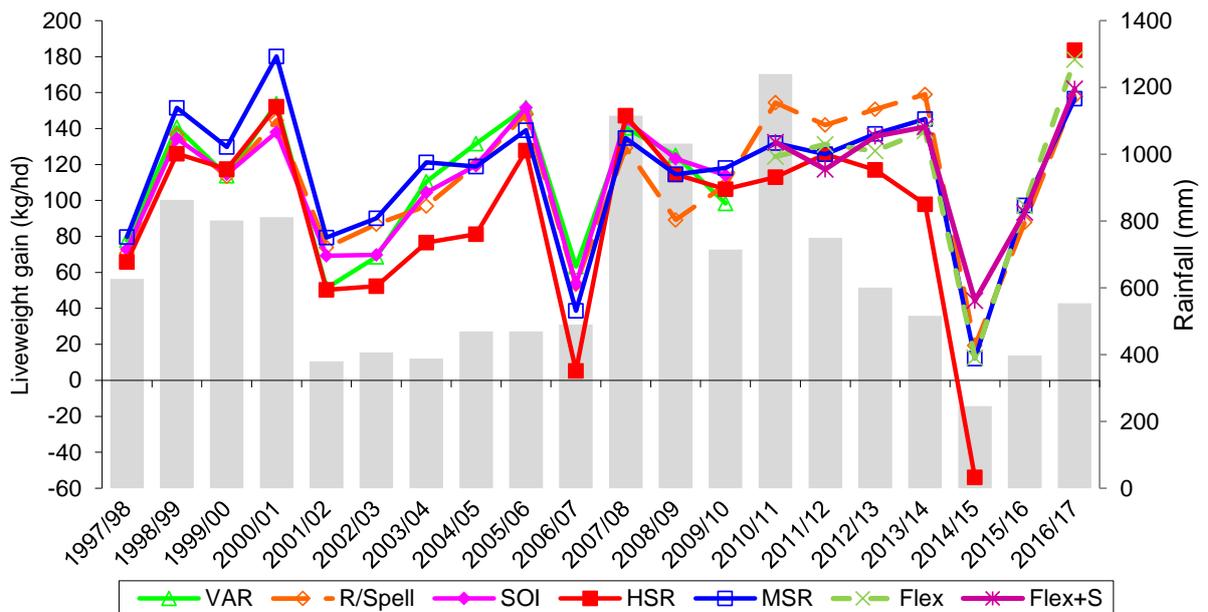


Fig. 5.2 Liveweight (LWG) gain per head (hd) for steers in different grazing strategies across Phases 1 and 2 and rainfall in mm (bars) from 1997/98 to 2016/17. Note treatment changes in 2010/11.

Treatment had an obvious impact upon individual LWG with marked differences between grazing strategies. However, the significant year by treatment interaction in both Phase 1 ($P < 0.049$) and Phase 2 ($P < 0.001$), indicates that the overall treatment effect was inconsistent with the relative performance of treatments varying between years (Table 5.1). This is not surprising given the range of rainfall years encountered and the range of stocking rates applied in some treatments.

For individual years, the effect of treatment was significant ($P < 0.05$) in 12 out of 20 years (Phase 1 & 2), with obvious, but non-significant treatment differences also apparent in all other years (Table 5.2). The lack of significance in some years despite apparent marked differences e.g. in 2010/11 and 2012/13, reflects variability in the relative performance of treatment replicates and the limited replication in the trial ($n=2$). For example, in 2012/13 the HSR had the lowest LWG (98 kg/hd) in replicate 1 but only the second lowest LWG (134 kg/hd) in replicate 2.

Clear treatment trends were nevertheless evident with LWG in the HSR being the lowest of all treatments in 12 out of 19 years (excluding 2015/16) or 63% of years. These differences were amplified in drought years, with the HSR steers losing an average of 16 kg/hd over the 2014/15 season (Fig. 5.2). Overall, average LWG in the HSR (97 kg/hd) was thus from 11-21 kg/hd lower than the average of other treatments in Phase 1 and from 18 – 27 kg/hd lower in Phase 2 (Table 5.3).

In contrast, LWG was generally highest in the lighter stocked MSR (average: 115 kg/hd) in Phase 1 and the R/Spell (average: 124 kg/hd) in Phase 2 (Table 5.3). The advantage in terms of moderate stocking relative to the HSR was particularly pronounced in the lead up to and during droughts; thus as conditions deteriorated rapidly in 2013/14 with the transition into the second drought, LWG/hd in the R/Spell (159 kg/hd) was still well above the long term average for that strategy and far better than that in the HSR (98 kg/hd) that year. One anomaly however, is the very low LWG/hd in the R/Spell in 2008/09 (89 kg vs. 115 kg/hd in the HSR). This cannot be explained by stocking rate differences or the adverse effects of the 2001 fire in the R/Spell and thus must be attributed to some random effect e.g. 3-day sickness, that adversely affected weight gain in both replicates of the R/Spell.

Individual LWG in the VAR/Flex strategies was, on average, slightly lower than that in the MSR and R/spell. However, the relative LWG in these strategies was very dependent upon the stocking rate applied in a particular year: thus in the early good years (1999-2001) when stocking rates in the VAR and SOI were very high, the LWGs/hd were similar or even lower than the HSR. In contrast, reduced stocking rates in the VAR and SOI strategies in drought years like 2005/06 and 2006/07 ensured that LWGs were the highest or close to highest of the other treatments (Table 5.3).



Fig. 5.3. On 24 April 2015 conditions were extremely poor following the fourth driest year in 105 years. In the heavy stocking rate paddocks were bare and the few remaining steers were on drought feeding (top). In contrast, in the moderately stocked rotational spell treatment there was still more than adequate pasture available with steers still in excellent condition (bottom).

Table 5.3: Mean liveweight gain per head (LWG) per year for (a) Phase 1 treatments from 1997/98 to 2009/10 and (b) Phase 2 treatments from 2010/11 to 2016/17. Treatment abbreviations as before. Means with different letters within the same columns differ significantly ($P < 0.05$).

(a) Phase 1

	Liveweight gain per head (kg/hd)												
	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	117	152 a	50 a	52 a	77 a	81 a	128	5 a	147	115 ab	106
MSR	80	152	130	180 b	79 b	90 b	121 b	119 b	139	39 b	135	114 ab	118
R/Spell	71	137	113	145 a	74 ab	87 b	97 ab	120 b	148	53 b	129	89 a	109
SOI	73	134	115	138 a	69 ab	70 ab	104 b	120 b	152	53 b	145	123 b	114
VAR	78	141	114	154 ab	51 a	69 ab	110 b	132 b	152	63 b	140	125 b	98

(b) Phase 2

	Liveweight gain per head (kg/hd)						
	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16 ^A	2016/17
Flex	124 ab	131	128 ab	139 b	11 b	97	178 ab
Flex+S	132 ab	117	137 ab	141 b	44 c	93	162 ab
HSR	113 a	126	117 a	97 a	-54 a	*	184 b
MSR	132 ab	126	137 ab	145 b	12 b	97	157 a
R/Spell	154 b	142	150 b	159 b	18 b	88	158 a

^AHSR data for 2015/16 not presented – see text for details.

5.3.2 Total liveweight gain per hectare

Total LWG per unit area (LWG/ha) varied markedly with rainfall over the 20 years of the trial, from 34 kg/ha (averaged over all treatments) in 2000/01 to as little as 5 kg/ha in the 2006/07 drought year (Fig. 5.4). The effect of both year and treatment on LWG/ha was highly significant ($P < 0.001$) in Phase 1 with no year by treatment interaction ($P < 0.143$). However, in Phase 2 there was a significant ($P < 0.021$) year by treatment interaction indicating that the effect of treatment on LWG/ha varied with year (Table 5.4)

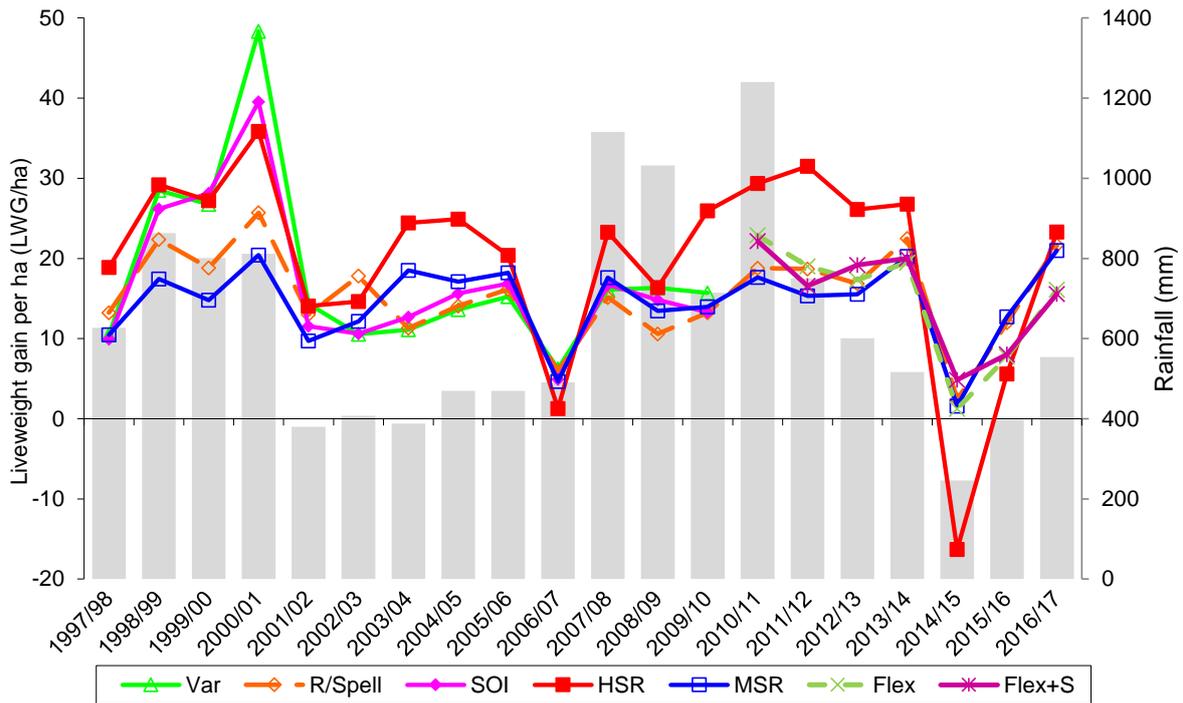


Fig. 5.4 Liveweight gain per hectare (LWG/ha) for steers in different grazing strategies across Phases 1 and 2 and rainfall in mm (bars) from 1997/98 to 2016/17. Note treatment changes in 2010/11.

Taken across both Phases 1 and 2, treatment differences were significant ($P < 0.05$ – $P < 0.001$) in 13 out of the 20 years (Table 5.5). Overall, LWG/ha in the HSR was highest (or at least, joint highest) in 16 out of the 20 years i.e. 80% of years. In contrast LWG/ha was lowest in the MSR and/or the R/Spell in 13 out of 20 years i.e. 65% of years. LWG/ha in the Variable/Flexible strategies varied with stocking rate with LWG/ha similar or even higher than the HSR in earlier good years (1998/99 to 2001/02) but similar to the MSR or R/Spell in other years.

Table 5.4 Significance of model terms for total liveweight gain (LWG) per hectare for Phase 1 and Phase 2.

Variable	Year	Treatment	Year*Treat
<u>LWG per ha</u>			
Phase 1: 1997-2010	<0.001	<0.001	<0.143
Phase 2: 2010-2017	<0.001	<0.001	<0.021

Overall, average LWG/ha over the 20 years was thus highest in the HSR (20 kg/ha) and four to five kg/ha greater than the average in the MSR (15 kg/ha) and the R/Spell (16 kg/ha), respectively. However, there was a large range in the magnitude of treatment differences between years with LWG/ha in the HSR up to 15 kg/ha greater than other treatments in 2000/01, 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 (-23 kg/ha) in 2014/15 (Fig. 5.4). While LWG/ha was also very low in other treatments that year (range: 1-5 kg/ha), it was far greater than that in the HSR.

5.4 Discussion

Individual liveweight gain (LWG/hd) varied sharply between years driven by rainfall differences, variation in stocking rate in the VAR/Flex treatments and presumably, longer term changes in pasture condition. As expected, production was greatest in above average rainfall years and/or years with well distributed rainfall but lowest in drought years (Fig. 5.2). There was also a marked treatment effect with LWG/hd consistently higher in more moderately stocked treatments, particularly the MSR and R/Spell, and lowest in the HSR. In the VAR/Flex strategies, LWG/hd varied based on the stocking rate applied in particular years. The higher LWG/hd under more moderate stocking rates is a direct reflection of the superior dietary crude protein (CP) and *in vitro* digestibility (IVD) of animals in these treatments, compared to heavier stocked strategies (O'Reagain *et al.* 2008; unpublished data).

Although LWG/hd in the HSR was as good or better than other treatments in some years, this only occurred in good rainfall years when the stocking rate in the HSR was reduced below normal level e.g. 2008/09, or when stocking rates in the VAR or SOI were similar or even higher than in the HSR e.g. 2000/01. In most other years, however, LWG/hd was lowest in the HSR (Fig. 5.2).

Overall, LWG per unit area was highest in the HSR and lowest in the R/Spell and MSR. Animal production per unit area varied in the VAR/Flex strategies depending upon the stocking rate applied. These results are consistent with earlier data (O'Reagain *et al.* 2009) showing that maximum production per ha was achieved with heavy stocking rates. It is surprising however that the HSR is still capable of achieving these high production levels at least in better seasons, despite nearly 20 years of heavy stocking.

Despite this, the recent drought indicates that animal production in the HSR is far more sensitive to reduced rainfall than in previous years. Thus in 2013 dry season, steers in the HSR required drought feeding far sooner than in the previous drought while animals in other treatments were still in very good condition. However, this could only be achieved by drought feeding stock in the HSR in six of the 20 years of the trial. Animals also had to be completely withdrawn from the HSR strategy on two occasions to prevent mortality. In contrast, drought feeding was not required in the other treatments apart from a relatively short period in 2014/15 which was the fourth driest year in 112 years.

Stocking rate reductions were also required for extended periods in the HSR with stocking rates being cut from 4 ha/AE by one-third to about 6 ha/AE between 2005/06 and 2008/09. Even more drastic reductions were required in the later drought with the stocking rate reduced to 30 ha/AE in 2015/16 and 9 ha/AE in 2016/17. In contrast, stocking rates have been able to be maintained throughout the trial in the MSR and the R/Spell and have not yet had to be reduced, despite the recent severe drought.

Given that the R/Spell and MSR were run at the same stocking rate, it is worth examining the differences in performance between these strategies. Overall, individual animal performance in the R/Spell was similar to that in the MSR (20 year average: 113 vs 115 kg/hd respectively). However, the relative performance of the R/Spell was somewhat poorer in Phase 1, particularly in the 2003/04 seasons and 2008/09 seasons. The poorer performance in 2003/04 is probably attributable to the fact that the R/Spell was initially stocked at a slightly heavier rate than the

MSR. More importantly, the effects of the ill-timed fire in this treatment in October 2001 had a major impact on pasture condition in this treatment (Section 3.5).

The generally higher LWG/hd in the R/Sspell relative to the MSR in Phase 2 (124 vs 114 kg/hd respectively) is an interesting reversal of the trend observed in Phase 1 (Table 5.3; Fig. 5.2). This switch is noteworthy because although stocking rates are identical in both treatments, wet season spelling in the R/Sspell results in a higher stocking rate in the grazed (non-spelled) area than in the MSR. Given that 70-80% of total LWG occurs in the wet season, these heavier wet season stocking rates might be expected to reduce LWGs relative to those in the MSR. The superior LWGs in the R/Sspell thus suggest that spelling has improved pasture condition in the R/Sspell, possibly buffering the effects of these increased wet season stocking rates on animal production. If this trend continues when seasons improve, it will be amongst the first quantitative data evidence of the beneficial effects of wet season spelling on animal production and profitability.

Although the differences in LWG per head and LWG/ha between treatments were not significantly different in all years, the trends observed were very consistent. Accordingly, their significance for management are obvious i.e. the best individual animal production is obtained at moderate stocking. Conversely, heavy stocking rates appear to maximise total production per unit area, at least in the moderate term (20 years). However, this was completely dependent upon drought feeding in dry years and the requirement to cut stocking rates drastically in droughts. There is also clear evidence of a decline in pasture condition and productivity (Chapter 8). Whether the trend of higher LWG/ha in the HSR can be maintained in the longer term as pasture condition and production decline further are a key reason the present work needs to be continued.

5.5 Summary

1. Individual liveweight gain per head per year (LWG/hd) varied markedly over the 20 years of the trial from between 43 kg/hd to 168 kg/hd depending upon rainfall and its distribution. However, in the extreme drought year of 2014/15, average LWG/hd over all strategies was only 7 kg/hd.
2. Treatment had a significant effect on LWG/hd although this effect varied with year. Over all years, mean LWG/hd per annum was highest in the MSR (115 kg/hd) and R/Sspell (113 kg/hd) and lowest in the HSR (98 kg/hd). Treatment effects were most pronounced in drought years with LWG/hd in more moderately stocked treatments up to 50 to 60 kg/hd higher than in the HSR.
3. Live weight gain per unit (LWG/ha) area also varied markedly between years due to rainfall variability and, to a lesser extent, changes in stocking rate in the VAR/Flex treatments. Average LWG/ha thus varied from 5 kg/ha in 2006/07 to as much as 34 kg/ha in 2000/01. In the extreme drought year of 2014/15 LWG/ha was as low as -1 kg/ha.
4. Treatment also had an obvious effect on LWG/ha, although this was dependent upon year. Overall LWG/ha was highest in the HSR (20 kg/ha) but this was only achieved with drought feeding in six of 20 years, and the withdrawal of some stock for emergency feeding in two of these years.
5. Overall, LWG/ha was lower in the moderately stocked MSR (15 kg/ha) and the R/Sspell (16 kg/ha), and in the VAR/Flex (17 kg/ha) strategies. However, in contrast to the HSR, drought feeding was only required once in these strategies over the 20 years of the trial.

Table 5.5 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 2016/17. Treatment abbreviations as before. Means with different letters within the same columns differ significantly ($P < 0.05$).

(a) Phase 1

	Liveweight gain per hectare (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	29 a	27 a	36 b	14	15 ab	24	25 a	20	1	23	16 a	26 a
MSR	10	17 c	15 b	20 c	10	12 bc	18	17 b	18	5	18	13 b	14 b
R/Spell	13	22 b	19 b	26 c	13	18 a	11	14 c	16	6	15	11 c	13 b
SOI	10	26 ab	28 a	40 b	12	11 c	13	16 bc	17	5	17	15 ab	13 b
VAR	10	28 a	27 a	48 a	14	11 c	11	14 c	15	6	16	16 a	16 b
P	0.055	0.01	0.004	<0.001	0.337	0.026	0.116	<0.001	0.369	0.056	0.052	0.006	0.034
LSD	5.98	4.79	4.61	5.36	6.02	3.93	11.78	2.24	6.6	3.17	5.03	2.08	7.49

(b) Phase 2

	Liveweight gain per hectare (kg/ha)						
	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17
Flex	23 ab	19 b	17 a	19	1 b	8 a	16 a
Flex+S	22 a	17 ab	19 ab	20	5 b	8 a	16 a
HSR	29 b	31 c	26 b	27	-16 a	-	23 c
MSR	18 a	15 a	15 a	20	2 b	13 b	21 b
R/Spell	19 a	19 b	17 a	22	2 b	12 b	22 cb

6 Effect of different grazing strategies on carcass characteristics

6.1 Introduction

In this chapter data is presented on the carcass characteristics of cattle from the five grazing strategies on the trial. This is key information, with the price realised per kilogram of carcass weight determining the annual relative price differential for different strategies in the economic analysis in the chapter that follows.

6.2 Objective

To compare the effects of different grazing strategies on the main carcass characteristics of trial cattle.

6.3 Procedure and statistical analysis

Trial animals only started being sent to the meatworks at the end of the 2003/04 grazing year, hence carcass data are only available from 2003/04 to 2016/17. Note that in 2003/04 only 10% of the HSR steers were in good enough condition to go to the meatworks with the remainder going to the local Charters Towers cattle sale. Thus the 'carcass' price, weight and value for the HSR that year are derived from both the sale and meatworks steers. Conversely, the fat thickness data for the HSR in this year is only from meatworks steers.

Meatworks cattle had usually been on the trial for two years and were usually older (3.5 year) steers. However, in a few years, meatworks cattle had only been on the trial for one year e.g. 2013/14, and/or were younger steers (2.5 years old), as in 2011/12.

In the statistical analysis two data groups were analysed to accommodate the treatment changes implemented in 2011 i.e.:

- Phase 1: (2004 – 2010) – 'old' Phase 1 treatments (HSR, MSR, R/Spell, SOI, and VAR).
- Phase 2: (2011 – 2017) – 'old' (HSR, MSR, R/Spell) plus 'new' Phase 2 treatments (Flex, Flex+S).

The 2015/16 HSR carcass data was excluded from the above analyses as there were only five steers in each HSR paddock due to drought, resulting in an extremely low stocking rate (23 ha/AE). This data is thus not indicative of the actual treatment effect i.e. heavy stocking.

Carcass value data were analysed using residual maximum likelihood (REML) in Genstat (v18). The appropriate random model was determined first after which the 'fixed' model was assessed. The random effects over time of 'replicate' and 'paddock' were tested using the random models (Rep/Pdk).Year and Rep.Pdk.Year. Various covariance models were trialled, including: Identity, Uniform, AR1 and AR1 allowing for heterogeneity across time. The AR1 models allows for serially correlated errors. The most appropriate random model (for nested random models) was chosen through assessing the significance of the change in deviance between the two models using a chi-square distribution. Non-nested models were compared using the Akaike Information Criterion (AIC) value, with the lowest AIC value indicating the better model. Residual plots (residual versus fitted values and normal probability plots) were also used to check assumptions for the models. A natural logarithm transformation was applied where necessary to improve these residual plots to an adequate pattern.

The fixed term was Trt * Year (equivalent to Trt + Year + Trt.Year). The significance of the interaction was tested when it was dropped from the model after all model terms had been fitted (i.e. Trt, Year, Trt.Year). Pairwise comparisons for treatments within each year were determined through Fisher's protected least significant difference (Lsd). Appropriate degrees of freedom were

obtained from the REML output. Only pairwise comparisons between treatments within any one year have been quoted. All analyses were performed using GenStat (v18) statistical software.

6.4 Results

Note that in comparing within-year treatment effects for all carcass data presented below, the HSR can only be validly compared to other treatments for 13 of the 14 years of data, due to the exclusion of the HSR data for the 2015/16 data.

Table 6.1 Significance of model terms for carcass variables analysed for Phase 1 and Phase 2 treatments.

Variable	Year	Treatment	Treat*Year
<u>Carcass weight</u>			
Phase 1: 2004-2010	<0.001	0.076	0.003
Phase 2: 2011-2017	0.006	<0.001	0.017
<u>Fat depth</u>			
Phase 1: 2004-2010	<0.001	0.003	0.109
Phase 2: 2010-2017	<0.001	0.002	0.131
<u>Price/kg</u>			
Phase 1: 2004-2010	<0.001	<0.001	<0.014
Phase 2: 2011-2017	<0.001	<0.001	<0.001
<u>Carcass value</u>			
Phase 1: 2004-2010	<0.001	0.006	0.027
Phase 2: 2011-2017	<0.001	<0.001	<0.002

6.4.1 Carcass weight

Carcass weight varied markedly between years (Fig. 6.1); averaged across treatments, carcass weight varied from 226 kg in 2003/04 to 306 kg in 2012/13. This variation resulted from differences in rainfall both in the year in question and the preceding year, age at slaughter (usually 3.5 years but sometimes 2.5 years) and the time spent on the trial (generally two but sometimes only one year). The two latter effects were particularly noticeable in 2011/12: although rainfall was above average (750 mm), carcass weights were relatively low (average: 250 kg). This was due to the fact that these steers had only been in the trial for a year, most of which time was spent on agistment (Section 3.5).

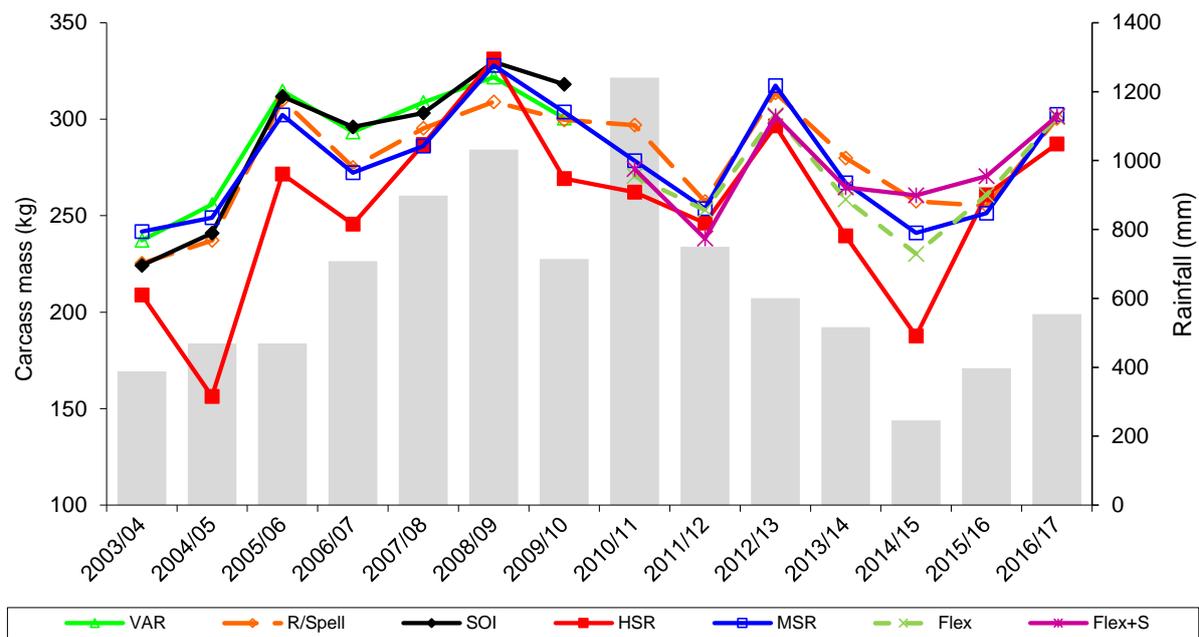


Fig. 6.1 Carcass weight of steers from different grazing strategies across Phases 1 and 2 and rainfall in mm (bars) from 2003/04 to 2016/17. Note changes in treatments in 2010/11.

There was a significant treatment by year interaction in both Phase 1 ($P < 0.003$) and for Phase 2 ($P < 0.017$), indicating that the effect of treatment on carcass weight was inconsistent and varied between years (Table 6.1).

Considered over both Phase 1 and Phase 2, carcass weight in the HSR was the lowest (or equal lowest as in 2007/08) of all treatments in 12 out of the 13 years i.e. 91% of years, in which valid comparisons can be made between the HSR and other treatments. These differences were significant ($P < 0.05$) in eight of these years with HSR carcass weight significantly lower than either some or all of the other strategies (Table 6.2).

Averaged over all years, carcass weight in the HSR (253 kg) was from 15 kg to 37 kg lighter than other treatment averages. However, within years these differences were extremely variable: while differences were relatively small in better seasons, carcass weights in the HSR were up to 70 kg to 100 kg lighter than other treatments in drought years like 2003/04 and 2014/15.

An obvious exception was 2008/09 when HSR average carcass weight (331 kg) was equal highest with the lightly stocked SOI (330 kg) and similar to the MSR (328 kg) strategies. This anomaly was due to the good seasons encountered and the lower stocking rates applied in the HSR over that period.

Table 6.2 Average carcass weight for (a) Phase 1 treatments from 2003/04 to 2009/10 and (b) Phase 2 treatments from 2010/11 to 2016/17. Treatment abbreviations as before. Means with different letters within the same columns differ significantly ($P < 0.05$).

(a) Phase 1

Treatment	Carcass weight (kg)						
	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
HSR	209 b	156 a	272 a	246 a	287 a	331 a	269 a
MSR	242 a	249 b	302 ab	272 ab	286 a	328 ab	304 b
R/Spell	225 ab	237 b	310 b	275 ab	295 a	309 ab	300 ab
SOI	224 a	241 b	312 b	296 b	303 a	330 ab	318 b
VAR	237 a	256 b	315 b	293 b	309 a	322 ab	301 b

(b) Phase 2

Treatment	Carcass weight (kg)						
	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16 ^A	2016/17
HSR	261 a	246	296	239 a	188 a	-	287
MSR	278 ab	254	317	266 ab	244 bc	250	302
R/Spell	297 b	257	313	280 b	256 c	255	299
Flex	271 ab	253	302	260 ab	228 b	261	301
Flex+S	274 ab	238	302	265 ab	261 c	272	303

^AHSR data for 2015/16 not presented – see text for details.

Averaged over all years, carcass weight in the HSR (253 kg) was from 15 kg to 37 kg lighter than other treatment averages. However, within years these differences were extremely variable: while differences were relatively small in better seasons, carcass weights in the HSR were up to 70 kg to 100 kg lighter than other treatments in drought years like 2003/04 and 2014/15.

An obvious exception was 2008/09 when HSR average carcass weight (331 kg) was equal highest with the lightly stocked SOI (330 kg) and similar to the MSR (328 kg) strategies. This anomaly was due to the good seasons encountered and the lower stocking rates applied in the HSR over that period.

While carcass weight was nearly always heavier in more lightly stocked treatments, no treatment consistently outperformed the others. Thus carcass weights tended to be highest in VAR and SOI from 2004/05 to 2007/08, and in the flexible stocking strategies in 2015/16, due to their lower stocking rates relative to the MSR and R/Spell in those years. In contrast, carcass weights were heavier in the R/Spell and MSR in wetter years like 2010/11 and 2012/13 when the VAR/Flex strategies were more heavily stocked. The relatively low carcass mass in the Flex strategy in 2014/15 drought year is difficult to explain but reflects the relatively poor performance of steers that year in one replicate of that strategy. Note that the particularly low carcass weights in the HSR in 2016/17, was because most HSR meatworks steers (6 out of 8) were a year younger than in other treatments and hence had lighter carcasses.

6.4.2 Fat thickness

Fat thickness varied significantly ($P < 0.001$) between years for both Phase 1 and 2 treatments (Table 6.3).

Table 6.3 Fat thickness (averaged over all treatments) in different years in Phase 1 and Phase 2
Means with different letters within the same rows differ significantly ($P < 0.05$).

Fat thickness (mm)						
Phase 1	2003/04	2004/05	2005/06	2006/07	2007/08	2009/10
	5.3 a	6.7 b	14.5 e	11.3 d	11.8 d	9.9 c
Fat thickness (mm)						
Phase 2	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16
	9.0 c	7.4 ab	15.1 d	7.4 ab	6.5 a	8.9 bc

In Phase 1, fat thickness, averaged over all strategies, ranged from 5.3 mm in the drought of 2003/04 up to 14.5 mm in 2005/06; although rainfall was relatively low (469 mm) in 2005/06 it was very well distributed. Similarly, fat thickness in Phase 2 was lowest in the very poor seasons of 2013/14 and 2014/15 but greatest in 2016/17; again, although rainfall was below average (553 mm) in the latter season, it was relatively well distributed.

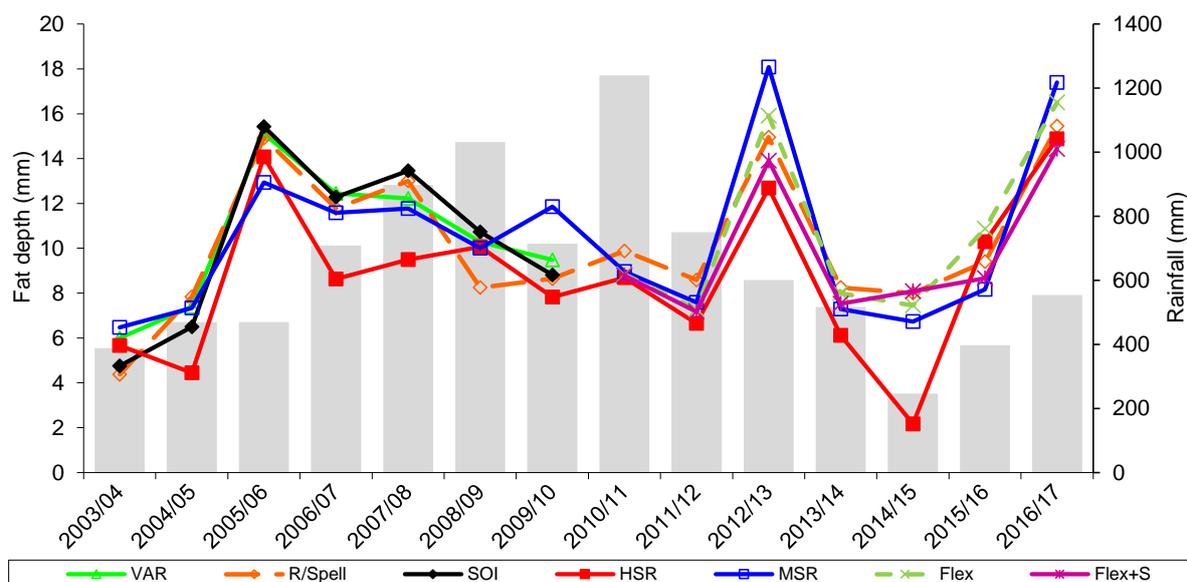


Fig. 6.2 Fat thickness of meatworks steers from different grazing strategies across phases 1 and 2 and rainfall in mm (bars) from 2003/04 to 2016/17. Note changes in treatments in 2010/11.

Treatment also significantly affected fat thickness in both Phase 1 ($P = 0.003$) and Phase 2 ($P = 0.002$) with the year by treatment effect non/significant (Table 6.3). In Phase 1, average fat thickness in the HSR (8.5 mm) was significantly ($P < 0.05$) lower than any of the other treatments (range: 9.7 to 10.7 mm). However, within individual years there were occasions when fat thickness in the HSR was similar (e.g. 2008/09) to other treatments (Fig. 6.2, Table 6.4). Although fat thickness in the HSR was greater than in the SOI and R/Spell in 2003/04 this is not a fair comparison; only 10% of the Phase 1 HSR steers that year were in good enough condition to go to

the meatworks, compared to 64% in the SOI and R/Spell treatments, with the remaining poorer condition steers going to the Charters Towers sale. The HSR data is thus from only the best condition steers in that treatment and is an unrepresentative sample.

Table 6.4 Average fat thickness by treatment (meaned across all years) for Phase 1 treatments (2003/04 to 2009/10) and Phase 2 treatments from 2010/11 to 2016/17. Treatment abbreviations as before. Means with different letters within the same columns differ significantly ($P < 0.05$).

Phase 1		Phase 2	
Treatment	Fat depth (mm)	Treatment	Fat depth (mm)
HSR	8.5 a	HSR	8.3 a
MSR	10.3 bc	MSR	10.7 b
R/Spell	9.8 bc	R/Spell	10.6 b
SOI	9.7 b	Flex	10.7 b
VAR	10.7 c	Flex+S	9.8 b

In Phase 2, average fat thickness was lowest ($P < 0.05$) in the HSR (8.3 mm) but greatest in the MSR, Flex and R/Spell (range 10.6-10.7 mm). The relatively low fat thickness in the Flex+S (9.8 mm) is inexplicable but may be due to the slightly higher wet season stocking rates in this treatment due to wet season spelling. Although spelling also occurred in the R/Spell, the Flex+S was also run at a higher stocking rate for at least four of the seven years of this Phase 2.

6.4.3 Price per kg

There was a big variation in carcass price per kg between years due to normal market fluctuations. To a lesser extent, the variation in the condition of trial cattle between years would also have influenced this variation. There was a significant year by treatment interaction for both Phase 1 ($P = 0.014$) and Phase 2 ($P < 0.001$), with treatment effects varying between years due to the seasons encountered and stocking rates applied (Table 6.1). Overall however, the HSR had lowest price per kg in nine out of 13 years (69%); and was equal lowest in two other years i.e. a total of 84% of years. Averaged over all years within Phase 1 and Phase 2, the price per kg of HSR steers was on average $-\$0.19/\text{kg}$ and $-\$0.33/\text{kg}$ lower than those in other treatments for Phase 1 and Phase 2 respectively. Again, there was a big difference between years with the price per kg in the HSR being up to $\$1.20/\text{kg}$ lower than other treatments in the 2003/04 drought. Differences were however far less marked in good years: in 2008/09 for example the price per kg in HSR was only marginally ($\$0.02/\text{kg}$) lower than the MSR and VAR treatments which had the highest price/kg.

Table 6.5 Average price per kg (means of back transformed data) for (a) Phase 1 treatments from 2003/04 to 2009/10 and (b) Phase 2 treatments from 2010/11 to 2016/17. Treatment abbreviations as before. Means with different letters within the same columns differ significantly (P<0.05).

(a) Phase 1

Treatment	Price per kg (\$/kg)						
	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 a
MSR	2.75 b	2.96 a	3.28 a	2.84 ab	2.83 a	2.60 a	2.82 a
R/Spell	2.26 c	2.93 ac	3.28 a	2.79 ab	2.85 a	2.58 a	2.80 a
SOI	2.27 c	2.97 a	3.29 a	2.94 b	2.87 a	2.60 a	2.82 a
VAR	2.05 c	2.96 a	3.30 a	2.92 b	2.90 a	2.59 a	2.81 a

(b) Phase 2

Treatment	Price per kg (\$/kg)						
	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16 ^A	2016/17
HSR	2.82	2.79	2.64 a	2.80 a	3.34 a	-	4.74
MSR	2.87	2.83	2.72 bcd	2.95 b	3.83 bc	4.64 a	4.72
R/Spell	2.89	2.86	2.74 d	2.99 b	3.87 cd	4.68 ab	4.73
Flex	2.85	2.83	2.67 abc	2.94 b	3.80 b	4.69 ab	4.73
Flex+S	2.88	2.79	2.66 ab	2.91 ab	3.94 d	4.72 b	4.72

^AHSR data for 2015/16 not presented – see text for details.

Overall, price per kg was higher in more lightly stocked treatments like the MSR or R/Spell or in the VAR and SOI in drought years with lower stocking rates (

Table 6.5). One anomaly is that in 2011/12, the price per kg was joint lowest in the Flex+S and HSR. However, as noted previously, steers were only on trial for four months that year before going to the meatworks, limiting the time for the advantage of the lighter stocking rates in the Flex+S relative to the HSR to develop.

6.4.4 Carcass price

As with the other variables, there was a significant ($P < 0.027$) treatment by year interaction indicating that the effect of treatment on carcass price varied with year (Table 6.6). The variation in price between years was largely determined by seasonal driven variability in carcass weights and, in particular, market driven changes in price per kg as described earlier.

Table 6.6 Average carcass price (\$/head) for (a) Phase 1 treatments from 2003/04 to 2009/10 and (b) Phase 2 treatments from 2010/11/2016/17. Treatment abbreviations as before. Means with different letters within the same columns differ significantly ($P < 0.05$).

(a) Phase 1

Treatment	Carcass price (\$)						
	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
HSR	508 a	566 a	870 a	664 a	813 a	856	741 a
MSR	674 b	738 b	992 ab	768 ab	809 a	853	859 b
R/Spell	598 ab	696 b	1018 ab	782 ab	833 ab	802	838 b
SOI	603 ab	717 b	1025 b	875 b	871 ab	855	901 b
VAR	593 ab	758 b	1037 b	861 b	892 c	837	846 b

(b) Phase 2

Treatment	Carcass price (\$)						
	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16 ^A	2016/17
HSR	739 a	690	781	671 a	629 a	*	1361
MSR	802 ab	722	860	786 b	939 bc	1157 a	1424
R/Spell	859 b	737	856	840 b	994 c	1195 ab	1412
Flex	773 ab	718	806	768 ab	868 b	1220 ab	1426
Flex+S	790 ab	666	804	778 ab	1028 c	1284 b	1431

^AHSR data for 2015/16 not presented – see text for details.

In 10 of the 13 years i.e. in 76% of years, carcass price in the HSR was the lowest (and in one year equal lowest) of all treatments. Carcass price in the HSR was significantly ($P < 0.05$) lower than that of some or all other treatments in nine of these 10 years (Table 6.6). Carcass price in the HSR was also second lowest in 2011/12, with treatment differences still evident despite the steers only having been on the trial for four months post-agistment.

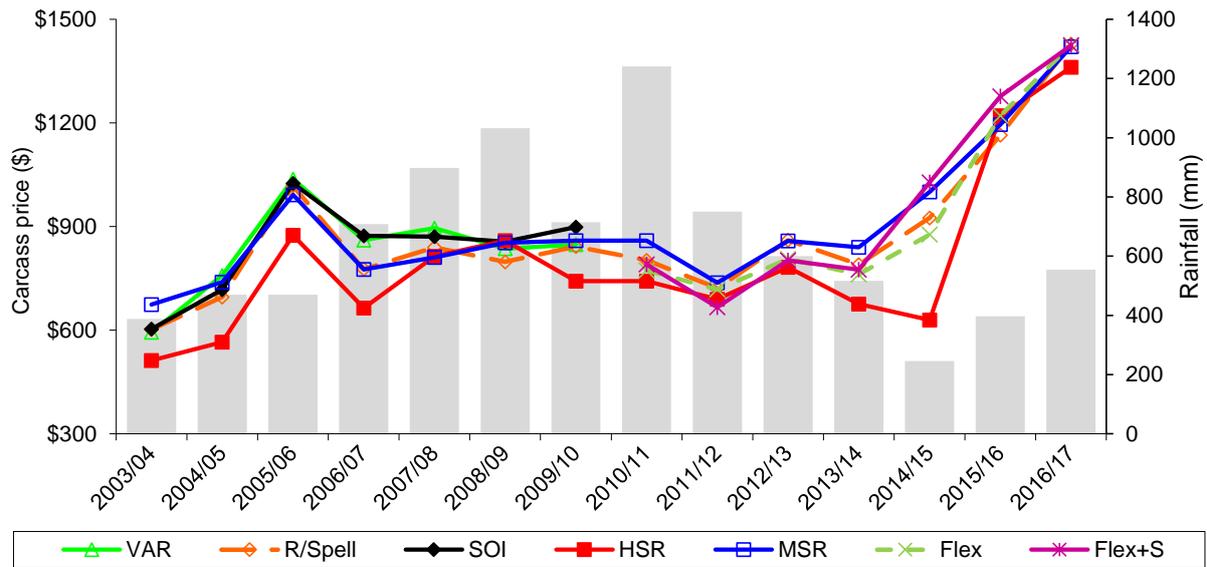


Fig. 6.3 Carcass price of steers in different grazing strategies across Phases 1 and 2 and rainfall in mm (bars) from 2003/04 to 2016/17. Note treatment changes in 2010/11.

In contrast, carcass price was generally highest in more lightly stocked treatments. Thus in Phase 1, this tended to be the SOI and VAR where stocking rates were relatively light post-2004 due to drought. If data had been available for the early, wetter years, average carcass price for MSR and R/Spell would probably have been higher than those in the SOI and VAR, which were relatively heavily stocked in those years. In Phase 2 carcass price was highest in the R/Spell and MSR for at least the first five years when the two Flexible strategies were relatively heavily stocked.

Overall, average carcass price in the HSR was thus \$96 to \$174 lower than in the other treatments. There was however a big variation between years with HSR carcass price being only slightly lower than other treatments in better years like 2008/09, to being as much as \$371 dollars lower in drought years like 2014/15 (Table 6.7).

Table 6.7 Relative advantage in terms of average carcass price of other treatments relative to the average for HSR for Phase 1 and Phase 2

Phase 1:	MSR	R/Spell	VAR	SOI
	+\$96	+\$77	+\$116	+\$114
Phase 2:	MSR	R/Spell	Flex+S	Flex
	+\$143	+\$174	+\$153	+\$127

6.5 Discussion

There were large variations in carcass characteristic between years with, for example, average fat thickness in 2005/06 (14.5 mm) being almost three times that in 2003/04 (5.3 mm). While these differences are largely due to rainfall, other more subtle between year differences are likely to have resulted from differences in the age and/or origin of steers as well as the actual length of time that animals were on the trial. For example, analyses of previous data clearly showed that younger animals (2.5 year) grew faster and put on more weight than the older cohort (3.5 year). Conversely, the older animals put on more condition (O'Reagain *et al.* 2008). This indicates that younger animals might have had a lesser fat thickness and thus have received a lower price per kg at the meatworks, compared to older steers. These factors have not been fully investigated for the present data set and will be presented in journal papers.

In terms of treatment effects, the results clearly show that at lighter stocking rates, carcass mass, fat depth and price per kg are highest, which in turn maximises overall carcass price. In contrast, the price per carcass is generally lowest at heavy stocking rates because of the effects of heavy stocking on carcass weight and fat thickness, and hence price per kg. These results are in keeping with those in the previous chapter showing that individual LWG is maximised at lighter stocking rates.

The data does nevertheless indicate that there were years when carcass value in the HSR was equal to or even slightly better than those in lighter stocked treatments. For example in 2008/09, average carcass price in the HSR was similar to the MSR and SOI, and indeed better than the R/Spell. However, these were exceptions and only occurred during years with above average and/or well distributed rainfall and when the stocking rates had been reduced in the HSR following recent drought.

In periods of below average rainfall, the negative effect of the heavy stocking regime on carcass characteristics were extreme, with carcass prices up to \$170 lower than those under lighter stocking. Importantly, this invariably occurred in conjunction with drought feeding. The economic loss incurred by the lower carcass price would thus be further compounded by the cost of drought feeding in this instance, as will be shown in the following chapter.

Although carcass value was invariably greater at lighter stocking rates, this was not always in the MSR or R/Spell strategies. In drier years, carcass values in the VAR/Flex strategies were usually better than these fixed stocking strategies, despite the fact that the MSR and R/Spell were stocked at long term carrying capacity. This was clearly demonstrated in drier years from 2004/04 to 2007/08 with the SOI and VAR having the highest carcass value of all treatments. Similarly, carcass values in the two Flex treatments in 2015/16 were markedly higher than the two fixed stocking MSR and R/Spell strategies. This clearly demonstrates the benefits of reducing stocking rates in these dry years.

It is interesting to note that as with the LWG data, average carcass price in the R/Spell (\$987) was higher than that in the MSR (\$956) in Phase 2. This is slightly unexpected given that the stocking rate in these treatments was the same. Performance in the R/Spell might also be expected to be lower than in the MSR due to the heavier stocking rates in the grazed sections of that treatment during the wet season. Although the relative advantage to the R/Spell did partly disappear in the final two years, it does nevertheless suggest an emerging benefit of wet season spelling on animal production in this treatment, possibly via its positive impact on pasture condition and/or availability.

