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Prepared by: Dr Peter O'Reagain and John Bushell
Department of Agriculture, Fisheries and Forestry

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Wambiana grazing trial Phase 2: Stocking and spelling strategies for improving carrying capacity and land condition in north Australian grazing lands

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Abstract

In Phase 2 of the Wambiana trial (2010-2014) some treatments were modified to determine whether flexible stocking +/- wet season spelling could sustainably deliver higher profitability than constant moderate stocking (MSR), moderate stocking with rotational spelling (R/Spell) or heavy stocking (HSR). Due to wet conditions and a controlled burn, new treatments were only fully implemented for two seasons.

Despite seven good-average years, pasture condition was worst in the HSR but best in the MSR and R/Spell, followed by the two flexible strategies. *Bothriochloa pertusa* has increased dramatically in all treatments, with the greatest increase in the HSR. The decline in land condition in the HSR has reduced carrying capacity but not rainfall use efficiency. Individual animal performance (weight gain, carcass grade) was highest in the R/Spell and MSR, followed by the flexible strategies, but lowest in the HSR. Conversely, LWG/ha was greatest in the HSR. Despite recent good years, accumulated gross margin in the HSR remains far below that of the other treatments. The present short term results indicate that flexible stocking (+/-spelling) is no more profitable or sustainable than constant moderate stocking (+/- spelling) at long term carrying capacity.

Enterprise level bioeconomic modelling with breeders confirmed that profitability and pasture condition are maximised at moderate stocking rates under either constant or low flexibility stocking strategies. However, the optimum stocking rate varied with climate window reinforcing the need to adjust stocking rates with rainfall.

While there has been insufficient time to fully assess the new Flex and Flex+S strategies, the trial results and bioeconomic modelling, both indicate that profitability will be maximised and land condition maintained/improved by adjusting stocking rates as seasons change in a flexible, risk averse fashion, around long term carrying capacity.

Executive Summary

The Wambiana grazing trial was initiated in 1997 to test the ability of a range of stocking strategies to cope with rainfall variability. In Phase 1 (1998 to 2010) strategies tested were moderate stocking (MSR), heavy stocking (HSR), two variable stocking strategies (VAR and SOI-variable) and moderate stocking with rotational wet season spelling (R/Spell) with three sub paddocks. Following a review in 2009, some treatments were modified to reflect learnings from Phase 1 and to determine whether flexible stocking rates with or without spelling could sustainably deliver higher productivity and profitability than simply constant stocking at long term carrying capacity (LTCC).

In Phase 2 (2011-2014) the HSR and MSR remained unchanged with new/modified strategies (i) Rotational wet season spelling (R/Spell) with six sub-paddocks (ii) Flexible stocking without spelling (Flex) and (iii) Flexible stocking with spelling (Flex+S) with six sub-paddocks. Full implementation of new treatments was delayed due to exceptionally high rainfall in 2010/11 (1240 mm) which delayed fencing and a controlled burn in October 2011. New treatments were thus only fully implemented for two seasons (2012/13 and 2013/14).

The 2011 fire significantly changed woodland structure by shifting trees to smaller size classes. The fire also reduced *Carissa ovata* cover but the effect was relatively short term. However, the fire had very little effect on tree mortality. Significantly, virtually all of a large cohort of *Eucalyptus* seedlings survived and then regrew rapidly after the fire.

Phase 2 thus further reinforced and extended trends previously recorded in Phase 1 but also delivered important new findings and insights in a number of areas. Pasture yield and cover improved in all treatments with a seven year sequence of good to average rainfall years. However, in the HSR the apparent improvement in pasture condition was largely cosmetic with little, if any, increase in the abundance of 3P (productive, perennial and palatable) grasses. Thus despite the better seasons pasture yield, cover and 3-P density remain by far the lowest in the HSR and highest in the MSR and the R/Spell. The cover of the native woody weed *Carissa ovata* is also highest in the HSR. In the R/Spell, wet season spelling appears to be having a strong beneficial effect, with pasture condition in this treatment and animal production starting to exceed that in the MSR. Although wet season spelling has occurred in some sub-sections of the Flex+S since 2011/12, the response of pasture condition has been subdued.

A new development in Phase 2 has been the phenomenal increase of the exotic grass *Bothriochloa* pertusa, particularly on the box soils. This resulted from 1) the initial spread of *B. pertusa* into the area along district roadsides, 2) very low cover levels in trial paddocks during the early 2000's drought, 3) good dry season rains in 2007/08 and 2008/09 allowing isolated, invading *B. pertusa* plants to survive and set seed and lastly 4) a subsequent run of very good seasons. Although *B. pertusa* has increased dramatically in all treatments, the greatest increase by far has occurred in the HSR with frequency increasing exponentially from 1% in 2005 to about 60% in 2014.

The decline in land condition in the HSR has led to a major reduction in carrying capacity (CC) with estimated CC in the HSR (14 ha/AE) now less than half that in the MSR and R/Spell (both 6.7 ha/AE). Surprisingly, there has been no apparent decline in rainfall use efficiency, indexed as beef produced/100 mm of rainfall. This probably reflects the better seasons and the expansion of *B. pertusa*. Although there has been no apparent decline in animal production, preliminary indications are that relative profitability in the HSR has declined with reduced land condition.

There has been no major impact of reduced land condition in the HSR on water quality but evidence from Phase 1 suggests an increase in runoff frequency and intensity relative to the moderately stocked MSR and R/Spell. This could potentially increase downstream channel and bank erosion which are major contributors to sediment load. Pasture rainfall use efficiency is also likely to decline with obvious consequences for animal production, particularly at the break of the season when forage is scarce.

As in Phase 1, individual live weight gain (LWG) as well as carcass grades and prices were highest in the MSR and R/Spell followed by the Flex and Flex+S, but by far the lowest in the HSR. Conversely, LWG/ha was still by far the highest in the HSR and lowest in the MSR. LWG/ha was marginally higher in the Flex and Flex+S due to the slightly higher stocking rates applied in the last few seasons relative to the MSR. Despite generally high gross margins (GM) in the HSR with the recent good years, GM in the HSR was negative in 2013/14 and accumulated GM in the HSR remains far below those of the other treatments.

This relatively short term data from Phase 2 indicates that flexible stocking with or without spelling is no more profitable or sustainable than fixed stocking at long term carrying capacity (MSR & R/Spell). The lack of a clear benefit of the new 'optimum management' strategies may be attributed to (1) insufficient time for treatment effects to emerge, (2) good seasons buffering the performance of potentially less optimal management strategies such as fixed, moderate stocking rates without spelling (MSR), and (3), carryover effects on pasture condition and hence LWG from the previous Phase 1 treatments in the Flex and Flex+S paddocks. These factors reinforce the need to continue the trial until an extended sequence of dry years has been encountered.

Phase 2 of the trial has also provided valuable practical experience in, and demonstrated the effects of, adaptively managing for a variable climate. This has included first, managing the timing, area and duration of spelling relative to seasonal conditions. Second, using a combination of signals based on pasture availability, rainfall, modelling and climate forecasts to adjust stocking rates through the year as conditions change, and third; integrating fire and grazing management to manage tree thickening in a sustainable manner.

These practical learning experiences, input from the grazing industry and the data collected over the last 17 years have allowed development of robust guidelines and rules of thumb. Managing sustainably and profitably in a variable climate will thus involve all of the following elements:

1. Use of long term carrying capacity as a general guide for setting stocking rates for different land-types;
2. *Flexible* stocking rates adjusted in a risk-averse manner in line with forage availability, seasonal conditions and, if appropriate, climate forecasts. The principal stocking rate adjustment should be at the end of the wet season with other secondary control points at the end of dry and in the early wet.
3. Rotational wet season spelling, preferably for the full wet season, taking care to avoid overgrazing non-spelled sections.
4. Appropriate use of fire that takes into account time since last burning, land-type resilience and climate forecasts for the approaching wet season

As in Phase 1, these have been widely communicated and shared with industry, agency staff and a large number of tertiary students through field days, presentations, papers and popular publications.