6.6 Conclusions

1. Averaged across all treatments, carcass weight varied from 226kg/hd to 306 kg/hd depending upon rainfall, the stocking rate applied in different treatments and other factors such as steer age and length of time on the grazing trial.
2. Carcass weight was generally greatest in lightly stocked treatments and lowest in the heavy stocking rate. Averaged over all years, carcass weight in the HSR was 15-37 kg/hd lighter than in the other treatments. However in drought years, HSR carcasses were up to 70 kg/hd to 100 kg/hd lighter than in lighter stocked strategies.
3. Fat thickness also varied between years from 5.3 mm to 15.1 mm depending upon rainfall, steer age and the length of time steer had been on the trial. Average fat thickness in the HSR (8.4 mm) was significantly ($P<0.05$) lower than in the other treatments (range: 9.7 - 10.7 mm) in both Phase 1 and Phase 2.
4. There was a large variation in carcass price per kg between years due largely to market forces and, to a lesser extent, animal condition. In general price per kg was on average from \$0.15 to \$0.35/kg lower in the HSR than in the other strategies. However, there was a big variation in treatment

differences between years with little or no price differential in good years to as much as \$1.20/kg in drought years.

5. As a consequence of its lower carcass weight and fat thickness and hence price per kg, total carcass price in the HSR was lowest in 76% of years and from \$96 to \$174 lower than in other treatments. Again, while there was little or no difference in good years, in drought years this difference was as much as \$370 per carcass.
6. In summary, carcass quality and value in the HSR was generally markedly lower than in the remaining treatments. The only time carcass quality in the HSR was equal to those in the lighter stocked treatments was in very good years when stocking rates had been reduced in the HSR due to previous drought.

7 Economic performance of different grazing strategies

7.1 Introduction

In this chapter data is presented on the economic performance of the different grazing strategies over the 20 years of the trial. Economic performance is expressed in terms of annual gross margin and accumulated gross margin with time over the course of the trial.

7.2 Procedure

7.2.1 Value of beef produced

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 (Chapter 6).

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.

7.2.2 Variable and interest costs

Variable costs were the actual supplement, vaccination and HGP implant costs per strategy, 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 7.5%.

7.2.3 Economic analysis

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

$$GM = \text{MassOut} \times \text{value} - \text{variable costs} - \text{interest costs} - \text{MassIn} \times \text{value}$$

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.

7.2.4 Statistical analysis

Statistical analysis of the 1998 to 2009 data was presented previously (O'Reagain *et al.* 2011). The 2010 to 2017 economic data has yet to be statistically analysed and will be presented in a future

research paper. For present purposes treatment gross margins are presented as the mean of the two replicate paddocks in each treatment.

7.3 Results and discussion

7.3.1 Gross Margins of different grazing strategies

Annual gross margins (GM) varied widely in response to rainfall over the course of the trial (Fig. 7.1). In the early, wetter period (1997–2001), heavier stocked strategies like the HSR, VAR and SOI had exceptionally high GMs of up to \$39 to \$47/ha in some years (Fig. 7.1). In comparison, GMs in the moderately stocked MSR and R/Spell were markedly lower at around \$20 - \$30/ha due to their lower total LWG/ha. However, with the onset of the first drought in 2001/02, GMs in the heavier stocked strategies fell sharply to less than -\$10/ha due to reduced animal production, price penalties for lower body condition and the costs of drought feeding. In contrast, the decline in GM in the MSR was relatively minor with this strategy maintaining a positive GM through the drought years. Although GMs in the R/Spell were relatively high at the start of the first drought, complications arising from the ill-timed 2001 fire, caused a temporary drop in GMs in 2003/04 and 2004/05 (O’Reagain *et al.* 2011).

In the SOI and VAR, reducing stocking rates early in the drought allowed GMs to recover and by 2003/04 matched those in the MSR (Fig. 7.1). Thereafter, GMs in these strategies (and later the Flex/Flex+S) were similar to the MSR and R/Spell as stocking rates in the former strategies were adjusted to match forage availability. In the HSR in contrast, the maintenance of high stocking rates gave a consistently negative GM through the drought due to ongoing poor animal production, associated price penalties for lower condition animals, and in particular, the costs of drought feeding or ‘agistment’. These losses continued in 2005/06 and 2006/07, despite the reduction in stocking rates in the HSR by about a third in May 2005 (Fig. 7.1).

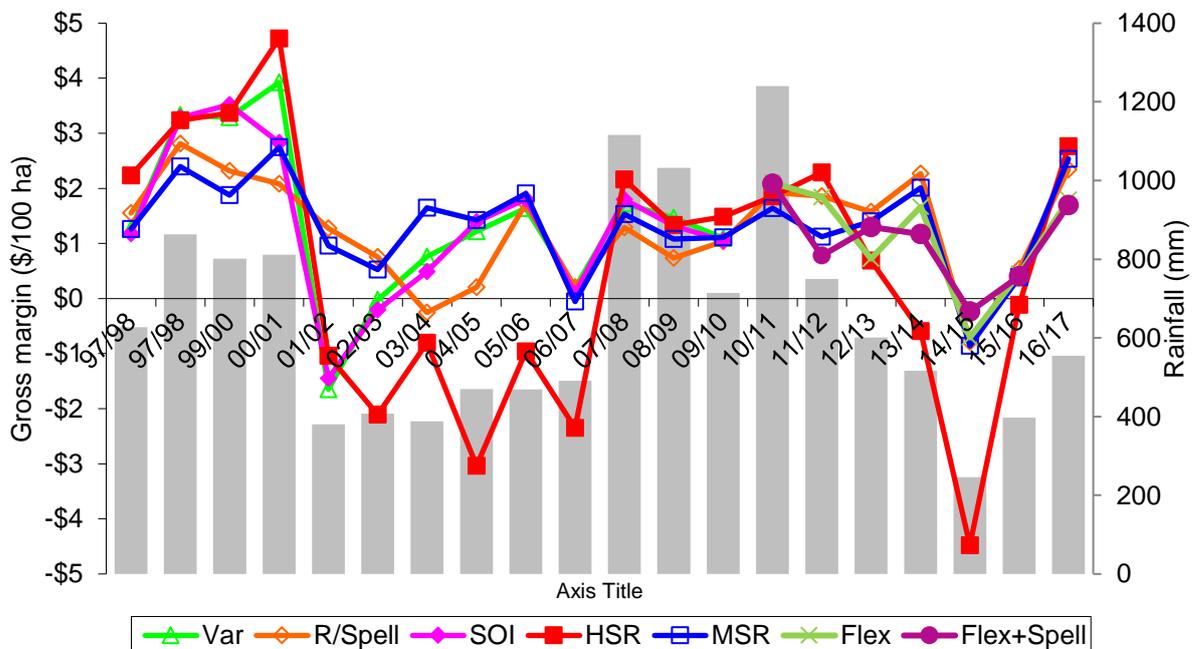


Fig. 7.1 Annual gross margin vs. rainfall for different grazing strategies at the Wambiana trial from 1997/98 to 2016/17. Note the change in treatments in 2009/10.

Despite the losses in the drought, GMs in the HSR rebounded sharply to +\$22/ha in 2007/08 with the start of the second wet cycle. This was at least partly due to the reduced stocking rates in the HSR at that stage (6.5 ha/AE) compared to ‘normal’ levels (4-5 ha/AE). Although full HSR stocking rates were restored in May 2009, GMs in the HSR remained high and matched those in lighter stocked strategies through the remaining wet years (Fig. 7.1).

With the arrival of the second drought in late 2013 however, GMs in the HSR again declined and by 2014/15 had plunged to -\$45/ha. While all strategies were adversely impacted by the drought, it is notable that in the HSR the decline in GM began two years before (2012/13) the other four strategies (2014/15). Moreover, while GMs in these latter strategies were also negative in 2014/15 (average GM = -\$6.5/ha), this loss was only a fraction (13%) of that in the HSR (-\$45/ha).

In summary, over the 20 years of the trial the HSR had a negative GM in nine out of 20 years. In contrast, the other strategies had negative GMs in only two (MSR & R/Spell) or three (VAR/Flex) out of the 20 years. Average GM in the HSR (\$5.32/ha) was also barely half that for the other strategies (range: \$10-13/ha). Inter-annual variability in GM as indexed by the co-efficient of variation (C.V.), was also far greater in the HSR (455%) than in the MSR (66%) and R/Spell (75%). The C.V.s. of the VAR/Flex strategies were somewhat higher (range: 70-103%) than the MSR and R/Spell due to their variation in stocking rates, but still significantly lower than in the HSR.

7.3.2 Accumulated gross margins

In the early wetter years, accumulated gross margin (AGM) increased fastest in the heavier stocked strategies due to their high annual GMs. Thus by 2000/01, the HSR had an AGM of \$136/ha compared to only \$83/ha in the MSR (Fig. 7.2). Thereafter however, AGM steadily declined in the HSR as the strategy ran at a consistent loss through the dry years. In contrast, in the VAR and SOI, after an initial loss in the first dry year, the reduced stocking rates allowed AGM to recover and continue to grow thereafter in both strategies (Fig. 7.2). While AGMs in the MSR and R/Spell were initially modest, AGMs grew steadily and by 2003/04 both strategies equalled, and then exceeded, the HSR. This difference widened through the drought: accordingly by 2007/08 the AGM in the HSR was between \$103/ha and \$108/ha less than in other strategies.

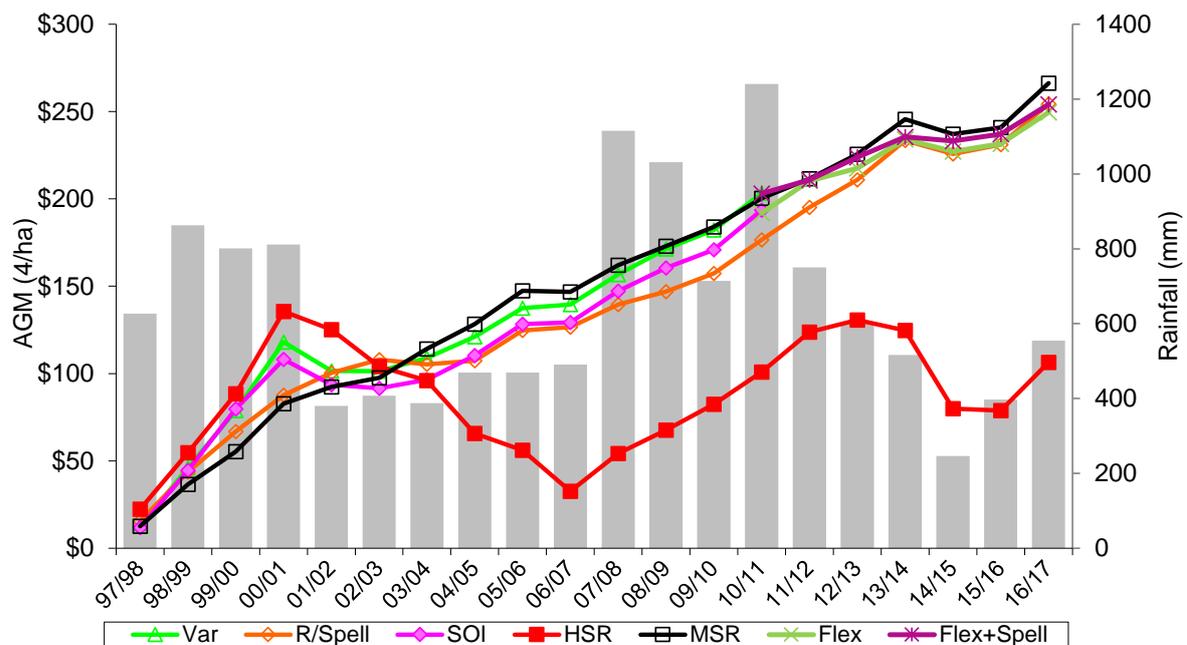


Fig. 7.2 Accumulated gross margin vs. rainfall in bars for different grazing strategies over the 20 years of the Wambiana trial from 1997/98 to 2016/17. Note the change in treatments in 2009/10.

With good, positive GMs in the second wet cycle, AGMs in the HSR grew steadily over the six years that followed (Fig. 7.2). Despite this, the other strategies maintained their clear advantage with AGMs \$70/ha to \$100/ha greater than the HSR. This difference widened even further in the second drought that followed shortly thereafter with the strongly negative GMs in the HSR. Despite a return to positive GMs in the HSR in 2016/17, AGM in the HSR remained by far the lowest at between \$143/ha to \$160/ha less than the other strategies.

For a 'typical' 25 000 ha district property, over 20 years this difference equates to an approximately \$3 million advantage of the other strategies over the HSR. While this is only a rough calculation, it nevertheless indicates that stocking above long term carrying capacity is an extremely unprofitable in the longer term.

In comparison to the HSR, there was very little difference in AGM between the remaining strategies: overall the MSR tended to have the highest AGM in most years from 2003/04 onwards while AGM tended to be lowest in the R/Spell (Fig. 7.1). However these differences were relatively minor, and by 2016/17 there was only a \$10/ha difference in AGM between the MSR and the Flex (7.2).

7.4 Summary

1. Gross margins (GM) varied markedly over the trial in response to inter-annual variability in rainfall. GMs also varied strongly between different grazing strategies due to differences in the beef produced per hectare, the price per kg of beef produced and the costs of production.
2. Gross margins in the HSR were high in the early good seasons due to high LWG/ha but collapsed in the subsequent drought due to reduced product value and high costs, particularly that of drought feeding and interest paid on livestock capital. GMs in the HSR recovered strongly in the second wet phase but then collapsed again in the second, later drought.
3. The VAR and SOI strategies were also initially very profitable but GMs fell sharply as rainfall declined, due to reduced animal performance and the sale of poor condition cattle. However, reducing stocking rates avoided the costs associated with heavy stocking and allowed GMs to recover strongly in subsequent years. This continued into Phase 2 with the Flex and Flex+S strategies.
4. Gross margins in the MSR and R/Spell initially lagged behind other treatments, but remained relatively constant across most years due to low costs and a higher product value.
5. Average GM in the HSR (\$5.32/ha) was also far lower than in the other strategies (average: \$10-13/ha). In contrast, inter-annual variability in GM in the HSR was far greater (C.V. =455%) with GMs negative in nine out of 20 years, compared to two (MSR and R/Spell) or three (Variable/Flexible strategies) out of 20 years for the other strategies.
6. After 20 years, accumulated gross margin in the HSR (\$106/ha) was by far the lowest of all strategies. In comparison, there was little difference in AGM between the other strategies range: (\$250-\$260/ha). Based on a 25 000 ha property this equates to an advantage of approximately \$3 million of these other strategies compared to heavy stocking.
7. In summary, the present data show that while heavy stocking may be profitable in the shorter term given good seasons, it is an extremely unprofitable strategy in the longer term.

8 Effect of grazing strategy on pasture yield, cover and species composition

8.1 Introduction

This chapter presents data on how pasture total standing dry matter (TSDM), ground cover and the contribution by weight of individual species groups to pasture TSDM changed under the different grazing strategies over the 20 years of the trial. Data on how pasture composition in terms of species *frequency* changed with the different strategies is presented in the next chapter.

8.2 Objective

To determine the long term effects of five different grazing strategies on pasture TSDM, species composition and ground cover.

8.3 Experimental procedure and statistical analysis

8.3.1 Data collection

Pasture total standing dry matter, the contribution by weight of species to yield and ground cover were assessed annually at the end of the dry (October/November) and wet (May) seasons using BOTANAL (Tothill et al. 1992). One hundred quadrat (0.25 m²) placements were made at regular intervals along each of two permanent transects that ran the length of each paddock, i.e. 200 quadrats per paddock. Depending upon paddock size, transects ranged from 1.7 to 3.5 km in length. The length of the transect across each soil type was roughly proportional to the percentage of that soil type in a particular paddock. Assessments were conducted by experienced operators, with the same operators being used across most years.

Each quadrat was classified according to soil-vegetation association. Major grasses were identified to the species level while less common species were identified to the genus level. Non-grasses were classified as forbs, sedges, native legumes or introduced legumes (*Stylosanthes scabra* and *S. hamata* spp.). Projected ground cover was scored according to a 6-class scale, i.e. 0-5%; 5-15%; 15-30%; 30-50%; 50-90% and > 90% cover. From 2002 onwards, the 50-90% class was subdivided into 50–75% and 75-90% making this a 7-class scale. Other data recorded but not presented in this report include ratings of quadrat defoliation area, defoliation intensity and *Carissa ovata* canopy cover.

For data analysis plant species were grouped into 10 functional groups based on life history traits, palatability, productivity and management significance (Table 8.1). 3P grasses are those that are 'perennial, palatable and productive' while 2P grasses are very loosely defined here as shorter lived, perennial species that are less productive and/or less palatable than 3P grasses.

Table 8.1: Species groups and associated species used in presentation of pasture composition data. Letters indicate the soil – vegetation association(s) on which each species commonly occurs (B=Box, C=heavy clays/Brigalow, I=Ironbark).

Species group	Species group members
3P grasses	<i>Bothriochloa ewartiana</i> (B,C), <i>Dichanthium fecundum</i> (B), <i>Dichanthium sericeum</i> (C), <i>Eulalia aurea</i> (C), <i>Heteropogon contortus</i> (I,B), <i>Themeda triandra</i> (B)
2P grasses	<i>Chloris</i> spp. (C,B), <i>Chrysopogon fallax</i> (B,I), <i>Digitaria brownii</i> , <i>D. ammophila</i> (B,I), <i>Enneapogon virens</i> (I), <i>Enteropogon acicularis</i> (B,C), <i>Eragrostis lacunaria</i> (I,B), <i>Eriochloa crebra</i> (C), <i>Leptochloa divaricatissima</i> (C), <i>Panicum effusum</i> (I,B), <i>P. queenslandicum</i> (C), <i>Paspalidium caespitosum</i> (C,B), <i>Sporobolus</i> spp. (C).
<i>Bothriochloa pertusa</i>	<i>B. pertusa</i> (B,C,I)
Annual grasses	<i>Brachyachne convergens</i> (C), <i>Dactyloctenium radulans</i> (C), <i>Echinochloa colona</i> (C), <i>Eragrostis</i> spp. (B,I,C), <i>Iseilema vaginiflorum</i> (C), <i>Mnesithea formosa</i> (I,B), <i>Schizachyrium fragile</i> (I,B), <i>Sporobolus australasicus</i> (C), <i>Tripogon loliiformis</i> (B,C) etc.
Aristida spp.	<i>Aristida benthamii</i> (I,B), <i>A. calycina</i> (I,B), <i>A. holathera</i> (I), <i>A. hygrometrica</i> (I), <i>A. ingrata</i> (I), <i>A. jerichoensis</i> (I), <i>A. latifolia</i> (C), <i>A. muricata</i> (I), <i>A. queenslandicum</i> (I,B),
Eriachne spp.	<i>Eriachne glauca</i> (C), <i>E. mucronata</i> (I), <i>E. rara</i> (I).
Sedges	<i>Cyperaceae</i> spp.(C), <i>Fimbristylis</i> spp. (B,I,C)
Forbs	<i>Asteraceae</i> spp. (I), <i>Brunonia australis</i> (I,B), <i>Goodenia</i> spp (I,B,C), <i>Hibiscus</i> spp. (B,C,I), <i>Malvastrum</i> spp. (B,C,I), <i>Polymeria</i> (I,C), <i>Sida</i> spp. (B,C,I), <i>Spermacoce</i> (I) etc.
Legumes	<i>Cassia absus</i> (I), <i>Desmodium</i> spp.(C,B), <i>Glycine</i> spp.(I,B), <i>Indigofera</i> spp (I), <i>Tephrosia</i> spp. (I,B), <i>Vigna lanceolata</i> (I), <i>Zornia</i> spp.(I,B), <i>Rhynchosia minima</i> (B,C)
Stylos	<i>Stylosanthes scabra</i> (I,B), <i>S. hamata</i> (I,B)

8.3.2 Statistical analysis

Data analysis focused on end of wet season (EOW) TSDM and end of dry season (EOD) cover as key variables of interest; the former because it determines the number of stock that can be carried through the dry season and the latter break-of-season ground cover directly determines runoff in the first, often high intensity, storms of the wet season. Analysis of changes in species composition focussed on 3P and 2 P grasses as they provide the bulk of pasture TSDM, as well as *Bothriochloa pertusa*. While *B. pertusa* is classified as a 2P species, it is of special interest due to its exotic status and ongoing expansion throughout north and central Queensland.

For statistical analysis the experimental unit was considered to be the area of the various paddock by soil type combinations. Although the exact same quadrats were not assessed in these areas, the quadrats were samples of the same area. As the same experimental unit was measured over time, the data were analysed using residual maximum likelihood (REML) using Genstat (v18). The appropriate random model was determined first then the fixed model was assessed. The random effects over time of replicate and paddock were tested using the random models (Rep/Pdk).Year and Rep.Pdk.Year. Various covariance models were trialled, including: Identity, Uniform, AR1 and AR1 allowing for heterogeneity across time. The AR1 models allows for serially

correlated errors. The most appropriate random model (for nested random models) was chosen through assessing the significance of the change in deviance between the two models using a chi square distribution. Non nested models were compared using the Akaike information criterion (AIC) value, with the lowest AIC value indicating the better model. Residual plots (residual versus fitted values and normal probability plots) were also used to check assumptions for the models. A natural logarithm transformation or square root transformation was applied where necessary to improve these residual plots to an adequate pattern. The initial fixed model was Trt * Year * Soil type. The significance of the interaction were tested through dropping the term from the model.

When these overall treatment effects were significant, pair-wise differences between treatments at each time, soil types at each time or treatment by soil type combinations were determined using least significant difference (Lsd). The appropriate variance and degrees of freedom were saved from the model fitting to ensure the appropriate Lsd.

8.4 Results

8.4.1 End of wet season pasture total standing dry matter

End of wet season TSDM varied markedly between years with TSDM declining from 5000-6000 kg/ha in early wetter years to less than 500 kg/ha in the first drought (Fig. 8.1). Pasture TSDM recovered substantially with improved rainfall post 2007 but despite exceptionally good rainfall in the years that followed, never recovered to the levels observed in the earlier years. For example, the highest yield in 2011 (3648 kg/ha) was barely half that in 1999 (6593 kg/ha).

Table 8.2: Repeated measures analysis for the effects of year, treatment (Trt) and soil type on end of wet season (EOW) total standing dry matter and end of dry season (EOD) cover for Phase 1 and Phase 2 treatments. (Yr=Year, Trt=Treatment)

	Phase 1: 1998-2010		Phase 2: 2011-2017	
	TSDM-EOW	Cover-EOD	TSDM-EOW	Cover-EOD
Year	<0.001	<0.001	<0.004	0.001
Treat	0.049	0.293	<0.001	0.628
Soil	<0.001	<0.001	<0.001	<0.001
Year*Tr	<0.043	0.392	0.005	<0.001
Year*S	<0.001	<0.001	<0.001	<0.001
Trt*Soil	0.148	0.089	<0.001	0.007
Yr*Trt*	0.275	0.239	0.207	0.080

From 2012 onwards TSDM fell steadily as rainfall declined, and by May 2015 had fallen to only 50 kg/ha in the HSR. With the exception of the HSR, which was very lightly stocked in 2015/16, pasture TSDM declined slightly further in 2016. Despite relatively good (554 mm) well distributed rainfall in 2016/17, yields remained low (<900 kg/ha) in all treatments (Fig. 8.1).

Pasture TSDM was also affected by soil type although the effect varied with year (year*soil type: $P < 0.001$; Table 8.2). In general however, TSDM tended to be highest in the Brigalow and lowest in the Ironbark soils. Although these differences were quite marked in some years (data not shown), average TSDM for the Ironbark, Brigalow and Box soils for the 20 years were relatively similar i.e. 1896 kg/ha, 2035 kg/ha and 1940 kg/ha respectively.

The effect of treatment on TSDM was inconsistent and varied with year (Table 8.2) as indicated by the significant treatment by year interaction in both Phase 1 ($P < 0.043$) and Phase 2 ($P < 0.001$). However, in nearly all years, TSDM was substantially higher in lighter stocked strategies like the MSR or R/Spell and lowest in heaviest stocked strategies, usually the HSR. Treatment differences

amplified as time progressed (Fig. 8.1). For example, despite very good rainfall from 2009 to 2011, average TSDM in the MSR and R/Spell (3241 kg/ha) was almost twice that in the HSR (1770 kg/ha). These differences were even greater in dry years when HSR paddocks were often totally devoid of grass.

Table 8.3 Phase 2: Average end of wet season (EOW) total standing dry matter for the three main soils at the Wambiana trial. Statistical comparisons are for within soil types only: yields sharing the same letter are not significantly different (P=0.05). Note these letters relate to means on the log transformed scale.

Soil type	Ironbark	Box	Brigalow
Treatment	EOW season TSDM (kg/ha)		
Flex	1035 b	1094 bc	1029 b
Flex+S	1128 b	1057 b	1540 c
HSR	423 a	492 a	546 a
MSR	1227 b	1399 bc	1360 bc
R/Spell	1240 b	1459 c	1600 c

The effect of treatment also varied with soil type (P<0.001) in Phase 2. In the MSR and Flex, TSDM was highest on the Box and Ironbark, but in Flex + S and R/Spell pasture TSDM was highest on the Brigalow soils (Table 8.3). This aspect requires more detailed investigation and will not be discussed further.

8.4.2 End of dry season ground cover

End of dry season (EOD) cover changed markedly over the course of the trial (Fig. 8.1). EOD cover was high (60-70%) in earlier, wetter, years with only a minor, transient fall in cover in 2000 following the 1999 fire. Although rainfall declined markedly in 2002, cover remained relatively high in most treatments, presumably due to litter fall from trampling and detachment. Thereafter, cover fell significantly, remaining below 40% between 2003 and 2007. In subsequent wetter years, cover increased three to five fold, to average around 60% between 2008 and 2012, before declining again in the subsequent drought. Interestingly, cover did not decline to the same extent as in the previous drought. This possibly reflects the expansion of *B. pertusa* through the trial post-2007.

The effect of treatment on cover varied across years as shown by the significant (P<0.001) year*treatment interaction in both phases (Table 8.2). Although the performance of individual treatments per se was inconsistent, in most years cover was lowest in heavily stocked strategies, with this effect greatest in drier years. EOD cover was thus highest in the moderately stocked MSR and R/Spell strategies in 14 of the 19 years, but lowest in the HSR in nine of the 19 years in which EOD cover data are available. This effect was particularly evident in droughts with cover in the HSR declining to as low as 11% in 2006. As with TSDM, relative EOD cover in the Variable/Flexible strategies depended on the stocking rate applied. Nevertheless, EOD dry season cover still declined below 40% in five of the 20 years within the more lightly stocked strategies. Note that in 2016, EOD cover was actually lowest in the MSR and R/Spell strategies; this was because their nominally 'moderate' stocking rates (12.5 AEs/100ha) were, at that stage, relatively high compared to the other treatments.

The effect of treatment on cover varied across soil types (p=0.007) in Phase 2, with the tendency for EOD cover to be the highest on Box (51%) and lowest on Ironbark (44%).

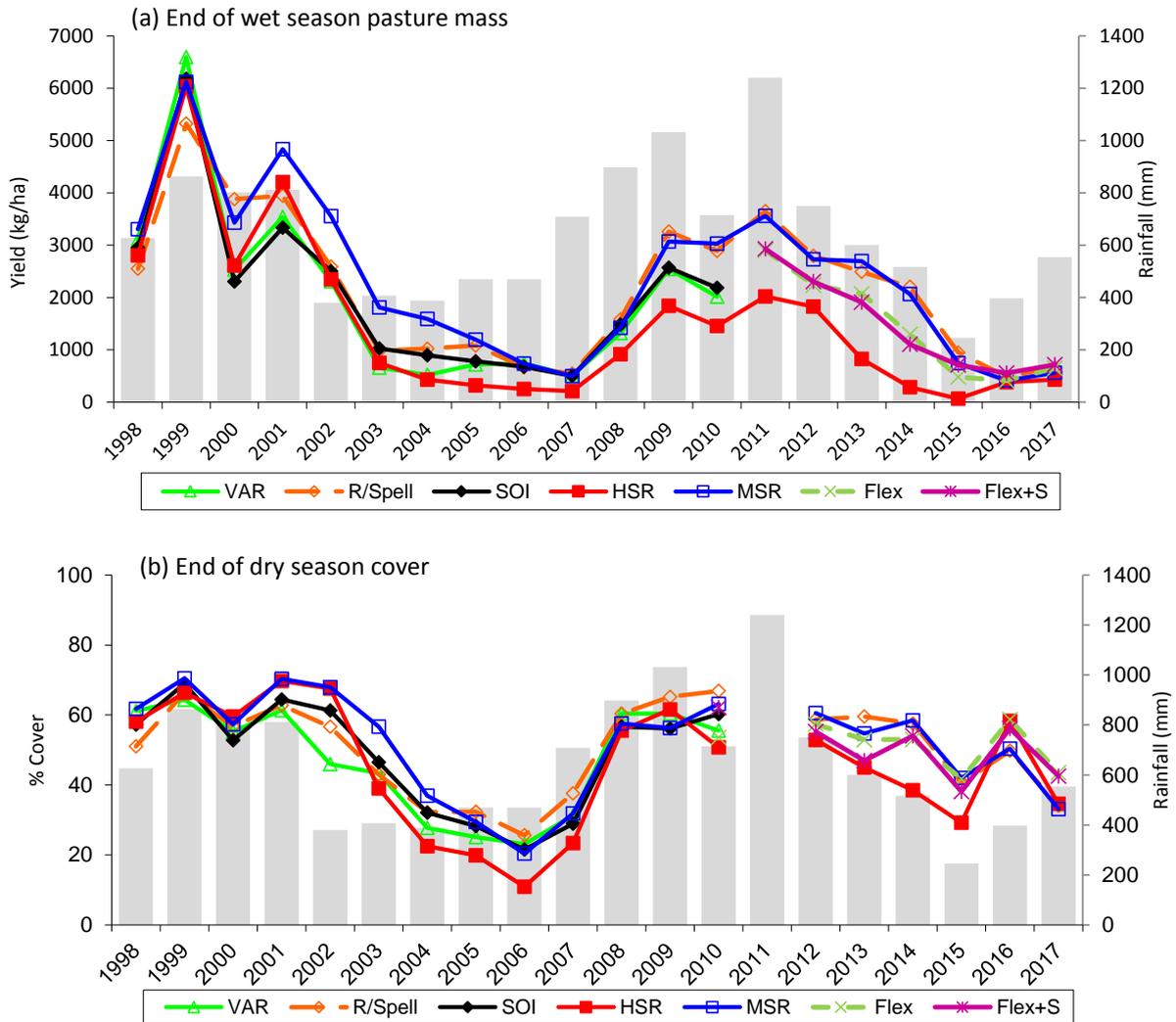


Fig. 8.1: Change in (a) end of wet season total standing dry matter and (b) end of dry season ground cover with rainfall in the five stocking strategies between 1998 and 2016/17. Treatment abbreviations as before. Note new treatments post 2010. In 2011, dry season cover was not measured due to the October fire that year.

8.4.3 Species contribution to yield

8.4.3.1 Overall changes in pasture species composition and yield

To illustrate the overall change in pasture species composition in the different grazing strategies over the course of the trial, five key, sentinel years contrasting widely in seasonal conditions were selected (Table 8.4).

Table 8.4 Sentinel years and associated two year drought indices -see text for details.

Sentinel Year	Drought index (DI)	Description
1999	+0.30	Second year of trial; good (883 mm) well distributed rainfall.
2007	-0.53	Final year of 6 year drought period.
2011	+0.99	Extremely wet year (1221 mm); mid- point of 5 year above-average rainfall period.
2015	-0.82	Extreme drought; fourth driest year (246 mm) in 105 years.
2017	-0.55	Below average (553 mm) but well distributed rainfall; year 20 of trial.

Pasture TSDM in 1999 was exceptionally high (average: 6051 kg/ha) due to good seasonal conditions (DI=+0.30) and comprised largely of *Aristida*, 3P grasses and to a lesser extent, 2P grass species. There were few if any treatment differences apart from minor variation in starting conditions between paddocks. Note that there was virtually no *B. pertusa* present in 1999.

Following six drought years, pasture TSDM in 2007 (DI=-0.53) was substantially lower (average: 445 kg/ha) and less than a tenth of that in 1999 (Fig. 8.2). Although the yields of all species declined, the collapse of *Aristida* yields was particularly pronounced. Treatment differences were also apparent in terms of both TSDM and species composition with a TSDM of only 206 kg/ha in the HSR. The 3P yield in the HSR (20 kg/ha) was only a tenth of that in other treatments (range: 175-227 kg/ha). Overall, the percentage contribution of 3P species to yield (3P%) was highest in the MSR and R/Spell (44%), slightly lower in the VAR and SOI (34%), but by far the lowest in the HSR (10%). In the HSR the percentage contribution of 2P species to yield (2P %) also increased relative to 1999. Note that *B. pertusa* was still almost absent in 2007.

By 2011 (DI= 0.99), pasture TSDM was far higher (average: 3011 kg/ha) than in 2007, but nevertheless only about half that in 1999. Despite the good conditions, treatment differences persisted with 3P yields in the HSR only a third to half that of remaining treatments. The 3P% in the HSR was also only 26% or just over half that in other treatments (range: 42 - 49%). Within the latter, 3P yields were highest in the R/Spell (1808 kg/ha) and lowest in the Flex (1297 kg/ha).

The most dramatic change however, was the huge increase in *B. pertusa*. Although this occurred across all treatments, the greatest increase occurred in the HSR with *B. pertusa* comprising 20% of pasture yield in 2011. Although this figure was lower (6-11%) in the other treatments, it is nevertheless a five-to-six fold increase in percent contribution from 2007 to 2011. Legume (largely stylo) yields also increased markedly in the MSR, R/Spell and Flex from only 2-16 kg/ha in 2007 to between 314–598 kg/ha or 10-16% of yields in 2011.

By May 2015, pasture TSDM had declined again in all treatments (average: 588 kg/ha) due to drought (DI=-0.82). Stark treatment differences were also evident, with the HSR having the lowest (64 kg/ha) and the R/Spell highest (945 kg/ha) TSDM. 3P yields were also effectively zero in the HSR (14 kg/ha). In the remaining treatments, 3P yields were highest in the R/Spell (734 kg/ha or 78% of yield) and lowest in the Flex (305 kg/ha or 63% of yield), with little difference between the MSR and Flex+S. In the HSR the percentage contribution of 3P species (21%) was thus only about a third but conversely that of 2P grasses was four-to-five fold higher than in other treatments. The percentage contribution of *B. pertusa* in the HSR (17%) to yield was also six-to-eight fold greater than in other treatments (range: 1 - 2%).

By May 2017 (DI=-0.55), pasture composition had changed dramatically with 3P% declining markedly in all treatments. Again, 3P yield (39 kg/ha) and 3P% (9 %) were lowest in the HSR, with few obvious differences between other strategies. In contrast, 2P% as well as the % contribution

of *B. pertusa* and legumes increased across all strategies to comprise 25 to 35% of pasture mass by 2017. Surprisingly, while the proportion of *B. pertusa* in the HSR was highest (26%), this was only marginally higher than that in the R/Spell and Flex+S (19%). The % contribution of forbs also increased in 2017, particularly in the HSR (13%) while legumes, mainly stylo, also recovered in the MSR and R/Spell to 2011 levels. Overall, while species composition and yield was markedly different in the HSR, there were few obvious differences between the remaining treatments.

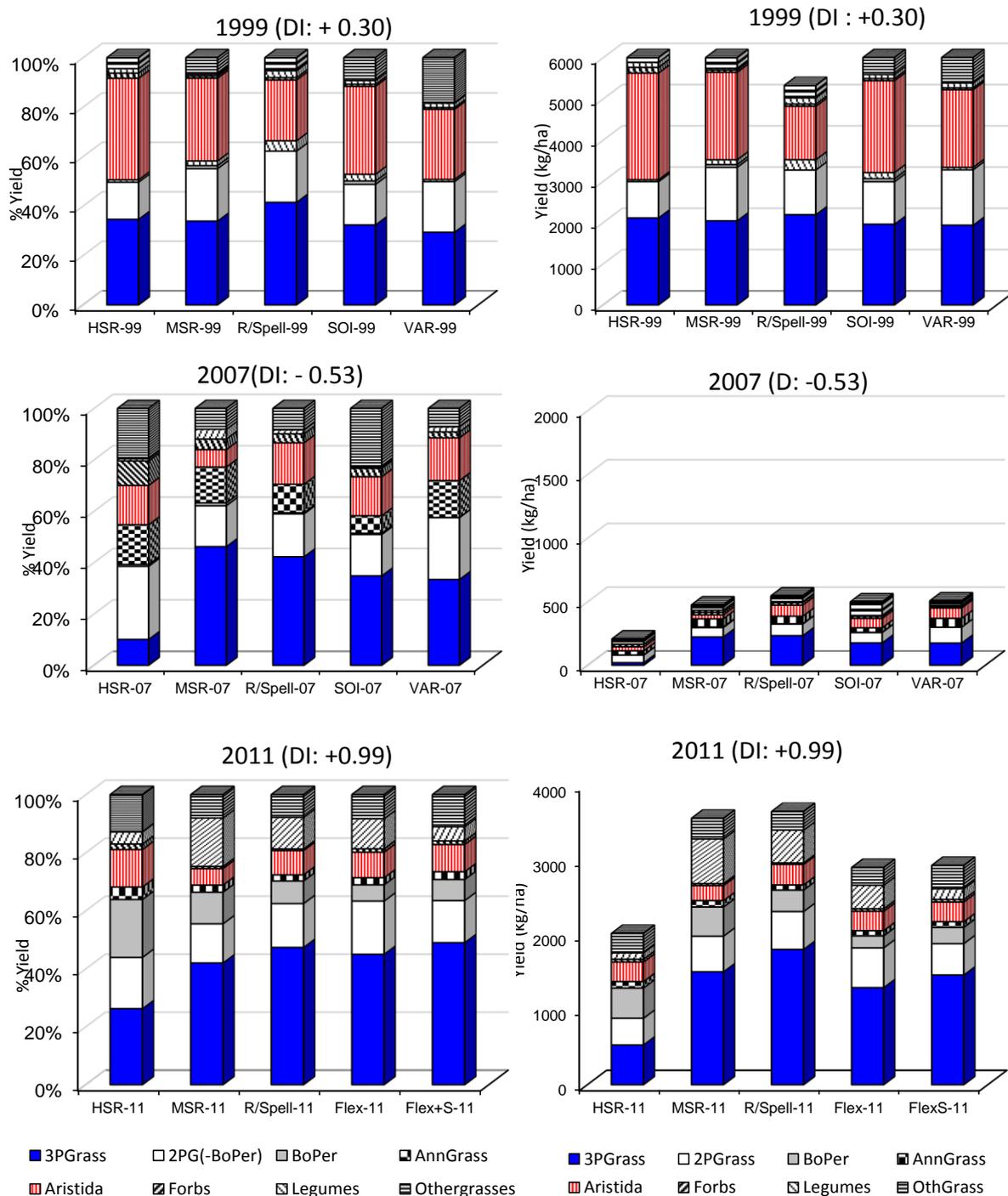


Fig. 8.2 Pasture species composition expressed as percentage contribution to yield (left) and species yield (right) in 1999, 2007 and 2011. Note the differences in the scale of axes between years. Treatment abbreviations as before. DI= drought index, AnnGrass= annual grasses, BoPer= *B. pertusa*, 3PGrass = 3 P grasses, 2PG (-BoPer) = 2 P grasses excluding *B. pertusa*, Others= other grasses; see text for details.

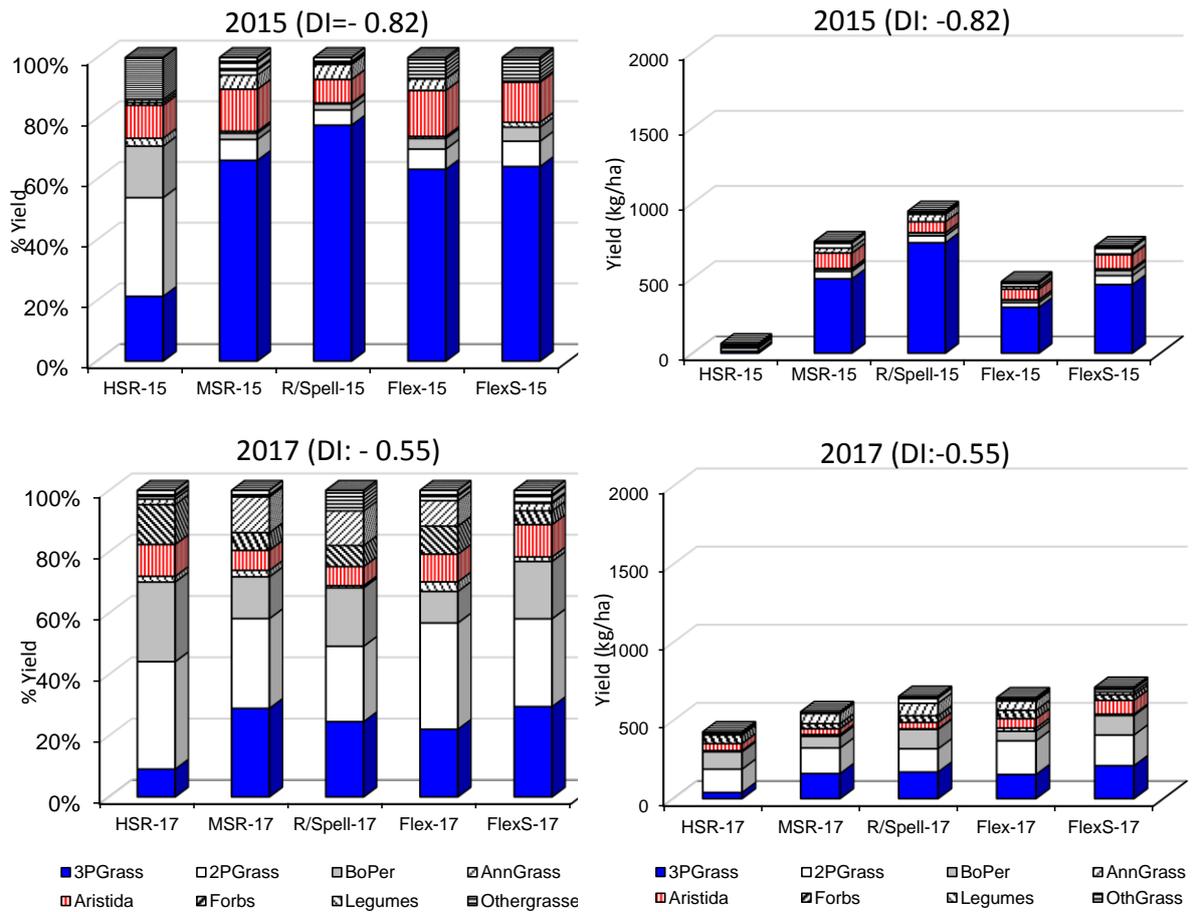


Fig. 8.3 Pasture species composition expressed as percentage contribution to yield (left) and species yield (right) in 2015 and 2017. Note the differences in the scale of axes between years. Treatment abbreviations as before. DI=drought index, AnnGrass= annual grasses, BoPer= *B. pertusa*, 3PGrass = 3 *P* grasses, 2PG (-BoPer) = 2 *P* grasses excluding *B. pertusa*, OthGrass= other grasses; see text for details

8.4.3.2 Response of individual species groups

8.4.3.2.1 3P grasses

3P grass yields and their percentage contribution to TSDM changed markedly over time, largely in response to rainfall (Fig. 8.4). In the first four relatively wet years, 3P grass yields were high (1500-2000 kg/ha) comprising 30-40% of pasture composition but by 2007, had declined markedly due to drought, with yields as low as 200 kg/ha. With increased rainfall post-2007, the yield of 3P species and 3P% recovered substantially in all treatments, before again falling sharply in the second drought post-2012. These changes over time also interacted significantly ($P < 0.001$) with soil type but this aspect is of secondary interest and will not be discussed further.

The effect of treatment on 3P grass composition (3P %) varied markedly with time ($P < 0.001$) in both Phase 1 and Phase 2 (Table 8.5). Although initially relatively small, treatment effects emerged within two years (2000) of the start of the trial. However, with the onset of drought in 2002, treatment differences widened with 3P% in the HSR declining from 47% in 2003 to only 10% in 2007 (Fig. 8.5). Whilst 3P% also declined in other treatments, the decline started a year later and was less pronounced than in the HSR. Over the 2003 to 2007 drought, 3P% was highest in the MSR followed by the R/Spell, intermediate in the VAR and SOI, and by far the lowest in the HSR.

Table 8.5 Significance of model terms from repeated measures analysis for the effects of year, treatment and soil type on the % contribution of 3P grasses, 2P grasses and *B. pertusa* to end of wet season DM yield for Phase 1 and Phase 2 treatments. NB: In Phase 1 *B. pertusa* formed a minor part of yields and was included with the 2P grasses.

	Phase 1: 1998-2010		Phase 2: 2011-2017		
	3PG	2PG	3-PG	2PG	BoPer
Year	<0.001	<0.001	<0.004	0.001	<0.001
Treatment	0.001	0.018	<0.041	0.282	<0.001
Soil type	<0.001	<0.001	<0.001	<0.001	<0.001
Year*Trt	<0.001	0.019	<0.001	0.408	0.039
Year*Soil	<0.001	0.005	<0.001	0.022	0.050
Trt*Soil	0.721	0.002	0.003	0.003	0.012
Yr.*Trt*So	0.668	0.499	0.999	0.450	0.050

With good rains post 2007, 3P yields increased in all treatments. Despite this, treatment differences persisted; even when 3P yields were at their peak in the HSR in 2011 (531 kg/ha) this was only a third to half that in other treatments (range: 1297–1808 kg/ha). Similarly, the peak 3P% in the HSR (40%) in 2014, was still considerably lower than that in the Flex (55%), the Flex+S (62 %) or the MSR and R/Spell (65%).

With the onset of the second drought after 2012, 3P yields slumped again with 3P% falling by an average of 25% percentage points across all treatments. As before, the decline started a year earlier in the HSR with 3P% falling from 2014 onwards to only 9% in 2017. Although the subsequent decline in 3P% was greater in other treatments, the contribution of 3P species to yield in 2017 in these treatments (22-29%) was still two-to-three fold larger than in the HSR.

The effect of treatment also varied with soil type ($P < 0.001$), at least in Phase 2 (Table 8.5). On all three soil types the 3P% in the HSR was markedly and significantly ($P < 0.05$) lower than the other treatments. The MSR and R/Spell tended to have the highest 3P% and were about 10 percentage points higher than the Flex and Flex+S on the Box and Ironbark soils, but these differences were non-significant. In contrast, there was little or no difference in the 3P % between these four, better managed treatments for the Brigalow soils (Table 8.6).