In the modelling component of Phase 2 the GRASP model was parameterised and calibrated for the box land-type at the trial site. Resultant model predictions showed good agreement with observed pasture TSDM, % of 3P species and steer LWGs, improving confidence in the model. GRASP was then linked to the property-level Enterprise economic model and used to extrapolate upwards from the trial to an enterprise level breeder herd for different stocking strategies over a range of stocking rates and climate windows. In agreement with the trial, model outcomes showed that enterprise profitability was maximised at moderate stocking rates. However, the optimum stocking rate varied markedly depending upon the climate window used and the sequence of seasons encountered, reinforcing the importance of adjusting stocking rates as climate varies. Comparison of different stocking strategies showed that fixed stocking rates or low flexibility stocking (+/-15%) were more sustainable and are financially superior to high flexibility stocking (+/-40%).

In summary, while there has been insufficient time to fully assess the new Flex and Flex+S strategies, previous data from the trial as well as simulation modelling indicate that profitability will be maximised and land condition maintained or improved by adjusting stocking rates in a flexible, risk averse fashion around long term carrying capacity as seasons change.

Acknowledgments

We are deeply grateful to the Lyons family of Wambiana for their continued co-operation, support and encouragement in running the trial. We also thank the Wambiana Grazier Advisory Committee for their commitment and the continued sharing of their knowledge on land and cattle management.

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Peter O'Reagain and John Bushell

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1 Background

The Wambiana grazing trial, south-east of Charters Towers, began in 1997 with support from the Federal government's Drought Regional Initiative with further support from the Natural Heritage Trust and Great Barrier Reef Marine Park Authority. MLA has provided funding support of $546,000 for the Wambiana trial since 2002 under two projects (NBP.318 and B.NBP.0379).

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. The findings have been communicated through a range of MLA and DAFF activities.

The first research phase however, 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 a paddock scale more so than fixed moderate stocking. This is despite these strategies being widely promoted as core extension messages. Following a detailed technical review of the results and a study site visit with local producers and researchers in 2009, a revised experimental design has been developed which addresses these key gaps in grazing management knowledge.

This second phase of Wambiana grazing research was aimed at quantifying the impacts and economic cost benefits of flexible stocking rate and rotational wet season spelling strategies for improving carrying capacity and land condition. In addition, it would also describe the long-term impacts and costs of reduced land condition and its impacts on water quality.

Phase 2 of the trial maintained the two baseline treatments (heavy and moderate stocking) but modified the other three treatments in an adaptive management fashion based on trial learnings to date. The aim was to deliver additional evidence based grazing management guidelines and data to industry, both directly and through other collaborative work.

There was strong and unanimous support for a second phase of the trial, which has been modified to seek additional productivity gains for the industry while minimising environmental impacts. The Northern Beef Industry Council (NBIC) strongly supported the proposal for a second phase of the Wambiana trial at its December 2009 meeting, and received strong MLA Board support.

2 Objectives

By September 2014 the project will have:

1. Quantified the impacts and economic cost-benefits of adaptive, flexible stocking and wet season spelling strategies on animal production, carrying capacity and land condition compared to both moderate and heavy set-stocking.

2. Quantified the long-term impacts of reduced land condition on carrying capacity, productivity, profitability and water quality.

3. Validated and improved the reliability of bioeconomic modelling using data from the grazing strategies tested at Wambiana in Phase 1 and 2.

4. Evaluated the implications of the Wambiana trial findings for a breeder-grower enterprise with bioeconomic modelling.

5. Developed recommendations (including decision rules and/or rules-of-thumb) to (a) manage stocking rate over time and (b) implement wet season spelling for breeding and growing herds that will cost-effectively improve carrying capacity and/or land condition.

3 Methodology

A brief description of the Wambiana trial is given below. For more detail see (O'Reagain and Bushell 2011).

3.1.1 Site description and treatments

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 *c.* 100 ha in size and contain similar proportions of three different soil-vegetation associations. Mean annual rainfall is 650 mm and is highly variable (C.V. = 40%) and largely (70%) concentrated in the wet season (December to April).

In Phase 1 of the trial (1998-2010), five stocking strategies were tested (Table 1). However, following the technical review of the trial in November 2009 and consultation with the Wambiana grazier advisory committee, some treatments were adapted as indicated for Phase 2.