Table 8.6 Mean percentage contribution of 3P grasses, 2P grasses and *B. pertusa* to end of wet season yield on Box, Brigalow and Ironbark soils for the five treatments in Phase 2 of the Wambiana trial. Data are means over the years 2011 to 2017. Species means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Box	Brigalow	Ironbark
	3P grasses (%)		
Flex	52 c	58 d	22 b
Flex+S	51 c	59 d	22 b
HSR	28 b	32 b	16 a
MSR	60 c	61 d	33 b
R/Spell	60 c	59 d	34 b
	2P grasses (%)		
Flex	17 ab	13b	18 ab
Flex+S	16 ab	10 b	20 a
HSR	24 a	20 a	17 ab
MSR	13 bc	9 b	14 bc
R/Spell	12 bc	11 b	17 bc
	<i>B. pertusa</i> (%)		
Flex	8 bc	8 b	2 c
Flex+S	11 b	10 ab	4 bc
HSR	24 a	14 a	16 a
MSR	6 c	8 b	4 bc
R/Spell	7 c	8 b	3 bc

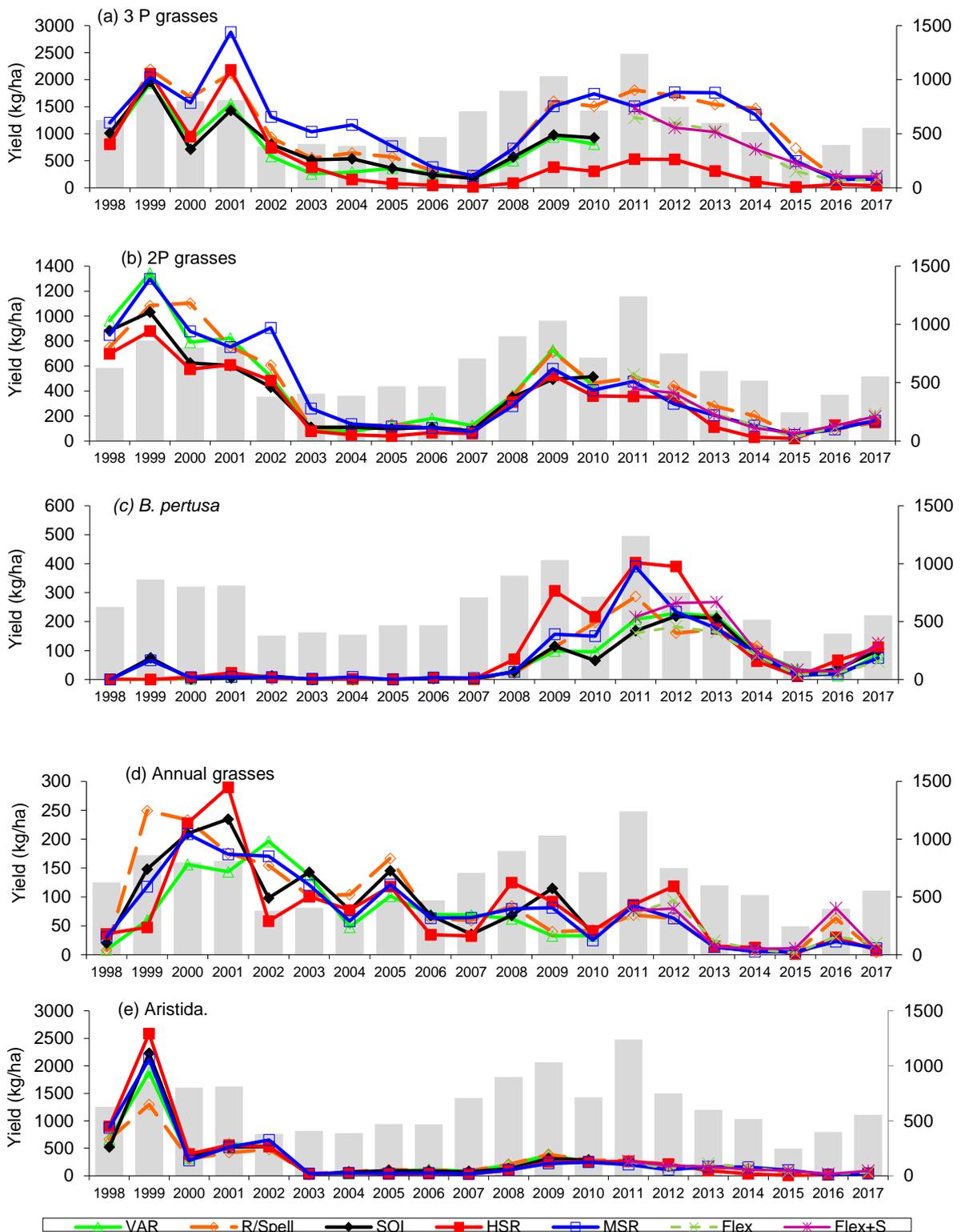


Fig. 8.4 Yield of (a) 3P grasses, (b) 2 P grasses, (c) *B. pertusa* (d) annual grasses and (e) *Aristida* spp in different strategies, and annual rainfall in mm (bars) from 1998 to 2017. Treatment and species group abbreviations as before.

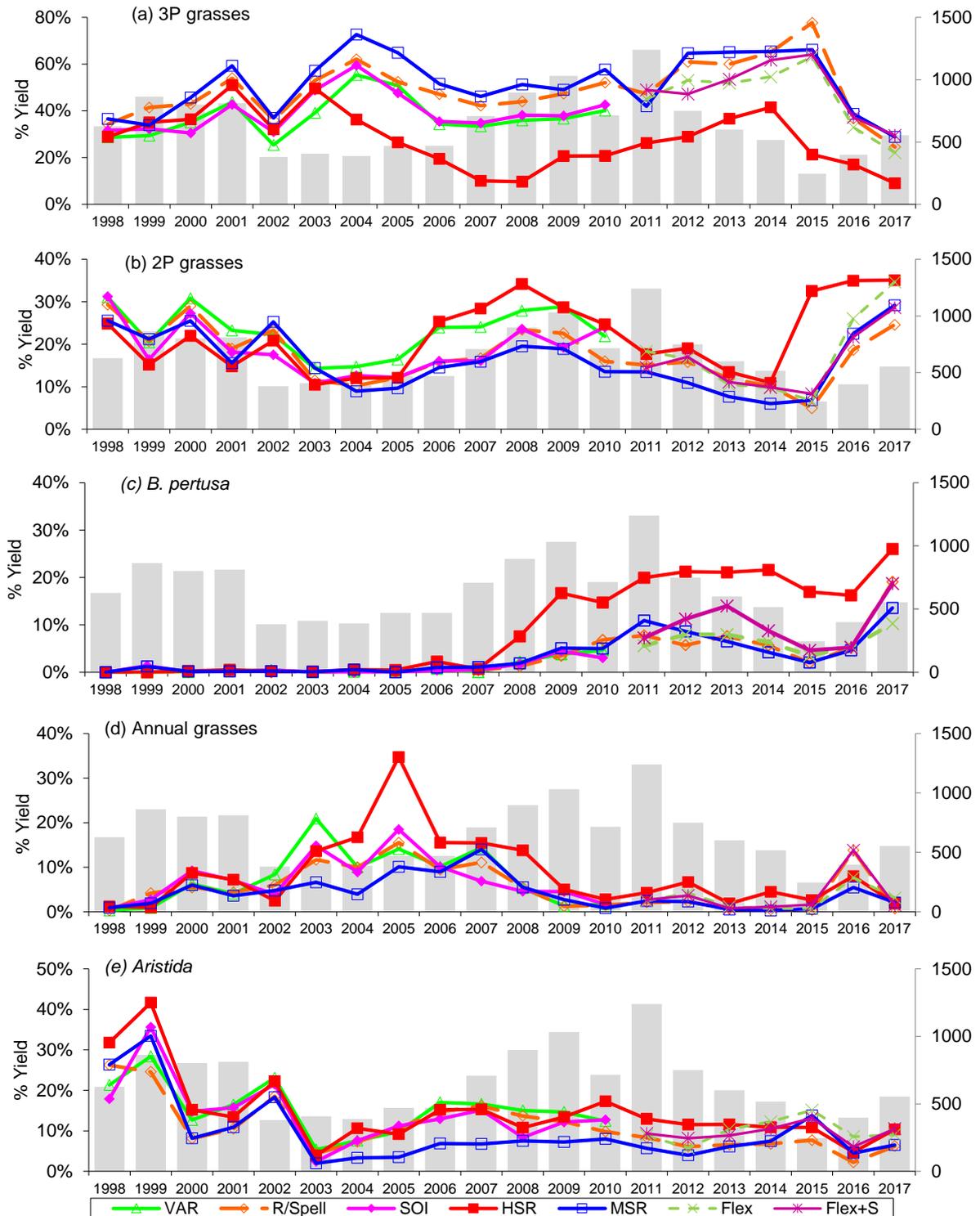


Fig. 8.5 Percentage contribution to end of wet season pasture yield of (a) 3P grasses, (b) 2 P grasses, (c) *B. pertusa* (d) annual grasses and (e) *Aristida* spp to yield in different strategies, and annual rainfall in mm (bars) from 1998 to 2017. Treatment and species group abbreviations as before.

8.4.3.2.2 2-P grasses

2P grass yields changed markedly over time with peak production in wet years, and major collapses in dry years (Fig. 8.4). Like 3P species, the peak in 2P yields in the second wet period (2009) was markedly lower (500 - 700 kg/ha) than that observed in the first (800-1300 kg/ha). The % contribution of 2P species to total yield (2P%) also varied with time. Treatment effects on 2P% varied significantly ($P < 0.001$) with year in Phase 1 (Table 8.5). Treatment differences were initially minor but widened later with drought: from 2006 onwards, the HSR had the highest or joint highest 2P% of all treatments. This was most noticeable from 2015 onwards when 2P species comprised almost 30% of the yields in the HSR. In contrast, the MSR generally had the lowest 2P % of all treatments from 2004 to 2014. Despite this, the actual 2P yields as opposed to % contribution to yield were usually by far the lowest in the HSR.

Although 2P% also increased sharply in other treatments late in the trial period, the increase was smaller and occurred a year later than in the HSR (2016 vs 2015). While there was a modest increase in actual 2P yields after 2015, the increase in 2P% is more likely a reflection of the low 3P yields in those years, rather than any indication of increased dominance by 2P grasses.

Treatment effects on 2P% also varied significantly (Table 8.5) with soil type in both Phase 1 ($P < 0.002$) and Phase 2 ($P < 0.003$) of the trial. Accordingly, the 2P% was highest ($P < 0.05$) in the HSR on the Box and Brigalow soils (Table 8.6). In contrast, on the Ironbark, 2P% was highest ($P < 0.05$) in the Flex+S treatment, with only minor differences amongst other treatments.

8.4.3.2.3 *Bothriochloa pertusa*

Bothriochloa pertusa initially comprised less than 2% of pasture yields but following the first drought, increased dramatically to become a significant component of pasture yield (Fig. 8.4). Averaged over all treatments and soils *B. pertusa* thus increased from 2 kg/ha (1% of yield) in 2007 to 440 kg/ha (19% of yield) in 2011.

The effect of treatment on the percentage contribution of *B. pertusa* to yield (*B. pertusa* %) was inconsistent and varied significantly ($P < 0.05$) with year and soil type (Table 8.5). Although there was variation in the relative *B. pertusa* levels in other treatments, from at least 2008 onwards *B. pertusa* % was by far the highest in the HSR. Analysis of Phase 2 data shows that this difference was significant in nearly all years (Table 8.7). *B. pertusa* also increased from 2008 onwards in other treatments, but the rate and extent of increase was far less than that in the HSR. For example, while *B. pertusa* yield in the MSR in 2011 was 390 kg/ha this was only 11% of total pasture yield.

The effect of treatment also varied with soil type; nevertheless on all three soil types the *B. pertusa* % was consistently highest in the HSR (Table 8.6). The relative performance of the other treatments varied somewhat between soil types. On the Box soil, the *B. pertusa*% in the Flex (11%) was significantly higher than the R/Spell (7 %) and MSR (6 %). However, on the Ironbark and Brigalow soils there were few if any differences between these other treatments.

B. pertusa yields in all treatments declined sharply post 2012 to only 40 kg/ha in 2015, before partly recovering in 2017. The recovery in *B. pertusa* % in particular, to levels similar to or even above pre-drought levels, suggests that the grass will increase further when good seasons return.

Table 8.7 *B. pertusa* percentage of yield (averaged across soil types) in different Phase 2 treatments from 2011 to 2017. Means followed by the same letter are not significantly different ($P < 0.05$). Treatment abbreviations as before.

	2011	2012	2013	2014	2015	2016	2017
	Percentage of yield (%)						
Flex	5.3 a	7.1 a	7.2 a	7.5 a	3.36 a	4.3 a	7.4 a
Flex+S	6.5 a	10 ab	14.4 a	8.4 a	3.70 a	3.8 a	16.9 cd
HSR	19 b	15 b	19.8 b	16.7 b	21.9 b	14.1 b	23.3 d
MSR	10.8 a	8.4 ab	5.1 a	4.2 a	2.0 a	4.5 a	11.7 bc
R/Spell	6.6 b	5.0 a	6.8 a	5.3 a	1.9 a	4.4 a	19.2 cd

8.4.3.2.4 *Annual grasses*

Annual grass (AG) yields were generally very low, peaking in early wetter years at 200-250 kg/ha (Fig. 8.4). Thereafter, yields fluctuated markedly, but generally declined as the trial progressed. Although the percentage AG contribution to yield (AG%) was initially low (range: 2-12%), a pronounced treatment-dependent increase occurred through the first drought. This was most pronounced in the HSR with AG forming 35% of the yield in 2005 compared to only 10% in the MSR. Although the AG% later declined across all treatments, in most years the HSR had the highest AG%. Annual grass yields recovered briefly in some treatments in 2016 before collapsing again in 2017 (Fig. 8.4).

8.4.3.2.5 *Aristida spp*

Aristida yields were initially extremely high, peaking at 1800 to 2500 kg/ha or 30-40% of pasture composition in 1999 (Fig. 8.4). However, yields plummeted to around 400 kg/ha in 2000 following the October 1999 fire. While some recovery occurred in the next two years, mass mortality of *Aristida* occurred in 2003 due to drought, with yields collapsing to almost zero. *Aristida* yields slowly recovered thereafter, to peak at around 300 kg/ha (10-15% composition) in 2009, before declining subsequently partly due to the 2011 fire, but more importantly due to the later drought.

The percentage contribution of *Aristida* to yield tended to be lowest in the MSR or R/Spell and highest in heavily utilised treatments like the HSR and, in some earlier years, the VAR strategy. Thus, while *Aristida* seemed to be favoured by higher utilisation rates, its response was relatively muted, suggesting that it is a weak increaser species (Fig. 8.4).

8.4.3.2.6 *Stylosanthes spp.*

Stylosanthes (Seca and Verano) initially comprised less than 5% of pasture composition. Yields declined further during the first drought, but levels increased sharply after 2007, in a treatment and soil dependent fashion. The greatest increases were on the Ironbark in the MSR and, to a lesser extent, the R/Spell strategies, with yields of up to 400-500 kg/ha, forming 10-30% of pasture composition. Despite declines following the 2011 fire and the later drought, by 2017 stylo formed 15-20% of yields in the R/Spell and MSR paddocks. While average stylo yields in the VAR/Flex strategy were also relatively high, these were largely confined to one replicate of this treatment. Stylo levels were by far the lowest in the HSR and Flex strategies; this is probably due to grazing pressure in the HSR, but in the Flex may simply reflect pre-trial differences in stylo density.

8.4.3.2.7 *Native legumes*

Overall, the yield of native legumes was very low and comprised an insignificant part of pasture composition (Fig. 8.7). Although the yield of native legumes increased sharply in 2000 after the 1999 fire, this effect was relatively transitory with yields declining to very low levels by 2003 (Fig. 8.6). Interestingly, there was no similar increase in native legume yields following the second

fire in 2011. Aside from the fact that the yield of native legumes was markedly higher in the MSR and the R/Spell in 2000, there appeared to be no obvious treatment effect on this species group.

8.4.3.2.8 Forbs

Forbs typically formed an extremely small proportion of yield (approx. <5%) but this amount varied between years and treatments (Fig. 8.1). In general, the forbs % tended to be higher during, or in the years immediately following drought and highest under heavy stocking. For example, in the first drought, the forb % in the HSR increased to 10%, i.e. two to four times greater than in other treatments. Similarly, while the forbs % increased in all treatments later in the second drought as conditions improved, the greatest increase occurred in the HSR (Fig. 8.1).

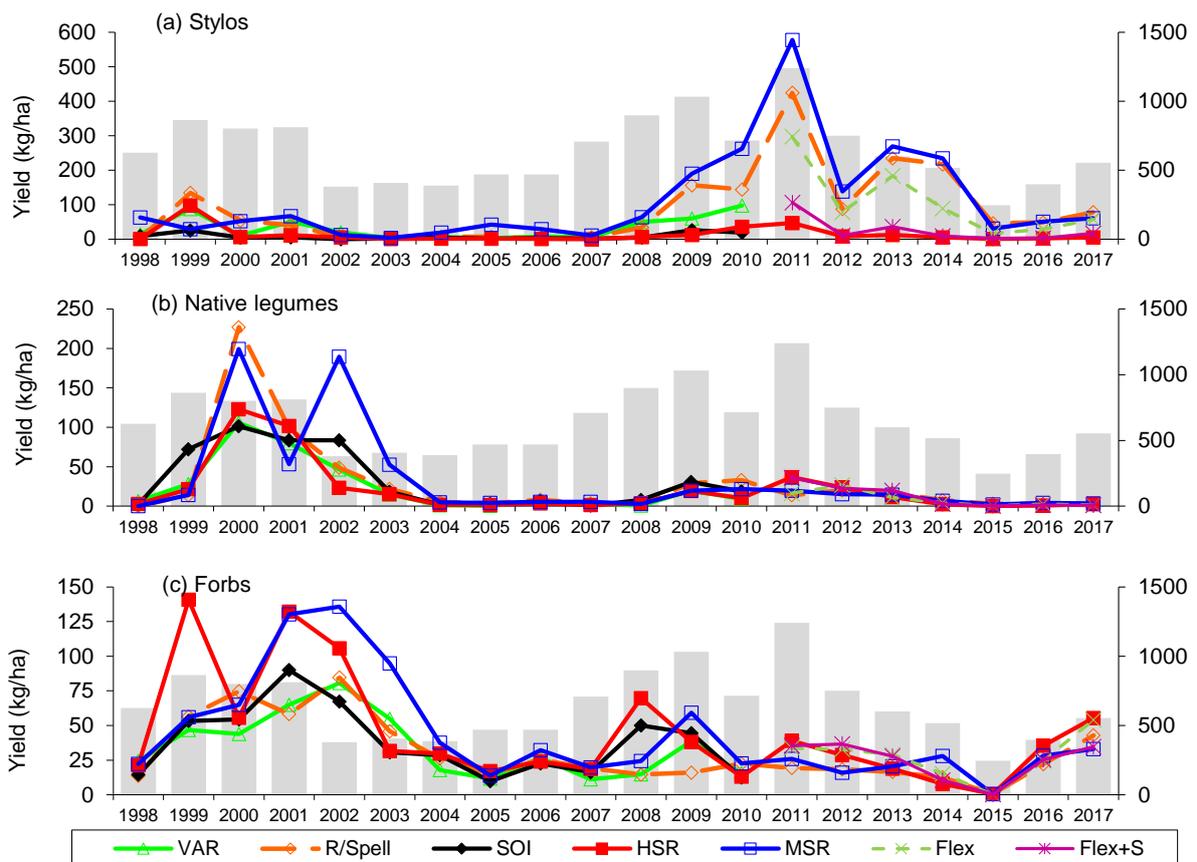


Fig. 8.6 Yield of (a) *Stylosanthes* spp., (b) native legumes and (c) forbs in different strategies, and annual rainfall in mm (bars) from 1998 to 2017. Treatment abbreviations as before.

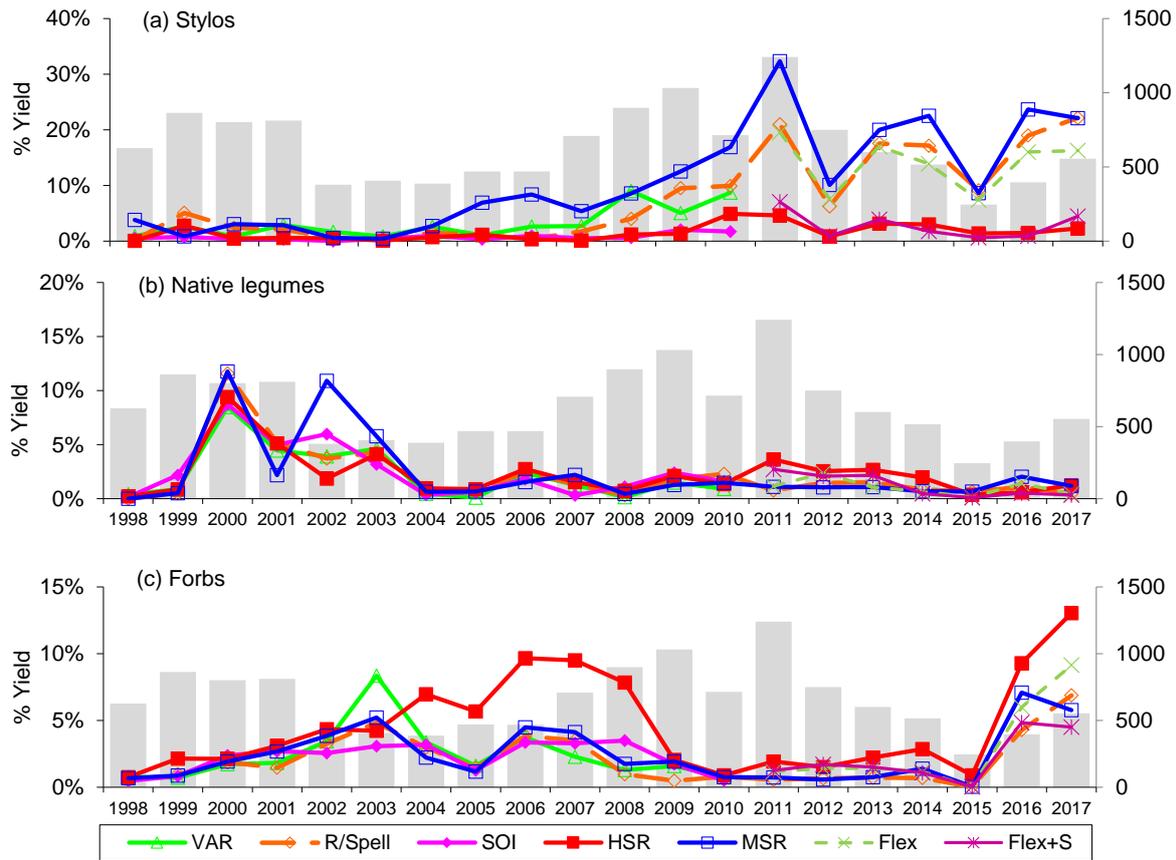


Fig. 8.7 Percentage contribution to end of wet season pasture yield of (a) *Stylosanthes* spp., (b) native legumes and (c) forbs in different strategies, and annual rainfall in mm (bars) from 1998 to 2017. Treatment abbreviations as before.

8.5 Discussion

Pasture production varied sharply over the 20 year experimental period in response to major variations in rainfall. Overall, pasture TSDM varied from 5000-6000 kg/ha to as little as 200 kg/ha, a variation of approximately 30-fold in TSDM. Although primarily rainfall driven, this was also strongly affected by treatment, with variability in TSDM increasing as stocking rates increased. The total variation in pasture TSDM over the 20 year period for the HSR (95 fold) was thus far greater than in other treatments (average: 13 fold). The inter-annual variation in EOW pasture TSDM in the HSR (Coefficient of variation (C.V.) =104%) was also much higher than in the MSR (C.V. = 65%) and R/Spell (C.V. = 63%). This illustrates how poor grazing management amplifies the effects of inherent rainfall variability (C.V. =38%) on forage availability, further increasing the challenge of managing in a variable climate.

The increased variability in TSDM in heavier stocked strategies undoubtedly resulted from first, lower rainfall use efficiency resulting from reduced soil surface condition, lower cover and reduced infiltration and greater runoff. And secondly, the decline in the longer lived, more drought tolerant and productive 3P grasses (Fig. 8.5). While these were largely replaced by 2P grasses, annuals and forbs, these latter species are all far less drought tolerant and productive than the 3P species.

A striking feature of the present results is how TSDM generally declined with time across the experiment. This is evidenced by the fact that after the first drought, pasture TSDM never recovered to the levels observed in the initial years, despite very good seasons between 2008 and

2012. For example, in 2011 the highest pasture TSDM (3648 kg/ha) was barely half that in 1999 (6593 kg/ha).

Significantly, this decline was not confined to the HSR but occurred across all treatments, so cannot be simply ascribed to the obvious outcome of high pasture utilisation rates e.g. (Ash et al 2011). There are a number of possible, not necessarily mutually exclusive, explanations to explain the present result. These include first, the increased competition from woody species with time, resulting primarily from the marked increase in *Carissa ovata* over the trial period (O'Reagain unpublished data). This occurred mainly on the Box soils but also on many clay areas. Second, the extremely high pasture yields in the early years may reflect a major spike in soil nitrogen availability following the severe 1990s drought that predated the trial; if so, it is puzzling why this did not also occur in the second wet period following the 2003 – 2007 drought.

Third, the 1040 ha trial area was previously part of a very large, relatively poorly watered, paddock. The creation of small paddocks with closer spacing of waters, may have increased grazing intensity and utilisation rates far above those previously experienced. This may have led to a loss of pasture vigour and an overall decline in productivity. However, the wet season spelling regime in the R/Spell and in the Flex+S in Phase 2, might have been expected to increase pasture productivity over time, at least in these treatments. At present, the most plausible reason for the observed decline in pasture yields is probably the increase in woody competition with time.

Like TSDM, cover also changed markedly over the trial period. This was mainly in response to rainfall, with cover falling to very low levels in dry years, particularly the 2003-2007 drought. It is noteworthy that although the second drought post 2012 was more severe, cover did not decline to the same extent as in 2006. This probably reflects the expansion of the stoloniferous *B. pertusa* through the trial post-2007, which would have increased cover levels across all treatments to varying extents.

Cover was also significantly affected by treatment with cover lowest on the heaviest stocked strategies. Note however, that even in the 'better' managed treatments, cover still declined to very low levels in droughts, falling < 40 % in a number of years (Fig. 8.1). This is significant, as it relates directly to the target cover levels of 70% at the end of the dry season to reduce runoff to the GBR lagoon (Anon. 2013 p.16), although it is acknowledged that these targets 'may be ambitious in drought years'. The present results suggest that even under good management, these target cover levels would be unachievable in all but the best of years.

Species composition also varied markedly with rainfall, but marked treatment effects were also obvious. Overall, 3P yield and the percentage contribution to yield of 3P species was lowest in the HSR and declined faster and to lower levels in drought compared to other strategies. Yields also recovered more slowly and to lower levels in wetter cycles than in more moderately stocked strategies. Within remaining treatments, in most years, 3P yields and 3P% were generally higher in the MSR and R/Spell than in the two flexible strategies. Although these two flexible strategies have been relatively well managed, both were still recovering from the severe over-utilisation of these paddocks that occurred going into the 2002 drought (O'Reagain *et al.* 2008).

By 2017 however, most of the differences between the MSR, R/Spell, Flex and Flex+S treatments appeared to have disappeared. This could be attributed to first, the drought induced mortality of 3P grasses in all treatments observed in 2016. This, together with the explosion of 2P species in the 2016/17 season across all paddocks, would have tended to minimise treatment differences. Second, the higher stocking rates in the MSR and R/Spell through the drought, relative to those in the two flexible treatments. This higher utilisation rate combined with drought stress may have caused pasture condition in the MSR and R/Spell to decline to the levels of those in the latter treatments. The extent to which this may or may not have occurred will only be definitively

known once good seasons return and the degree of recovery of the different treatments can be quantified.

8.6 Summary

1. Pasture TSDM changed dramatically over the 20 years of the trial from around 5000-6000 kg/ha in early wet years to well below 1000 kg/ha in the first drought cycle. TSDM recovered in the next wet cycle but then fell sharply in the second drought post-2013.
2. Changes in TSDM were largely rainfall driven but were also strongly influenced by grazing strategy. TSDM was consistently higher in the MSR and R/Spell than in the HSR in most years. Treatment effects were exacerbated in dry years with TSDM declining faster and to lower levels in the HSR compared to other treatments.
3. Inter-annual variability in TSDM increased with stocking rate, with the coefficient of variation in the HSR (104%) far higher than in other treatments (64%). This illustrates how grazing management can amplify the effects of normal rainfall variability, making management more challenging.
4. Ground cover also varied with rainfall from 60-70% in wet years to below 40% in drought years in all treatments. Despite the relative severity of the second drought, ground cover never fell as low as that in the first, probably due to the expansion of *B. pertusa*.
5. Treatment also had a major impact with ground cover consistently lower in the HSR treatment than in the MSR and R/Spell. Again this was most noticeable in dry periods.
6. Cover and yield in the VAR/Flex strategies were generally in-between that of the HSR and MSR, and varied with the stocking rate applied.
7. Pasture species composition also changed profoundly over the trial due to rainfall and treatment. Overall, the yield and proportion of *Aristida* declined, while that of *B. pertusa*, 2P grasses and Stylo increased. The increase in *B. pertusa* was particularly dramatic with this species going from less than 2% of yield in 2007 to over 20% of yield in 2012.
8. Treatment had a profound effect on species composition with the yield and proportion of 3P grasses far greater in the MSR and R/Spell than in the HSR. Conversely, the proportion of 2P grasses, annual grasses and *B. pertusa* was markedly higher in the HSR.
9. Species composition in the VAR/Flex treatments was similar to, but slightly poorer than in the MSR and R/Spell treatments. Due to the relative shortness of the time over which the Flex and Flex + Spell have been applied, there was no clear advantage in terms of pasture composition of these treatments over the MSR or R/Spell.

9 Multivariate analysis of pasture species composition

9.1 Introduction

Grazing systems contain a multitude of plant species with different growth strategies and habitat preferences. The abundance of these different species relative to one another changes constantly in response to rainfall, grazing management, fire and often, subtle environmental factors. While univariate analyses of the changes in abundance (frequency) of individual species can be extremely useful, it is extremely difficult to interpret community level changes in species composition by this method alone. In this chapter multivariate analysis in the form of distance based redundancy analysis and non-metric multi-dimensional scaling is used in an attempt to interpret changes in species composition in response to rainfall and grazing management.

9.2 Objective

To use multivariate analyses to:

- (i) Analyse and interpret the changes in species composition in the different grazing treatments over time.
- (ii) Determine the relative significance of factors like rainfall and stocking rate in driving these changes.

9.3 Procedure

Seventy-one permanent monitoring sites, stratified by soil type, were established across the trial in 1998, with two monitoring sites randomly located per soil type in each paddock. For the *E. brownii* (Box) communities, sites were further stratified with one site being close to (< 500 m), and the other site far from, water. Additional sites were also located on the small areas (1-5 ha) of soil anomalies e.g. seasonally inundated areas, that occurred in some paddocks. Data from these latter sites was not used in the present analysis. Monitoring sites consist of five parallel 100 m transects marked with steel pickets at either end. Transects are 20 m apart and generally run S to N. Although sites were chosen to be as homogenous as possible, some sites were relatively heterogeneous with some transects crossing transition zones between soil types.

Sites were monitored annually from 1998 to 2017 for species frequency and ground cover in the mid-late wet season using BOTANAL (Tothill et al. 1992). Sites were sampled by systematically placing a 0.25 m² quadrat at c. 5 m intervals along each transect i.e., 20 quadrats per transect, 100 quadrats per monitoring site. All grass, forb and sedge present in a quadrat were identified to the species level and recorded as being either present or absent. Ground cover and *Carissa ovata* canopy cover were also scored but that data is not presented in this report.

9.4 Statistical analysis

9.4.1 Data processing

Data analysis largely focused on grasses as most forb and legume species were relatively transient and/or formed a relatively minor component of the pasture. Data was generally analysed at the species level. However in some cases, species were grouped at the species group, genus and/or functional group level due to either their relative rarity, perceived lack of importance or, in the case of certain *Aristida* spp., the difficulty in correctly distinguishing certain species in the field. Examples of some of these groups include *Aristida* annual species, native legumes, 'Fire grasses'

(*Schizachyrium* and *Mnesithea* spp) and an *Aristida benthamii-jerichoensis-muricata* complex (ABCom).

Data was prepared as follows: (1) all species with a maximum frequency across all sites <10% were deleted for ease of interpretation. Such rare species also often distort species ordinations. (2) Data was then log transformed ($\log_{10} + 1$) to compensate for the zero or low frequencies recorded for certain species at different sites (McCune and Grace 2002).

All grass, legume and forb species recorded were included in the initial MVA analyses, as is standard procedure. However, this made interpretation extremely difficult due first, to the very large number of species involved and second, the ephemeral nature of some species. To circumvent this issue, a set of key Indicator species or those considered as important indicators of land condition change were selected. This group was largely made up of perennial grasses but also included some annuals and forbs. In general, species that responded strongly to rainfall but that showed little or no response to management were excluded. The Indicator species for the different soil types are listed below.

9.4.2 Phase 1 vs Phase 2 treatments

In analysing treatment effects with time, an important issue was how to cope with the treatment changes from Phase 1 to Phase 2 of the trial. Specifically, the adaptation of the VAR and SOI strategies in Phase 1, to the Flexible stocking and Flexible stocking+spelling treatments in Phase 2.

In reality, these Phase 2 treatments were an evolution via adaptive management of the original Phase 1 SOI and VAR treatments, rather than a major treatment change. Moreover, examination of both the animal and pasture data showed that the VAR and SOI had performed similarly through Phase 1. Finally, the two replicate paddocks in the Flex and Flex+S treatments were drawn both from the former SOI and VAR treatments, to ensure the carryover of previous effects would be shared equally between the two new treatments. Accordingly, for the sake of continuity and simplicity, for the present MVA it was assumed that paddocks stayed in their Phase 1 treatments over the course of the trial i.e. data was analysed as though the VAR and SOI had remained intact over the 20 years of the trial. This approach obviously differs from the other analyses in this report where data from the two phases was analysed separately.

9.4.3 Distance based redundancy analysis

Distance-based redundancy analysis (db_RDA) was selected to analyse species composition data and determine the significance of treatment effects (Legendre and Anderson 1999). The first part of the methodology involves the use of multivariate analysis i.e. non-metric multidimensional scaling, to graphically display patterns and associations in the data. Distance based RDA then goes beyond traditional multivariate analysis as it allows the significance of different factors e.g. time, rainfall, treatment, soil type etc., as well as the interactions between factors, to be assessed. A mixed effects model was considered appropriate given the nature of the data i.e. the effect of year changes with time since a treatment was implemented.

In the first step of the db_RDA analysis, species frequency data from all treatments over all years (1998 to 2016) was grouped by individual year (i.e. treatment was not coded into the analysis) and the data analysed. Results showed a strong response of all year-groups to rainfall. This response was largely driven by fluctuations in the presence and abundance of annual grasses, forbs and less persistent, perennial grasses such as *Panicum effusum* and *Digitaria ammobila* (results not shown).

In the second step, 'treatment' was coded into the analysis with the data from all three soil types included in the same analysis. Thereafter the relative effects of stocking rate, wet and dry season rainfall and years since fire were included to elucidate their relative effects on species

composition. Stocking rate was included as the stocking rate applied each year (SR), the previous seasons stocking rate (SR_P), and average stocking rate over the last two years (SR_Av). This was done first for all soil types combined, followed by the three main soil groups i.e. Box, Brigalow (heavy clays) and Ironbark (see below).

9.4.4 Non-metric multidimensional scaling

To graphically explore the changes in species composition over time, non-metric multidimensional scaling (NMS) analysis was also conducted using PC-Ord 7 (MjM software, Oregon). NMS is an indirect gradient technique that ordines sample units (sites/treatments) in species space and is recommended as the most appropriate form of MVA to interpret trends in species composition data (McCune and Grace 2002; Peck 2016).

Interpretation of the ordination diagrams for the three main soil-vegetation associations was however complicated by a number of factors. First, there is a significant degree of variation in species composition within some soil types due to inherent variability within the soil grouping. To reduce this variation, cluster analysis of species composition at the start of the trial (1998) using PATN (Belbin 2004; <http://www.patn.com.au/>) was used to separate the Ironbark and Brigalow into subgroups as described previously (O'Reagain 2008). Thus the Ironbark was split into the 'hard' Ironbark: low ridges tending to be dominated by *Eriachne mucronata* and the 'soft' Ironbark: sites dominated by mixtures of *Aristida spp*, *H. contortus*, *C. fallax* and other species. The Brigalow soil-vegetation association was in turn split into 'open clays', 'scrubby clays' and 'melonholes'. The Box sites were relatively homogenous and did not require splitting.

Second, to make interpretation easier and reduce 'noise', in most analyses only data from four key 'sentinel' years were used i.e. years when some particularly significant event e.g. high or low rainfall, mid drought etc. when significant change in pasture composition might be expected (Table 9.1).

Table 9.1 Sentinel years used in NMS multivariate analysis of pasture frequency data and reasons for selection.

Sentinel Year	Reason selected
1999	Wet year; second year of trial
2005	Late in first drought
2011	Very wet year, pre-fire 2012 fire
2015	Extreme Drought

The NMS analysis was run separately for the soil sub-types described above. NMS using the Sorenson distance as the dissimilarity measure was performed with sufficient iterations to produce a stable solution with stress values usually less than 15. All Monte Carlo tests were significant ($P < 0.0196$) and showed that the NMS axes extracted were stronger than might be expected compared to those randomly extracted by chance alone (McCune and Grace 2002). Resultant ordination graphs were interpreted based on correlation scores of individual species with different axes and the association between sites and species in ordination space with joint plots.

9.5 Results

9.5.1 Redundancy analysis (RDA) of treatment effects over all years and soils

In the RDA analysis of the effects of different factors on species composition across all soils, the terms for wet season rainfall, dry season rainfall and years since fire were not significant and dropped from the model. In contrast, both ‘year’ and ‘treatment’ were significant ($P < 0.001$) showing that they both significantly affected species composition (Table 9.2)

Table 9.2 Redundancy analysis of the effect of year and treatment on species composition. Data analysed across all soils types and all years.

	<i>DF</i>	<i>SS</i>	<i>F</i>	<i>Pr(>F)</i>
Year	18	25.313	42.554	0.001
Treatment	4	4.726	35.75	0.001
Residual	1177	42.414		

In the second model, stocking rate was used instead of ‘treatment’. Dry season rainfall and years since fire were again non-significant, as was the average stocking rate applied over the previous two years. These variables were dropped from the model and the analysis rerun. The resultant analysis showed that while stocking rate in a particular year was non-significant ($P = 0.081$), both the stocking rate applied the previous year and wet season rainfall significantly ($P < 0.001$) affected species composition (Table 9.2). This particular model should however be interpreted with caution given the fact that stocking rate, previous years stocking rate and average stocking rate are not independent.

Table 9.3 RDA of the effect of year, stocking rate (SR), previous years stocking rate (SR_P) and wet season rainfall (WS_Rain) on species composition. Data analysed across all soils types and all years.

	<i>DF</i>	<i>SS</i>	<i>F</i>	<i>Pr(>F)</i>
Year	18	25.313	39.057	0.001
SR	1	0.076	2.099	0.081
SR_P	1	0.882	24.49	0.001
WS_Rain	1	0.25	6.95	0.002
Residual	1178	42.414		

9.5.1.1 Analysis of treatment effects over time

In the next step, the effect of treatment on species composition over all soil types was analysed on a year by year basis. These results showed that although treatment had a strong effect, it only became consistently significant ($P < 0.05$) in the drier years post-2004 i.e. some six years after the start of the experiment (Fig. 9.1). This highlights the strong interaction between rainfall and management in driving pasture change and the fact that there are lag effects with treatment changes often taking some years to occur. It is also noteworthy that P-values did not increase i.e. decline in significance, with the onset of higher rainfall years after 2007. This indicates that treatment effects were persistent and not reversed with good seasons.

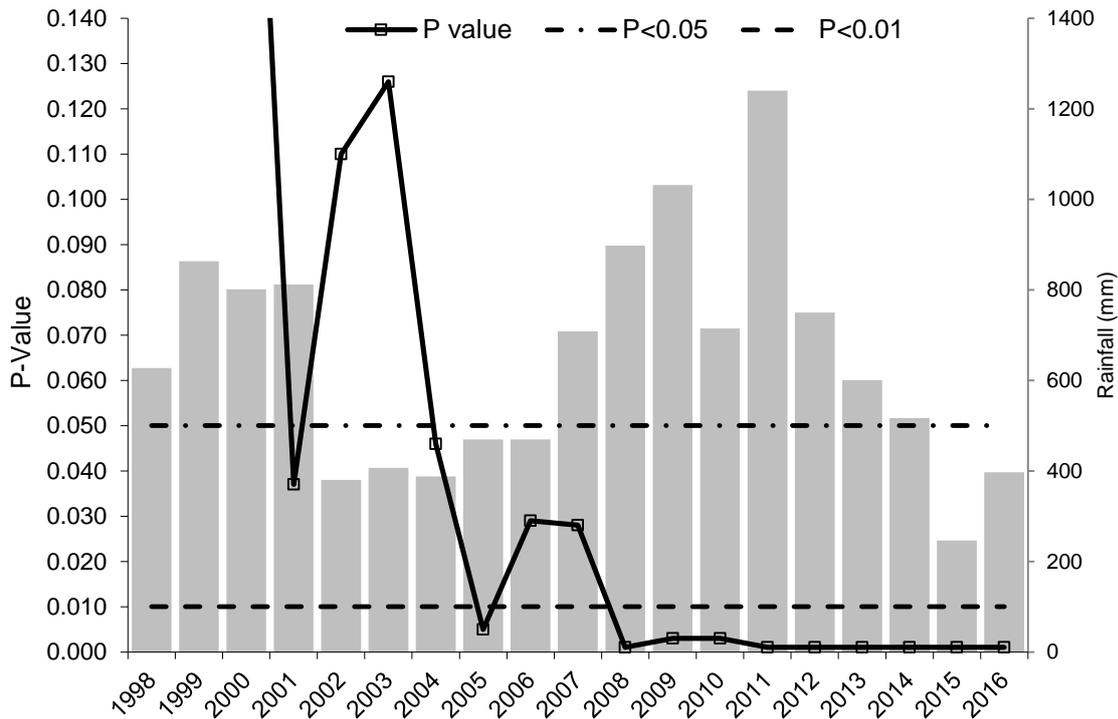


Fig. 9.1 P-values for redundancy analysis (RDA) of pasture frequency data plotted against year with annual rainfall on the second y-axis. The $P < 0.05$ and $P < 0.01$ significance levels are plotted as horizontal lines. The change in the species composition of treatments over time is very evident in the ordination diagrams presented for individual soil types and soil sub-types in the sections below.

9.5.1.2 RDA of effects of different factors on different soil types

The effects of treatment, rainfall and stocking rate and years since fire on species composition were then analysed for the three main soil types at the trial with data analysed over all years combined. For the Ironbark and Brigalow, rainfall (dry and wet season), stocking rate and years since fire (YSF) were non-significant and dropped from the models. In contrast, the effect of year and treatment were both significant (Table 9.4). For the box soil, both the current year's stocking rate ($P=0.012$) and the previous year's stocking rate ($P=0.015$) were significant, in addition to year and treatment.

Table 9.4 Outcomes of redundancy analyses (RDA) on species composition (indicator species only) for the Ironbark, Brigalow and Box soil-vegetation combinations over all years (1998-2016). SR= stocking rate for the year in question; SR_P= the previous year’s stocking rate.

	D.F.	Sum of squares	F-value	Probability
Ironbark				
Year	18	7.99	23.23	0.001
Treatment	4	3.41	44.68	0.001
Residual	375	7.16		
Brigalow				
Year	18	11.06	16.70	0.001
Treatment	4	3.81	25.93	0.001
Residual	392	14.42		
Box				
Year	18	8.09	31.60	0.001
Treatment	4	1.25	22.05	0.001
SR	1	0.038	2.688	0.012
SR_P	1	0.038	2.684	0.015
Residual	361	5.13		

9.5.2 Non metric multidimensional scaling of changes in species composition

9.5.2.1 Box soil vegetation association

Non metric multidimensional scaling (NMS) of the box soil-vegetation association using the selected indicator species (Table 9.5) was conducted for the four sentinel years i.e. 1999, 2005, 2011 and 2015. This produced a three dimensional solution after 59 iterations, with a stress value of 11.62 and the first three axes having r^2 s of 0.38, 0.35 and 0.15 respectively. *C. fallax* was negatively correlated (-0.689) with axis 1 with *B. pertusa* (+0.886), *D. fecundum* (+0.624) and *Seca stylo* (+0.575) positively correlated with this axis. *B. ewartiana* (-0.514) and *D. fecundum* (-0.509) were negatively correlated with axis 2 while the *A. benthamii* complex (+0.677), *A. calycina* (+0.669) and *Eragrostis* species (+0.534) were positively correlated with this axis. *B. ewartiana* (-0.695) and *Eragrostis spp.* (-0.526) were both negatively correlated with axis 3.

Table 9.5 Box soil-vegetation association: Species correlations with axes 1 to 3 derived from NMS analysis of species frequencies for sentinel years 1999, 2005, 2011 and 2015.

Species Code	Species name	Axis 1	Axis 2	Axis 3
ABCom	<i>A. benthamii</i> complex	0.006	0.677	-0.343
AriCal	<i>A. calycina</i>	-0.291	0.669	-0.253
BoEwa	<i>B. ewartiana</i>	-0.201	-0.514	-0.695
BoPer	<i>B. pertusa</i>	0.886	0.262	0.172
ChFal	<i>C. fallax</i>	-0.689	0.444	0.154
DiBro	<i>D. brownii</i>	-0.027	0.035	-0.33
DiFec	<i>D. fecundum</i>	0.624	-0.509	-0.105
Erag	<i>Eragrostis spp.</i>	-0.062	0.534	-0.526
HeCon	<i>H. contortus</i>	0.303	0.102	-0.123
Seca	<i>S. scabra</i>	0.575	-0.172	-0.297

The analysis arranged sites into a number of groups across the species-site ordination space (Fig. 9.2). Axis 1 shows a separation from left to right between species composition in 1999 and the later years of 2011 and 2015. This reflects the general change that occurred across all

treatments over the period, in particular the invasion and spread of *B. pertusa* across the trial site. The 3P grass *D. fecundum* and the introduced legume *Seca* also increased from extremely low to moderate levels in most (but not all) treatments. In contrast, *C. fallax* declined in most treatments over the same period.

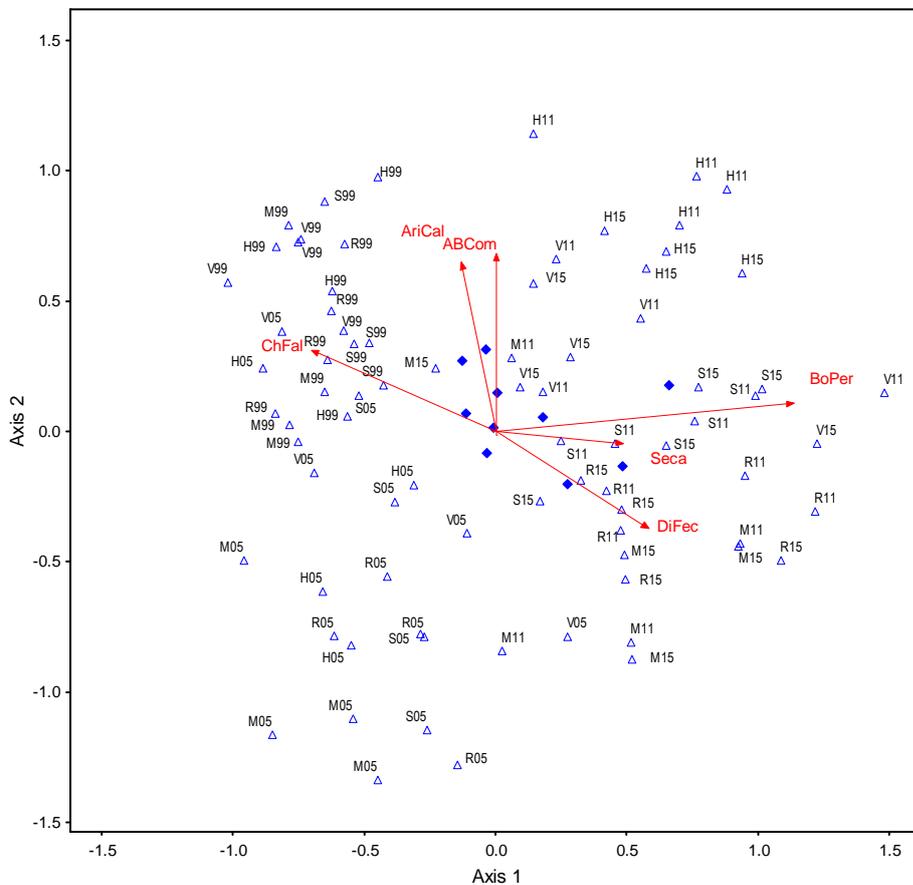


Fig. 9.2 Box soil-vegetation association. NMS joint plot of the first two axes of the ordination of treatment sites by year combination in species space for the years 1999, 2005, 2011 and 2015. H=HSR, M=MSR, V=Variable, S=SOI and R=R/Spell. Species abbreviations are given in Table 9.5.

Axis 2 appears to reflect a combined drought and treatment gradient. This shows the wetter years of 1999 and 2011 at the top of the graph with higher abundancies of *A. benthamii*, *A. calycina* and *Eragrostis spp.* In contrast, the drier years of 2015, and in particular 2005, were at the bottom with extremely low levels of these less drought tolerant species. However, it also shows a general increase in *D. fecundum* at least in some treatments in later years. Inspection of axis 3 also indicates that HSR sites were associated with lower levels of *B. ewartiana* in later years.

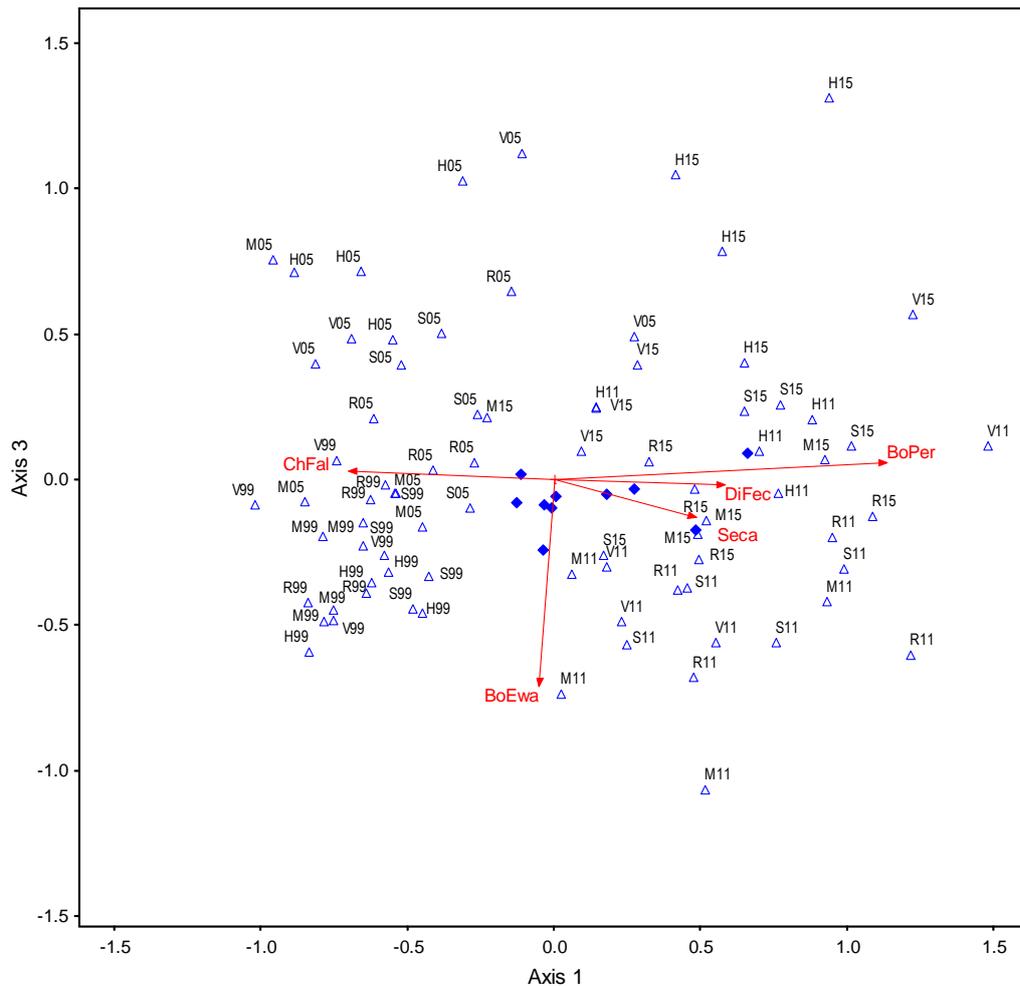


Fig. 9.3 Box soil-vegetation association. NMS joint plot of axis 1 and 3 of treatment sites by year in ordination space for the years 1999, 2005, 2011 and 2015. H=HSR, M=MSR, V=Variable, S=SOI and R=R/Spell. Species abbreviations are given in Table 9.5.

To facilitate the graphical interpretation of treatment effects, the VAR and SOI strategies were grouped into a single group (VS) as were the R/Spell and MSR treatments (MR), while the HSR was left on its own (Fig. 9.4). This decision was based on the observation that there were marked similarities in species composition in the VAR and SOI treatments and in turn, in the R/Spell and MSR treatments. The HSR was in contrast, conspicuously different from the other four treatments.

In the resultant ordination there was marked overlap between treatments in 1999 with the MSR-R/Spell and the HSR in particular, in close proximity to each other with all sites characterised by high levels of *A. calycina*, *A. benthamii*, *B. ewartiana* and *C. fallax*. This reflected the good rainfall received in 1999 and the fact that treatment effects had yet to emerge.

By 2005 however, all treatment groups had shifted downwards on axis 2 with sharp declines in the abundances of *A. benthamii*, *A. calycina* and *Eragrostis spp.* With treatments having being applied for eight years, there was also far less overlap between treatment groups with the HSR as well as the VAR-SOI starting to separate from the MSR-R/Spell. This reflected the decline in *B. ewartiana* initiated in the HSR due to ongoing heavy stocking, as well as the damage inflicted on the VAR-SOI paddocks by the period of heavy stocking applied, leading into the 2001 drought.

By 2011 and 2015 there had been a marked shift of all treatment groups to the right of ordination space partly due to the decline in *C. fallax* across all treatments from around 55-70% in 1999 to

around 40-55% in 2015. However, the key driver of the shift was the exponential increase in *B. pertusa* from <5% in 2005 to between 20-50% in 2011 and 2015. Strong treatment effects across axis 2 were also evident with HSR sites at the top of axis 2 and associated with high frequencies (51%) of *B. pertusa* but low levels of *D. fecundum* (5%) and *B. ewartiana* (19%) relative to the other treatments.

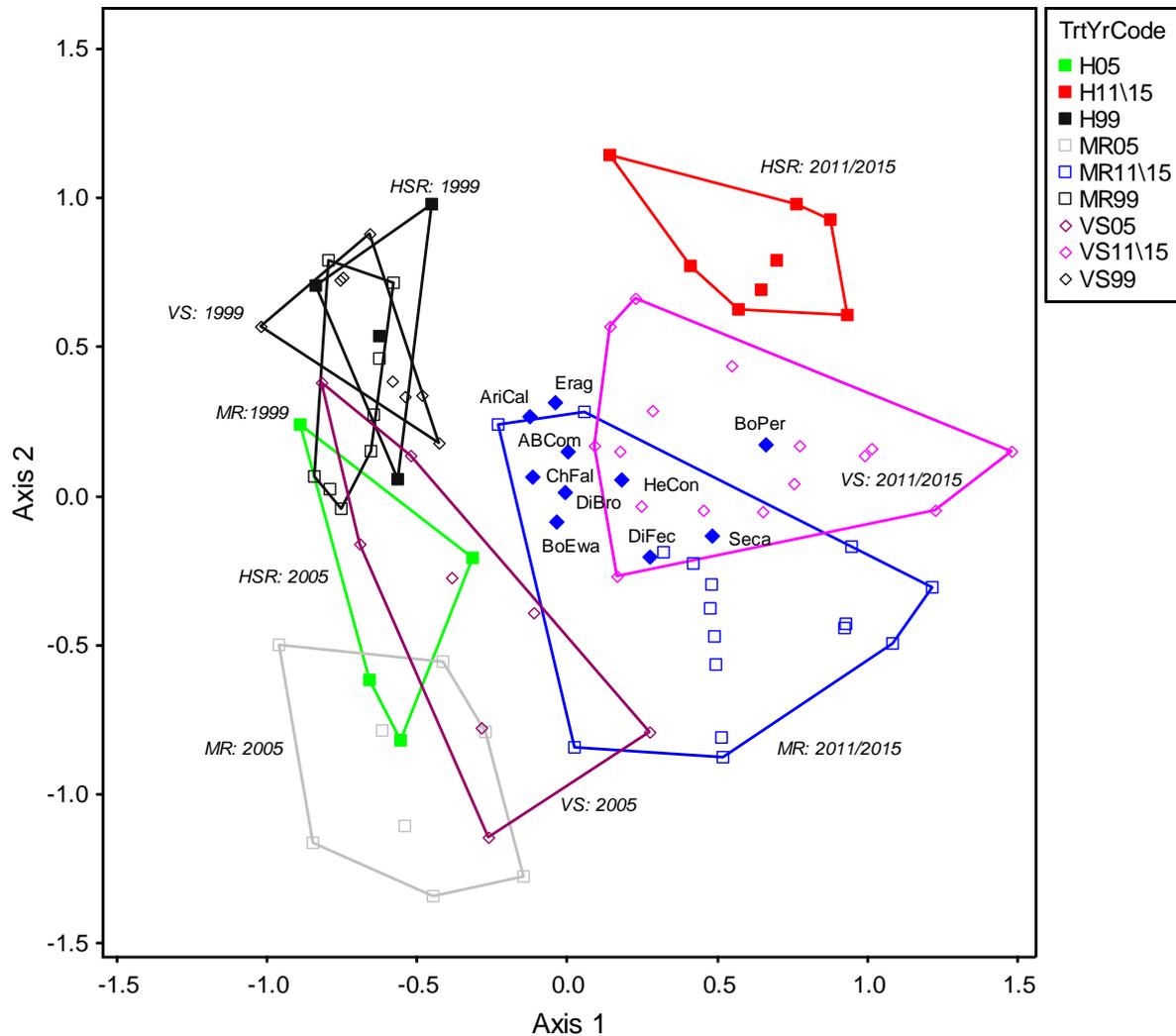


Fig. 9.4 NMS ordination of box soil sites for 1999, 2005 and a combined 2011/15 year group. Convex hulls enclose groups in different years. Treatment groups are: MR=MSR and R/Spell sites, VS= VAR and SOI sites, HSR= HSR site only. See text for more details. Species abbreviations are given in Table 9.5.

In contrast to the HSR, the MSR-R/Spell group at the bottom was characterised by much lower levels of *B. pertusa* (average: 21%), and far higher frequencies of *B. ewartiana* (46%), *D. fecundum* (27%) and *Seca*. The Variable-SOI in 2011/15 partially overlapped this group, but was relatively distinct and generally appeared to have an intermediate composition relative to the HSR and the MSR-R/Spell. Most of this discrimination appeared to reflect the fact that *B. pertusa* levels (average: 35%) were intermediate between the HSR (51%) and MSR-R/Spell groups (21%).

9.5.2.2 ‘Hard’ Ironbark

Ordination of the species composition of the ‘hard’ Ironbark sites i.e. those dominated by *E. mucronata*, produced a three dimensional solution with stress =12.06 after 43 iterations with r^2 of 0.51, 0.22 and 0.14 respectively. *Eragrostis spp.* (-0.753) and the *A. benthamii* complex (-0.714) species groups were negatively correlated with axis 1 (Table 9.6) as were *D. brownii* (-0.650) and

A. calycina (-0.651), and to a lesser extent, *P. effusum* (-0.559). *B. pertusa* was positively (+0.682) and *E. mucronata* (-0.786) negatively correlated with axis 2. *C. fallax* (-0.671) was the only species significantly correlated with axis 3.

Table 9.6 Ironbark (hard) soil-vegetation association: Species correlations with axes 1, 2 and 3 derived from NMS analysis of site by species composition for 1999, 2005, 2011 and 2015.

Species Code	Species name	Axis 1	Axis 2	Axis 3
<i>ABCom</i>	<i>A. benthamii</i>	-0.714	0.044	0.373
<i>AriCal</i>	<i>A. calycina</i>	-0.651	0.108	-0.458
<i>BoPer</i>	<i>B. pertusa</i>	0.011	0.682	-0.107
<i>ChFal</i>	<i>C. fallax</i>	-0.317	0.370	-0.671
<i>DiBro</i>	<i>D. brownii</i>	-0.650	-0.414	-0.018
<i>Erag</i>	<i>Eragrostis spp.</i>	-0.753	0.028	0.493
<i>ErMuc</i>	<i>E. mucronata</i>	-0.223	-0.786	-0.182
<i>HeCon</i>	<i>H. contortus</i>	-0.287	-0.200	-0.341
<i>PaEff</i>	<i>P. effusum</i>	-0.559	-0.015	0.282
<i>Seca</i>	<i>S. scabra</i>	-0.299	-0.021	0.477

The site by species ordination showed a marked separation between the 2005 sites on the right of axis 1 with the other years grouped loosely on left (Fig. 9.5). Axis 1 clearly reflects a response to decreasing rainfall from left to right. Thus sites in the wetter year of 1999 were associated with relatively high levels of shorter lived perennials like *Eragrostis spp.*, *P. effusum*, *D. brownii*, *A. benthamii* and *A. calycina*. By 2005 however, sites had shifted strongly to the right due to drought, with very low levels of these less drought tolerant species. In contrast, there was little if any decline in the long lived perennial *E. mucronata* which is extremely drought tolerant.

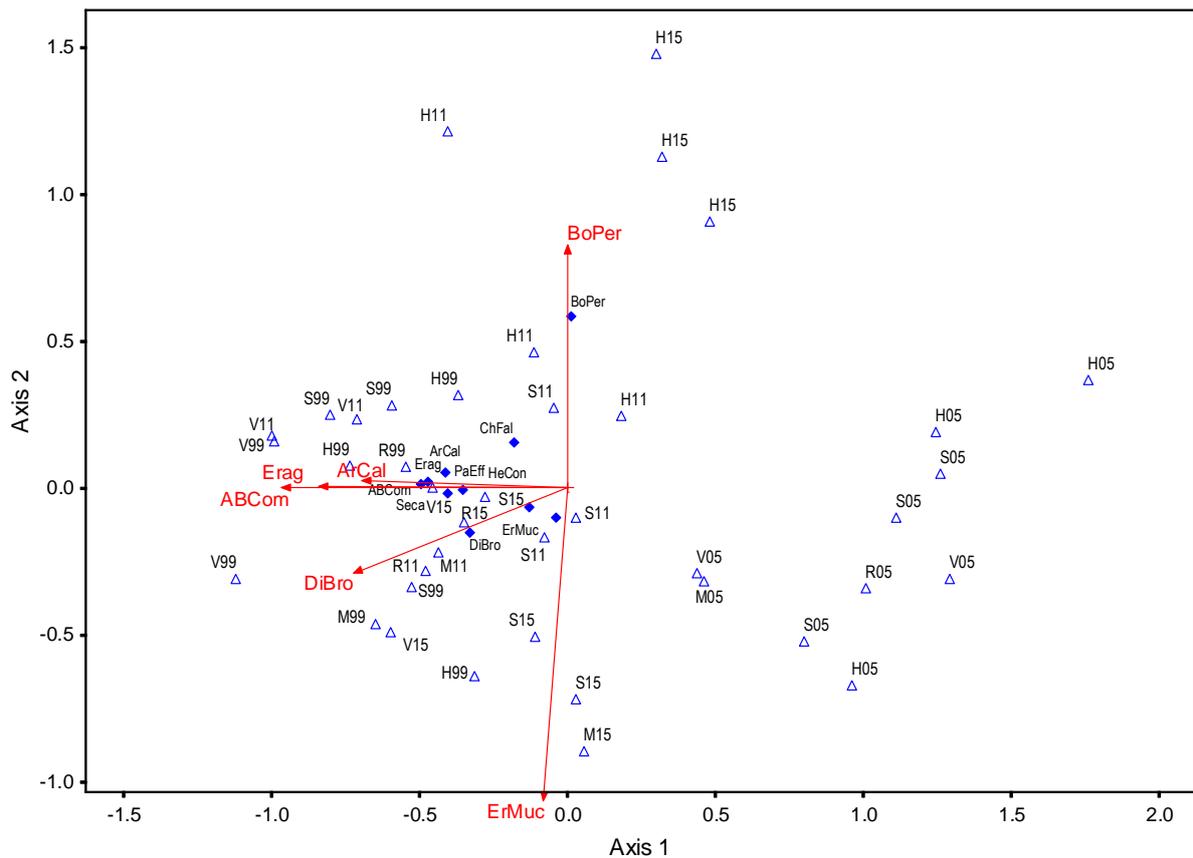


Fig. 9.5. ‘Hard’ Ironbark: NMS joint plot of sites in species ordination space for 1999, 2005, 2011 and 2015. Numbers refer to years; V=Variable, S=SOI, R=R/Spell, M=MSR, H=HSR. See Table 9.6 for species codes.

Following good rainfall in the preceding three years, sites in 2011 were again associated with increased levels of these shorter lived perennials like *Eragrostis* and *P. effusum* (Fig. 9.5). Accordingly, all sites had shifted back along axis 1 to overlap extensively with 1999 sites. Although the 2015 group had some commonality with the 2011 and 1999 sites, the shorter lived perennials had declined with reduced rainfall and most sites in 2015 had shifted back again towards the right or drier end of the axis.

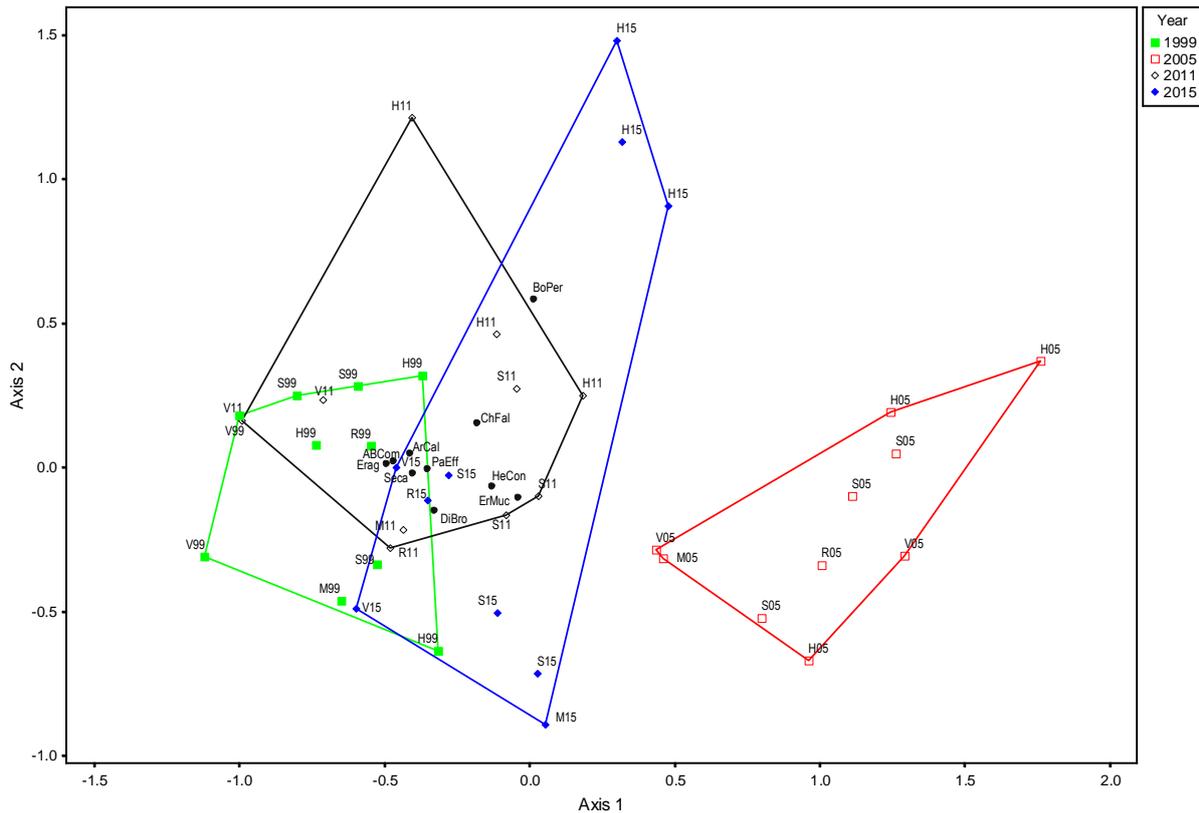


Fig. 9.6 ‘Hard’ Ironbark: NMS ordination of sites in species ordination space for 1999, 2005, 2011, and 2015. Convex hulls group different years. Treatment and year codes as before. See Table 9.6 for species abbreviations.

While treatments were relatively tightly grouped in 1999, there was increasingly wide dispersion along axis 2 in later years (Fig. 9.6). By 2015, sites from different treatments were thus stretched over almost three times the distance on axis 2 compared to the 1999 group. This increased dispersion seems to reflect treatment effects and in particular, the dramatic increase in *B. pertusa* in later years. Thus in 2011 and 2015, the HSR sites shifted upwards on axis 2 as *B. pertusa* increased from almost 0% in 2005 to between 24 – 58% at different sites in 2015. While *B. pertusa* also increased in other treatments, the increase was far smaller. Axis 2 also reflects differences in the abundance of *E. mucronata* with sites with higher abundancies tending towards the lower end. While some sites inherently had higher abundances of *E. mucronata*, there was also a possible treatment effect with *E. mucronata* increasing slightly in the MSR and R/Spell from 2005, but decreasing on some (but not all) HSR sites.

9.5.2.3 ‘Soft’ Ironbark sites

NMS analysis of the ‘soft’ Ironbark sites produced a three dimensional solution after 63 iterations with a stress value of 11.78. The three axes had r^2 of 0.61, 0.18 and 0.08 respectively and collectively accounted for 0.87 of the variation in the data. The firegrasses (+0.931) and to a lesser extent, the annual *Aristida spp.* (+0.520), were positively associated with axis 1 while *H. contortus* (-0.689), *Eragrostis spp.* (-0.544), and *Seca* (-0.619) were negatively associated with this axis (Table 9.7). In turn, *A. benthamii* (+0.693), *P. effusum* (+0.511) and *A. calycina* (+0.590) were positively correlated with axis 2 while *H. contortus* (-0.636) and *Seca* (-0.524) were negatively associated with this axis. *P. effusum* (+0.485) and the *Eragrostis* species group (+0.464) were weakly positively correlated with axis 3, and *B. pertusa* negatively correlated (-0.464) with the same axis.

Table 9.7. Ironbark (soft) soil-vegetation association: Species correlations with axes 1, 2 and 3 derived from NMS analysis of species composition for sites in 1999, 2005, 2011 and 2015.

Species Code	Species name	Axis 1	Axis 2	Axis 3
ABCom	<i>A. benthamii. complex</i>	-0.368	0.693	-0.274
ArAnn	<i>Aristida - annuals</i>	0.52	-0.254	0.19
AriCal	<i>A. calycina</i>	-0.283	0.59	0.187
BoEwa	<i>B. ewartiana</i>	-0.479	-0.229	-0.072
BoPer	<i>B. pertusa</i>	-0.081	0.191	-0.464
ChFal	<i>C. fallax</i>	-0.248	-0.037	0.027
DiBro	<i>D. brownii</i>	-0.421	-0.091	0.147
Erag	<i>Eragrostis spp.</i>	-0.544	0.5	0.464
ErMuc	<i>E. mucronata</i>	0.339	0.249	0.367
Fire	<i>Firegrasses</i>	0.931	0.01	0.169
HeCon	<i>H. contortus</i>	-0.689	-0.636	-0.073
PaEff	<i>P. effusum</i>	-0.452	0.511	0.485
Seca	<i>S. scabra</i>	-0.619	-0.524	0.278

Examination of the species by site ordination shows sites in 1999, 2011 and 2015 grouped on the left, with 2005 on the (extreme) right (Fig. 9.7). Within the former group there is some overlap between 1999 and 2011 sites. There was also overlap between sites in 2011 and 2015, but with 2015 sites starting to move downwards and across towards the 2005 group.

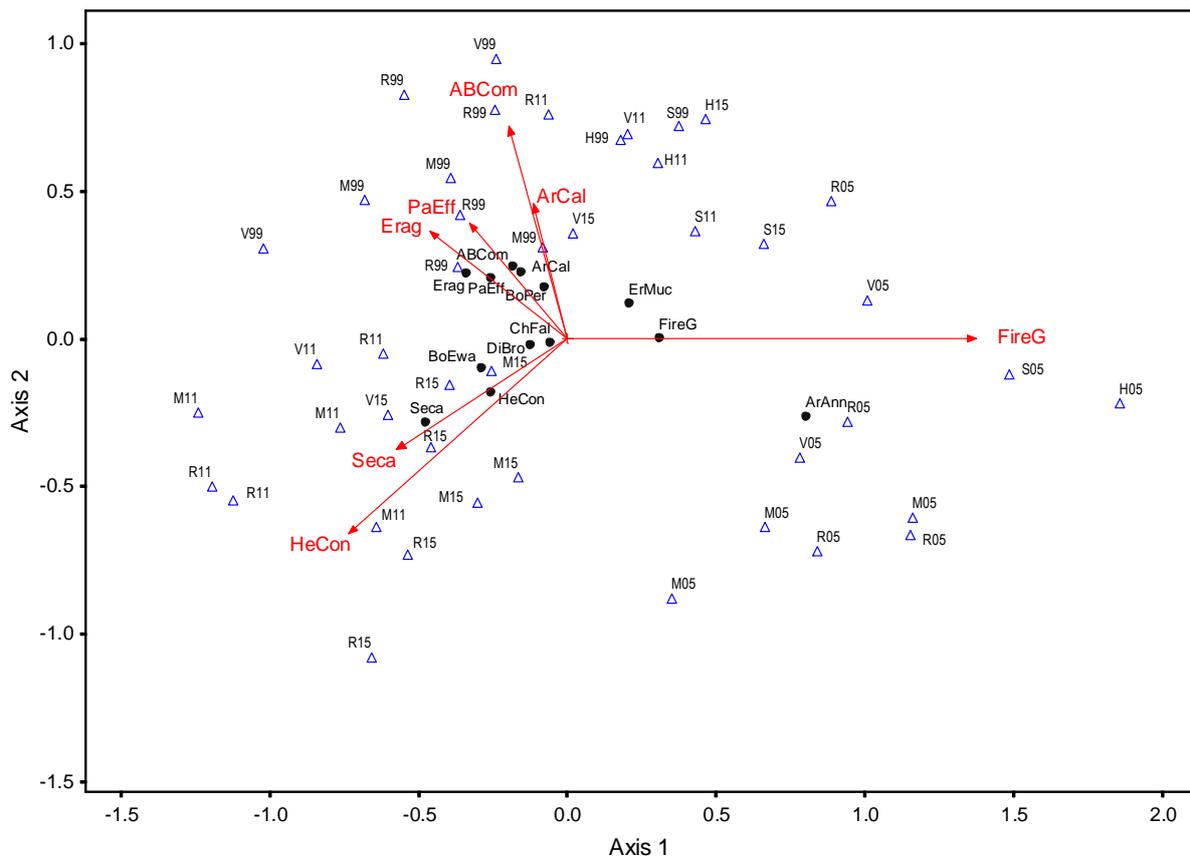


Fig. 9.7 Ironbark (soft): NMS ordination joint plot of axes 1 and 2 for sites in species ordination space for 1999, 2005, 2011 and 2015. Treatment and year codes as before. See Table 9.7 for species abbreviations.

The positions of the different year groups in ordination space reflects a rainfall gradient along axis 1 with the wetter years 1999 and 2011 grouped on the left and the dry year 2005 on the extreme right. The joint plot (Fig. 9.7) shows that sites in 1999 were associated with higher levels of *Eragrostis spp.*, *P. effusum*, *A. benthamii* and *A. calycina*. However, following four low rainfall years, sites in 2005 had shifted to the right due to the sharp declines in these less drought tolerant species. In contrast, the annual firegrass species, and to a much lesser extent, annual *Aristida spp.*, increased at all sites in 2005 due to the increased availability of bare ground. Although *H. contortus* levels appeared largely unchanged, mass mortality of the species occurred in the severe drought in 2003. However, massive recruitment from seed in the 2003/04 wet season allowed the species to quickly recover to 1999 levels by 2005.

Following four good years, by 2011 most sites had shifted left across ordination space towards the 1999 group (Fig. 9.7). This was due to partial recovery of species like *A. benthamii* and *P. effusum*, and a decline in firegrass. While there is some overlap between the 1999 and 2011 groups, the 2011 sites were associated with relatively higher levels of *H. contortus* and *Seca*, in at least some paddocks. 2011 sites also had relatively lower levels of *C. fallax* due to a combination of extreme drought and treatment effects.

However following two drought years, by 2015, sites were shifting right again across ordination space due to declines in *A. benthamii*, *Eragrostis spp.* and *P. effusum*. There were also increases in *H. contortus* and *Seca*, at least in some sites, and increases in firegrass.

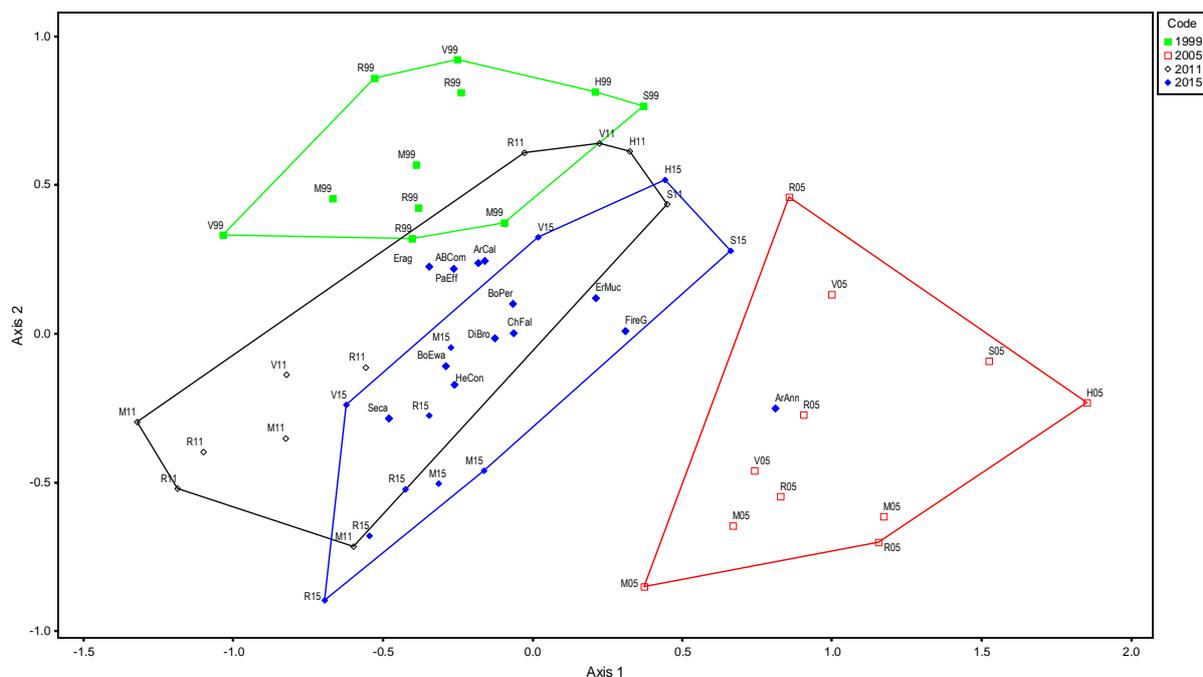


Fig. 9.8 Ironbark (soft) NMS ordination of treatment sites in species ordination space for 1999, 2005, 2011 and 2015. Sites within the same year group are enclosed by convex hulls.

While sites from different treatments were initially relatively closely grouped, by 2005 fairly marked separation of treatments had occurred with the single HSR site and to a lesser extent, the SOI site, on the extreme right and other treatments on the left (Fig. 9.8). As all treatments had moderate to high levels (53-99%) of Firegrass in 2005, most of this separation can be attributed to the low levels of *H. contortus* in the HSR.

Treatment effects were more pronounced by 2015 and 2011; here the HSR sites tended to be on the upper side and the R/Spell and MSR sites on the lower side of axis 2, with the VAR and SOI somewhat in between these two groups. This pattern reflects the contrast between the high

levels of *H. contortus* and, to a lesser extent *Seca*, in the MSR and R/Spell relative to the HSR. Overall however, the separation due to *Seca* was less clear cut with higher levels of *Seca* in one VAR site than in the other and low levels in the SOI site. There appears to be no obvious explanation for these latter differences aside from chance and/or subtle soil differences between paddocks.

It is notable that while *B. pertusa* was far higher in the HSR (33%) in 2015 than in any of the other treatments, the present analysis did not identify it being of significance in the ordination. Note however, that when the drought year 2005 was excluded from this analysis, *B. pertusa* emerged as a significant factor separating the HSR from the other treatments in 2015 and 2011 (analysis not shown).

9.5.2.4 Heavy clays

Preliminary NMS analysis of species composition for the heavy clay soil sites for the four sentinel years identified significant between-site variability due to inherent variation within the general 'heavy clay' soil grouping (vertosols-grey earths) at the trial site. Previous classification analysis (O'Reagain *et al.* 2008) showed that the clay sites could be split into the following sub-groups: open clays, melonhole-gilgai sites and 'scrubby' clay/sodic soil sites i.e. those with marked understory and often shallower soils. The allocation of monitoring sites to these subgroups across the treatment paddocks was also unbalanced. For example, the HSR and the SOI 'heavy clay' monitoring sites in one replicate were located on melonhole Brigalow, while the other replicate was a more open clay that lacked Gilgai's. This variation also meant that the HSR had only one monitoring site on the open clays compared to four in the MSR. Even for sites within different soil sub-groups, significant within-site variation also existed with transects sometimes crossing two clay sub-groups e.g. open clay areas and more scrubby patches. This variability made the extraction of treatment effects extremely challenging.

Accordingly, NMS analyses were conducted separately for sites on each of the main soil sub-groups for the four sentinel years using from six to 20 grass species. Despite this, most of the ordination patterns for the different clay sub-groups still reflected inherent between or within-site soil differences. Shorter term changes in species composition driven by rainfall also tended to dominate analyses making the detecting of treatment differences difficult.

Consequently, it was decided to focus on the largest subgroup, the open clays, using a selection of ten key pasture species (Table 9.8). To highlight any potential treatment effects, and reduce more transient rainfall effects, only data from 1999 (year 2) and 2015 (year 18) were used in the analysis presented below.

Table 9.8 Open clay soils: Species correlations with axes 1 and 2 derived from NMS analysis of species composition for 1999 and 2015. There was no third axis.

<i>Species Code</i>	<i>Species name</i>	<i>Axis 1</i>	<i>Axis 2</i>
<i>BoEwa</i>	<i>B. ewartiana</i>	-0.006	0.016
<i>BoPer</i>	<i>B. pertusa</i>	0.674	-0.494
<i>BrCon</i>	<i>Brachyachne convergens</i>	0.551	-0.393
<i>DaRad</i>	<i>Dactyloctenium radulans</i>	0.158	0.059
<i>DiSer</i>	<i>D. sericeum</i>	0.456	0.09
<i>Erag.</i>	<i>Eragrostis spp.</i>	-0.876	0.086
<i>ErCre</i>	<i>Eriochloa crebra</i>	-0.451	0.559
<i>EuAur</i>	<i>Eulalia aurea</i>	0.600	0.659
<i>IsVag</i>	<i>Iseilema vaginiflorum</i>	-0.760	-0.371
<i>Sporo</i>	<i>Sporobolus spp.</i>	-0.878	-0.013

NMS analysis of the ‘open clay’ species composition data for 1999 and 2015 produced a two dimensional solution after 37 iterations with stress =11.65. The two axes had r^2 of 0.51 and 0.38 respectively. *Sporobolus* (-0.878), *Eragrostis spp.* (-0.876) and *I. vaginiflorum* (-0.760) were negatively correlated with axis 1 while *B. pertusa* (+0.674), *E. aurea* (+0.600) and *B. convergens* (+0.551) were positively correlated with this axis (Table 9.8). *E. aurea* (+0.659) and to a lesser extent *E. crebra* (+0.559), were positively correlated with axis 2.

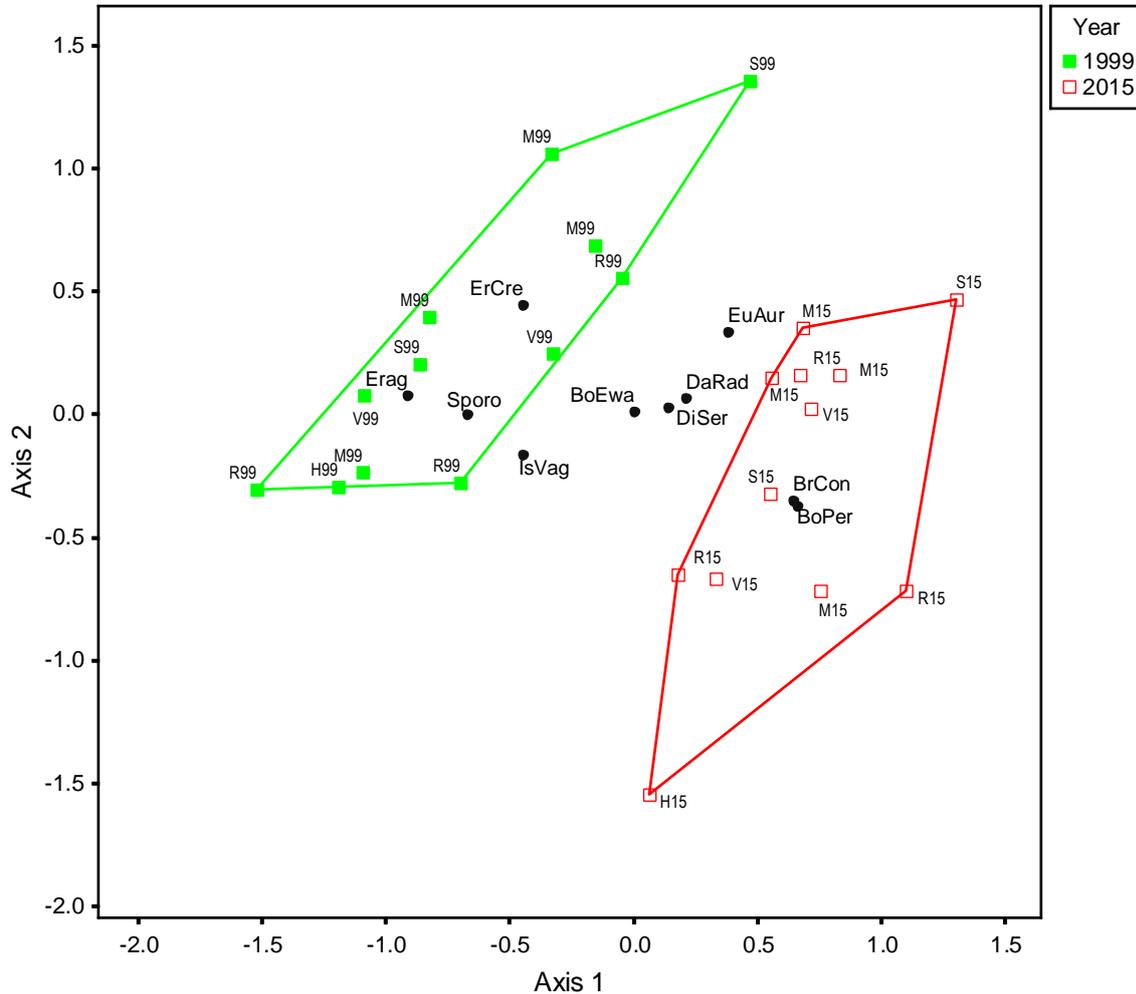


Fig. 9.9 NMS ordination of the open clay sites in species space with convex hulls delineating sites for 1999 and 2015. Treatment codes as before. See Table 9.8 for species codes.

The resultant ordination is complex making interpretation challenging. Nevertheless, there is clear separation between sites in 1999 and those in 2015. Thus sites in 1999 were characterised by shorter lived perennials like *E. crebra* and the *Sporobolus* and *Eragrostis* species groups. However, these species declined markedly with the later drier years. In contrast, sites in 2015 were characterised by modest levels of the exotic *B. pertusa* and the native *B. convergens*, both of which had been essentially absent in 1999 (Fig. 9.10). With one exception (see below), there were few notable changes in the levels of the longer lived perennials like *B. ewartiana* and *D. sericeum* between 1999 and 2015. There was however, some increase (c. 10%) in the long lived *E. aurea* over this period.

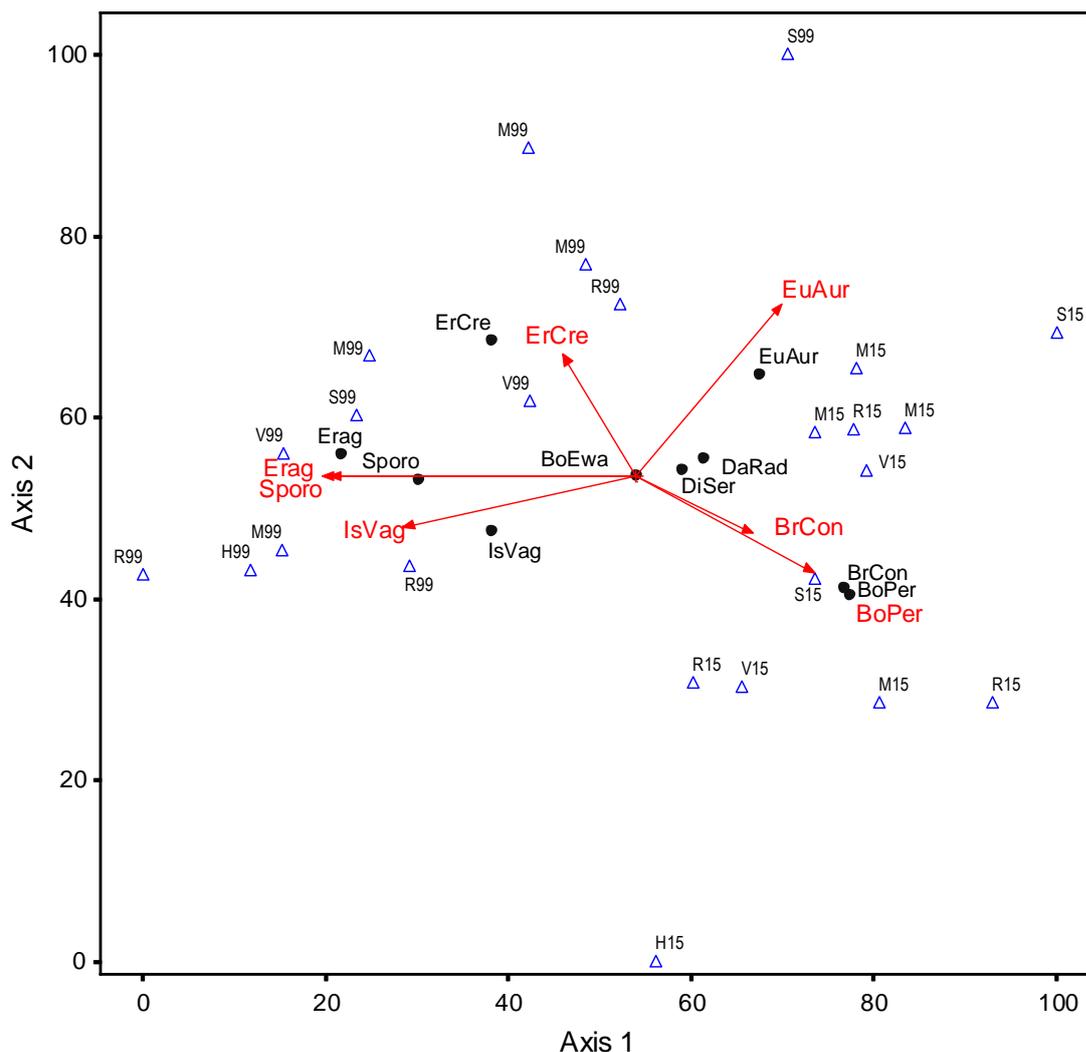


Fig. 9.10 Open clays. NMS ordination joint plot of axes 1 and 2 for sites in species ordination space for the years 1999 and 2015. Treatment and year codes as before. See Table 9.8 for species abbreviations.