Table 1: Comparison of the Wambiana Phase 1 and Phase 2 grazing strategies (HSR=Heavy stocking rate, MSR=moderate stocking rate, WS=Wet season spelling).

Phase 1 Strategy	Phase 2 Strategy
HSR (4 ha/AE)	HSR (4 ha/AE)
MSR (8 ha/AE)	MSR (8 ha/AE)
R/Spelling (3 sub paddocks-8 ha/AE)	R/Spelling (6 sub paddocks-8 ha/AE)
Variable (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 as well as outputs from Northern Grazing Systems project (Scanlan and McIvor 2010). 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.

3.1.2 Wambiana Phase 2: treatment application

Exceptional (1240 mm) rains in 2010/11 delayed erection of the paddock sub-division fences required for full implementation of two new Phase 2 treatments (Table 1). Thus, for 2010/11 the new Flex+S was run as '*Flexible'* stocking without spelling while the '*Rotational wet season spell'* continued to be run as a three as opposed to a six sub-paddock system. The new subdivision fences were completed in early 2012 and the full treatments implemented in February 2012.

3.1.3 Burning of the trial site

Following an earlier burn (1999), the entire trial was site burnt for a second time in 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 the trial was not grazed for six months (June to November) prior to burning. The site was then spelled for 12 weeks post-fire until 1 February 2012 when sufficient pasture growth had occurred to allow grazing to resume. The effects of the 2011 fire on the structure and density of the woody community are presented in Appendix 2

3.1.4 Spelling history

As specified in the trial procedure the grazing strategies are applied and managed adaptively based on conditions in each paddock replicate. In the treatments with spelling, the sub sections are spelled based on need and time since they were last spelled and are accordingly designated 'priority' or 'secondary' sub sections. In 2011/12, paddocks in all treatments were spelled following the October 2011 fire until 1 February 2012. Thereafter, both the priority and secondary sections of the R/Spell and Flex+S were spelled until June 2012 i.e. both had a full wet season spell (Appendix Table 1a).

In 2012/13, the two sub-sections to be spelled in Flex+Spell and R/Spell were only locked up on 29 January after 114 mm fell over a few days. However, on 8 March after six weeks of spelling the secondary section in the Flex+S was opened up to grazing again. This decision was based on the lower wet season rainfall (particularly in February) and slow pasture response in 2013, the poorer pasture condition (relative to the R/Spell) in the Flex+S and the need to avoid overgrazing of the non-spelled areas. This action was also considered in the R/Spell but was not applied due to the good pasture condition in these paddocks and their perceived resilience. In the R/Spell both subsections were thus spelled for the full wet season (Appendix Table 1a).

In 2013/14, early rains were very patchy with the northern replicate (Rep 1) of the R/Spell and Flex+S receiving 91 mm compared to 20-30 mm in the southern replicate (Rep 2). Accordingly, Rep 1 was locked up four weeks earlier and had a longer spell than Rep 2. The secondary sections in the R/Spell and Flex+S in both reps were subsequently opened up in March 2014 due to relatively poor rainfall and growth rates and the need to reduce grazing pressure on non-spelled areas. The length of time that sections were spelled over the wet season thus ranged from 25 (Rep 1) or 21 (Rep 2) weeks in the priority sub-sections, to seven or eight weeks in the secondary sub-sections (Appendix Table 1a).

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.

4 Results and Discussion

4.1 Rainfall

Following six dry years from 2001 to 2006, conditions improved dramatically with above average to well-above average rainfall between 2007/08 and 2011/12 (Figure. 1). Rainfall in the last two years has been slightly below average, but reasonably well distributed, giving acceptable cattle production.