The only clear treatment effect related to the single HSR site located on the ‘open clays’ subgroup. This site was closely associated with R/Spell and at least one MSR site in 1999 but by 2015 had migrated to the bottom right of the ordination, well away from other treatments. This drastic shift primarily resulted from the decline in *B. ewartiana* in the HSR from an average frequency of 21% in 1999 to only 6% in 2015. In contrast, there was little change in the frequency of *B. ewartiana* in other treatments.

9.6 Summary

1. Distance based redundancy analysis of species frequency data over all years and soils indicated that ‘treatment’ and ‘year’ i.e. had significant impacts on changes in species composition.
2. Other significant factors driving species composition change were, ‘year’ i.e. time since the start of the trial, wet season rainfall and the stocking rate applied the previous year in any treatment. The latter factor highlights the carryover effects of the previous year’s management on species composition.
3. When analysed on a year by year basis, the effect of treatment on species composition only became significant in 2004 i.e. six years after the start of the trial, midway through the first drought.

This highlights the strong interaction between management and rainfall in driving change in species composition.

4. The effect of ‘treatment’ did not decline in later wet years, highlighting the lagged, long term effects of management on species composition. Importantly, it also emphasises that detrimental changes in species composition do not simply reverse with the return of good seasons.
5. Both ‘treatment’ and ‘year’ had significant effects on species composition for all three soil types. For the box soils, the effect of stocking rate and the stocking rate applied the previous year, were also significant.
6. Fire had no effect on species composition as shown by the non-significance of the term ‘years since fire’ in all models. This accords with the species contribution to pasture yield data presented in the previous chapter.
7. Species composition varied markedly on all soils with time. This was largely driven by rainfall with shorter lived perennials like *Eragrostis*, *Aristida* and *Panicum* increasing strongly in good years but declining sharply in droughts. In turn annual grasses like Firegrass and *D. radulans* increased in droughts, taking advantage of the increased bare ground.
8. In contrast, longer lived perennials like *B. ewartiana*, *D. sericeum*, *E. aurea* and *E. mucronata* were remarkably stable and responded to rainfall far more slowly. *H. contortus* in contrast, was far less drought tolerant, but was able to recover rapidly post drought through rapid recruitment from seed
9. Other general changes observed were a general decline in *C. fallax* and an increase in *D. fecundum* and, to a lesser extent *Seca*, over time. The most dramatic change however was the rapid increase in *B. pertusa* across all treatments in the later stages of the trial.
10. Treatment effects on species composition were relatively subtle in comparison to rainfall, and took longer to emerge, but were nevertheless still significant. On the box soils, heavy stocking rate sites were characterised by high levels of *B. pertusa* but low levels of *D. fecundum* and *B. ewartiana* compared to the MSR and R/Spell sites. VAR and SOI sites were intermediate in species composition between these two treatments.
11. Treatment effects were also evident on Ironbark and heavy clay sites but were less marked than on the Box. On the ‘soft’ Ironbark, the R/Spell and MSR had higher levels of *H. contortus*, and *Seca* relative to the HSR, which in turn had more *B. pertusa* than the former treatments. On the ‘hard’ Ironbark, effects were far more subtle, but HSR also tended to have more *B. pertusa*. On the open clays, the HSR sites had a far lower levels of *B. ewartiana* than other sites.

10 Bio-economic modelling

(Prepared by Lester Pahl, Joe Scanlan and Peter O'Reagain)

10.1 Introduction

Despite the great value of grazing trials, extrapolation of results to other areas with different soil types and/or different rainfall sequences can be problematic. This is particularly so in extrapolating up to the enterprise level due to a number of challenges. These include the differences in spatial scale and the uncertainty of translating results with steers to breeding animals. Previous simulation modelling with the GRASP (GRASs Production) model has been successful in extrapolating trial data up to the property scale over a number of historical rainfall windows (Scanlan *et al.* 2013).

In this third phase of the Wambiana project, the bio-economic modelling (BEM) process which commenced in Phase 2 (O'Reagain 2014; Scanlan *et al.* 2013), was extended to assess how the sustainability and economics of fixed stocking, flexible stocking and wet season pasture spelling strategies were impacted by differences in initial pasture condition, climate period and stocking rate.

In this chapter we present a brief summary of the methods used and the results of this detailed modelling exercise. A detailed description of the modelling process and the complete results are presented in Appendix 1.

10.2 Methods

The GRASP and ENTERPRISE models were parameterised and calibrated for the box soil type at the Wambiana grazing trial (Scanlan *et al.* 2013). A hypothetical cattle property typical of the Charters Towers district was used to simulate several annual stocking rate flexibilities and wet season spelling strategies under a range of starting pasture conditions, stocking rates and different climate windows as described below.

10.2.1 Stocking rate strategies

Fixed stocking was run at high (25 AE/100 ha) and low (12.5 AEs/100 ha) stocking rates. The low stocking rate is equivalent to the 'moderate' stocking rate strategy at the Wambiana trial. Fixed stocking was also simulated at a maintenance stocking rate i.e. that required to maintain pasture composition. A moderate stocking rate i.e. mid way between a low and maintenance stocking rate, was also simulated (Appendix 1).

Flexible stocking was run using a number of flexibility strategies where various percentages of stocking rate increase or decrease respectively were allowed annually depending upon pasture availability. These were 05 05 %, 10 20 %, 20 40 % and a 40 40 % flexibility. The low flexibility was also simulated with three initial stocking rates (

Table 10.1).

Four wet season pasture spelling strategies were simulated i.e.

1. Spelling with loading up of other paddocks in the rotational spelling system in all years.
2. Spelling with no loading up of other paddocks during the first cycle – during the first four years (first rest period for each paddock), cattle from the spelled paddocks were agisted off-property.
3. Spelling with no loading up of other paddocks during spelling in any years – the cattle from the spelled paddock were agisted off-property for the duration of the spell period.
4. No Spelling.

The stocking rate flexibilities and pasture spelling strategies were simulated with three different initial pasture conditions and over two different climate periods. These were A, B and C pasture condition with 70%, 50% and 20% perennial grass composition respectively.

Two 30-year periods of actual climate for Charters Towers were used: climate period 1 (1952-1982) was chosen because it was particularly wet. Climate period 2 (1982-2011) was selected because it was much drier and also covered the ‘working life’ of many current landholders and researchers. The different combinations of annual stocking rate flexibilities, spelling strategies, initial pasture conditions, initial stocking rates and climate periods simulated are shown in

Table 10.1

Table 10.1 The combinations of stocking rate flexibilities, spelling strategies, initial pasture condition, initial stocking rate, and climate periods simulated (Hi=high, Md=moderate, Mt=maintenance, Lo=low).

Flexibility	Spelling strategy				Pasture condition			Stocking rate				Climate period	
	1	2	3	4	A	B	C	Hi	Md	Mt	Lo	1	2
Fixed	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
05 05%			✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
10 20%			✓	✓	✓	✓	✓		✓			✓	✓
20 40%			✓	✓	✓	✓	✓		✓			✓	✓
40 40%			✓	✓	✓	✓	✓		✓			✓	✓

For spelling, 1 = Spell with loading up of paddocks in all years; 2 = Spell with no loading in the first cycle; 3 = Spell with no loading in any year; 4 = No spelling.

10.2.2 Case study property and herd parameters

The stocking rate flexibilities and spelling strategies were simulated for a beef grazing property and cattle breeding herd typical of the Charters Towers region where the Wambiana grazing trial is located. The property consisted of nine paddocks with a total area of 23,000 hectares. Four paddocks contained around 1000 head of breeders, four paddocks contained steers up to the age of two years, and the remaining paddock contained one-year old heifers. All paddocks were designated as the box land type (See Appendix 1 for more detail).

10.2.3 Key modelled outputs and statistical analysis

Key outputs from GRASP, annual live-weight gain per head (LWG/hd) and annual stocking rate (ha/AE) during each 30-year simulation period, were read into the ENTERPRISE model. These outputs were used to determine herd productivity, and subsequently economic performance.

The key result from GRASP simulations relating to sustainability was the percent perennial grass composition averaged over the last five years of each simulation period, here referred to as final %P. Economic performance was compared using the spreadsheet economic model ENTERPRISE (MacLeod and Ash 2001, MacLeod et al. 2011, Scanlan et al. 2013, Whish et al. 2016). The main economic metric used to compare grazing land management strategies was net present value (NPV) with a 5% discount rate (opportunity cost of funds available). The economic metric NPV was used because it converts future cash-flows into present day values; it discounts the value of income that can take a long time to arise from a change in management. Average annual total gross margin (TGM) was also provided as an additional economic indicator of grazing land management strategies.

10.3 Summary of modelling results

The majority of sustainability and economic effects were due to differences in the extent that both fixed- and flexible-stocking strategies aligned stocking rates with feed supply, i.e. the stocking rate applied and the extent to which it matched the amount of feed on offer. As the climate period encountered and initial pasture condition determine forage production, these factors also influenced sustainability and economic outcomes (see Appendix 1 for more detail).

During the relatively rare combination of circumstances where rainfall was high, such as during the wet decades of the 1950s and 1970s (climate period 1: average rainfall 723 mm; C.V.=39%), and when pastures were in A condition, fixed stocking at the high stocking rate (25 AE/100 ha) achieved the highest average annual total gross margin (TGM) while maintaining A pasture condition over 30 years.

However, under the more typical lower rainfall conditions (climate period 2: average rainfall 637 mm; C.V.=49%) and with poor to moderate condition pastures, fixed stocking at the low stocking rate (12.5 AE/100 ha) achieved a higher TGM than the moderate (+/-16 AE/100ha) and high stocking rates, while also maintaining or improving pasture condition.

The poor long-term economic viability of heavy stocking under more typical northern Australia conditions was evident in the rapid decline that occurred in pasture condition and total gross margin (TGM). During more typical conditions of drier rainfall decades and B pasture condition, annual gross margins for heavy fixed stocking were only positive for the first 10 years. After 12 years, even accumulated TGM became negative. Furthermore, the economic outcome was only marginally better during the wetter climate period 1.

Fixed stocking was also simulated with a number of spelling strategies. These included spelling involving agistment of cattle from the spelled paddock off-property each year (no loading up), and two other forms of spelling where cattle from the spelled paddock were distributed across other paddocks in the rotational spelling system (loading up) or spelling with loading in all but the first spelling cycle.

When fixed stocking rates were moderate or high, wet season spelling with no loading improved pasture condition compared with fixed stocking alone or fixed stocking with the two forms of spelling with loading. This occurred regardless of climate window or initial pasture condition. The addition of spelling (+/- loading) did not improve pasture condition with a fixed light stocking rate, as the low stocking rate itself allowed pasture condition to improve. Average annual TGM under fixed light stocking was also not improved with any form of spelling relative to fixed stocking alone. In contrast, under moderate or heavy fixed stocking, all forms of spelling improved TGM relative to fixed stocking alone, particularly with B or C initial pasture condition. Even so, when initial pasture condition was A, the highest TGM occurred for fixed moderate stocking without any form of spelling. Similarly, when initial pasture conditions were B or C, the highest TGMs occurred for fixed low stocking without spelling.

Overall, relative to fixed stocking, the magnitude of improvements in pasture condition and TGM due to spelling increased as (i) more cattle from spelled paddocks were agisted off-property, (ii) initial pasture condition declined, and (iii) stocking rates increased. However, in absolute terms, the highest TGM occurred with fixed low or moderate stocking rates, with spelling having little influence on these outcomes

Wet season pasture spelling was also simulated with several forms of flexible stocking, where stocking rates were either increased or decreased at the end of the growing season in response to the amount of forage available at that time. However, the amount that stocking rates could be increased or decreased annually was capped, and varied from 5 to 40% in any one year. Four flexibilities were simulated, being 05 05%, 10 20%, 20 40% and 40 40%, with the first number being the limit for increases and the second being the limit for decreases in stocking rate

annually. Additionally, the absolute increase in stocking rate which could occur during each 30-year simulation period was capped at 60% above the moderate stocking rate.

Relative to a fixed moderate stocking rate, even a small degree of annual stocking rate flexibility (05 05%) improved pasture condition, particularly for the combinations of A, B and C initial pasture conditions and the drier climate period. However, similar improvements in annual average TGM were not observed. In fact, the TGM for fixed moderate stocking was higher than that for the 05 05% flexibility for all initial pasture conditions during the wetter climate period 1, and for A condition pasture during the drier climate period 2. This trend was reversed for climate period 2, where the TGM for the 05 05% flexibility for B and C initial pasture conditions was much higher than that for fixed stocking.

All of the more flexible strategies (10 20%; 20 40%; 40 40%) improved pasture condition relative to fixed moderate stocking, regardless of climate period or initial pasture condition. The only exception was A condition pasture during the wetter climate period 1 when fixed stocking achieved the same pasture condition as all forms of flexible stocking. Again, these trends were mostly not reflected in the average annual TGMs. As was seen for the 05 05% flexibility, the TGM for fixed moderate stocking was higher than those for the three more flexible strategies for all initial pasture conditions during the wetter climate period 1, and for a condition pasture during the drier climate period 2. This was reversed for B and C initial pasture conditions during climate period 2, where those for fixed stocking were much lower than the three more flexible strategies.

Pasture spelling with no loading only improved pasture condition for fixed moderate stocking and the 05 05% flexibility, particularly during the drier climate period 2. In comparison, the more flexible strategies improved pasture condition to the maximum amount allowed in the GRASP model irrespective of climate period or initial pasture condition. Hence spelling could not improve pasture condition any further. Similarly, spelling only improved the TGMs for fixed moderate stocking and the 05 05% flexibility during the drier climate periods and when initial pasture conditions were B or C. Nevertheless, this improved TGM was still lower than the TGMs for the more flexible strategies without spelling. Consequently, the benefits from flexible stocking were greater than the benefits of pasture spelling.

Overall, the sustainability and economics of fixed moderate stocking was only superior to flexible stocking during the wetter climate period 1 in combination with A condition pasture, which are circumstances rarely encountered in northern Australia. The more flexible strategies without spelling achieved better pasture condition and higher TGM than fixed moderate stocking with or without spelling when initial pasture conditions were B or C. Hence, flexible stocking may be a more cost-effective method of improving pasture condition, probably due to its capacity to improve pasture condition without the costs associated with spelling paddocks and agisting cattle.

It is important to note that the flexible stocking strategies simulated were relatively risk-averse with limits set on the rate and extent of stocking rate changes over time. Less risk-averse, flexible stocking with greater changes in stocking rate between years or no limits set upon the maximum stocking rates applied, would carry a far higher degree of risk and would be far more likely to cause overgrazing when sudden changes from good to poor years occurred. The full results from the present simulations are presented in more detail in Appendix 1.

10.4 Congruence of BEM with results of Wambiana grazing trial

Simulation modelling indicated that under typical climate conditions and on poor to average pasture condition, low to moderate stocking rates give higher gross margins and result in better pasture condition than heavy stocking. These findings are in general agreement with trial results showing that the pasture condition was maintained and economic performance far superior under moderate compared to heavy stocking.

The simulation modelling nevertheless also showed that on good condition pasture and in wetter years profitability was highest under heavy stocking. This is in agreement with initial trial results where the HSR was extremely profitable for the first five wetter years with little apparent pasture degradation. However, by the sixth year accumulated gross margin in the HSR had declined irreversibly below that in the MSR due to the effects of drought, while an ongoing decline in pasture condition was also obvious. Similarly, simulation models showed that heavy stocking inevitably led to a decline in gross margins and pasture condition under more 'typical' rainfall conditions.

The superior performance of the more risk averse, flexible stocking strategies in the modelling is in partial agreement with trial results; while the clear superiority of the flexible strategies has yet to be demonstrated at the trial, the present drought has clearly highlighted the benefits of flexible- relative to fixed-stocking. Experience in Phase 1 of the trial also demonstrated and adverse consequences for pasture condition and profitability that can occur with less risk averse strategies, as happened in the Variable and SOI strategies leading into the 2002 drought.

10.5 Extension messages

Stocking rate is the major driver of long-term pasture condition and economic performance. The more that stocking rates can be aligned with forage supply, the more sustainable and profitable a grazing enterprise will be. Hence, stocking rates should be decreased to avoid overgrazing in dry years and increased to take advantage of good years. However, these changes need to be made in a risk averse fashion with limits set on the rate of change and the maximum stocking rate applied.

Under average climate conditions and when pasture condition is poor to moderate, maintaining a low or moderate stocking rate results in higher total gross margins and better pasture condition over time than heavier stocking does.

Good economic performance and pasture condition can only be obtained under heavy stocking when initial pasture condition is good (A condition) combined with wetter climate sequences, such as occurred in the 1950s and 1970s. Under all other conditions, heavy stocking rates inevitably lead to a decline in pasture condition and gross margins.

Pasture spelling, especially when cattle from spelled paddocks are agisted off-property, will improve pasture condition and gross margins with fixed stocking at moderate or high stocking rates and when pasture condition is poor to moderate. Even so, better pasture condition and higher gross margins were achieved with fixed stocking at a low stocking rate, as wet season pasture spelling cannot overcome the adverse effects of excessive stocking rates on pasture condition and profitability.

Flexible stocking, where stocking rates are adjusted in a risk-averse manner, i.e. increased by 10-20% after good wet seasons or decreased by 20-40% after poor seasons, generally results in improved pasture condition and gross margins relative to fixed moderate stocking. This is particularly so under drier climate conditions and on poor to moderate condition pastures. Spelling appears to be less beneficial when flexible stocking is applied but this requires further field testing, as is currently happening at the Wambiana grazing trial.

11 Summary of key findings from Wambiana trial

1. Moderate stocking is profitable and is sustainable

Constant moderate stocking at long term carrying capacity (LTCC) gave the best individual animal performance in terms of weight gain (LWG), growth rates and carcass value. At a property level, animals would reach target weights sooner and hence increase turnover and efficiency. Although total LWG per ha was markedly lower than under heavy stocking, drought feeding was only required once in 20 years compared to six out of 20 years. Moderate stocking was accordingly far more profitable and annual returns far less variable, due to lower costs and higher product value.

Constant moderate stocking was generally sustainable, with pastures maintaining a high proportion of 3P grasses. However, present indications are that fixed stocking rates, even at LTCC, lead to over grazing in drought years which could precipitate pasture degradation. The absence of spelling in the MSR might also prevent recovery of selectively grazed areas, leading to a gradual decline in land condition.

2. Heavy stocking rates are unprofitable and unsustainable

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 six out of 20 years. Accordingly, profitability was by far the lowest in the HSR. In contrast, income variability was by far the highest, with the HSR having a negative gross margin in nine of the 20 years of the trial. The heavy stocking rates in the HSR were unsustainable, with forced reductions in stock numbers in a number of drier years.

Heavy stocking rates resulted in a marked decline in land condition with the proportion of 3P grasses declining significantly over the course of the trial. The exotic grass *B. pertusa* also increased the most in the HSR. Ground cover and pasture yields were generally lowest, while inter-annual variation in yields the highest, in the HSR. This increased vulnerability to drought by first, amplifying the effects of rainfall variability on forage supply, making management for climate variability substantially more challenging. And second, reducing drought resilience. This was obvious in the second drought with HSR animals requiring drought feeding, and in one paddock needing to be withdrawn, far earlier than in the previous (2003-2007) drought period.

3. Rotational wet season spelling is profitable and is sustainable

Constant moderate stocking at LTCC with wet season spelling (R/Spell) was profitable and gave good individual animal performance. In recent years, individual LWGs were better than in the MSR suggesting that spelling was indirectly improving animal production through its effects on pasture condition.

Constant stocking at LTCC with wet season spelling was sustainable and with the MSR, had the best pasture condition of all strategies. Surprisingly, the effects of spelling on pasture condition were not as strong as expected. This may be attributed to the long-lasting effects of the ill-timed fire in October 2001 in the R/Spell and the subsequent drought on pasture condition in this strategy (O'Reagain et al. 2008). Current observations are however that pasture condition in the R/Spell will surpass that in the MSR in the near future.

Note that like the MSR, the fixed stocking rates at LTCC in the R/Spell will also lead to the overgrazing in drier years, as happened in late 2017. Accordingly, long lasting degradation may still occur in a fixed stocking strategy with spelling if stocking rates are not adjusted accordingly.

4. Flexible stocking confers no major advantage over constant moderate stocking....yet

Individual animal production was far better in the Flexible/Variable strategy than with fixed, heavy stocking. Flexible stocking was also far more profitable than the HSR as it avoided the costs of drought feeding in dry years. Pasture condition in both Flexible strategies was far better than in the HSR but was poorer than in the MSR and R/Spell. This reflects the long lasting effects of overgrazing in the 'variable strategies' at the start of the 2002 drought.

Overall, the Flexible strategies appear to be no more profitable than simply stocking at LTCC. However, experience in the current drought has clearly demonstrated the superiority of flexible over fixed stocking, even at LTCC. The longer term impacts of these strategies through the current drought on pasture condition and profitability will be reported in the next stage of this project.

5. Wet season spelling is important but pasture responses can be slow

There is widespread evidence that wet season spelling is beneficial for pasture condition, e.g. (Ash *et al.* 2001; Scanlan *et al.* 2014). While the present data are in partial agreement, the overall response to spelling has been slow. Detailed work by Jones at the Wambiana trial site (Jones *et al.* 2016) has yielded similar results with a number of wet season spelling strategies. However, given that 3P grasses like *B. ewartiana* are long lived and recruit only sporadically (Orr and O'Reagain 2011), the response to spelling can be very slow and dependent upon seasonal conditions. Regular spelling is thus needed increase the probability of a recruitment event and to maintain and improve vigour of key grass species.

Importantly, overgrazing of non-spelled areas may outweigh the benefits of spelling if stocking rates are too high and grazing pressure is not managed appropriately. Spelling thus needs to be applied adaptively to maximise the chances of success and avoid overgrazing of non-spelled areas.

6. Modelling indicates that these findings also apply at the enterprise level

Simulation modelling at the property scale produced outcomes in general agreement with trial results. Thus under most conditions, low to moderate stocking rates will be more profitable and result in better pasture condition than heavy stocking. While high stocking rates are profitable in wetter climate sequences with good starting pasture condition, under all other conditions it inevitably leads to a pasture degradation and a decline in profitability.

Simulations also indicated that flexible stocking applied in a risk averse manner, improved pasture condition and gross margin relative to fixed stocking, particularly under drier conditions and on poor to moderate pasture condition. This is at variance with earlier trial results with the Variable and SOI-Variable strategy. However, the experience in Phase 2 with the more risk averse Flexible strategies, particularly in the current drought, is in closer agreement with the modelling results.

These modelling results show that the trial outcomes are also likely to apply at the enterprise level under a range of rainfall scenarios. Flexible stocking rates around long term carrying capacity with numbers adjusted in a risk-averse manner as seasons change, coupled with wet season spelling, are thus likely to maximise profitability and land condition.

7. Factors hindering the adoption of improved grazing management

Industry adoption of improved grazing management principles such as matching stocking rates to forage supply has been slower than expected. Some of the main obstacles to adoption identified by producers and extension staff include a lack of motivation to change, financial barriers to change, a lack of awareness about business performance or declining land condition, uncertainty about the outcomes of management change and the potential risks involved in making such

changes. The long feedback lag between management changes and eventual results as well as the lack of support in such transition phases were also identified as reasons for low adoption.

8. Extension activities to encourage adoption of improved management

Workshops conducted with producers identified a number of activities to improve adoption. These include the need to inspire producers to change through clear demonstration of the benefits of improved management via case studies and research, training in business and land management and importantly, ongoing support and mentoring by both extension staff and peers through transition phases. The next phase of the current project will be closely involved in a number of these activities in at least three major catchments in Queensland.

12 Key extension messages from trial

The key extension messages from the grazing trial and associated bio-economic modelling can be summarised as follows:

12.1 Stock paddocks *around* long-term carrying capacity (LTCC)

Stocking around LTCC will:

1. Maintain land condition and carrying capacity, maintain system resilience and reduce the variability in pasture production between years.
2. Give the best individual animal performance, reduce time to turn-off by between 12 and 18 months and give price premiums at the meatworks.
3. Maximise profitability in the medium to long term through reduced costs, faster turnover, better market prices and having multiple market options.
4. 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.

Conversely, on all but the best condition country and in the wettest years, heavy stocking rates will:

1. Cause land condition to decline in the longer term, dramatically reduce carrying capacity and exacerbate fluctuations in pasture production between years. This in turn will both increase the frequency of 'droughts' and reduce resilience to these perturbations when they occur.
2. Give higher total animal production in most years but dramatically increase costs due to increased drought feeding and greater investment in livestock capital.
3. In the longer term (>5 years) heavy stocking rates will be far less profitable than stocking at LTCC with lower gross margins and more years with negative income.

12.2 Adjust stocking rates in a risk averse, flexible manner

Adjusting stocking rates in line with forage availability will:

1. Reduce the impact of dry years and/or droughts, maintain acceptable individual animal production and prevent overgrazing of pastures.
2. Allow increased animal production and gross margins in wetter years through increased animal numbers.
3. However, stocking rates need to be adjusted in a risk averse manner with upper limits set in even the best seasons.
4. Stocking rates must also be reduced promptly with the onset of dry years/drought to avoid long lasting degradation.

12.3 Use regular wet season spelling.

Wet season spelling will:

1. Maintain pasture vigour, facilitate recruitment and allow recovery of overgrazed patches and landtypes.
2. Accordingly, stocking at LTCC with wet season spelling will give superior pasture condition and production than simply stocking at LTCC without spelling.
3. In the longer term, spelling will also give better individual and total animal production than that achieved by stocking at LTCC without spelling.
4. Importantly, spelling does not appear to buffer the impacts of higher stocking rates relative to LTCC.

12.4 Use fire to maintain an open savanna structure

Appropriate use of fire will:

1. Change woodland structure to a more open structure with smaller trees and shrubs (O'Regain & Bushell 2011).
2. Reduce canopy cover of *Carissa ovata*.
3. Cause limited, but significant mortality of smaller woody individuals.
4. However, fire must be used with caution and paddocks should be spelled post-fire.

13 Management recommendations from trial

13.1 Managing stocking rate in a variable climate

Guidelines:

1. Stock paddocks using the long-term carrying capacity (LTCC) of constituent landtypes as a general guide.
2. Adjust stocking rates in a constrained, flexible manner as seasons vary, based on available forage, seasonal conditions and where appropriate, climate forecasts.
3. Upper limits to stocking rate should be set based on LTCC in even the best seasons to prevent overgrazing.
4. Changes in stocking rate should be made in a risk averse manner i.e. rapid reductions e.g. 20-40% with the approach of poor seasons but gradual increases in stocking rate e.g. 10-15% in good seasons.
5. The primary stocking rate adjustment point should be at the end of the wet season, as certainty is greatest at that stage regarding available forage, possibility of rain and how long forage must last.
6. Other secondary stocking rate adjustment points are in the mid and late dry season and in the early-mid wet season.
7. Stocking rates may be increased or decreased at the end of wet. However, secondary adjustment points at the end of the dry and early wet are *correction* points to ensure earlier stocking rate adjustments were appropriate.
8. Stocking rate estimates are imprecise and hence should be used cautiously and applied adaptively.

Rules of thumb

1. Stocking rates should be adjusted according to a forage budget based on available pasture, expected time until the first significant rains (plus a two month buffer) and expected wet season pasture growth.
2. Expected pasture growth for the next wet season can be estimated from GRASP based predictions of pasture growth expected in 70 % of rainfall years for a site.
3. Whatever the expected growth, the stocking rate 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.
4. 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.

13.2 Implementing wet season spelling

Guidelines:

1. Wet season spelling is secondary to stocking rate in terms of its effects on land condition but is nevertheless important to maintain or improve pasture condition.
2. Spelling does not appear to buffer the effects of higher stocking rates (O'Reagain & Bushell 2011), hence stocking rates should still be maintained around LTCC.
3. When paddocks are spelled, grazed (non-spelled) paddocks must be monitored to prevent overgrazing. If this occurs, spelled sections should be reopened and/or the overall stocking rate reduced.

Rules of thumb

1. Spell as much as possible without placing undue pressure on non-spelled areas.
2. Spelling priority should be based on pasture condition and time since last spell – however, all paddocks need occasional spelling.
3. Spell paddocks after about 50 mm of rain in two days after 1 December or even earlier in exceptionally wet years.
4. Spell paddocks for the full wet season if possible- the longer the better.
5. During spelling, closely monitor grazed paddocks – if these are being over utilised, open up spelled paddocks progressively to reduce grazing pressure. Open lower priority spelled paddocks first and then, if necessary, higher priority paddocks.

14 Unanswered and emergent questions

14.1 Unanswered questions

1. Can more sophisticated management strategies i.e. flexible stocking+/-spelling, increase productivity and profitability without adversely impacting pasture condition? Are such strategies any better than simpler systems such as constant moderate stocking at LTCC?
2. Is fixed stocking at LTCC sufficient to maintain or improve pasture condition in a variable climate? Up until 2017, trial results suggested that it was. However, the recent (January 2018) need to destock the MSR and R/Spell treatments suggest that this may not be the case.
3. How important is wet season spelling if stocking at LTCC or applying flexible stocking? Is it required at all? What are its relative benefits and costs? What is the optimum timing of (relative to the start of the wet season) and duration of spelling?
4. Given the marked decline in land condition in the HSR why has there been no decline in animal productivity or rainfall use efficiency? Does this simply reflect more recent (2007-2012) good seasons or a shift to a new, lower yielding but higher quality *B. pertusa* pasture? If so, how stable will this state be in the longer term?
5. Once *B. pertusa* is a significant pasture component, is it possible for the more desirable 3-P species to recover with good management? If not, what management guidelines are necessary to maintain *B. pertusa* dominated pastures and prevent further declines in land condition?

14.2 Emergent questions

1. Regarding the timing of stocking rate adjustments: How far can pastures be pushed (in terms of utilisation rate) and under what conditions before irreversible degradation occurs? How is this affected by drought, rainfall and existing pasture condition?
2. Why has pasture production i.e. rainfall use efficiency, declined in all treatments over the course of the trial?
3. Re: pasture budgeting: what are the appropriate utilisation and wastage factors for use in dry season forage budgeting? How are these affected by pasture mass and sward structure?
4. How can C condition land like that in the HSR be economically regenerated? How can recovery be accelerated?
5. What are the main determinants of stability and resilience in pasture communities? How can resilience be increased?
6. Aside from rainfall, what are the main drivers of animal liveweight gain between years and how is this affected by soil N availability? What are the main drivers of N availability in these landscapes?
7. What are the long term effects of *B. pertusa* invasion on pasture and pasture production, and system resilience?
8. How can the regeneration of key 3P species like *Bothriochloa ewartiana* be encouraged? What drives recruitment and establishment in this species?
9. How will pasture production and species composition respond to the widespread death of Ironbark trees and many perennial grasses in the recent drought? How will the woody component respond?
10. What effect does the ongoing expansion of *Carissa ovata* have on grazing capacity? To what extent is *Carissa* expansion related to grazing strategy?
11. How can modelling be improved to better simulate pasture dynamics especially relating to spelling and rainfall and the associated effects on animal (esp. breeder) production?
12. How does the stocking rate – liveweight gain relationship in steers translate into breeder reproductive performance?

15 Extension brief

15.1 Increasing adoption of better grazing management practices

Note: This section was directly informed by the outcomes of the Wambiana Trial Extension Officers workshop held on 27 October 2015 (Appendix 2) and the Producer Extension workshop held on 15 March 2016 (Appendix 3).

Prior to considering extension products *per se*, it is important to recognise the main processes driving adoption. A number of important processes and steps in increasing adoption were repeatedly identified in the producer workshop. While an attempt is made to list them in a logical sequence, the processes are not discrete and should operate in a continuous cycle. The processes identified were:

- 1. Increase motivation** – this can be done by:
 - *Inspiring change* – showing people examples of successful change, what can be achieved, changing their thinking?
 - *Shocking* – showing people the extent of land degradation and loss of productive capacity, the poor performance of their business and likely outcomes if management is not changed.
- 2. Increasing knowledge and training** – this involves:
 - *Educating* people about what they don't know, i.e. changing attitudes, increasing knowledge of pasture, animal and business management.
 - *Showing* them *what* needs to be done and *can* be done to improve management.
 - *Showing* them the steps to follow over time to implement this management.
 - *Making information* available for them to research management options etc.
 - *Training to continually improve management skills, knowledge and increase confidence to make management changes.*
- 3. Assessment and planning** – involves:
 - *Conducting a full business analysis* and audit of natural resources, pasture condition and trend etc. to identify strengths, weaknesses etc.
 - *Creating a detailed business plan* with visions, goals and objectives.
 - *Scenario analysis of management options* and likely impacts upon profitability, human resources and land condition.
 - *Creating a detailed management plan* to implement change.
- 4. Monitoring** – of business performance, animal production and land condition etc. to measure impacts of change. This could also involve benchmarking within and between small groups.
- 5. Support** - this should involve :
 - *Extended on-going support*, either one-on-one or in small groups by technical staff, experienced managers as change is implemented.
 - *Peer support* by like-minded producers with similar objectives.

15.2 Suggested extension products

A number of potential extension products were identified in the extension workshops. As noted previously, these should align with the processes important in increasing adoption listed above.

Aligns with processes:	Extension product
1,3,4,	<p>Business analysis, planning and management courses</p> <ul style="list-style-type: none"> • Conduct full business analysis and property audit- must have NRM component. • Allow time for pre-training and to gather and use own property data. • Conduct courses over extended period with periodic reporting back. • Analyse business performance, identify major profit drivers, costs etc. • Analyse potential management changes – use Breedcow, Enterprise etc. to model changes in profitability, productivity and pasture condition over time. • Determine visions, goals and objectives– make a detailed management plan. • Confidential support with farm financial counsellors may be required. • Additional supporting courses e.g. time management, personal development, succession planning may also be needed.
1,2,5	<p>Pasture and grazing management courses.</p> <ul style="list-style-type: none"> • Upgrade courses to include the latest science. • Specific tools for calculating long-term carrying capacity and practical guidelines essential. • Demonstrate the financial benefits of better management with good financial data. • Proposed management change must be linked and integrated with whole of business. • Give specific steps for implementation including possible changes to herd structure, breeding policy, marketing etc. • Follow up and long term support important.
1,2,5	<p>Animal production courses</p> <p>As for other courses – full integration with NRM management required.</p>
1,2,5	<p>Case studies – producer case studies where recommended practices were implemented.</p> <ul style="list-style-type: none"> • Show a compelling case for change. • Include failures and successes, document costs and benefits via herd and economic modelling. • Document the ‘journey’ & possible application to other situations. • Presented by producers in person, on the web, in print etc.
1,2,5	<p>Research & demonstration sites</p> <ul style="list-style-type: none"> • Make a compelling case for change - show the visual differences, quantify outcomes, profitability and specific benefits for producers. • Scale up in time and space to longer-term enterprise level outcomes. • Give possible steps for implementation of practices.

1,2,5	<p>Field days</p> <ul style="list-style-type: none"> • Research sites or on different properties. • Physically show the benefits of better management or the consequences of poor management. • Quantify economic and social costs and benefits. • Maximise producer involvement and/or presentations.
1,2	<p>Invited speakers</p> <ul style="list-style-type: none"> • Successful producers, experts or technical staff. • Could be controversial to generate interest and discussion. • Could be topics only indirectly linked to grazing management in Australia.
1,2,4,5	<p>Extension groups</p> <ul style="list-style-type: none"> • Small groups of producers with similar objectives. • May be a mix of ages and management styles. • Enable peer support and mentoring within group. • Provide technical support as required – structured or unstructured.
1,2,4,5	<p>One-on-one extension</p> <ul style="list-style-type: none"> • Target certain producers based on catchment, land condition etc.? • Analyse different management pathways – use Breedcow, Enterprise etc. to model changes in profitability, productivity and pasture condition over time. • Set up ‘stepping stones’ for change with ongoing support. • Use results and story in fully documented case studies.
1,2,5	<p>Fact sheets, guidelines, results etc. including</p> <ul style="list-style-type: none"> • Research outcomes in an accessible format for extension officers and better managers e.g. ‘<i>Wambiana key learnings book</i>’. • Simple ‘how to’ fact sheets giving guidelines, application steps and rules of thumb for basic grazing management principles. • Make widely available e.g. web based, post outs, hand-outs etc.

16 Futuring workshop June 2016: summary of outcomes

A workshop was held at Charters Towers DAF on 23 June 2016 to review and discuss the future of the long term Wambiana grazing trial (WGT); the full outcomes of this workshop are presented in Appendix 4. The workshop was attended by 29 people, 8 of which were graziers. The remainder were agency, JCU or MLA staff and included senior management, extension staff, modellers, remote sensors, rangeland scientists and a biodiversity specialist. Four members of the Lyons family, the property owners of Wambiana, were among the graziers present.

Results from the main Wambiana trial were reviewed to identify unanswered/new questions and decide whether to continue/modify/terminate trial. Results from collaborative studies involving remote sensing, faunal biodiversity, bio-economic modelling, carbon sequestration wet season spelling and runoff were also briefly considered. The impact of the trial results on the beef industry were also considered in terms of extension effort, management change and producer support for WGT.

- The review of the main WGT determined that while many initial objectives had been answered, a number of important unanswered questions remained. In particular, there had been insufficient time to properly test the flexible stocking strategy (+/- spelling) relative to simply stocking at long term carrying capacity.
- Multiple benefits were identified by collaborative partners in keeping the trial going – in particular, the value of having long term, credible data to document and demonstrate the economic and environmental benefits of good management. Data from the WGT has also been essential in parameterising and validating bio-economic models informing reef policy and extension as well as ground truthing and developing remote sensing applications and products currently in use in Australia and overseas. There was also very strong producer support for the trial in terms of its credibility and value in developing and demonstrating better grazing management strategies to industry.
- The workshop considered three options for the future, i.e. continuation of the project as before, continuation with modification or trial termination. Continuation carried major benefits in terms of continuity, data credibility and the maintenance of a platform for collaborative projects. Modification of the trial to allow establishment of linked satellite sites on commercial properties to demonstrate key management principles, extend the influence of the trial and increase the adoption was also strongly supported, provided the underlying rigour of the main site was not compromised.
- **There was no support whatsoever for termination of the trial.**
- The most important unanswered questions identified were how different grazing strategies impact soil loss and runoff and the extent to which flexible stocking can improve productivity without reducing land condition relative to simply stocking at LTCC.
- Key emergent questions were understanding and managing trigger points that precipitate pasture change and identifying practical, cost effective strategies of regenerating C condition land.
- With current MLA funding terminating in September 2016 a plan has been developed as follows: DAF to continue the project until 30 June 2017 allowing time to seek further funding from MLA in the December 2016 open call and explore possible co-funding arrangements with other agencies and/or funding sources associated with the improvement of water quality entering the Great Barrier Reef lagoon.

17 Success in meeting project objectives

Progress will be reported against individual project objectives as indicated below.

17.1 Maintenance of treatments at trial

Trial management was challenged by the severe drought in 2014/15 which was the fourth driest year (246 mm) in the 105 year record. This was followed by two years of well below average rainfall in 2015/16 (397 mm) and 2016/17 (553 mm). Despite this, all treatments were maintained, although a number of animals had to be withdrawn from the heavy stocking rate treatment for welfare reasons. For the first time in the trial's history drought feeding was also required for a small number of steers in the other treatments as well. Greater detail on the rainfall and management of treatments through the drought and subsequent years is provided in Chapter 4.

In January 2018, pasture yields were so low that both the MSR and R/Spell treatments were completely destocked to avoid significant pasture degradation occurring.

While the above conditions were extremely challenging to manage, they were an extremely valuable learning experience in adaptively managing for a highly variable climate and will form a solid foundation in further developing improved management principles. These learnings and the outcomes of these management actions over the next few years will be reported in detail in the next phase of this project.

17.2 Analysed the Wambiana animal production and pasture data.

The animal production data regarding liveweight gain per head and total liveweight gain per hectare for the period 1997/98 to 2016/17 has been analysed in detail. These results are presented in Chapter 5. The carcass data for the years 2003/04 to 2016/17 has also been analysed and the results are presented in Chapter 6.

Detailed analysis of pasture data has been conducted on two main aspects. In Chapter 8, data is presented on how pasture mass, ground cover and species contribution to pasture mass changed over the course of the trial in the different treatments. This univariate data was analysed using a form of repeated measures analysis.

Multivariate analysis (MVA) was conducted to interpret changes in species composition (frequency) in different treatments over the trial period. Two forms of complementary MVA were conducted. First, distance based redundancy analysis was used to determine the relative effects of factors such as treatment, rainfall, stocking rate and years since fire on changes in species composition. Second, non-metric multidimensional scaling was used to help identify species-treatment associations and track the trajectories of different treatments over time through species ordination space. The results from both these MVA analyses are presented in Chapter 9.

17.3 Undertaken more detailed modelling and economic analysis.

Bio-economic modelling using the GRASP and ENTERPRISE models has been conducted on all stocking strategy by spelling combinations for three starting land conditions (A, B and C) and two climate windows. The main findings and extension messages from the modelling are presented in Chapter 10. The full results are presented in Appendix 1.

17.4 Outlined draft extension messages.

Following a review of the trial results and a workshop with agency extension officers on 27 October 2015, a number of draft extension messages from the Wambiana project were formulated. These draft extension messages are presented in Chapters 12 and 13.

17.5 Convened the producer advisory group to develop an extension brief.

An extension workshop was held with the Wambiana Grazier Advisory Committee and other interested producers on 15 March 2016. The main outcomes of this workshop are presented in Chapter 12 with the detailed outcomes presented in Appendix 3.

17.6 Review and futuring workshop of project.

The Wambiana review and futuring workshop on 23 June 2016 in Charters Towers was attended by representatives from a range of agencies as well the Wambiana Grazier Advisory Committee and other interested graziers. The meeting highlighted the many strengths of the project and its importance for a number of other important, related projects. These include its importance for ground truthing existing and emerging remote sensing tools, the value of the long term data for modelling related to reef water quality outcomes and the importance of the site for training graziers and agency staff. In summary, there was very strong support for the trial to be continued, albeit with some modification to include possibly, satellite demonstration sites in other areas. There was no support whatsoever for termination of the project. These recommendations are presented in Chapter 16 and a summary of the workshop proceedings is provided in Appendix 4.

17.7 Decommission trial site if recommended by 30 November 2016.

It is recommended that the trial be continued until at least 31 May 2017. Continuation past that date will depend on further funding from MLA and/or other funding agencies.

17.8 Drafted two journal manuscripts

A paper on the analysis of the pasture yield, cover and species composition data from 1998 to 2011 has been drafted but requires updating to include the most recent results before submission to a journal. Work is still required on drafting papers based on the modelling and economic analysis of the data. A co-authored paper with JCU colleagues on the trade-off between reptile biodiversity and profitability (Neilly *et al.* 2017) in the different grazing strategies has been published in *Rangeland Ecology and Management*, the official journal of the American Society for Range Management.

A remote sensing paper entitled '*Integration of optical and X-band radar data for pasture biomass integration estimation in an open savannah woodland*' based on data collected at the trial site has also been published in the journal *Remote Sensing* (Schmidt *et al.* 2016).

18 Extension of trial results

Table 18.1 Total number and breakdown by category of visitors to the Wambiana trial site and the total audience at presentations between January 2010 and August 2017.

	Agency staff	Graziers	Students	Total
Visitors to trial site	138	201	303	701
Presentations: total audience ¹	510	348	104	900

¹ Presentations ranged from national, to international conferences such as the International Grasslands Congress, to grazer meeting in sheds.



Fig. 18.1 An example of an extension activity at the trial site: The Wambiana field day on 29 August 2015 was attended by 172 people, 96 of whom were graziers. Collectively, they managed 1.4 million ha of country. Analysis of the feedback sheets showed a very high level of satisfaction with the day.

19 Project publications

19.1 Scientific publications

19.1.1 Trial based papers with project team as (co) authors

O'Reagain P.J. & Scanlan J. 2013 Sustainable management for rangelands in a variable climate: evidence and insights from northern Australia. *Animal* 7; s1: 68-78

Scanlan, J., Macleod, N & **O'Reagain P.J.** 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. *Rangelands Journal* 35, 193-200.

Allen, D.E., Pringle, M.J., Bray, S., Hall, T.J, **O'Reagain, P.**, Phelps, D., Cobon, D.H., Bloesch P.M., Dalal, R.C. 2013. What determines soil organic carbon stock in the grazing lands of north eastern Australia? *Soil Research* 51(8), 695-706).

O'Reagain, P.J., Scanlan, J., Cowley, R., Hunt, L. & 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.

Bray, S.G., Doran-Browne, N. and **O'Reagain, P.J.** 2014. Northern Australian Pasture and Beef Systems. 1. Net Carbon Position. *Animal Production Science* 54, no. 12 (2014): 1988-94.

Doran-Browne, N. A., Bray, S.G., Johnson, I.R., **O'Reagain, P.J.** and Eckard, R.J. 2014. Northern Australian Pasture and Beef Systems. 2. Validation and Use of the Sustainable Grazing Systems (SGS) Whole-Farm Biophysical Model." *Animal Production Science* 54, no. 12 (2014): 1995-2002.

Segoli, M., Bray, S., Allen, D., Dalal, R., Watson, I., Ash, A. & **O'Reagain, P.** 2015. Managing cattle grazing intensity: effects on soil organic matter and soil nitrogen. *Soil Research* 53, 677-682.

Schmidt, M., Carter, J., Stone, G. & **O'Reagain P.J.** 2016. Integration of optical and X-band radar data for pasture biomass integration estimation in an open savannah woodland. *Remote Sensing* 2016. 8(12), 989; doi:10.3390/

Neilly, H., **O'Reagain, P.**, Vanderwal, J. & Schwarzkopf, L. 2017. Profitable and sustainable cattle grazing strategies support reptiles in tropical savanna rangeland. *Rangeland Ecology and Management*. 71(2):205-212. <https://doi.org/10.1016/j.rama.2017.09.005>

19.1.2 Papers based on trial data - other authors

Neilly H, Nordberg E, VanDerWal J, Schwarzkopf L. 2017. Arboreality increases reptile community resistance to disturbance from livestock grazing. *Journal of Applied Ecol.*; 00:1–14. <https://doi.org/10.1111/1365-2664.12982>

Scarth, P and Trevethick, R. 2017. Management effects on ground cover 'clumpiness': scaling from field to Sentinel-2 cover estimates. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XLII-3/W2 37 th International Symposium on Remote Sensing of Environment, 8-12 May 2017, Tshwane, South Africa.

Neilly H, & Schwarzkopf, L. 2018. Heavy livestock grazing negatively impacts a marsupial ecosystem engineer. *Journal of Zoology* (London) *in press*.

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](https://doi.org/10.1038/s41598-017-17829-6)

19.2 Conference proceedings

O'Reagain, P.J., Bushell, J.J. 2016. Is variable stocking more profitable than fixed stocking in a variable climate? *Proceedings of the Northern Beef Research Update Conference*, Rockhampton, 2016, 163.

O'Reagain, P.J., Bushell, J.J. & Lewis, A. 2016. The effect of fire on the long term dynamics of Currant bush. *Proceedings of the Northern Beef Research Update Conference*, Rockhampton, 2016, 164.

O'Reagain, PJ, Bushell, JJ 2013. Managing for a variable environment: long term results from the Wambiana grazing trial. *Proceedings of the Northern Beef Research Update Conference*, Cairns, 12-15 August, 2013, 55-60.

O'Reagain, PJ, Bushell, JJ 2013. Fire affects structure but not density in semi-arid tropical savanna. *Proceedings of the Northern Beef Research Update Conference*, Cairns, 12-15 August, 2013, 145.

19.3 Popular publications

Performance of Wambiana grazing trial strategies through drought, *Brahman News*, March 2016, #190, 60-62.

Performance of Wambiana grazing trial strategies through drought, *Northern Muster*, February 2016.

Stocking rates- no more trial and error, *MLA Feedback* magazine, February 2016, 18-19.

Flexibility drives profit, *North Qld Register*, 10 December 2015, 33.

Aim to sustain, *MLA Feedback* magazine, December 2015, 23.

Wambiana field day looks at long-term stocking strategies, *Northern Muster*, 27 August 2015,

Grazing for the climate *Qld. Country Life*, 27 November 2014, 46.

Biodiversity in the Burdekin, *MLA Feedback* magazine, October 2013, 14-16.

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21 Appendix 1: Bio-economic modelling report

21.1 Introduction

In this third phase of the Wambiana project, the bio-economic modelling (BEM) process which commenced in Phase 2 (O'Reagain 2014; Scanlan *et al.* 2013), was extended to cover a range of additional scenarios and factors and determine how they affect long-term profitability and sustainability.

Bio-economic modelling was used to assess how the sustainability and economics of fixed stocking, flexible stocking and wet season pasture spelling strategies were impacted by differences in initial pasture condition, climate period and stocking rate.

21.2 Methods

The GRASP and ENTERPRISE models were parameterised and calibrated for the box soil type at the Wambiana grazing trial (Scanlan *et al.* 2013). A hypothetical cattle property typical of the Charters Towers district was used to simulate several annual stocking rate flexibilities and wet season spelling strategies under a range of starting pasture conditions, stocking rates and different climate windows.

21.2.1 Stocking rate flexibilities

Five forms of annual stocking rate flexibility were simulated. These were:

Fixed stocking: the same stocking rate was used for each year of each simulation period.

Fixed stocking was simulated with four stocking rates. These were:

- i. High stocking rate – A rate of 25 animal equivalents (AEs=450 kg steer) per 100 ha (equivalent to the heavy stocking rate at the Wambiana grazing trial)
 - ii. Low stocking rate – A rate of 12.5 AEs per 100 ha (equivalent to the moderate stocking rate at the Wambiana grazing trial)
 - iii. Maintenance stocking rate – The GRASP model was run for each starting land condition and all climate periods using a wide range of fixed stocking rates. From these simulations, the stocking rate that maintained an average perennial grass percentage over the whole simulation similar to the starting value was classed as the 'maintenance' stocking rate. For example, for land initially in C condition, the maintenance stocking rate was 10 AE/100 ha and 17 AE/100 ha for the 1982-2011 and 1952-1981 climate periods respectively.
 - iv. Moderate stocking rate – This was selected to be mid-way between the maintenance and high stocking rate. It was included as an approximation of a stocking rate that might produce some pasture deterioration, and may also be commonly applied in the Charters Tower district (Note: This is heavier than the 'moderate' stocking rate at the Wambiana trial).
1. 05 05% Flexibility:
Annual stocking rates were allowed to increase by up to 5% when pasture production was such that stock numbers could be increased, or reduced by up to 5% when pasture production required stock numbers to be decreased.

This low flexibility was simulated with three initial starting stocking rates (stocking rate in the first year of simulation periods). These were:

- i. High stocking rate – 25 AEs per 100 ha
 - ii. Moderate stocking rate – 17.5 AEs per 100 ha
 - iii. Low stocking rate – 12.5 AEs per 100 ha
2. 10 20% Flexibility:
Stocking rates could be increased by up to 10% and decreased by up to 20% annually depending on pasture production. This higher flexibility was simulated with only a moderate starting stocking rate (17.5 AEs per 100 ha).
 3. 20 40% Flexibility:
Stocking rates could be increased by up to 20% and decreased by up to 40% annually depending on pasture production. This higher flexibility was simulated with only a moderate starting stocking rate (17.5 AEs per 100 ha).
 4. 40 40% Flexibility:
Stocking rates could be increased by up to 40% and decreased by up to 40% annually depending on pasture production. This higher flexibility was simulated with only a moderate starting stocking rate (17.5 AEs per 100 ha).

For the low 05 05% flexibility, there were no limits on the total amount that stocking rates could increase or decrease over the 30-year simulation periods. For each of the higher flexibilities, stocking rates could increase by a maximum of 60% or decrease by a maximum of 67% relative to the initial stocking rate (moderate stocking rate of 17.5 AEs per 100 ha in year 1 of simulations).

21.2.2 Wet season spelling strategies

Four wet season pasture spelling strategies were simulated. These were:

1. Spelling with loading up of other paddocks in the rotational spelling system in all years – all cattle from the spelled paddock were evenly distributed across the three paddocks not spelled in that year.
2. Spelling with no loading up of other paddocks during the first cycle – during the first four years (first rest period for each paddock), cattle from the spelled paddocks were agisted off-property. Thereafter, cattle from the spelled paddocks were spread evenly across the remaining three paddocks.
3. Spelling with no loading up of other paddocks during spelling in any years – the cattle from the spelled paddock were agisted off-property for the duration of the spell period.
4. No Spelling in any year.

Each spelling strategy consisted of a six-month wet season spell starting on 1 December with a frequency of 1 year in 4 years. This was simulated within a rotational spelling strategy involving four equal-sized paddocks.

21.2.3 Climate windows and pasture condition

The stocking rate flexibilities and pasture spelling strategies were simulated with three different initial pasture conditions and two different climate periods. The three initial pasture conditions were:

- A condition –70% perennial grass composition (by weight)
- B condition –50% perennial grass composition
- C condition –20% perennial grass composition.

The two 30-year periods of actual climate for Charters Towers were:

1. 1952-1981
2. 1982-2011

Climate period 1 (1952-1982) was chosen because it was particularly wet. Climate period 2 (1982-2011) was selected because it was much drier (Table 1) and also covered the ‘working life’ of many current landholders and researchers.

Table 1: Rainfall data for the two Charters Towers 30-year climate periods used in GRASP simulations.

Rainfall	Period 1:	Period 2:
Mean (mm)	723	637
Maximum (mm)	1633	1287
Minimum (mm)	344	0
Years <400 mm	4	10
Years <500 mm	6	13
Years >650mm	17	13
Rainfall C.V. over 30 years.	39%	49%

The combinations of annual stocking rate flexibilities, spelling strategies, initial pasture conditions, initial stocking rates and climate periods simulated are shown in Table 2.

Table 2. The combinations of stocking rate flexibilities, spelling strategies, initial pasture condition, initial stocking rate, and climate periods simulated (Hi=high, Md=moderate, Mt=maintenance, Lo=low).

Flexibility	Spelling strategy				Pasture condition			Stocking rate				Climate period	
	1	2	3	4	A	B	C	Hi	Md	Mt	Lo	1	2
Fixed	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
05 05%			✓	✓	✓	✓	✓	✓	✓			✓	✓
10 20%			✓	✓	✓	✓	✓		✓			✓	✓
20 40%			✓	✓	✓	✓	✓		✓			✓	✓
40 40%			✓	✓	✓	✓	✓		✓			✓	✓

For spelling, 1 = Spell with loading up of paddocks in all years; 2 = Spell with no loading in the first cycle; 3 = Spell with no loading in any year; 4 = No spelling.

Fixed stocking was simulated with all three pasture spelling strategies, the three initial pasture conditions, all four stocking rates, and both climate periods. There were a total of 96 simulations for fixed stocking.

The low 05 05% flexibility was simulated with only spelling strategies 3 (no loading) and 4 (no spelling), three pasture conditions, three stocking rates and both climate periods. Total simulations was 36.

The three higher flexibilities were also simulated with spelling strategies 3 (no loading) and 4 (no spelling), three pasture conditions and both climate periods, but only one stocking rate (moderate). Total simulations was 36.

21.2.4 Case study property and herd parameters

The stocking rate flexibilities and spelling strategies were simulated for a beef grazing property and a cattle breeding herd typical of the Charters Towers region where the Wambiana grazing trial is located. The property consisted of nine paddocks with a total area of 23,000 hectares. Four paddocks contained around 1000 head of breeders, four paddocks contained steers up to the age of two years, and the remaining paddock contained one-year old heifers. All paddocks were designated

as the box land type. This single land type was used because it is the dominant land type at the Wambiana grazing trial site and because GRASP had been accurately parameterised for this land type (Scanlan *et al.* 2013).

All weaner steers and heifers were retained, steers were sold at the age of two years regardless of weight. Other sale animals were cull-for-age cows (10 years), 15% of the breeders which failed to have a calf in any year, and surplus heifers. First-calf or 2.5 year old heifers and one year old steers were purchased in the years when the herd simulated in ENTERPRISE did not meet the stocking rate targets used in GRASP. These purchased heifers had the same probability of having a calf as the other maiden heifers on the property.

Bulls were purchased for \$3000 per head, and cull bulls were sold for \$1.20/kg live-weight at an assumed weight 550 kg. For steers, heifers and cows, the purchase and sale prices used in ENTERPRISE were based on the Gracemere sale records from 2009 to 2015, collated and supplied by Mick Sullivan (DAF, Rockhampton).

One year old steers were purchased each year for \$493 per head if required. The selling price for steers was \$1.65/kg live-weight (the 50th percentile price for 400-500 kg steers sold at Gracemere), at their GRASP simulated live-weight at the age of two years (sum of their weaning weight and two consecutive years of live-weight gains or losses).

If necessary, first-calf or 2.5 year old heifers were purchased for \$612 per head each year. The selling price for heifers was \$1.55/kg live-weight (the 50th percentile price of 200-300 kg heifers sold at Gracemere), and their live-weight was estimated to be 300 kg plus the annual live-weight gain or loss simulated by GRASP.

For cows, the sale prices used were the average live-weight prices from Gracemere for cows at a range of live-weights. These were \$1.00/kg for cows with a live-weight up to 300 kg, \$1.15/kg for cows with a live-weight of 360 kg, \$1.20/kg for cows with a live-weight of 425 kg, and \$1.35/kg for cows with a live-weight 450 kg or more (Fig. 1). These prices and weights were used to derive the regression equation ($y = 0.002x + 0.3924$; $r^2=0.909$), where y is the sale price in \$/kg and x is the live-weight. This regression equation was then used in ENTERPRISE to calculate the sale price given the sale weight of cows each year. The sale weight of cows each year was estimated to be 400 kg plus the annual live-weight gain or loss simulated by GRASP.

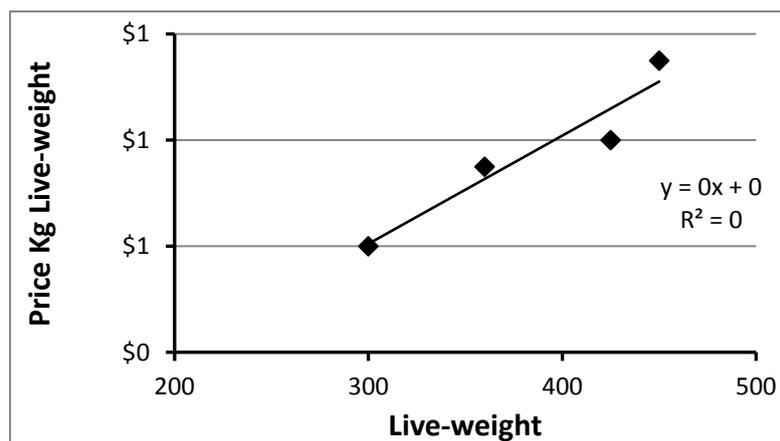


Fig. 1 The relationship between live weight and sale price per kg used to determine sale prices in the present simulations (data from M Sullivan, DAF, Rockhampton).

Breeders and steers were agisted for the spelling strategies which did not involve loading up of paddocks within the rotational spelling system. The agistment rate was \$3 per week for breeders with a calf and \$2.30 for steers.

21.2.5 Key modelled outputs and statistical analysis

Key outputs from GRASP, annual live-weight gain per head (LWG/hd) and annual stocking rate (ha/AE) during each 30-year simulation period, were read into ENTERPRISE. The annual stocking rate and annual LWG/hd determine herd productivity, and subsequently economic performance. For example, Scanlan et al. (2013) explained that the LWG of steers from GRASP is used in ENTERPRISE to estimate mortality separately for steers and breeders, as described in MacLeod and McIvor (2004), and is based on the work of Gillard and Money Penny (1988) in the same region of north Queensland. Specifically, the following mortality and branding rate equations are used within ENTERPRISE:

$$\text{Mortality (breeders) \%} = 6 + 94e^{-0.027*[\text{LWG}(\text{steers})+50]} \quad (1)$$

$$\text{Mortality (dry stock) \%} = 2 + 88e^{-0.034*[\text{LWG}(\text{steers})+50]} \quad (2)$$

$$\text{Branding \%} = 0 \leq 15.6 + 0.488 \text{ LWG (steers)} \leq 80 \quad (3)$$

The key result from GRASP simulations relating to sustainability was the percent perennial grass composition averaged over the last five years of each simulation period, here referred to as final %P. Economic performance was compared using the spreadsheet economic model ENTERPRISE (MacLeod and Ash 2001, MacLeod et al. 2011, Scanlan et al. 2013, Whish et al. 2016). The main economic metric used to compare grazing land management strategies was net present value (NPV) with a 5% discount rate (opportunity cost of funds available). The economic metric NPV was used because it converts future cash-flows into present day values; it discounts the value of income that can take a long time to arise from a change in management. Average annual total gross margin (TGM) was also provided as an additional economic indicator of grazing land management strategies.

The final %P, NPV and TGM for the 168 simulations were analysed using analysis of variance (ANOVA) in GenStat (2015) by Dr. David Mayer (DAF, Brisbane). When interpreting ANOVA results from data generated by models, particularly those involving large data sets derived from deterministic models such as GRASP and ENTERPRISE, the relative sizes of treatment mean squares is more important than calculated probability (p) levels (Mayer *et al.* 1994). Indeed, it is not appropriate to use calculated statistical probability values in any ANOVA of results from deterministic models, due to the lack of an error term. Accordingly, relative differences in the mean squares were used to show relative differences in the influence of factors on final %P, NPV and TGM.

21.2.6 Limitations of models

The GRASP and ENTERPRISE models have limitations in their applications to extensive beef grazing business analyses which may also affect comparisons of grazing management strategies. For example, GRASP is unable to account for improvements in forage quality and reductions in patch grazing which are known benefits of pasture spelling. There is also relatively limited empirical data on how pasture condition responds over time to changes in the frequency and length of spelling and how it interacts with rainfall and grazing, to support the detailed level of simulation required in the present project. For example, there is no empirical data on the relative impacts of wet season spelling with or without loading on overall pasture condition, i.e. the point at which the positive effects of wet season spelling are negated by the increased utilisation rates on non-spelled areas.

The annual live-weight gain model within GRASP does not predict intra-annual changes in live-weight and therefore is not capable of simulating changes in live-weight associated with six-month periods of pasture spelling, i.e. for the six months that stocking rates in a particular paddock are higher or lower due to spelling. GRASP also does not simulate the live-weights or live-weight changes of breeders. It only does this for steers. A live-weight typical of the age class of steers in the simulation region is allocated to each steer class each year, which in turn sets the amount of forage they consume annually. The live-weight of steers then varies over the year in accordance with the live-

weight changes simulated by GRASP. GRASP then resets the live-weight of steers to the nominated live-weight at the beginning of the next simulation year.

The version of ENTERPRISE used in this study was initially developed by Neil MacLeod (CSIRO, Brisbane) during the Northern Grazing Systems project (Scanlan *et al.* 2011). Development of this model was ongoing during that project as modelling requirements varied amongst regions, driven by varying characteristics of case study properties, herds, sale cattle, and management practices. Neil MacLeod and members of this BEM team have continued to review and revise ENTERPRISE after completion of the Northern Grazing Systems project.

One of the main limitations within ENTERPRISE is its inability to represent annual changes in the live-weights of breeders and heifers, and to account for the impact of these on selling and purchasing prices and on the conversion of AE's to head of breeders. ENTERPRISE also often struggles to maintain the herd size and stocking rates simulated in GRASP, for example, under high stocking rates when the simulated herd is not self-replacing. Under these conditions, ENTERPRISE must often purchase large numbers of heifers and steers in order to keep stocking rates aligned with those in GRASP. The lack of feedback on herd size at the end of the simulation year from ENTERPRISE to GRASP also limits the capacity of these models to compare grazing strategies.

At the beginning of Phase 3 of the Wambiana grazing trial, a number of further modifications were made to ENTERPRISE to better align the stocking rates of female and male cattle present on the property each year with those simulated in GRASP. The instances where stocking rates within ENTERPRISE did not match those within GRASP are identified below, along with the changes made to ENTERPRISE.

The previous version of ENTERPRISE did not account for the increase in AE of the breeder herd that was due to production of a calf. This was modified so that the annual AE for a breeder was adjusted and now includes 0.35 AE for those cows which had calves in each simulation year. However, a further adjustment to account for annual variation in female live-weight is required, as this will substantially influence the conversion of breeder AE to breeder head.

The previous version of ENTERPRISE also used a single AE value for steers in all simulation years. This was modified so that conversion of steer AE to steer head reflects changes in their age and live-weight annually.

Previously, the steer paddocks in ENTERPRISE were stocked each year with the number of steers generated by the breeder herd and thus did not necessarily have stocking rates aligned with those simulated in GRASP. This was modified so that the annual targets for steer numbers in each steer paddock were set in accordance with the steer stocking rates simulated in GRASP. This also required replacement of all formulas relating to the annual numbers of steers present and steers sold within the HerdDynamics worksheet of ENTERPRISE.

In some years, especially when stocking rates were well above carrying capacity, the live-weight gains predicted by GRASP were highly negative. In these instances, ENTERPRISE was originally parameterised to feed sufficient quantities of molasses, urea and protein meal to ensure that cattle did not lose weight annually (live-weight gain of at least zero). This was automatically applied in all years, ensuring there were no years when either female or male cattle lost weight. In addition, cattle were then fed M8U to ensure they achieved a nominated positive annual live-weight gain target set within ENTERPRISE, usually set at a minimum of +50 kg annually. Given that the original form of supplementation used within ENTERPRISE is unlikely to be practiced in northern Australia, supplementation was modified to include just one mix, i.e. a mixture of molasses, urea and protein meal (MUP). This was only fed to steers when the annual live-weight gain generated by GRASP was less than -20 kg. Similarly, MUP was fed to female cattle when the annual steer live-weight gain fell below -50 kg. In both cases, male and female cattle were fed quantities of MUP needed to achieve annual live-weight gains of at least -20 and -50 kg respectively.

There are also other instances where improvements could be made to the adjustment of AE within ENTERPRISE. One of these relates to the increase in forage intakes that occurs when cattle are fed supplements. Currently, this increase in forage intake is not accounted for within the AE conversions within ENTERPRISE. Another potential limitation is associated with the date on which cattle are sold. ENTERPRISE keeps sale cattle in the herd the whole year, whereas in reality, steers in particular will be sold when they reach target weights during the year. Hence, their AE value should be discounted, as it is within Breedcow and Dynama, to reflect the shorter time they spend on the property. However, this would also need to be incorporated into the GRASP simulations, which may not be possible with some models, such as flexible stocking. There is also an error within GRASP in how it calculates the LWG/hd of cattle that move out of a paddock when it is spelled. This is based on the utilisation rate and green days for the rested paddock, whereas cattle only spend the dry season in this paddock and the wet season elsewhere. As such, the utilisation rate used within GRASP would be only about 50% of the actual utilisation rate if the cattle were agisted, or possibly even lower for cattle moved into adjacent paddocks (loaded up). Even so, this error is likely to be relatively small, given that it occurred in two paddocks annually, and does not appear to greatly over-estimate LWG. For example, if the annual utilisation was 30% if kept in the spelled paddock all year, and if GRASP used only 15% due to the animal not being in that paddock during the wet season, then the LWG from the regression equations would be 11 kg per head higher than it would have been.

Originally, ENTERPRISE also had one selling price and selling weight for cull breeders and one selling price and selling weight for cast-for-age breeders that were used in all simulation years. This was modified so that annual selling prices and selling weights reflected the change in condition of breeders annually. Regression equations, based on sale yard data are now used to adjust annual selling prices, and annual live-weights for sale female cattle are adjusted in accordance with the annual live-weight gains or losses simulated by GRASP (described above under *Case study property and herd parameters*).

21.3 Results and Discussion

Differences in pasture composition as indicated by differences in the percent perennial grass composition at the end of simulations (final %P), and differences in NPV and TGM were first compared for fixed stocking. This was followed by a comparison of all the flexibilities (fixed, 05 05%, 10 20%, 20 40% and 40 40%) which had the same climate periods (1 and 2), stocking rate (moderate), initial pasture conditions (A, B and C) and spelling strategies (no spelling and spelling with no loading in any years).

21.3.1 Fixed stocking and pasture spelling

21.3.1.1 Pasture condition

As described earlier, an ANOVA was used to generate mean squares (MS) for the main and interaction effects of initial pasture condition, stocking rate, climate period and pasture spelling strategies on final %P for the 96 fixed stocking simulations.

Amongst the main effects, stocking rate, with a MS of 57, had the dominant influence on final %P, while initial pasture condition (MS = 34) and climate period (MS = 31) had lower but similar influences. Spelling strategies (no spelling and three forms of spelling) had the least influence (MS = 10) on final %P.

These main effects are illustrated in Figures 1 to 4. Figure 1 shows the differences in average final %P that occurred for the four stocking rates. These are the final %P for all high, moderate, maintenance and low stocking rates, averaged across all other factors (pasture conditions, climate periods and spelling strategies). Overall, final %P increased as stocking rate declined with the average final %P for

the high stocking rate only 30% compared with 80% for the low stocking rate. However, there was little difference final %P between the maintenance and low stocking rates.

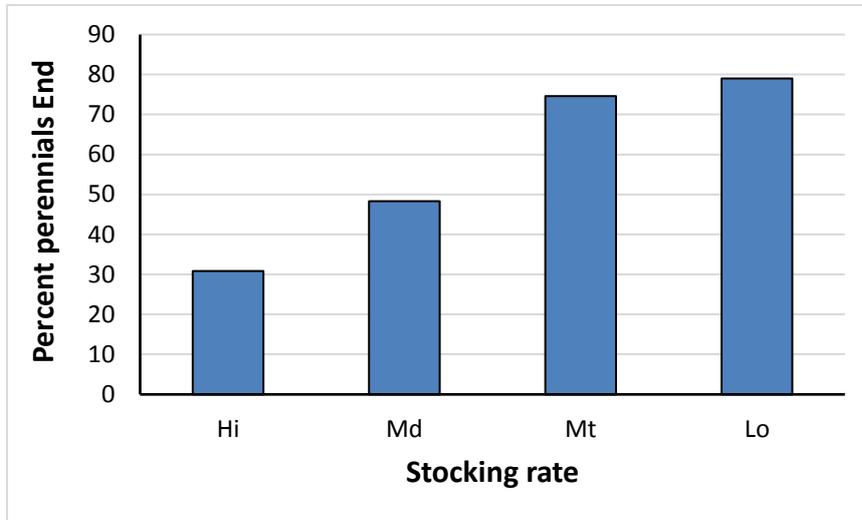


Fig. 1. Average final %P at the end of the 30 year simulation period for four fixed stocking rates (Hi= high, Md = moderate, Mt = maintenance, Lo = low).

Starting pasture condition also had a marked effect on final %P at the end of the 30 year simulation periods. The final %P for the three initial pasture conditions, when averaged across all other factors, ranged from around 40% for C condition to 70% for A condition (Fig. 2).



Fig. 2. Average final %P at the end of the 30 year simulation periods averaged across all stocking rates and spelling treatments for the three initial (starting) pasture conditions.

The final %P for the two climate periods, again averaged across all other factors, ranged from 50% for the dry climate period 2 to 67% for wetter climate period 1 (Fig. 3). This is due to the high and moderate stocking rates used in simulations being more appropriate for the climate period 1. Climate period 2 was drier and as such had a lower livestock carrying capacity, hence the high and moderate stocking rates resulted in high pasture utilisation rates causing a decline in % of perennial grasses relative to period 1 (Fig. 3).

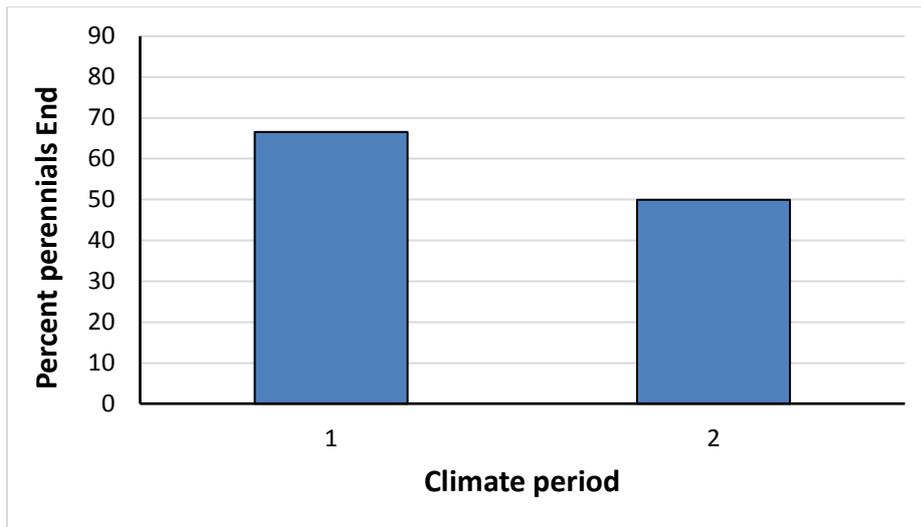


Fig.3. Average final %P for climate periods 1 (1952-1981) and 2 (1982-2011).

In relation to spelling, when averaged across all other factors, final %P was lowest for fixed stocking with no spelling (48%) and highest for spelling (71%) with no loading in any year (Fig. 4). This is expected, as spelling with no loading in any year resulted in a 12% reduction in overall stocking rates annually, whereas this only occurred during the first four years with spelling involving no loading in the first cycle, and not at all with spelling with loading every year. Spelling during the wet season is widely documented to improve perennial grass composition (e.g. Ash et al. 2011), which is evident in spelling with loading all years, having a higher final %P than no spelling (Fig. 4). However, the improvement due to the spelling effect *per se* is small relative to the effects of stocking rate (Fig. 1).

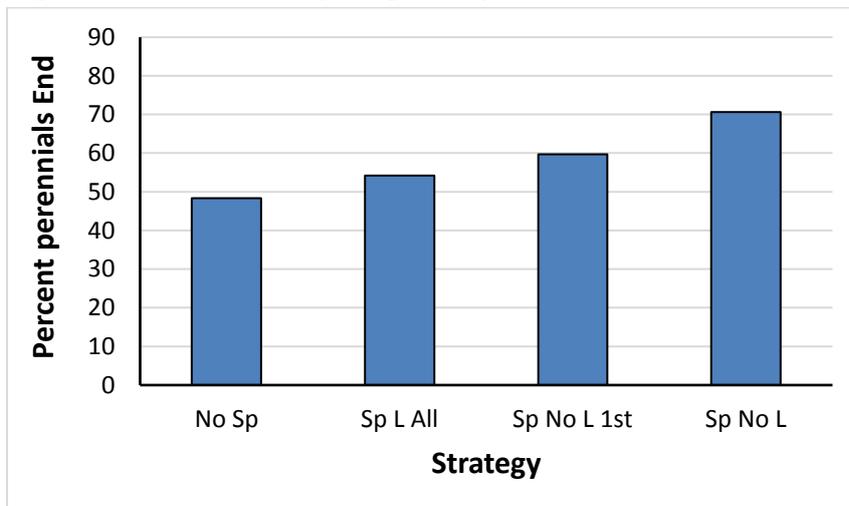


Fig. 4. Average final %P for fixed stocking and the spelling strategies (No Sp = no spelling, Sp L All = spelling with loading all years, Sp No L 1st = spelling with loading only in the first cycle, Sp No L = spelling with no loading in any year).

As with the main effects above, the final %P for the 2-way interactions were also dominated by stocking rate, initial pasture condition and climate period. The highest MS of 4.4 was for stocking rate x climate period, followed by a MS of 2.2 for stocking rate x pasture condition. The combined dominating influence of these three factors is further shown in the MS for the 3-way interactions, being 8 for pasture condition x stocking rate x climate period, whereas the next largest MS was 1 for stocking rate x spelling strategy x climate period. The results for the 3-way interactions are presented below.

The influence of pasture condition x stocking rate x climate period on final %P is illustrated in Fig. 5. During the wetter climate period 1 with initial pasture condition A, the high stocking rate appeared

to have no effect on final %P. However, this was probably an artefact of the rules used in the modelling which resulted in the stocking rates for the high, moderate and maintenance rates being essentially the same, i.e. 4 ha/AE for this particular simulation. In contrast, during the dry climate period 2, high and moderate stocking rates resulted in a large decrease in final %P irrespective of whether pastures were in A, B or C initial conditions. In climate period 2, the final %P also decreased even when stocking rates were low for initial pasture conditions B or C (but not A). This occurred because the maintenance stocking rate in these particular circumstances was actually lower than the low stocking rate used in simulations, i.e. the 'low' stocking rate applied was not light enough to prevent a decline in pasture condition for B or C condition pastures.

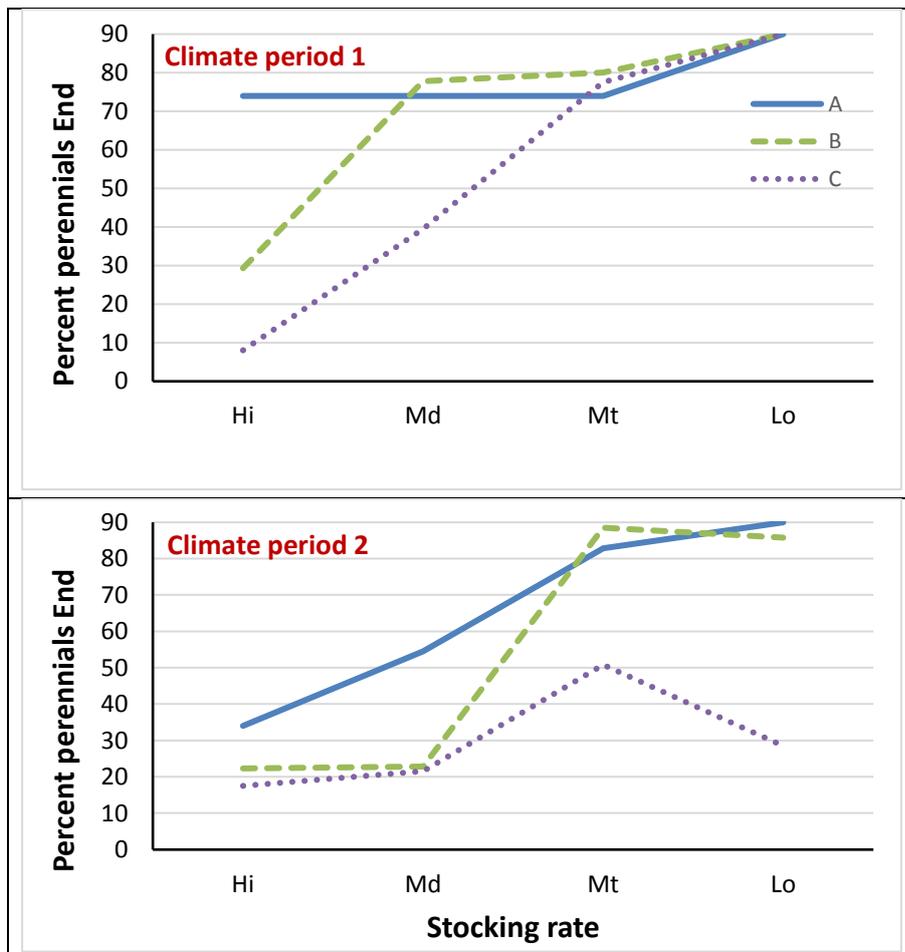


Fig. 5. The average final %P for all combinations of the four stocking rates and three pasture conditions, for (top) climate period 1 (1952-1981) and (bottom) climate period 2 (1982-2011).

While the influence of the interaction between stocking rate x spelling x climate period (MS = 1) was much less than that for pasture condition x stocking rate x climate period (MS = 8), it does show how the influence of the spelling strategies varied with other factors (Fig. 6). During the wetter climate period 1, spelling with no loading in any years achieved a higher final %P than the other two spelling strategies and the no-spell control, except when the stocking rate was low. Low stocking rates allowed final %P to improve to GRASPs maximum level of 90%, hence spelling could not improve this further. Spelling with no loading during the first cycle was able to improve final %P relative to no spelling, but only under moderate or high stocking rates. Again, the maintenance and low stocking rates in their own right enabled increases in final %P. During this wetter climate period there was no difference in final %P for spelling with loading in all years and no spelling.

In contrast, during the drier climate period 2, the three spelling strategies all improved final %P relative to no spelling. The one exception was where spelling with loading in all years occurred with

a low stocking rate, where final %P was the same as that for no spelling. Otherwise, spelling with loading in all years achieved a higher final %P than no spelling when stocking rates were maintenance, moderate and high, clearly demonstrating the benefit of the wet-season spell. During this dry period, the final %P for spelling with no loading and spelling with no loading in the first cycle were often higher than those for spelling with loading in all years. The main exception was when the stocking rate was high, in which case the three forms of spelling did not differ in their impact on final %P.

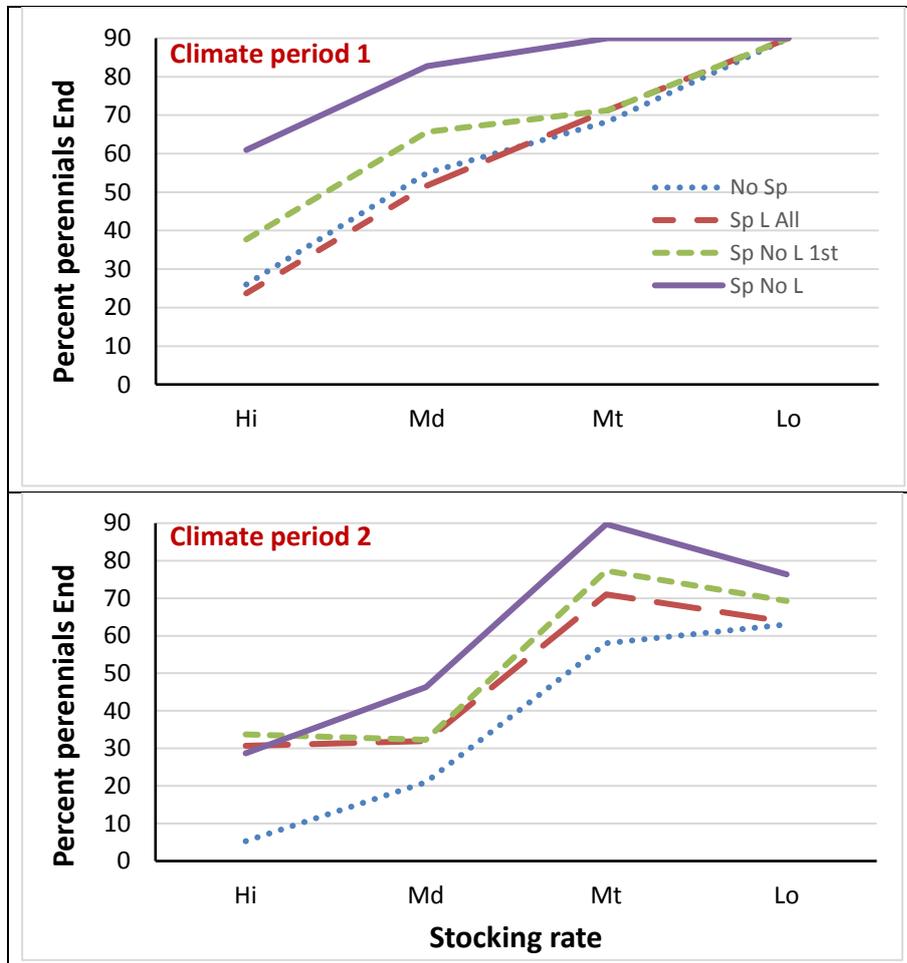


Fig. 6. The average final %P for all combinations of the four stocking rates and four spelling strategies, for climate period 1 (1952-1981) and 2 (1982-2011). (No Sp=no spelling, Sp L All=Spelling with loading up in all years, Sp No L 1st=spelling with no loading in cycle 1; Sp no L=spelling with no loading)

The influence of spelling in combination with stocking rate on final %P also varied with initial pasture condition (Fig. 7). When initial condition was A, spelling with no loading achieved higher final %P than the other two spelling strategies and no spelling, except when the stocking rate was low. When initial pasture condition was poorer, i.e. B or C, greater differences in final %P emerged amongst the spelling and no spelling strategies. Spelling with no loading in all years and spelling with no loading during the first cycle achieved much higher final %P than did spelling with loading all years and no spelling when initial pasture condition was B and stocking rate was high. When initial pasture condition was C, there were larger differences in final %P between these strategies, with these differences being greatest with moderate and maintenance stocking rates. This indicates the somewhat obvious point that the potential benefits from spelling are greatest with poorer condition pastures.

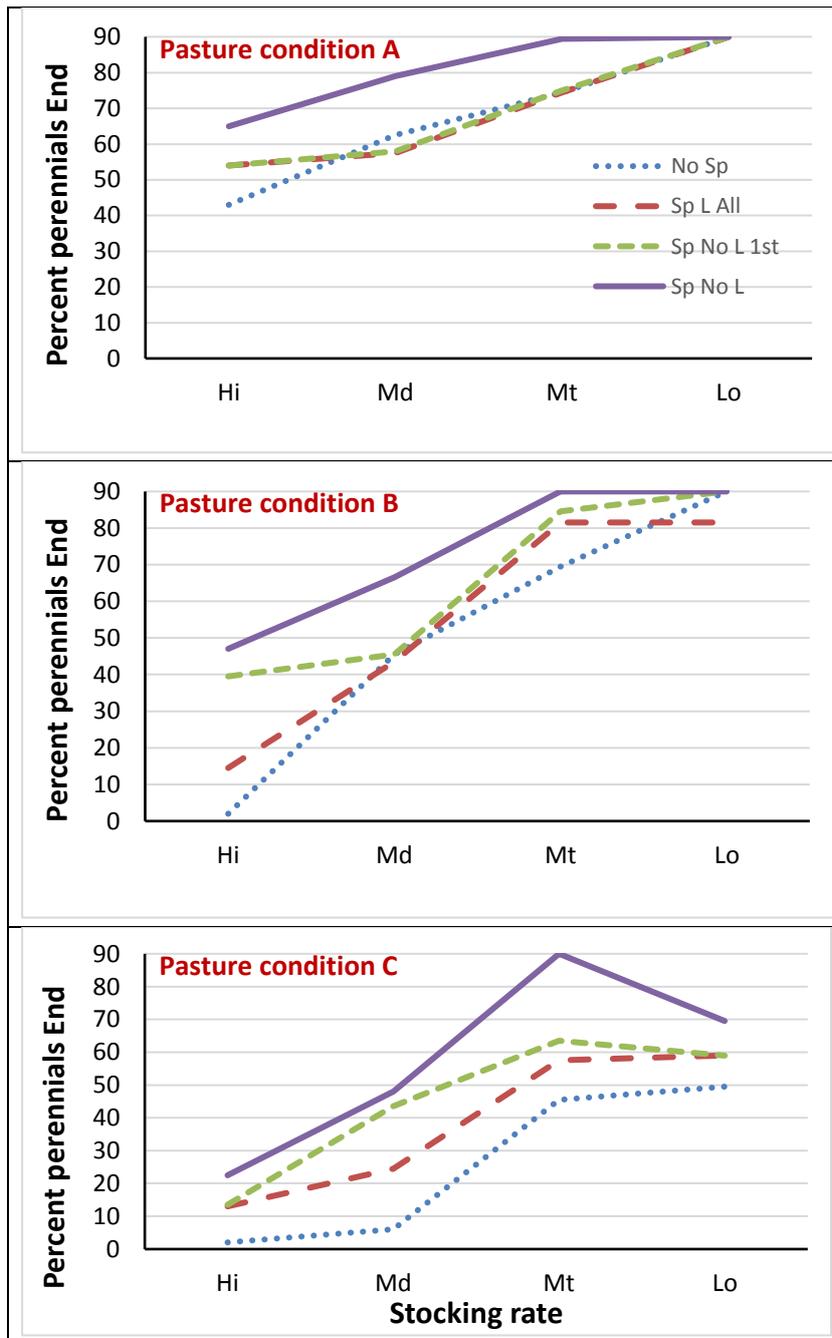


Fig. 7. The average final %P for all combinations of the four stocking rates and four spelling strategies, for initial pasture conditions A, B and C.). (No Sp=no spelling, Sp L All=Spelling with loading up in all years, Sp No L 1st=spelling with no loading in cycle 1; Sp no L=spelling with no loading)

In summary, stocking rate had the greatest impact on final %P, followed in order of decreasing influence by initial pasture condition, climate period and then spelling. As such, the final %P achieved tended to increase most with decreasing stocking rates and increasing initial pasture condition. The final %P was also higher for the wetter climate period 1, due to more favourable growing conditions, higher pasture production and hence the relatively lower utilisation rates associated with the high stocking rate. Within this context, pasture spelling for six months over the wet season only tended to increase final %P under certain circumstances. Overall, spelling with no loading any year was able to improve pasture condition more than the other spelling strategies, and this was most marked when long-term carrying capacity (LTCC) was highest, i.e. with the wettest climate period 1 and pasture conditions A and B, and when stocking rates were higher (high,

moderate and maintenance), i.e. with low stocking rates and good-moderate pasture condition, the model suggests that spelling may be unnecessary. When LTCC was low (period 2 and C condition pasture), the greatest difference in final %P between spelling with no loading any years and the other two spelling strategies tended to occur with the maintenance and low stocking rates.

When the LTCC was high, i.e. with good years and good pasture condition, there was also little difference in final %P between spelling with no loading during the first cycle, spelling with loading all years, and no spelling. However, differences between these strategies emerged when LTCC was lower, i.e. drier years and poorer pasture condition, and particularly when it was at its lowest, i.e. period 2 and pasture condition C. This indicates that wet-season spelling is most effective when it does not involve loading up of other paddocks and when stocking rates are at or not markedly above LTCC. This improvement in pasture condition is partly due to a stocking rate effect, as spelling with no loading effectively results in 12% lower average annual stocking rate than does spelling with loading up of paddocks within the rotational spelling system. However, there is also an effect due to the actual resting during the wet season (as opposed to simply the benefit of reduced stocking rates), which is most apparent during the dry climate period 2 when initial pasture condition was C (Fig. 7). Spelling with loading every year, hence the same overall stocking rate as no spelling, achieved higher final %P than no spelling.

If the stocking rate is considerably lower than LTCC, then final %P will remain high or improve from low levels, irrespective of any spelling treatment. Spelling may increase the rate of improvement but will not affect the final values reached (at least within the constraints of GRASP). If the stocking rates are considerably higher than LTCC, then pasture condition will decline or remain at low levels if already in C condition, irrespective of any spelling treatment, i.e. spelling does not buffer the effects of heavier stocking rates on pasture condition. When the stocking rate is close to the LTCC, spelling can lead to an improvement in final %P or prevent a decline if initial pasture condition is high. The largest effect will be from the no-loading treatment as this has a 12% lower stocking rate as well as having benefits from spelling the pastures during the growing season every fourth year. Spelling with loading up the other paddocks will generally be better than no spelling, although there is the potential for a 'fourth paddock problem', where condition for the last paddock spelled in the rotation declines (see Fig.4 in Scanlan et al. 2011).

21.3.1.2 Net present value and total gross margin

As detailed earlier, an ANOVA was used to generate mean squares (MS) for the main and interaction effects of initial pasture condition, stocking rate, climate period and spelling strategies on NPV and TGM for the 96 fixed stocking simulations.

The relative magnitude of the mean squares for the main effects shows that climate period had by far the dominant influence on NPV (MS = 571), followed by stocking rate (MS = 211), initial pasture condition (MS = 200) and the spelling strategies (no spelling and three forms of spelling) (MS = 5). The relative magnitude of the mean squares for TGM followed the same trends as for NPV. These main NPV and TGM effects are illustrated in Figures 8 to 11.

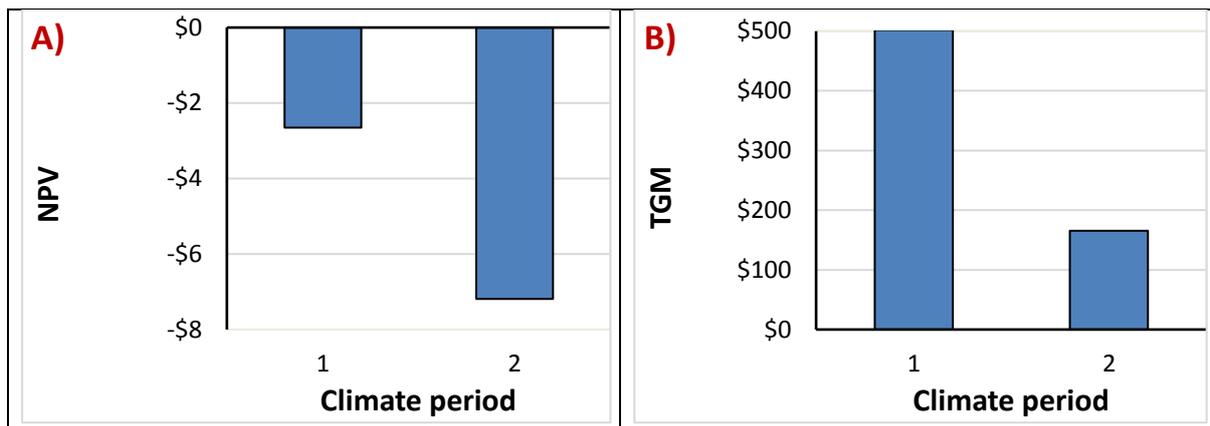


Fig. 8. The net present value (NPV) (A) and average annual total gross margin (TGM) (B) for the climate periods 1 (1952-1981) and 2 (1982-2011).

Figure 8 shows the influence of climate period on NPV, with that for wetter period 1 being \$4.5 M or 180% higher than that for period 2 when averaged across all other factors. Similarly, average annual TGM for period 1 was \$336,000 or 200% higher than that for period 2. The wetter period was able to maintain relatively high live-weight gains and reproductive rates even at the higher stocking rates, leading to high herd productivity and income.