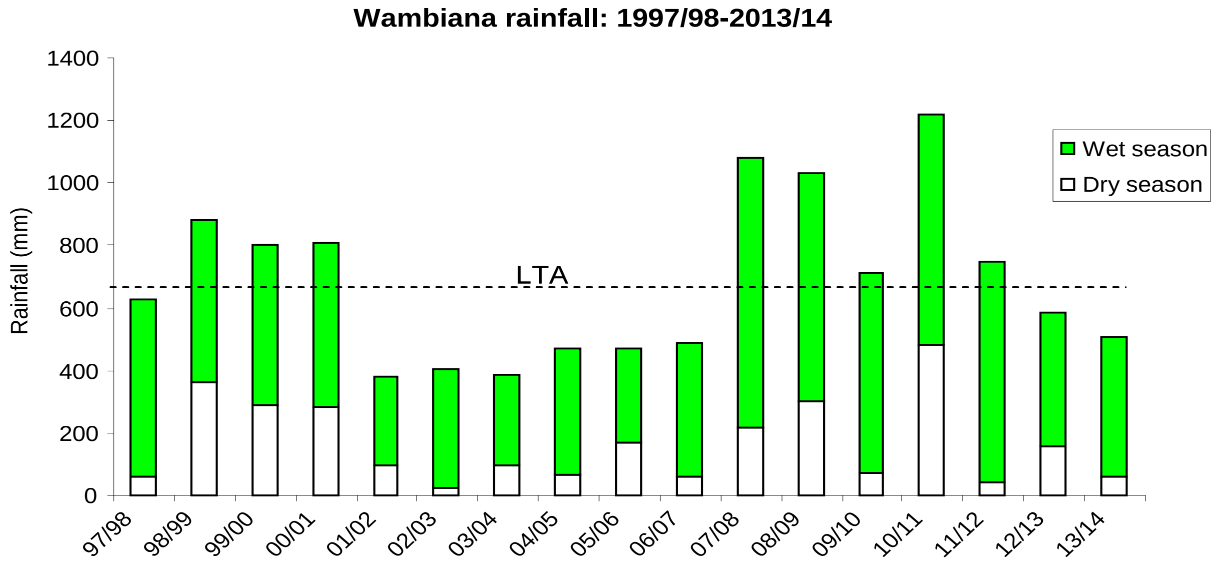


Figure 1. Annual rainfall between 1997/98 and 2013/14 at the Wambiana grazing trail. LTA=long-term average (650 mm).

4.2 Stocking rates

The HSR, MSR and R/Spell were run at their designated stocking rates as per the experimental procedure (Figure 2). In contrast, stocking rates in the Flex and the Flex+S were increased slightly in 2010/11 with the good seasons but thereafter were reduced as rainfall declined. More detail on how adaptive management decisions were made in adjusting these stocking rates is provided in Appendix Table 1b.