The influence of stocking rate on NPV when averaged across all other factors is illustrated in Fig. 9, with that for the high stocking rate \$5 to \$7 M less (approx. 130%) than those for moderate, maintenance and low stocking rates. The highest NPV occurred with the maintenance stocking rate. Results for average annual TGM followed a similar trend, although that for maintenance stocking rate was \$411,000 or 420% higher than that for the high stocking rate. At high stocking rates, mortality rates were often high and reproduction rates low. Accordingly, herds were not able to produce sufficient replacement heifers or steers, making it necessary to regularly purchase young cattle to meet the stocking rate targets simulated in GRASP.

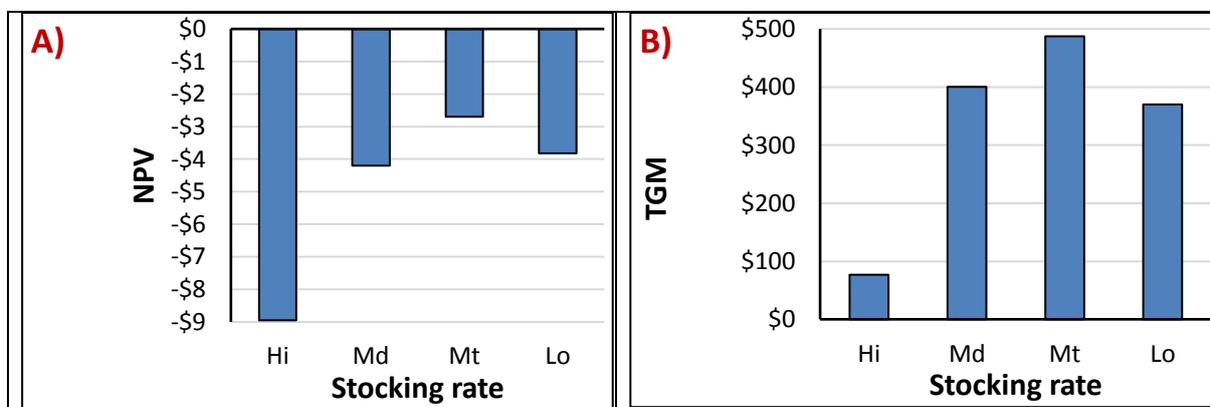


Fig. 9. The net present value (NPV) (A) and average annual total gross margin (TGM)(B) for the four fixed stocking rates (Hi= high, Md = moderate, Mt = maintenance, Lo = low).

Initial pasture condition also impacted NPV, with that for A condition \$2 and \$5 M (90 to 180%) higher than those for B and C condition respectively. These trends were similar for average annual TGM (Fig. 10). Again, herd productivity often could not be maintained when pastures were in B and C condition, resulting in lower income. This clearly illustrates the economic advantages of maintaining land in good condition.

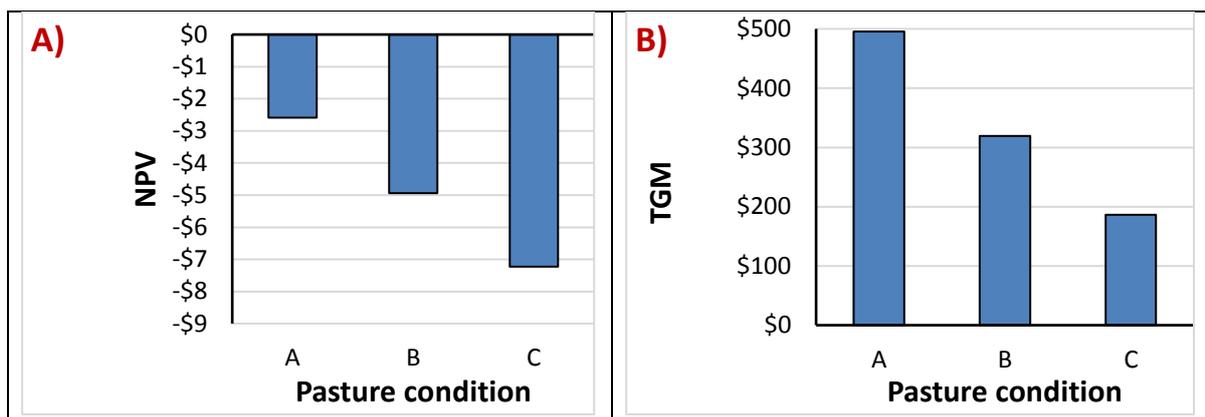


Fig. 10. The net present value (NPV) (A) and average annual total gross margin (TGM) (B) for the three initial pasture conditions (A, B and C).

In contrast to the effects of stocking rate and initial pasture condition, the impact of spelling on NPV and TGM across both climate periods and all stocking rates and initial pasture conditions was comparatively small (Fig. 11). Spelling with no loading in any year resulted in the highest NPV and TGM, being \$1 M and \$80,000 higher respectively than the worst performing strategy, i.e. no spelling. This occurred in spite of the costs for the no loading strategy of agisting cattle from the paddock which was spelled each year of the simulation period.

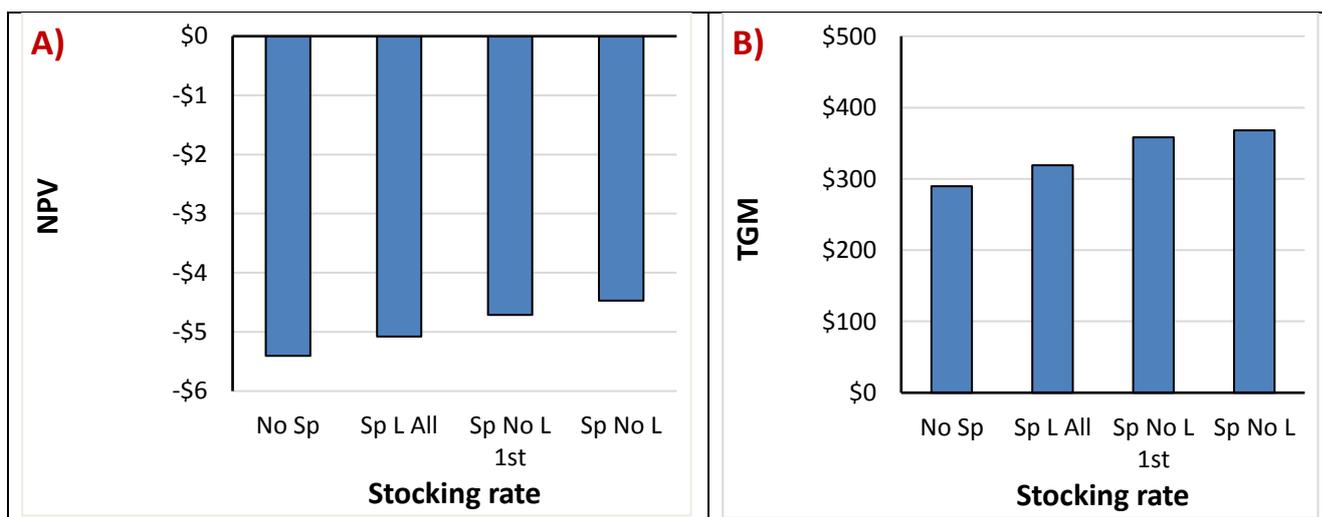


Fig. 11. The net present value (NPV) (A) and average annual total gross margin (TGM) (B) for the three spelling strategies and no spelling (No Sp = no spelling, Sp L All = spelling with loading all years, Sp No L 1st = spelling with loading only in the first cycle, Sp No L = spelling with no loading in any year).

As with the main effects above, stocking rate, climate period and initial pasture condition dominated both the 2-way and 3-way interactions with NPV and TGM. For the 2-way interactions, stocking rate x climate window had the highest MS, which was 3-fold higher than that for stocking rate x initial pasture condition, and at least 12-fold higher than all other 2-way interactions. Similarly, for the 3-way interactions, stocking rate x climate window x initial pasture condition had an MS which was 2- to 11-fold higher than all other 3-way interactions. The results from the 3-way interactions are presented below.

The highest NPVs and TGMs were obtained for the combination of the wetter climate period 1 and initial pasture condition A, for high, moderate and maintenance stocking rates (Fig. 12). Note that in this particular case the maintenance stocking rate was equivalent to the high stocking rate; hence it is possible that an even heavier stocking rate may have achieved a higher NPV. For pasture conditions B and C however, the high stocking rate was too heavy, even during the wet climate

period 1 and herd productivity and income declined. In contrast to period 1, in the drier climate period 2, maintenance and low stocking rates achieved the highest NPV and TGM for A, B and C pasture conditions.

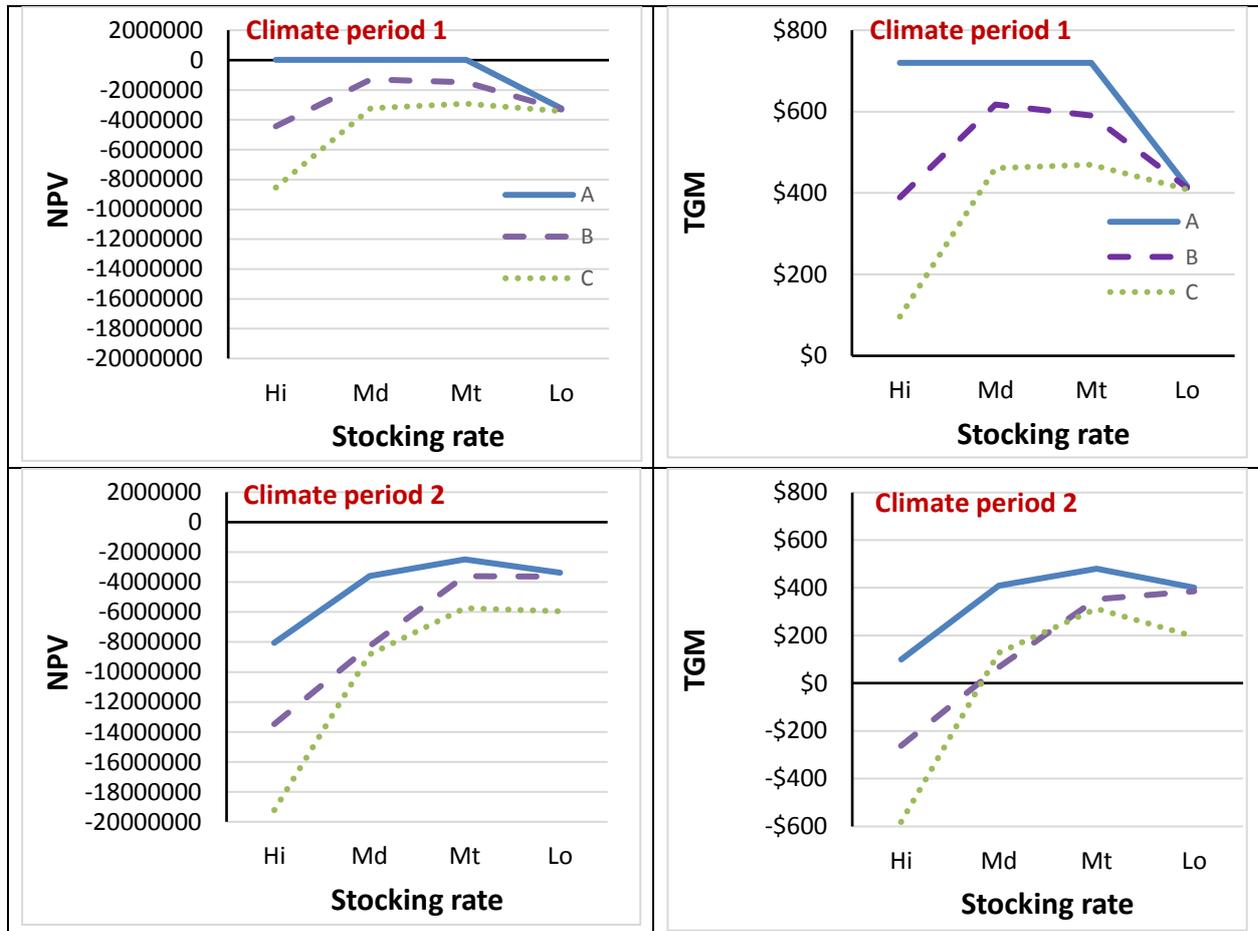


Fig. 12. The net present value (NPV) (left column) and average annual total gross margin (TGM) (right column) for all combinations of the four stocking rates and three pasture conditions, for climate periods 1 and 2. (Hi= high, Md = moderate, Mt = maintenance, Lo = low).

Spelling strategy (no spelling, spell load all years, spell no loading first cycle, spell no loading any year) had less influence on NPV and TGM than did climate period, stocking rate, and pasture condition (Fig. 13). For example, when initial pasture condition was A, there was less difference in the NPVs and TGMs between the four spelling strategies across all stocking rates compared with those when initial pasture conditions were B or C. Even so, for A condition pasture, the NPV and TGM for the moderate and maintenance stocking rates were around \$2 M and \$200,000 greater respectively than those for the low and high stocking rates (Fig. 13).

Differences in the NPVs and TGMs between spelling strategies were more evident when initial pasture condition was poorer (B and C), particularly with high (and to a lesser extent moderate) stocking rates. Here, the greatest NPV and TGM occurred with spelling with no loading, followed by spelling with no loading in the first cycle, spelling with loading all years, and then no spelling. The difference in NPV for spelling with no loading versus no spelling was \$6 M at the high stocking rate when initial pasture condition was B, and approximately \$4 M when initial pasture condition was C. Similarly, the difference in TGM for spelling with no loading versus no spelling was \$537,000 at the high stocking rate when initial pasture condition was B, and approximately \$256,000 when initial pasture condition was C. Hence, all forms of spelling appeared to increase NPV and TGM relative to no spelling when initial pasture condition was poor, and with moderate or high stocking rates.

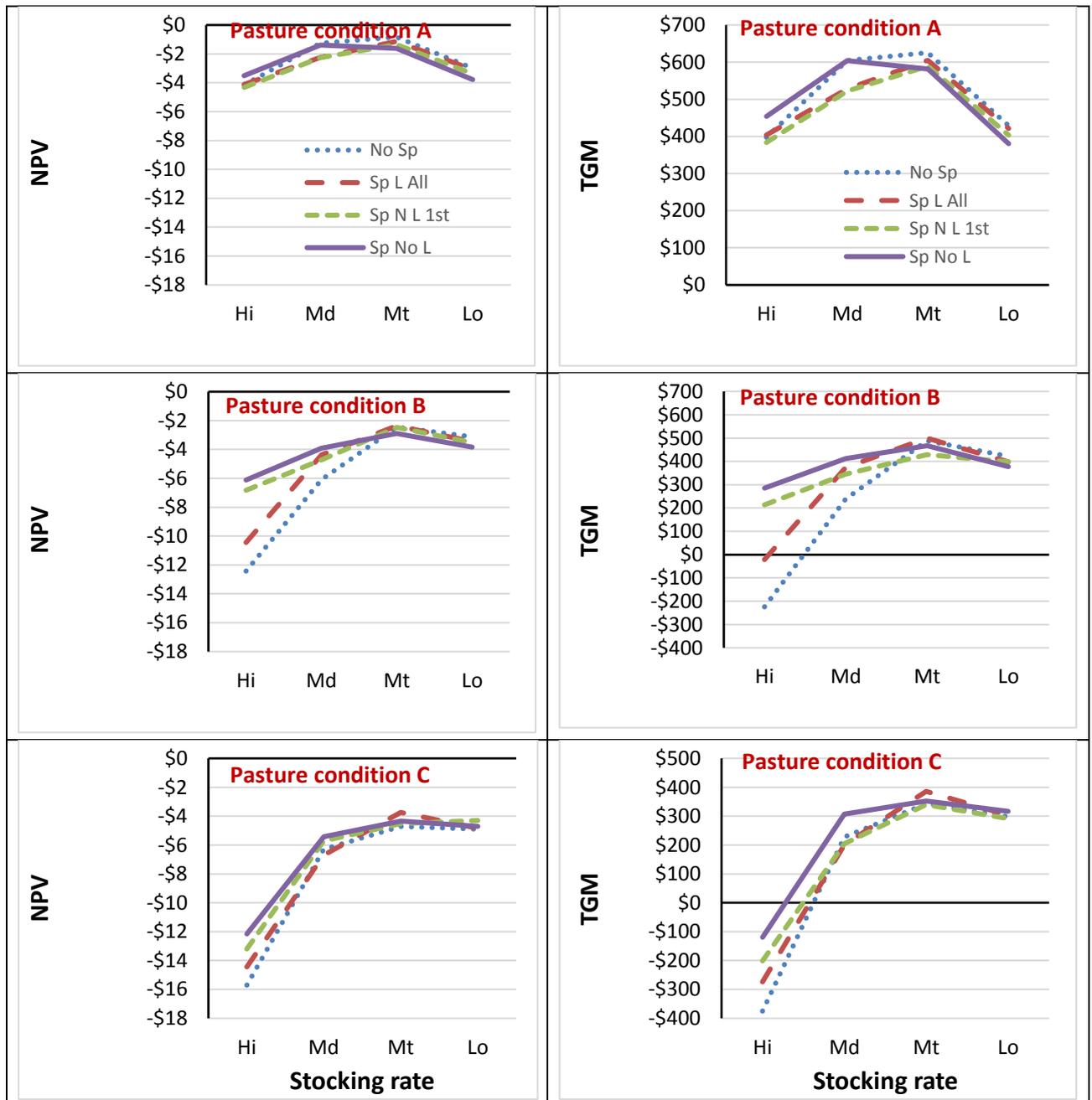


Fig. 13. The net present value (NPV) (left column1) and total gross margin (TGM) (right column2) for all combinations of the four stocking rates and four spelling strategies, for initial pasture conditions A, B and C. (Hi= high, Md = moderate, Mt = maintenance, Lo = low).

In summary, as expected, climate period had the dominant influence on NPV and TGM, due to the greater herd productivity and income associated with the high stocking rates possible with higher rainfall. Stocking rate had the next greatest influence with NPV and TGM, tending to be highest for the maintenance stocking rate, for both climate periods and all three initial pasture conditions. Overall, the highest NPV and TGM of all combinations of factors occurred with the wetter climate period 1, maintenance stocking rate and A condition pasture. Within this context, differences in the NPVs and TGM for the three spelling strategies versus no spelling were only evident when pasture condition was B and the stocking rate was high or moderate, and when pasture condition was C and the stocking rate was high. Here, NPV and TGM were greatest with spelling with no loading up of other paddocks, followed by spelling with no loading in the first cycle, spelling with loading all years, and finally no spelling (Fig. 13). While spelling did improve NPV and TGM when pasture condition

was B or C and stocking rates were moderate or high, its NPV and TGM were still much lower than fixed stocking at the maintenance stocking rate, both with and without spelling, i.e. stocking rate had a far greater effect on NPV and TGM than did spelling.

21.3.1.3 Annual changes in pasture condition and total gross margin

Annual percent perennial grass composition and accumulated annual TGM for fixed stocking at the high stocking rate for initial pasture conditions A, B and C are shown in Fig. 14 for climate period 1 and Fig. 15 for climate period 2.

The feature common to all of the graphs in Figures. 14 and 15 is that annual percent perennial grass composition and accumulated TGM for fixed stocking with spelling was almost always higher than those for fixed stocking alone.

During the wetter climate period 1 (Fig. 14) when initial pasture condition was A, pasture condition was largely maintained over 30 years, and accumulated TGM increased continually to just over \$20 M.

When initial pasture condition was B, spelling improved pasture condition whereas fixed stocking alone caused percent perennial composition to drop to near zero. The accumulated TGM for spelling increased continually to an amount similar to that when initial pasture condition was A. In contrast to this, the rate of increase in accumulated TGM for fixed stocking alone started to decline after 10 years, and then after 14 years annual TGM became negative. After 30 years, accumulated TGM for spelling was \$18 M higher than that for fixed stocking alone.

When initial pasture condition was C, spelling was able to maintain initial pasture condition while fixed stocking caused it to crash. Poor pasture condition and productivity resulted in much lower accumulated TGM compared with initial pasture conditions A and B. Again, annual TGM became negative after 14 years, and accumulated TGM for fixed stocking became negative after 20 years.

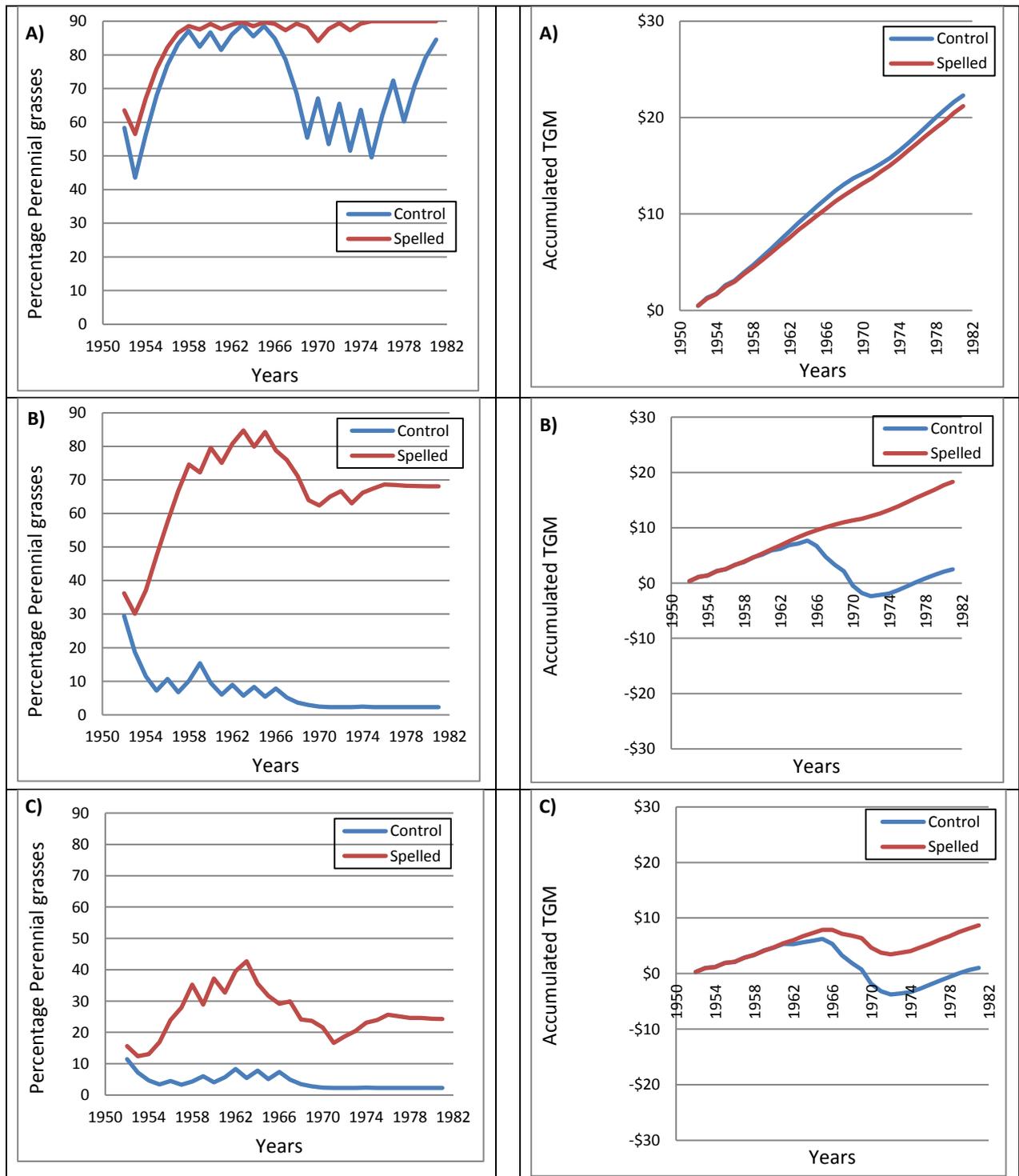


Fig. 14. Annual percent perennial grass composition and accumulated TGM during climate period 1 for fixed stocking at the high stocking rate when initial pasture condition was A (A), B (B) and C (C).

During the drier climate period 2 (Fig. 15) pasture spelling only maintained pasture condition when initial pasture condition was C, and resulted in slight declines when initial pasture conditions were A and B. Fixed stocking without spelling caused pasture condition to crash to near zero percent perennials, and this occurred rapidly when initial conditions were B and C.

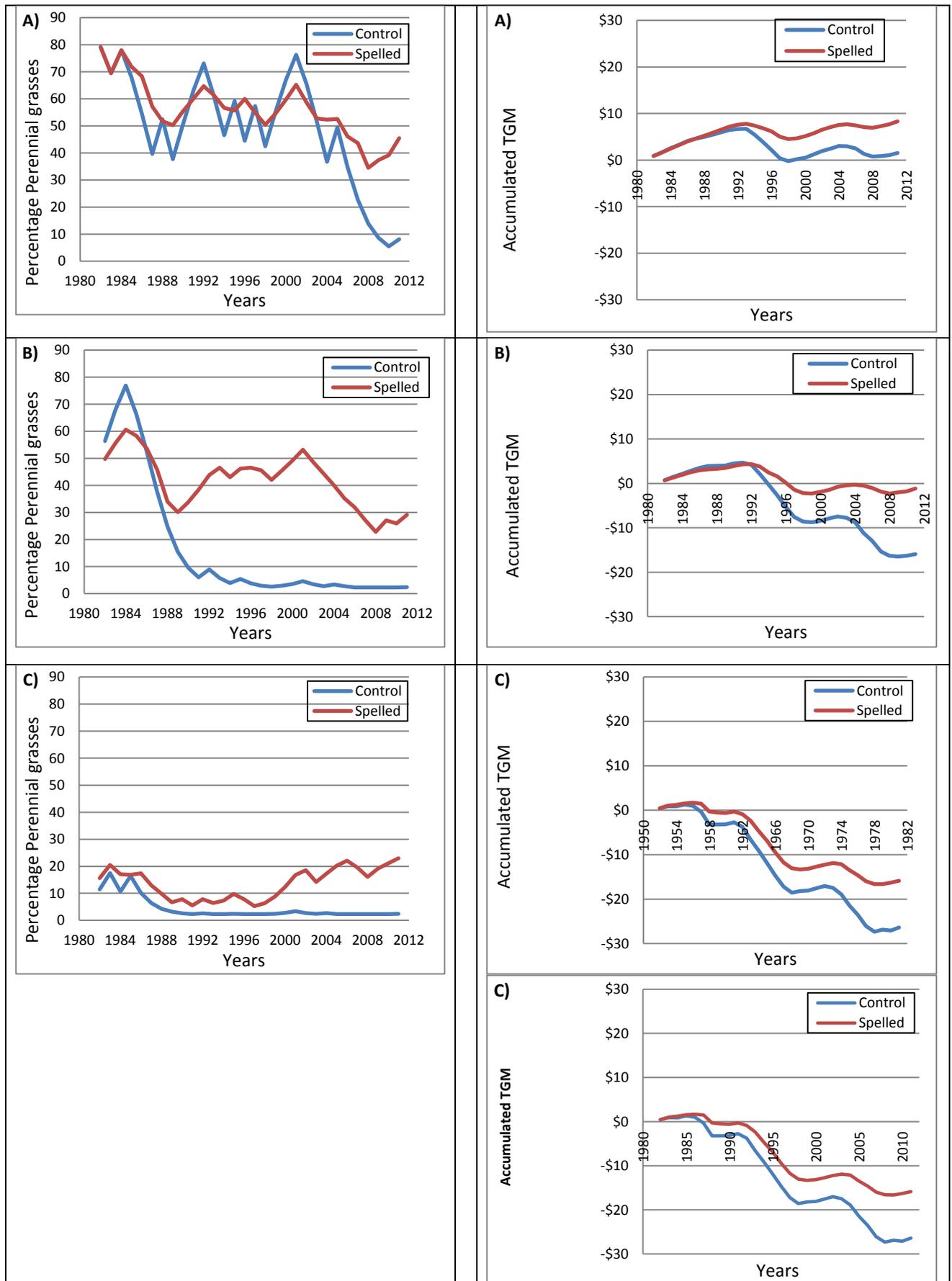


Fig.15. Annual percent perennial grass composition and accumulated TGM during climate period 2 for fixed stocking at the high stocking rate when initial pasture condition was A (A), B (B) and C (C).

Given this poor pasture condition, spelling was only able to achieve an accumulated TGM of around \$8 M after 10 years when initial pasture condition was A, which then remained steady for the remainder of the climate period (Fig. 15). When initial pasture conditions were B or C, spelling accumulated a small TGM in the first few years, but then annual TGM was largely negative for the remainder of the climate period, often culminating in negative accumulated TGM. In contrast to this, the annual TGM for fixed stocking alone when initial pasture conditions were A, B and C became negative after 12, 10 and 5 years respectively. Consequently, accumulated TGM remained at near-zero for the remainder of the climate period when initial pasture condition was A, and became strongly negative when initial pasture conditions were B and C.

The results presented in Figures 14 and 15 indicate that heavy fixed stocking may be economically viable in the long-term providing wet decades of rainfall are encountered and pastures were in A condition at the outset, but these circumstances are rare in northern Australia. During more typical drier rainfall decades and when pasture condition is moderate (B), annual gross margins for heavy fixed stocking are only positive for the first 10 years. After 12 years, even accumulated TGM became negative. Furthermore, the economic outcome was only marginally better during the wetter climate period 1 (Fig. 14).

21.3.2 Fixed stocking, flexible stocking and pasture spelling

The final %P, NPV and TGM were then compared for fixed and flexible stocking (05 05%, 10 20%, 20 40% and 40 40%) which had the same combinations of factors, i.e. climate periods 1 and 2, a moderate stocking rate, initial pasture conditions A, B and C, and spelling strategies (no spelling or spelling with no loading in any years). Note that moderate stocking rate here is defined as being midway between maintenance and high stocking rates (see stocking rate flexibilities in the Methods section). Thus, for the fixed 'moderate' stocking the *actual* stocking rate applied in simulations varied with climate window and pasture condition. There were a total of 60 simulations with these combinations of factors (Table 2).

21.3.2.1 Pasture condition

As before, the mean squares (MS) from an ANOVA were used to identify the dominant main and interaction effects of initial pasture condition, annual stocking rate flexibility, climate period and spelling strategies on the final %P for the 60 fixed and flexible stocking simulations.

Analysis of the main effects shows that the level of stocking rate flexibility (MS = 23) had the dominant influence on final %P, followed by climate period (MS = 18). No spelling and spelling with no loading, and initial pasture conditions, had similar but lower influences on final %P, with mean squares of 8 and 7 respectively (Figures 16 to 19).

Figure 16 shows the differences in final %P that occurred for the five levels of stocking rate flexibility. When averaged across both climate periods, both spelling strategies, and the three initial pasture conditions, fixed stocking resulted in the lowest final %P of just over 50%. The next highest final %P of 73% occurred for the 05 05% flexibility, while 10 20%, 20 40% and 40 40% all achieved the same final %P of 90%.

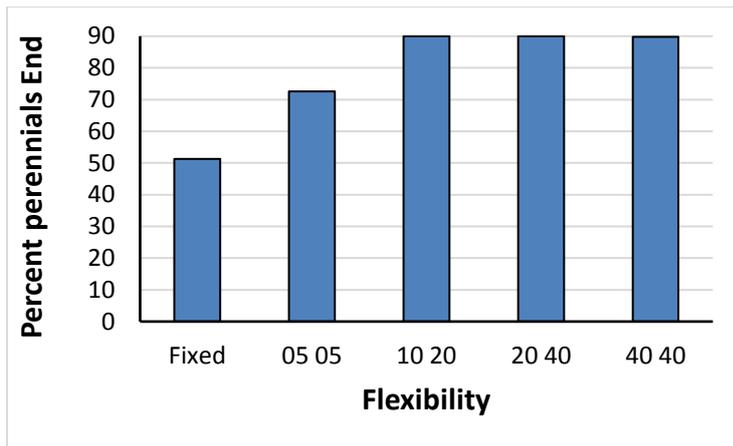


Fig. 16. Average final %P for the four stocking rate flexibilities versus fixed moderate stocking averaged over both climate windows and all starting pasture conditions.

Climate period had the next largest influence, with final %P being highest for the wetter period 1 (Fig. 17). However, differences in final %P between the two climate periods were not particularly large.

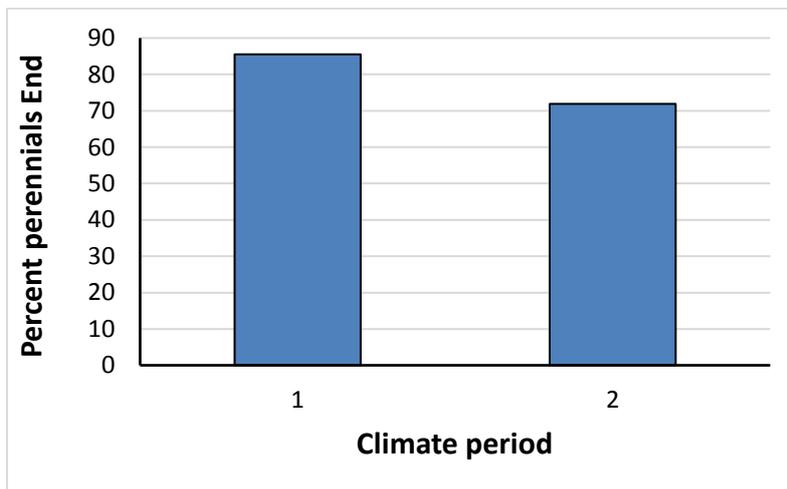


Fig. 17. Average final %P for climate periods 1 (1952-1981) and 2 (1982-2011) averaged over all stocking rate flexibilities, initial pasture conditions and spelling strategies.

Differences in final %P between the two spelling strategies i.e. no spelling (74%) and spelling (83%), were also relatively small (Fig. 18).

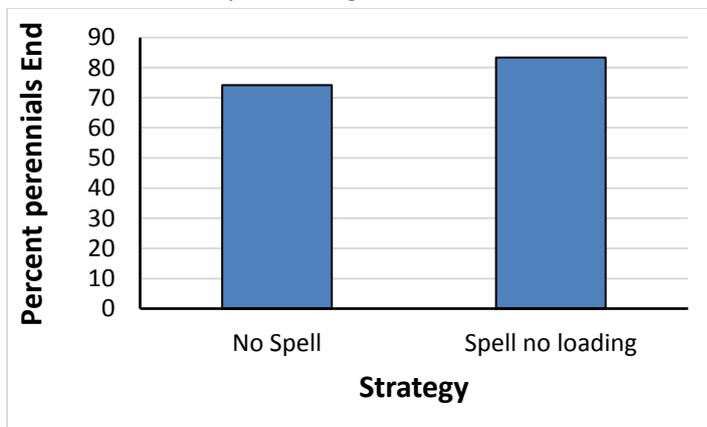


Fig. 18. Average final %P for the two spelling strategies, no spell and spell no loading averaged across all stocking rate flexibilities, climate periods, and initial pasture conditions.

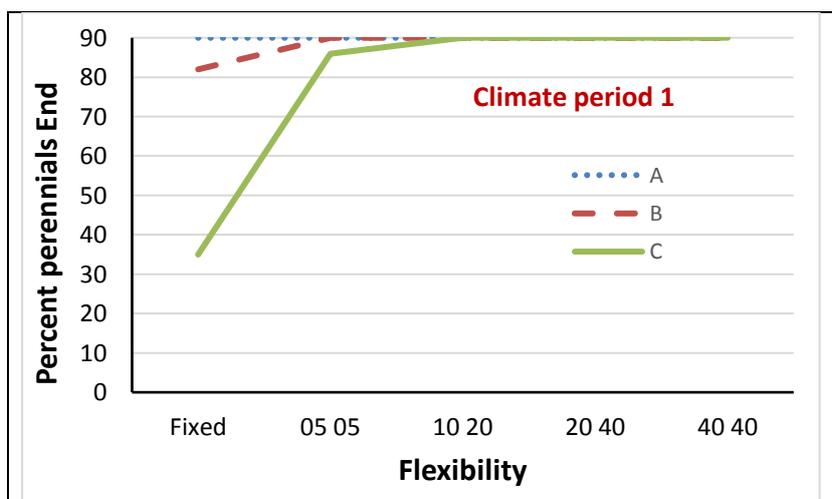
In relation to initial pasture condition, the highest final %P occurred for A condition (86%), followed by B (79%) and C (71%) condition (Fig. 19). Again, these differences were small relative to those observed between the different stocking rate flexibilities (Fig. 16).



Fig. 19. Average final %P for the three initial pasture conditions averaged over both climate periods, all stocking rate flexibilities and spelling strategies.

The dominant 2-way interaction occurred for the stocking rate flexibility x climate period (MS =7), while stocking rate flexibility x spelling strategy (MS = 3) and pasture condition x stocking rate flexibility (MS =3) had lower influences on final %P. These four factors were also involved in the dominant 3-way interactions, i.e. flexibility x climate period x spelling strategy (Figures 20 and 21). Results of the 3-way interactions are presented below.

The higher stocking rate flexibilities of 10 20%, 20 40% and 40 40% were able to achieve the maximum final %P composition (90%) regardless of climate period or initial pasture condition (Fig. 20). In contrast, the low 05 05% flexibility almost achieved maximum final %P for the wet climate period 1, but only achieved a final %P of 34% for the drier period 2. It is likely that the initial ‘moderate’ stocking rate was too high for climate period 2, and this low flexibility was unable to adjust stocking rates quickly enough to prevent declines in pasture condition. In comparison, fixed moderate stocking was only able to achieve a final %P of 90% in climate period 1, when initial pasture condition was A, but was nevertheless still able to improve B and C condition pasture in this climate period. However, in the dryer period 2, fixed stocking at a moderate stocking rate caused a decline in pasture condition for all three initial pasture conditions.



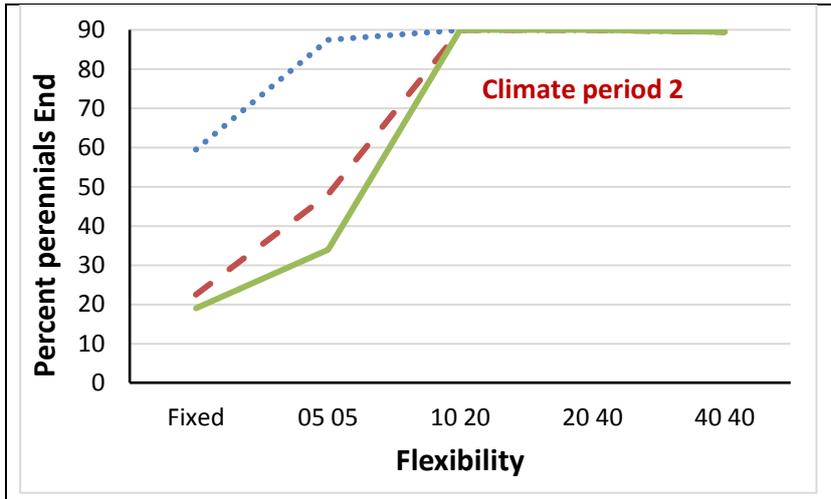
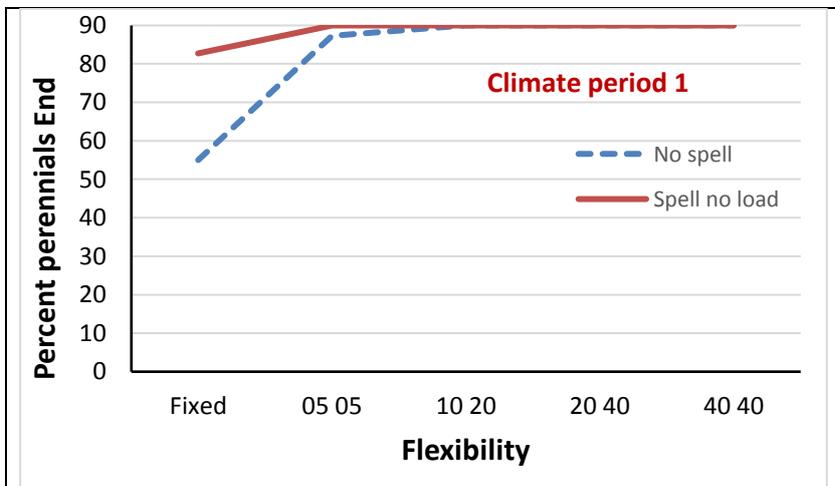


Fig. 20. The final %P for all combinations of the five stocking rate flexibilities and three pasture conditions, for climate period 1 (1952-1981) and 2 (1982-2011).

A similar pattern to the change in final %P seen above (Fig. 20) also occurred for the 3-way interaction effects between climate period, stocking rate flexibility and spelling strategy (Fig. 21); here the 10 20% and higher flexibilities achieved a final %P of 90% in both climate periods, both with and without spelling. Similarly, the 05 05% flexibility was almost able to achieve 90% perennials without spelling in climate period 1, and hence there was very little difference in final %P for this level of flexibility with and without spelling. However, in the drier climate period 2, the final %P for 05 05% flexibility *with* spelling was much higher than that *without* spelling. This trend was even more evident for fixed stocking, with final %P for fixed stocking with spelling being much higher than that without spelling in both climate periods.



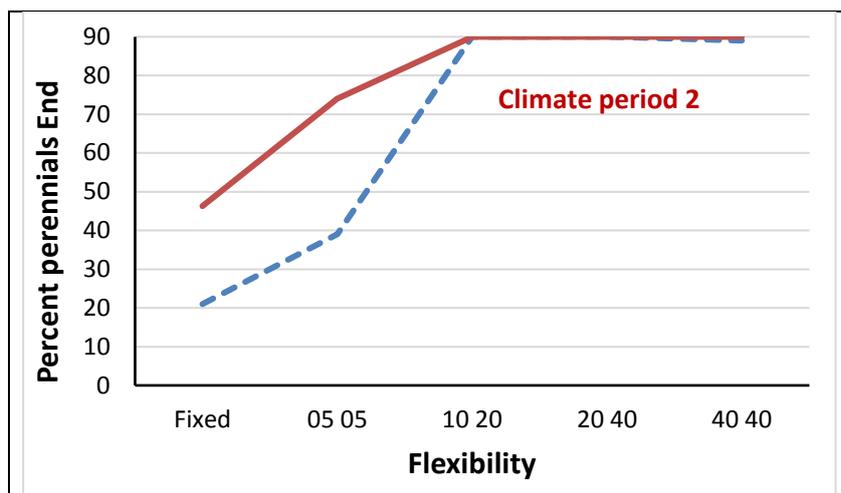


Fig. 21. The final %P for all combinations of the five stocking rate flexibilities and two spelling strategies, for climate period 1 (1952-1981) and 2 (1982-2011).

In summary, the degree of stocking rate flexibility and climate period used had the dominant influence on final %P present at the end of simulation periods. Flexibilities which were able to change stocking rates by at least +10% or -20% were also able to substantially improve pasture condition to the maximum possible (final %P = 90%) in both climate periods. This is similar to the findings of Pahl et al. (2016), who wrote, ‘constrained flexibility, which limited increases in stocking rates after good growing seasons to 10% but decreased them by up to 20% after poor growing seasons, provides sustainable productivity gains for cattle producers in northern Australia. This strategy can improve pasture condition and increase cattle productivity relative to fixed stocking at the long-term carrying capacity.’ Pahl et al. (2016) claimed that constrained flexible stocking is a risk-averse adaptation to high and unpredictable rainfall variability for the extensive beef industry of northern Australia. Given the capacity of these flexible strategies to improve pasture condition, it is not surprising that spelling was unable to further improve pasture condition.

Similarly, the low 05 05% flexibility was also able to improve pasture condition during the wet climate period 1, but not during the dry climate period 2. This suggests that the ‘moderate’ stocking rate employed was higher than the actual long-term carrying capacity of climate period 2, and that 5% changes in stocking rates annually were unable to lower stocking rates quickly enough to avoid damaging pasture condition. When this low flexibility was combined with spelling during period 2, the average final %P obtained was 75%, i.e. higher than the initial percent perennial grass composition of all initial pasture conditions. This indicates that spelling helped this low 05 05% flexibility improve pasture condition during the dry climate period 2. Fixed stocking at the moderate stocking rate relied more heavily on spelling to maintain or improve pasture condition during both climate periods.

Overall, wet season spelling was most beneficial in maintaining or improving pasture condition for fixed stocking and the low 05 05% flexibility. In contrast, by more closely balancing stocking rates with available forage, more flexible strategies were able to maintain or improve pasture condition in their own right. Spelling appeared to do little to improve this, at least for the one stocking rate and two climate periods simulated. However, as noted earlier, the GRASP model may not have captured all of the pasture benefits arising from spelling.

21.3.2.2 NPV and TGM

The mean squares (MS) from an ANOVA were again used to identify the main and interaction effects of initial pasture condition, annual stocking rate flexibility, climate period and spelling strategies on NPV and average annual TGM for the 60 fixed and flexible stocking simulations.

As observed with the economic analysis of fixed stocking in a previous section, the dominant influence on NPV was climate period (MS=694). Initial pasture condition was of lesser importance (MS=143) with the stocking rate flexibility (MS=4) and spelling strategy used (MS=3) of minor importance. The trends for TGM were similar.

The NPV and TGM for climate period 1, averaged across all flexibilities, initial pasture conditions and spelling strategies, were considerably higher than those for period 2 (Fig. 22). Again, this reflects the considerably higher rainfall for climate period 1 which resulted in higher herd productivity and income.

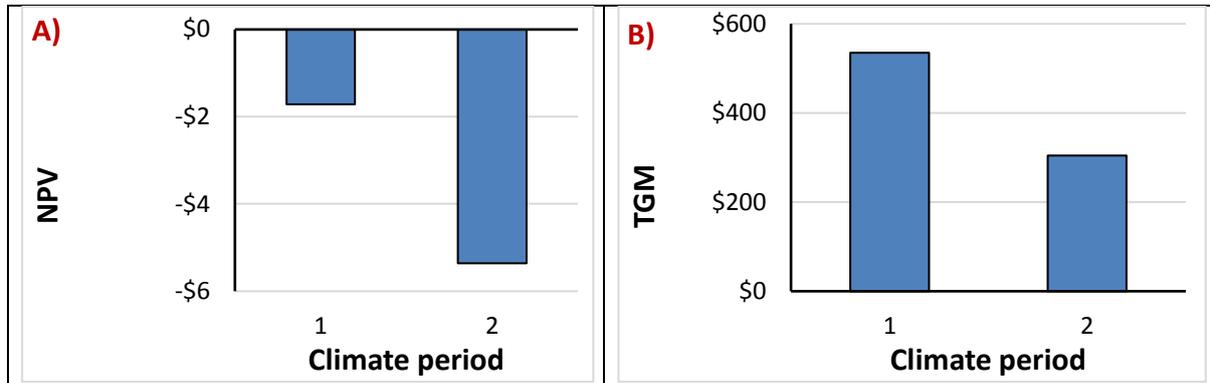


Fig. 22. The net present value (NPV) (A) and total gross margin (TGM) (B) for climate periods 1 and 2. Data averaged across all flexibilities, initial pasture conditions and spelling strategies.

There were also large differences in NPV for the three initial pasture conditions (Fig. 23), with the NPV for A condition almost \$3 M higher than for C condition. Similar trends occurred for TGM, although relative differences in TGM between A, B and C pasture conditions were less than those for NPV.

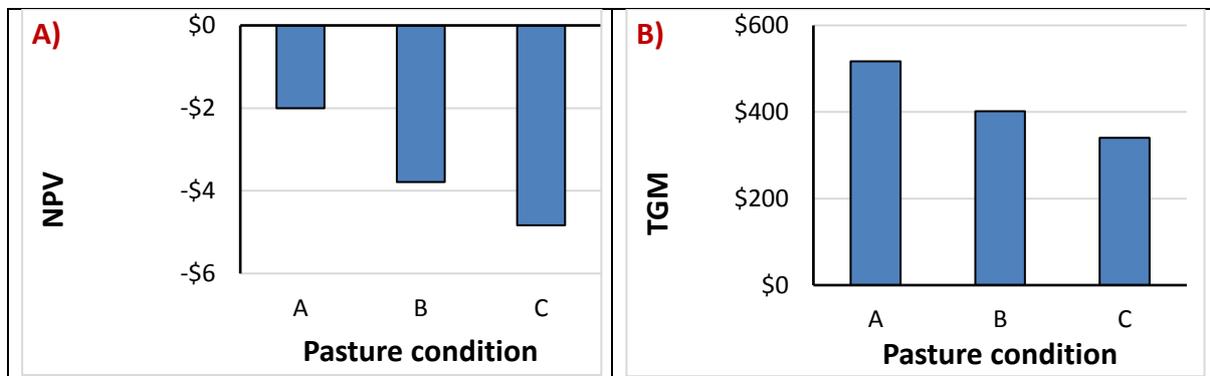


Fig. 23. The net present value (NPV) (A) and total gross margin (TGM) (B) for the three initial pasture conditions. Data averaged over both climate periods, flexibilities and spelling strategies.

In comparison, there was much less variation in NPVs and TGMs for fixed stocking and the four forms of flexible stocking (Fig. 24). As such, there was little difference in the NPVs for the four forms of flexible stocking, which were approximately only \$0.5 M higher than that for fixed stocking. Relative differences in TGM between fixed and flexible stocking were even lower.

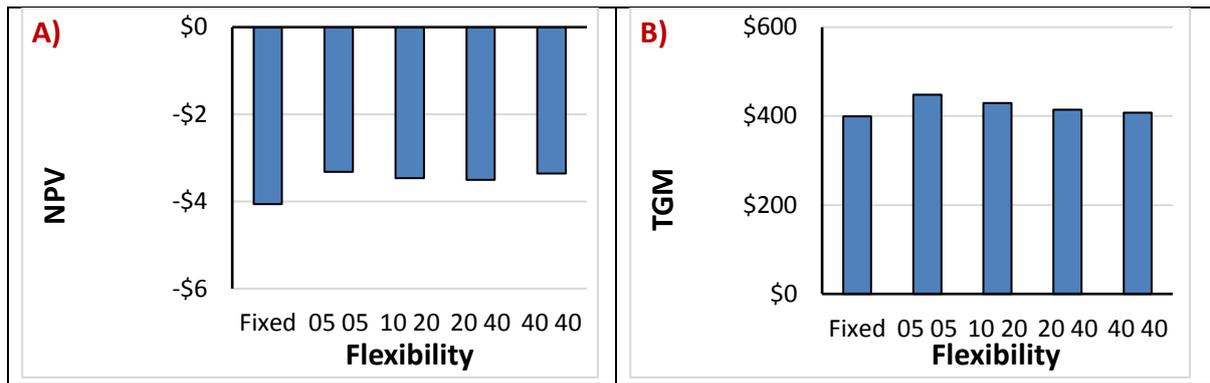


Fig. 24. The net present value (NPV) (A) and total gross margin (TGM) (B) NPV (A) and TGM (B) for fixed moderate stocking and the four flexible stocking simulations. Data averaged over both climate periods, initial pasture conditions and spelling strategies.

Similarly, there was little variation in the NPVs and TGMs between no spelling and spelling with no loading (Fig. 25). The NPV and TGM for no spelling were marginally higher than those for spelling.

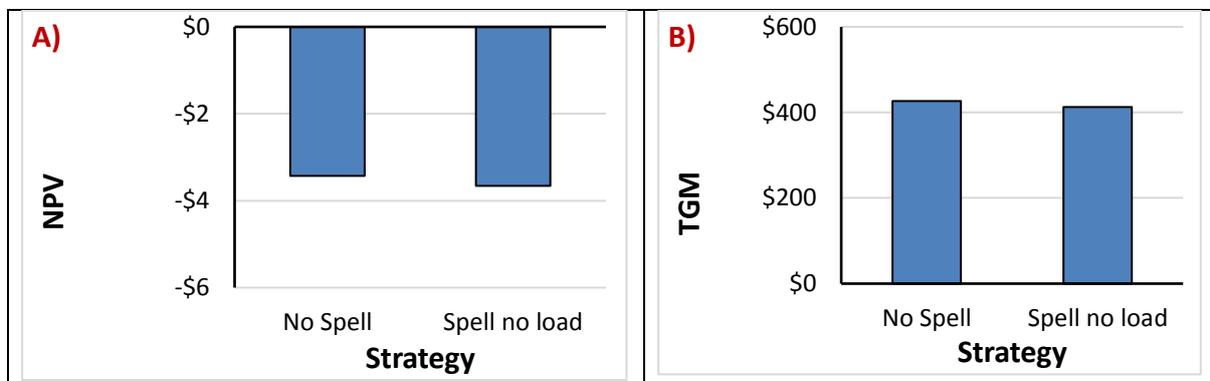
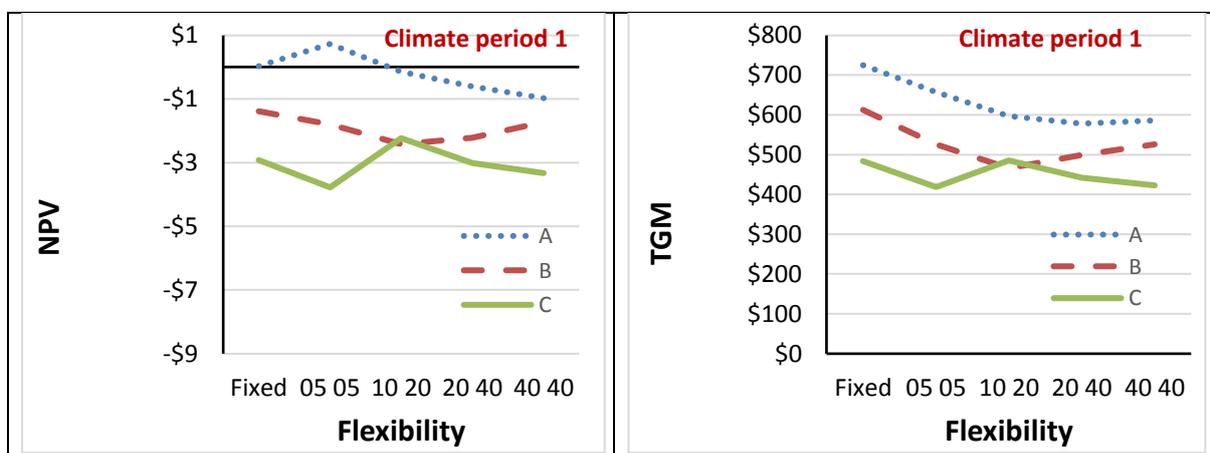


Fig. 25. The net present value (NPV) (A) and total gross margin (TGM) (B) NPV (A) and TGM (B) for the two spelling strategies (no spelling and spelling with no loading in any year). Averaged over initial pasture conditions, both climate periods and initial pasture conditions.

As with the main effects, the dominant 2-way interaction effects on NPV involved climate period, pasture condition and flexibility level. As such, the MS for climate period x flexibility was 10, the MS for pasture condition x flexibility was 8, and the MS for pasture condition x spelling strategies was 6. These influences on NPV are further demonstrated in the 3-way interactions, where pasture condition x flexibilities x climate period was again dominant (MS = 6). The next highest MS of 1 occurred for pasture condition x flexibilities x spelling strategy. The NPVs and TGMs arising from combinations of pasture condition x flexibilities x climate period (3-way interactions) are shown in Fig. 26.



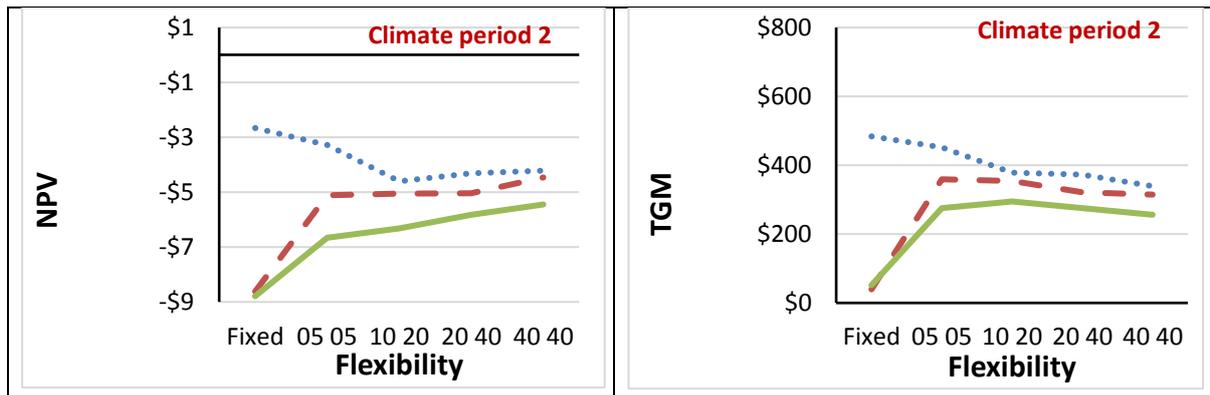
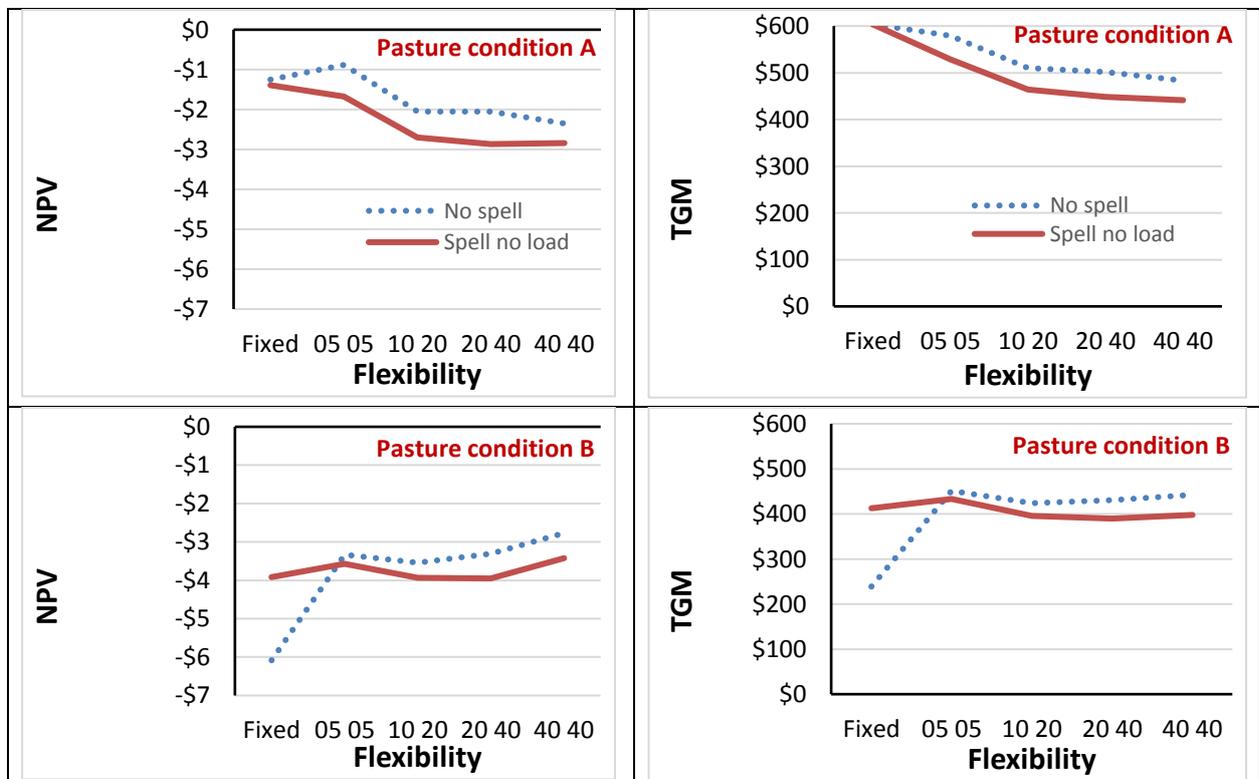


Fig. 26. The net present value (NPV) (left column) and total gross margin (TGM) (right column) for all combinations of the three pasture conditions, five flexibilities, and two climate periods (1 and 2).

The most obvious trends within Fig. 26 are the higher NPVs and TGMs associated with climate period 1 and initial pasture condition A, and the variation in NPVs and TGMs that occurs with differences in initial pasture condition. The NPVs and TGMs for A condition were higher than B and C condition in both climate periods, and particularly for fixed stocking and the low 05 05% flexibility. The NPVs and TGMs varied little for the higher flexibilities, in both climate periods and all initial pasture conditions. In period 2, when initial condition was B or C, the NPV and TGM for fixed stocking were much lower than those for the four flexibilities. However, the differences in NPVs and TGMs between fixed stocking and the flexibilities is difficult to interpret because a range of ‘moderate’ stocking rates were simulated with fixed stocking, with some being lower than the single moderate stocking rate simulated with the flexibilities.

Figure 27 shows how the two spelling strategies, spell and no spelling, interact with initial pasture condition and stocking rate flexibilities. Again, large differences in NPVs and TGMs occur with differences in pasture condition.



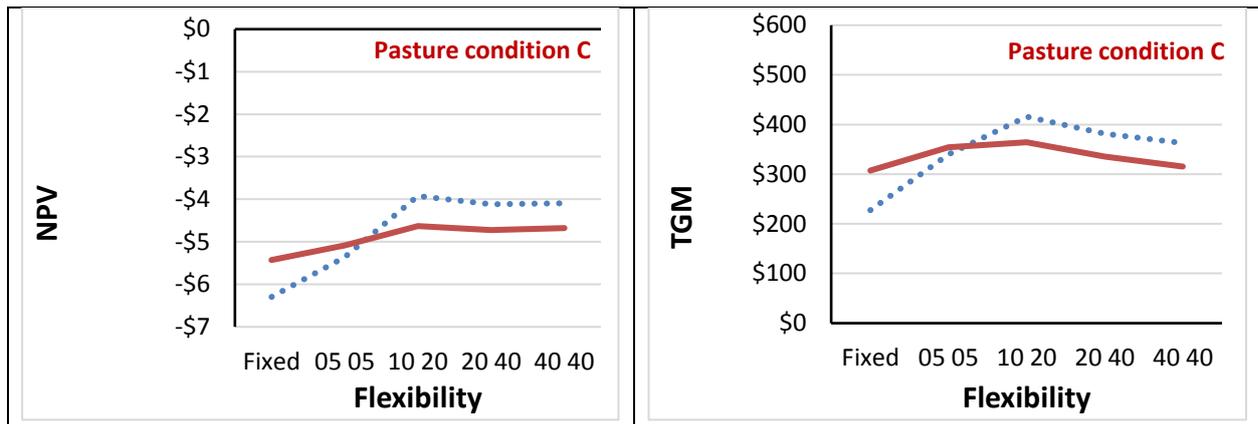


Fig. 27. The net present value (NPV) (left column) and total gross margin (TGM) (right column) for all combinations of the three initial pasture conditions (A, B and C), five flexibilities, and two spelling strategies.

When initial pasture condition was A, the NPVs and TGMs for no spelling were consistently, although only marginally, higher than those for spelling for each flexibility except fixed stocking. This probably reflects the additional costs of agisting cattle off-property with spelling and no loading. As noted for Fig. 26, it is likely that fixed stocking and the 05 05% flexibility were unable to align stocking rates with the lower carrying capacities in the drier climate period 2 and B and C pasture condition. Here, spelling is likely to be beneficial, as it slightly reduces stocking rates and rests pastures during the growing season when plants are most sensitive to grazing. This is obvious for C pasture condition, where the NPVs and TGMs for spelling with fixed stocking, and to a lesser extent with the 05 05% flexibility, are higher than those for no spelling (Fig. 27). With increasing flexibility which is able to improve pasture condition in its own right, the NPVs and TGMs for spelling are lower than those for no spelling, again due to annual agistment costs.

In summary, climate period and initial pasture condition had the greatest impact on NPVs and TGMs, with these being highest for the wetter period 1 and initial pasture condition A. The highest NPVs and TGMs were achieved by fixed stocking and the low 05 05% flexibility in climate period 1 when initial pasture condition was A, but this may have been in part due to the lower stocking rates simulated with fixed stocking. On average, the four flexibilities tended to achieve higher NPVs and TGMs than fixed stocking, and this was most evident for the drier climate period 2 and initial pasture conditions B and C. In these cases the relatively poor NPVs and TGMs for fixed stocking, and to a lesser extent that for the 05 05% flexibility, were improved by spelling with no loading. In comparison, the NPVs and TGMs of higher flexibilities varied little with initial pasture condition, and those for no spelling were consistently higher than those for spelling. As such, wet season pasture spelling, where cattle are agisted off the property, appears to increase NPVs and TGMs for simulations involving poor pasture condition, a dry climate period, fixed stocking or very low flexibility, and an initial stocking rate that is higher than LTCC. However, in these circumstances, the more flexible stocking strategies without spelling achieved the highest NPVs and TGMs, and therefore may be a more cost-effective method of improving pasture condition. This was likely due to their capacity to improve pasture condition without the need for agistment of cattle and the costs associated with this.

21.4 Conclusions

Stocking rate, climate period, initial pasture condition and annual stocking rate flexibility had the greatest impact on final pasture condition and economic performance. Wet season pasture spelling was of lesser importance than these factors and exerted its influence for particular combinations of these factors. Wet season pasture spelling most improved pasture condition when simulated with fixed stocking or the very low 05 05% flexibility, and particularly when stocking rates were moderate

or high relative to pasture condition and climate period.

Spelling pastures during the wet season can improve pasture condition in two ways. It can reduce overall stocking rates when cattle from spelled paddocks are agisted off-property. This also avoids increasing stocking rates in unspelled paddocks during the wet season which may negate the overall benefit of spelling. Spelling also prevents utilisation of grasses during the wet season when they are most sensitive to grazing. Thus pasture spelling involving agistment of cattle off-property improved pasture condition more than where cattle from spelled paddocks were loaded into other paddocks of the rotational spelling system on the property.

The higher stocking rate flexibilities were able to improve pasture condition in their own right by aligning stocking rates more closely with available forage at the end of the growing season. Hence their capacity to improve pasture condition was not aided by pasture spelling, at least in these simulations. However, in practice, pasture spelling may enable these flexibilities to improve pasture condition at a faster rate through its other benefits such as allowing recovery of heavily selected landtypes, patches or species but these potential benefits are not accounted for in the GRASP pasture model.

Like pasture condition, NPV and TGM were most strongly determined by climate period, initial pasture condition, stocking rate and stocking rate flexibility. Both NPV and TGM are largely determined by herd productivity, which was highest for simulations with the highest pasture productivity, such as the wetter climate period 1 with A condition pasture. The NPVs and TGMs for the four flexibilities were generally higher than those for fixed stocking, and particularly for the drier climate period 2 with B and C initial pasture conditions. Wet season spelling with no loading of paddocks was able to improve the NPVs and TGMs under these circumstances for fixed stocking and, to a somewhat lesser extent, the 05 05% flexibility. In comparison, the NPVs and TGMs for the higher flexibilities without spelling were higher than those with spelling largely due to the agistment costs associated with spelling. The higher flexibilities achieved the highest NPVs and TGMs in their own right, and thus may be a more cost-efficient method of improving pasture condition than wet season spelling. However the potential benefits of spelling to flexible stocking strategies need to be properly tested in field trials as is presently happening at the Wambiana trial.

The present conclusions are mainly based on the single moderate stocking rate, two climate periods and three initial pasture conditions which were common to all fixed and flexible stocking simulations. Results may have differed if a wider range of stocking rates and climate periods were used in simulations. Likewise, results may differ for properties with different cattle enterprises at different locations with different climates.

The GRASP and ENTERPRISE models need to be reviewed for their capacity to evaluate grazing strategies, and compared with the capacity of other models which are used for this purpose, such as APSIM (McCown *et al.* 1995), Keating *et al.* 2003), Breedcow and Dynama (Chudleigh 2013), NABSA (Ash *et al.* 2015), and the SGS model (Johnson *et al.* 2003). Decisions need to be made about which modelling framework to be supported, and then to provide the support that is needed to build capacity for modelling of the northern Australian beef industry.

Likewise, northern Australian beef industry modeller capacity also needs to be reviewed, as this is declining. For example, DAF Animal Science has only one person experienced in the use of GRASP and one in the use of ENTERPRISE. If these and other issues are not addressed, the ability to model northern grazing systems and their associated profitability and environmental impacts will be compromised. This will have obvious consequences for industry, policy and government decision making.

21.5 Congruence of BEM with results of Wambiana grazing trial

Simulation modelling indicated that under typical climate conditions and on poor to average pasture condition, low to moderate stocking rates give higher gross margins and result in better pasture condition than heavy stocking. These findings are in general agreement with trial results showing that the pasture condition was maintained and economic performance far superior under moderate compared to heavy stocking.

The simulation modelling nevertheless also showed that on good condition pasture and in wetter years profitability was highest under heavy stocking. This is in agreement with initial trial results where the HSR was extremely profitable for the first five wetter years with little apparent pasture degradation. However, by the sixth year accumulated gross margin in the HSR had declined irreversibly below that in the MSR due to the effects of drought, while an ongoing decline in pasture condition was also obvious. Similarly, simulation models showed that heavy stocking inevitably led to a decline in gross margins and pasture condition under more 'typical' rainfall conditions.

The superior performance of the more risk averse, flexible stocking strategies in the modelling is in partial agreement with trial results; while the clear superiority of the flexible strategies has yet to be demonstrated at the trial, the present drought has clearly highlighted the benefits of flexible- relative to fixed-stocking. Experience in Phase 1 of the trial also demonstrated and adverse consequences for pasture condition and profitability that can occur with less risk averse strategies, as happened in the Variable and SOI strategies leading into the 2002 drought.

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22 Appendix 2: Outcomes of DAF extension workshop October 2015

Summary of possible solutions:

Carrying capacity

- How to improve understanding of long term carrying capacity (LTCC)?
 - Training both practical and theoretical – use a range of methods e.g. web, 1 on 1, w/shops, producer groups etc.
 - Target bankers and accountants too
- Convince people to change paradigms towards sustainable stocking rate management (campaign)
- Show producers a systems approach via case studies

Complexity

- Start with business planning (inventory, plan, options, and cost benefit analysis) to show properties where they are going – use this as a motivation for change and to change SRs.
 - Templates, tools, technical support, implementation support
 - Review Future profit, Business Edge, RCS, producer group work
- Ensure key messages have wide business information linkages
- Persuasion skills applied to messages (engage marketing specialist)
- Ensure clarity and simplicity of messages.
- Emphasise importance of grazing ecosystem to business
 - Outline benefit to business
 - Persuade people of the other benefits – e.g. less stress in droughts etc.
 - Champions, detailed case studies
 - Explore business situation of properties individually.
- Outline the steps to reduce stocking rates over a number of years while maintaining cash flow/ productivity with business plan to enable this change (like ‘Six Easy Steps’); possibly would be one-on-one initially.

Business management

- Demonstrate how to transition to a profitable/sustainable business
- Use real case study properties
- **Critical factor**
 - Key business principles e.g. logical pathway decisions, record the right information.
 - Plus individual business assistance or for a producer group.

Wet season spelling

- Practical step by step spelling guide
- Business planning – forward planning 2 years in advance of spelling
- Ensure sufficient infrastructure (paddocks, waters for spelling-or maybe fewer herds to allow some paddocks to spell)
- Integration of spelling with herd structure and management (e.g. what class of animal goes on to spelled country?)
- Case studies of producers successfully implementing wet season spelling
- Review HRM claims against wet season spelling (might be more about a full wet season spell rather than spelling *per se*?)
- Trever Hall’s *et al* grazing systems study – need a 4 page summary for producers and/or Frontier article (maybe there is one already?)

General Observations from workshop

- DAF perceived not a place to go for whole of business management (our advice in not integrated, e.g. land and herd management)
- Huge influence of other factors from tools (?)
- Other organisations are talking about holistic management
- We could do it/should we (be trying to deliver a whole of property package, e.g. Futurebeef?)
- Skills to do, EDGE reviews
- Internal and external influences to business
- Target our audience – i.e. those managers who seldom have any contact with us or other advisors (the ‘unreachables’).

23 Appendix 3: Detailed outcomes of producer extension workshop March 2016

Attendees: 16 producers and 9 agency staff (6 DAF staff, 2 MLA staff, 1 DEHP staff member and 1 Dalrymple Landcare staff member.)

Note: Only the producers contributed to points recorded below. The agency staff present were there purely as facilitators or observers.

1. Obstacles to the adoption of better grazing management practices

Listed in descending order of votes cast (16 producers were each given 3 votes)

Lack of motivation (16 votes) – why should people change? People may be ignorant about management and the need to change, comfortable in their present situation and see no need to change.

Financial barriers (5 votes) – these may be partly *perceived*, i.e. the belief that more cattle = more money. May also be *actual*, i.e. need to service high debt levels, lack of funds or resources (labour and equipment), banks focussing on cattle numbers, building cattle numbers prior to business expansion, a focus on short rather than long term financial performance and the concern over having enough cattle when good seasons return.

Lack of awareness (5 votes) – because it can be slow and insidious, people are unaware of the decline in land condition and its impacts on production and profitability. People may also be unaware of better management practices and assume their management is fine.

Business analysis (4 votes) – not knowing if they are profitable or not, not knowing profit drivers, costs etc.

Uncertainty and risk (4 votes) – will it work? Uncertainty about the costs and benefits of BMP in terms of profitability, land condition, time and social costs reduce adoption i.e. lack of confidence can make people risk averse about investing in new management.

Time management (4 votes) – lack of time to think, plan, consider and implement new strategies. May be a real or perceived problem.

Peer support (3 votes) – lack of peer support (encouragement, advice, mentoring) to change management and put new strategies into practice.

Lack of infrastructure (3 votes) - such as fences and waters to spell pastures, mob cattle and/or distribute grazing pressure more evenly.

Extension (3 votes) - people not wanting to change until they see someone else do it first; research perceived as irrelevant or not done at property scale; conflicting advice from different agencies.

Business management (1 vote) – a complicated business structure, a lack of management control and different expectations within family businesses can be major barriers to adoption.

Lack of Knowledge (1 vote) - of pasture, animal and business management and importantly, how to initiate and *implement* change. Lack of technical skills to achieve goals, e.g. pasture budgeting, monitoring, cattle handling, accounting.

Social/attitudinal – these include a cattle culture that focuses on cattle numbers and animals at the expense of pasture, little or no respect for the environment, peer pressure against change and social attitudes to what is considered ‘good’ management.

2 Motivators of change identified by producers

- **Light bulb moments** – evidence/proof of positive results in grazing trials or on properties, grasping something for the first time.
- **‘Burning platform experience’** – drought, hardship, being forced to change management to reduce costs, improve ease of operations, survive and grow for next generation.
- **Inspiration** by other producers successfully implementing new ideas, saw benefits of improved GLM, inspirational speakers, e.g. Savory.
- **Confidence** that the change would be positive, the **faith** to do it and see it through, being encouraged by small successes.
- **Trial and error** – small successes encouraged further change.
- **Desire to improve** - pasture condition, animal performance and long-term sustainability.
- **Peer group** – provided examples of positive change and support.
- **New generation** with new ideas and attitudes, more willing to change.
- **Financial support** for infrastructure or bank support and understanding through early years.

2.1 Key steps taken by producers or that they would take in the transition to adopting better grazing management

- **Assess business enterprise**, profitability drivers, conduct resource audit, and assess pros and cons of different management options or scenarios.
- **Develop a plan** – set visions and goals, develop short and long-term plans etc.
- **Change grazing management** – adjust stocking rates, start wet season spelling, rotate cattle, lift productivity with stylos etc. - start small but start!
- **Change animal management** – start control mating, improve genetics, cull poor performers etc.
- **Monitor** production, profitability and pastures; periodically reassess performance against plan.
- **Infrastructure** – plan, get funding/support and establish to allow improved grazing management.
- **Get support** – from peers, agency staff, other producers, mentors.
- **Knowledge** - gather information from grazing trials, field days etc., attend workshops & courses, do your homework, learn from peers etc.

2.2 What helped or would help people make the change to adopting better grazing management?

- **Motivation and attitude** to want to change.
- **Seeing the evidence** of the benefits of positive change at field days, in case studies, on neighbours’ properties.
- **Knowing the costs and benefits** builds confidence to change.
- **A sound plan** laying out short, medium and long term objectives.
- **Resources** (finances, equipment and labour) to make planned changes.
- **Financial ability/flexibility** or accommodation by banks to make the change.
- **Training, information** to gain the knowledge to make change.
- **Support** via peers, technical experts, mentors through the whole change process.
- **Favourable conditions** – good seasons and good cattle prices.
- **Encouragement** – seeing improvement in cattle performance and pasture condition due to changes in management.
- **Government** – consistency of policy.

2.3 What doesn’t help or hinders change?

- **Criticism** and negative peer pressure.

- **Lack of support** from extension providers, peers, community.
- **Lack of funds**, resources and labour.
- **Government policy** – drought subsidies reward poor management; vegetation management laws restrict woody weed control options.
- **Big stick approach** by government- forced rather than a voluntary approach to improving land management.
- **Management** - lack of management control in business; not focussing on key issues.
- **Lack of knowledge** – treating symptoms not causes, not knowing how to implement change.
- **Property limitations** – unviable living area, inadequate infrastructure, lack of finishing country, complex mix of land types complicates management.
- **Poor seasonal and market conditions** – oversupply of cattle at critical times etc.
- **Lack of early success** reduces morale and motivation.

3. Looking at the barriers (5 top barriers as voted from section 1 above)

3.1 Motivating change

- **Business analysis** to identify weaknesses, potential for improvement and assess other strategies.
- **Extension** - show/prove a better way of doing things via field days, business cases, best practice groups, follow-up to support change.
- **Inspire people** with compelling stories, examples and what can be achieved.
- **Increase knowledge** re: pasture and cattle management, business, HR skills etc.
- **Increase accountability** to show positive image of industry, exert positive peer pressure on others.
- **Rewards** – better bank rates for good management, better access to extension, but more accountability etc.
- **Targeted extension** at slow adopters and ‘recalcitrants’.
- **Shocks** – show how production will suffer if land condition degrades.

3.2 Changing business management styles

- **Business analysis** – assess strategies and identify skills lacking.
- **Business planning** – determine vision, goals, strategies and options etc.
- **Extension** training, education and long term support.
- **Banks** – educate lenders on benefits of improved land management and need for support through change.
- **Support** – peer support, mentoring, coaching, extension support through different steps.
- **Research** – ensure applicability at whole property scale via modelling.

3.3 Overcoming ignorance

- **Increase motivation** – to keep up with beef industry peers; use field days, courses, field trips etc.
- **Extension** – keep ‘drumming the message’ via many different avenues e.g. social media, education courses, form small groups, involve graziers in presenting workshops, field days etc.
- **Targeted extension** - identify problem properties, take information to them, and be innovative.
- **Compliance** – as a last resort for non-compliers.

3.4 Lack of business management (not knowing if they are profitable)

- **Business analysis** - bench marking, keeping good financial records, attending accounting courses.
- **Training** - business management courses e.g. Business Edge and Profit Probe with own business data, critical thinking skills etc.
- **Extension** - one on one learning, working with next generation, more sharing of good and bad management outcomes.
- **Farm financial counsellors** - important as confidential advisors to 'walk' people through change.
- **Knowledge and skills** - increasing skills is self-empowering: breeds competence and confidence to change.
- **Mentoring** - support through change.

3.5 Improving time management and related issues etc.

- **Business analysis** - cost-benefit analysis can save time and money, improve efficiency; social and time costs can be hard to quantify.
- **Time management** - prioritise and focus on most important jobs, improve communication within business, make daily/weekly/monthly plans; business coaching to improve efficiency.
- **Peer support** - use team approach, peer pressure support, share labour and effort with trusted peer neighbours.
- **Research** – evidence and science based assistance.
- **Training** - personal development and critical thinking courses.

4. How are skills and knowledge best delivered to support and drive change?

4.1 Peer groups

- **Extension groups** - create catchment groups of different ages and management styles or communities of people with similar goals, aspirations; use benchmarking within and between groups, aim to positively influence slow adopters.
- **Extension products** - ongoing courses with periodic meetings for discussion and support; field days, Landcare meetings, grazier presentations etc.

4.2 One on one mentoring, targeted extension

- **Peer groups** - long term, can take 3-4 years to form; industry seen to influence its own direction and image.
- **One-on-one mentoring** - technical experts and/or experienced producers, mentoring via visits, phone calls, webinars, etc.
- **Targeted extension** - to non-adopters, confidential approach by experienced extension officers with evidence e.g. Vegmachine cover trends, show potential management solutions. Follow up and support essential, aim to involve them with system/peer groups.

4.3 Whole of business planning

- **Financial** - facilitate meetings with lenders and investment partners to gain their support.
- **Funding support** for infrastructure change, incentives to upskill.
- **Training** - all courses to have an NRM component, more innovative, interesting and flexible delivery, e.g. 'rewards' for implementing change, on the job courses.
- **Training peer to peer** – delivered by peers, educate managers to train each other, form like-minded groups to work together.

4.4. Critical thinking skills and identification of priorities

- **Mentoring** - access to mentors.
- **Extension groups** – workshops with small groups.

- **Training** – understanding oneself and others, decision-making processes, specialist training.

4.5 Case studies and cost benefit analyses

- **Case studies** - showing the 'journey', time-frames involved and accumulative effects on productivity and land condition. Importantly, how to apply methods and findings on other property situations and templates for cost: benefit analysis.
- **Extension products** - all courses have NRM component; field days, web pages, newspapers, fact sheets, other media etc., attention grabbing publications e.g. flip books of time series photos showing changes in pasture condition.

4.6 Seeing is believing

- **Case studies** - professionally done and presented e.g. short video on web page with producers presenting, incentives for people to participate in case studies and host demo sites.
- **Extension** – tag onto other social activities, field days on different properties with local producers speaking, bus trips to other areas to see success stories.
- **Extension products** - newspapers, web pages, video clips, road signs, Facebook etc.
- **Extension support** – detailed information on how to apply steps in new management system, ongoing learning/training over 3-4 years.

4.7 Myth busting

- **Public myth busting** - actively correct misconceptions and myths via field days, social media, case studies etc.

24 Appendix 4: Futuring workshop June 2016: detailed proceedings

Attendees: 29 people attended – 8 graziers, and staff from DAF, DSITI, JCU, DEH, CSIRO, MLA & JCU.

Core trial results: Peter O'Reagain (Principal Scientist) gave an overview of the results from the last 19 years of the Wambiana grazing trial (WGT) and outlined the extent to which objectives had or had not been met. While some of these had been met, the newer strategies initiated in 2012 like Flexible stocking (+/- wet season spelling) had not been running long enough to allow any firm conclusion to be reached on their efficacy and profitability.

1. Outcomes of associated projects at the site.

1.1. Effect of grazing strategies on biodiversity (Prof. Lin Schwarzkopf, James Cook University)

- JCU has collected detailed faunal data in 4 grazing treatments over 3 years at the WGT-, i.e. the biodiversity data is relatively short term and the work needs to be continued in the longer term.
- The data showed that strategies that were the most profitable also had the highest biodiversity, i.e. there was no trade-off between profitability and biodiversity. These results will be published shortly.
- Trial has been very important for post graduate work; to date one honours project and two PhD projects have been conducted at the site.

1.2. Regenerating C condition land with wet season spelling (Peter O'Reagain presenting for Paul Jones, DAF).

- Effects of different lengths and frequencies of wet season spelling investigated in small (30 by 30 m) plots at WGT and Monteagle (Clermont).
- The short term results over 3 years at Wambiana show very slow recovery of C condition land even with regular full wet season spelling.
- As response to spelling can be slow, it is very important to continue work.
- MLA funding for the spelling project is now finished, so further funding is essential to reap the full benefit of the investment already made in the establishment of the trial.

1.3. Use of WGT in remote sensing (Dan Tindall, Program leader, Dept. Science, Innovation, Technology & Industry).

- Data from WGT used to help develop landscape monitoring data and products for policy and land managers.
- WGT ground cover and yield data has been used in development of bare ground index (BGI) and fractional cover algorithms – these have flowed on to various current state and nation- wide monitoring programs, e.g. AussieGRASP.
- WGT used as a test case for development of ground cover reports and regional comparison reports – now implemented in *FORAGE*, *VegMachine* and *NRM Spatial Hub*.
- Grazing trial data essential for calibration/validation of pasture models at paddock to national scales.
- WGT is an excellent case study for extension and education for our products.
- Also used for training staff members.

1.4. Soil C and biomass work at WGT (Steven Bray, Principal Scientist, and DAF).

- The three major issues currently are: soil carbon, greenhouse gas emissions and reef water quality: the WGT is providing important long term data that addresses all of these issues.
- WGT has allowed determination of long term effects of grazing management on soil carbon sequestration.
- Woody biomass and cattle data from WGT has also been used for greenhouse gas accounting.

- Long term monitoring of woody species and their response to drought and fire important to understanding and developing control methods for woodland thickening.
- Detailed data from the WGT on how different grazing strategies affect rainfall infiltration, runoff and sediment loss has been used extensively in extension and modelling.

1.5. Bio economic modelling to extend WGT results (Lester Pahl, Principal Scientist, DAF).

- Detailed WGT data has been used to calibrate and parameterise GRASP model for area.
- GRASP with the Enterprise economic model has been used to investigate impacts of the different strategies at the enterprise level over different 30 year climate windows. Modelled results are in agreement with trial results.
- Current (Phase 3) modelling is investigating the effects of various forms of spelling combined with different stocking strategies.
- Preliminary results show that response to spelling is very slow and uneconomic in the short to medium term. Final results to be presented in Milestone 7 of Wambiana project.

2. What would be the value of the WGT in the future? What would be lost if it were closed?

2.1. Biodiversity (Prof Lin Schwarzkopf, JCU).

- WGT is the only trial available with cattle on it that also collects economic data.
- Without the WGT can only make assumptions about grazing impacts on biodiversity and the potential trade-offs between economics and biodiversity.
- The WGT site also very valuable for training students – their interaction and engagement with beef producers is particularly important.

2.2. Wet season spelling trial (P O'Reagain on behalf of Paul Jones, DAF)

- Spelling trial has only been going for three years and data very short term – loss of WGT means loss of investment in spelling project before meaningful data collected.
- Current short term results also do not support use of spelling in management.
- The main WGT complements spelling project and *vice versa* -allows scaling up from plot to paddock scale.
- Plant population studies of key 3P grasses in spelling project also directly complement and support larger scale pasture measurements in main trial.

2.3. Remote sensing work (Dan Tindall, DSITI)

- If trial continued WGT would be used as a data collection site for linking remote sensing with ground data, calibrating new sensors, developing and testing new extension products and for staff training.
- Risks of closing trial would be loss of ability to build and validate remote sensing products, high resolution radar etc. and measurements over long time periods, loss of cross agency linkages and loss of training site for DSITI staff.

2.4. Bio-economic modelling (Lester Pahl, DAF)

- Continuing WGT critical for further improvement and validation of existing models, including capturing patch grazing effects.
- Current ability to model pasture change is relatively basic and has deficiencies in simulating responses to, for example, different frequencies and lengths of spelling.
- Detailed pasture data and quantification of long terms responses to management and climate are essential to improve modelling capacity.
- Current modelling involves long term time frames e.g. for catchment management- thus long term data essential to support this process.

2.5. Importance of WGT for reef water quality programs (Leigh Smith, Dept. Environment and Heritage protection).

- The WGT important as a guide and demonstration of strategies and management recommendations for reducing runoff and sediment yield to the reef. Also important in developing and supporting BMP for better reef water quality outcomes.
- Would like mini Wambiana type trials on different land types in higher priority areas such as Bowen-Broken-Burdekin and upper Burdekin catchments. Use Wambiana as a guide to set up other trials in other areas.

2.6. Potential value to CSIRO (Andrew Ash, CSIRO).

- DAF and CSIRO have already conducted a number of collaborative projects at Wambiana or using the data, e.g. looking at management effects on soil fauna, water infiltration rates, modelling, faecal NIRS etc.
- Data from WGT important to validate models. Collecting a continuous data set on whole beef businesses to help better understand system dynamics also important.

2.7. Value to beef industry (Greg Brown, grazier and former Cattle Council member)

- Industry need WGT to reverse degradation and see the economic value of better land management.
- Engagement of JCU environmental science students with beef producers also very important for the future.
- WGT also important to develop land rehabilitation strategies post drought.

3. Extension value of WGT (Peter O'Reagain)

- Total visitors to WGT site = 1488 (2006-2016).
- Total audience at separate WGT presentations = 2760 (2006-2016)
- Major field days were held in 2007 and 2015.
- At 2015 field day, information rated as 'very useful': 90% of attendees expressed 'strong to very strong' support for trial to continue.
- Recommendations from trial widely disseminated via the MLA EDGE Grazing Land Management and Stocktake workshops and many popular publications.

A grazier's view on the WGT – (Raymond Stacey, grazier and consultant)

- The strategies being tested locally developed, real world linkage to profitability and linkages being made to downstream effects of grazing.
- More research needed on those trigger points for change in pasture condition.
- WGT can be used to ground truth models/technology.
- The trial collects basic animal and pasture data – confounding effect of people's management styles is removed. WGT has been going for 20 years and supports decision making.

4. Presentation: Scene setting: what are the major issues facing the industry? (Peter O'Reagain)

The pressure to be profitable and remain economic but also reduce sediment runoff to the reef to meet ambitious water quality targets etc.

5. Unanswered questions and emergent questions from trial (Peter O'Reagain)

The top 3 *unanswered* questions from the trial ranked by the workshop were:

Rank	Score	Question
1	7	How do different grazing strategies affect soil loss and runoff? What is the cost to the grazer in reduced long term productivity?
2	5	Can flexible stocking increase productivity and improve land condition relative to simply fixed stocking at LTCC?
2	5	How important is wet season spelling if stocking at LTCC or applying flexible stocking? What are its benefits/costs? What is the optimum timing and duration of spelling?
3	4	Development of improved guidelines/rules of thumb for forage budgeting and estimating short term stocking rates?

The top 3 ranked *emergent* questions from the trial as ranked by the workshop were:

Rank	Score	Question
1	11	How far can pastures be pushed and under what conditions (re: flexible stocking) before degradation occurs? How is this affected by rainfall/drought/stress etc.?
1	11	How to economically regenerate degraded (C condition) land i.e. HSR? Can recovery be accelerated with say, high density grazing and spelling? Seed addition - natives or exotics?
2	9	Would more intensive grazing systems e.g. rotational/cell grazing give superior results to the current relatively simple strategies being applied?
3	7	Can present results be extrapolated via modelling to other areas in N Australia? How can modelling be improved to better simulate pasture dynamics and associated effects on animal (esp. breeder) production?

6. Scenario evaluation by discussion groups:

Scenario 1: Leave the WGT as is with little or no change

CONS

- Opportunity costs of maintaining trial; lack of staff capacity may preclude other work/ access to other funding opportunities, e.g. reef.
- Restricted to steers – no breeder information
- May lose relevance or funding if not modified; however any modification needs to be justified and not just for cosmetic reasons.

PROS

- WGT is established, so set up costs are nil c.f. new work.
- Historical data can be compared to continuing data and trends (climate change) increasing scientific validity, rigour and strong inference
- Data widely relevant to north Queensland and northern Australia.
- Provides a collaborative platform for many other investigations; potential for new opportunities and partnerships
- Excellent case study of a long term project with great collaboration and co-investment.
- Expanding links between beef industry and environmentalists and major opportunity to demonstrate sustainability of grazing industry.
- Last grazing trial still functioning; needed for extension and demonstration.
- Will demonstrate the long term effects of newer, recently added treatments

Scenario 2: Continue WGT but Modify

CONS

- May limit research capacity in DAF to conduct work on satellite/other sites.
- Limits capacity to continue current, long term strategies on Wambiana (assuming these were changed/replication reduced/staff capacity diverted elsewhere).
- Modification needs additional money, resources and opportunities.

PROS

- Increased staff capacity to address new research questions, e.g. satellite sites (off site).
- Addition of satellite sites has potential to access other funding, increase audience, local relevance and uptake. Would also capture opportunities with new groups.
- Allow time for original and new grazing strategies to play out.
- Automation (precision pastoral equipment?) – opportunity to automate data processing and analyses for immediate and ongoing results to present to industry.
- Allows ability to respond to emerging needs, e.g. climate change and for management effects on water quality

Scenario 3: Terminate Trial Completely

CONS

- Loss of continuity of treatments and important demonstration site; major outstanding questions remain unanswered.
- Loss of potential to address other, related issues without a big capital outlay.
- Loss of opportunity for graziers to engage with outside (green) groups.
- Lose ongoing benefit to the industry—long term data validates treatment outcomes and substantiates management recommendations.
- Loss of collaborative platform and opportunity to do extra research and extension that relies on experiment continuing e.g. spelling project, biodiversity work, soil C storage, field days.
- Loss of credibility and goodwill by agency; lose relationship with Lyons family and a range of organisations

PROS

- Frees up money and resources for use elsewhere e.g. high priority issues (reef) in high priority areas (like the BBB).
- Allow more focus on Spyglass beef research station

7. Group report back on suggested future work or scenarios for trial

- *Maximise extension* effort, target extension activities at small groups, e.g. family business.
- *Establish satellite sites* to test treatments, demonstrate BMP, possibly on more erodible landscapes.
- Investigate *regeneration of C condition* land at paddock and plot scales.
- *Emphasise loss* to industry, other agencies and complimentary projects if trial closes.
- *Modify trial to answer different* questions at Wambiana and at other sites.
- *Retain replication*; more frequent recording of *grass basal area* required at WGT.