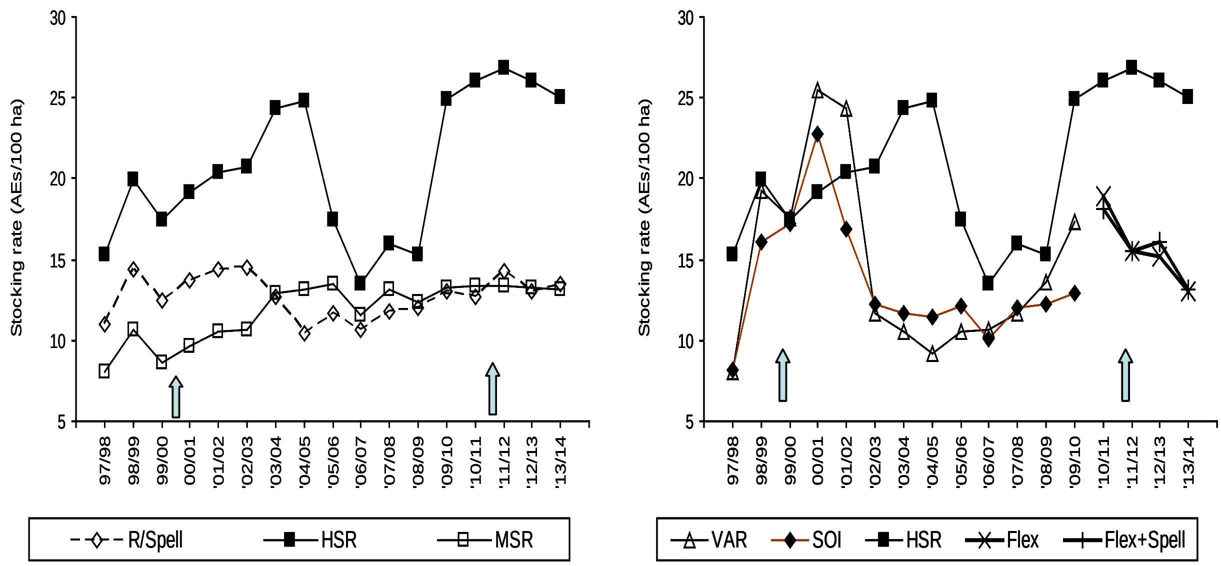


Figure 2. Change in stocking rate (expressed as Animal equivalents (AE)/100 ha) over different years at the Wambiana trial for (left) the R/Spell, MSR and HSR and (right) the HSR and different variable/flexible strategies. (AE = 450 kg steer). Note the new treatments from 2010 onwards. The 1999 and 2011 fires are designated by arrows.

Note that despite the very good years from 2008 to 2012, stocking rates in the variable/flexible strategies were still well below those applied in the early wet period 1998-2001. This reflects firstly the lessons learnt in Phase 1 regarding setting upper limits to stocking rates in even the best years. And secondly, the inherent decline in pasture productivity that appears to have occurred in these paddocks due to overgrazing in the earlier, wetter period.

4.3 Land condition

4.3.1 Pasture TSDM and ground cover

Pasture total standing dry matter (TSDM) increased sharply across most treatments from an average of around 600 kg/ha in 2006/07 to an average of more than 3000 kg/ha in May 2011 (Figure 3). However, TSDM in the HSR only increased to around 2000 kg/ha despite the very good rains that year. Pasture TSDM has since generally declined, particularly in the HSR, partly due to the 2011 fire, but mainly due to the lower rainfall post-2011. Thus in May 2014, pasture TSDM in the HSR was only one tenth (281 kg/ha) of that recorded in the R/Spell (2063 kg/ha) and the MSR (2063 kg/ha). Pasture TSDM in the Flex and Flex+S was far higher than in the HSR but still lower than in the MSR and R/Spell (Figure 3).

This marked difference in pasture TSDM between the HSR and the other treatments can be directly attributed to the loss of 3-P (perennial, palatable, productive) species (Table 2) and reduced pasture vigour. Although grazing pressure is substantially higher in the HSR, short term grazing pressure alone cannot account for these treatment differences i.e. assuming a daily intake of 10 kg/hd/day over the wet season, the greatest amount that consumption by grazing could have reduced TSDM over the wet season in the HSR would be 270 kg/ha: far less than the actual treatment differences recorded.

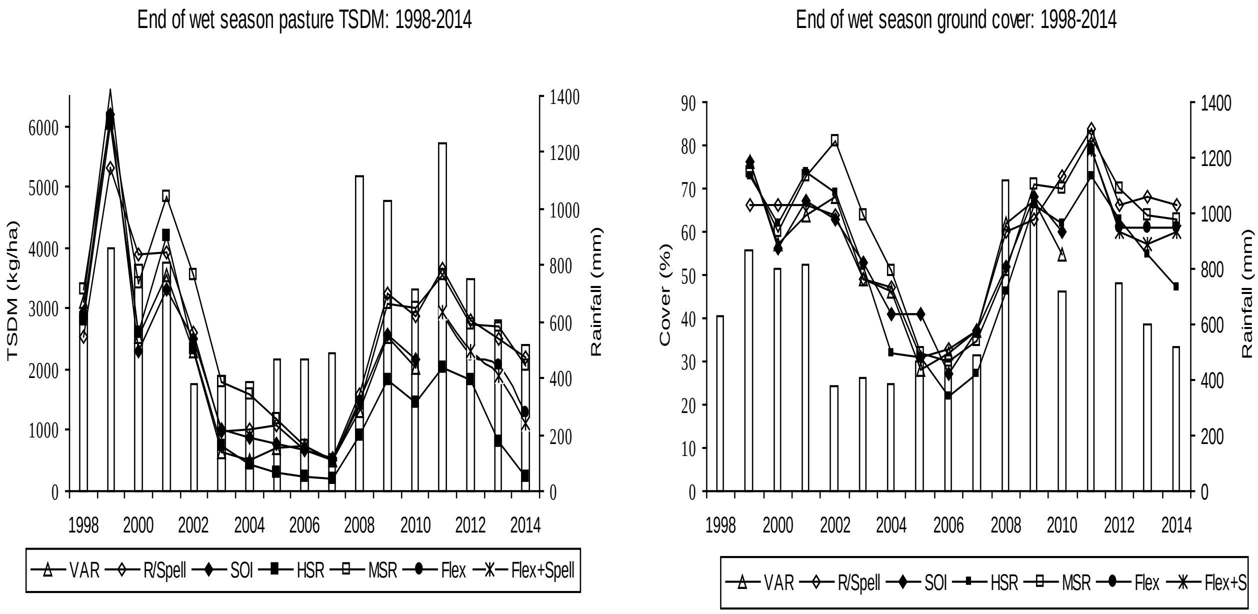


Figure 3. Change in end-of-wet season total standing dry matter (TSDM) (left) and ground cover (right) in the five stocking strategies with rainfall between 1998 and 2014. Note new treatments post 2010.

Projected ground cover increased steadily from an average across all treatments of around 30% at the end of the dry years in 2006 to reach a peak of 70-80 % in the high rainfall year of 2011. Thereafter cover declined, partly due to the fire in late 2011 but due largely to the reduced rainfall (Figure 3). By May 2014, end of wet season ground cover in the HSR (47%) was far lower than in any of the other strategies.

4.3.2 Pasture composition

In May 2014, pasture TSDM was highest in the R/Spell and MSR, followed by the Flex and Flex+S with TSDM by far the lowest in the HSR (Figure 4). The yield of 3P grasses followed a similar trend with 3P yield in the HSR only about 1/5th that in the MSR and R/Spell and about 1/3 that in the Flex and Flex+S. Conversely, the proportional contribution of 2P (weaker perennials with lower productivity/palatability) grasses to total yield was markedly higher in the HSR than in the other treatments. With time and ongoing spelling the contribution to yield of 3P grasses should increase in the Flex+S relative to the Flex treatment, but there is no clear indication of this yet occurring.

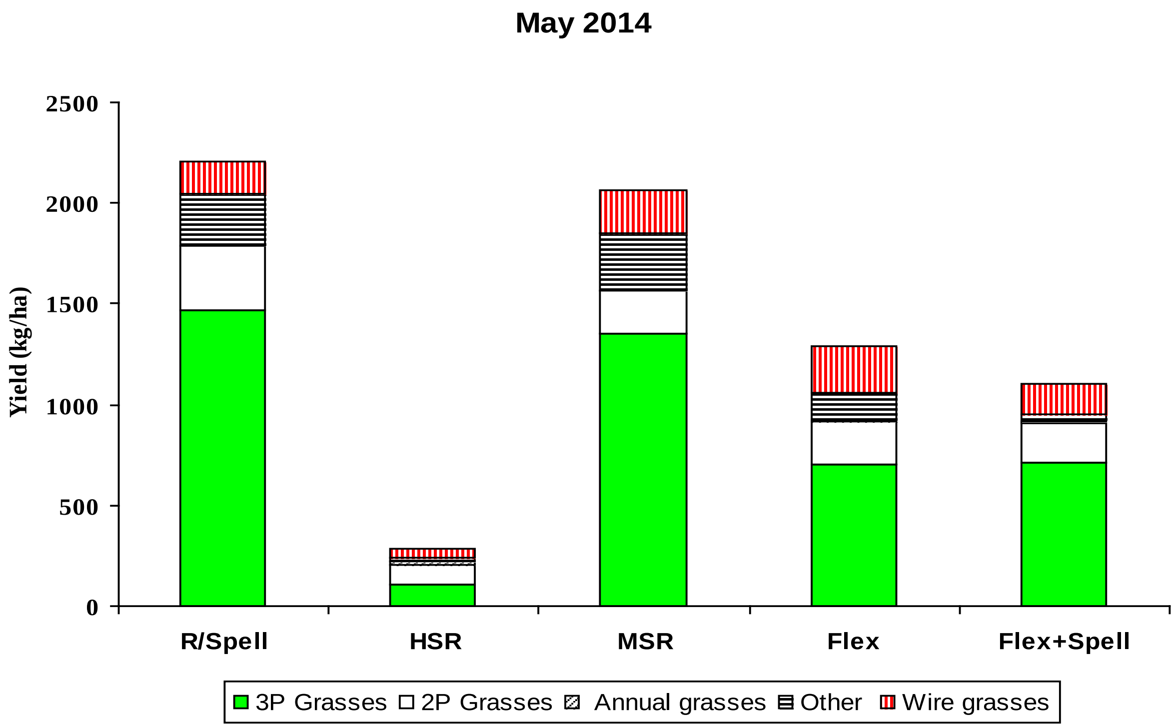


Figure 4. Mean contribution (kg/ha) of different species groups to total end of wet season yield in May 2014 across five stocking strategies at Wambiana.
(N.B. 2P grasses include *B. pertusa*; Wiregrasses=*Aristida & Eriachne* spp.)

4.3.3 Changes in species frequency

For simplicity and ease of interpretation, frequency data for only a few key grass species are presented (Figure 5). After 17 years, the 3-P species *Bothriochloa ewartiana* and *Heteropogon contortus* are both highest in the MSR and R/Spell but by far the lowest in the HSR, with frequencies in the Flex and Flex+S intermediate between these levels (Figures 5a and 5 b). The strong response of the relatively shorter lived *H. contortus* to rainfall is also clearly evident with this species increasing steadily across all treatments with the good rainfall post-2007.

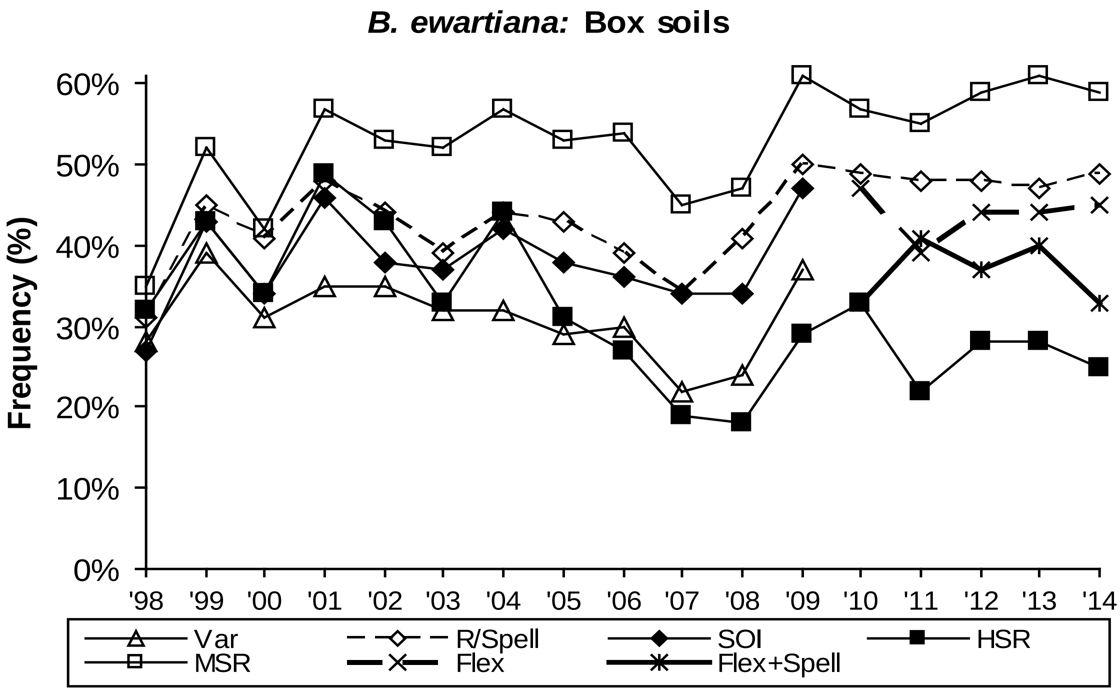


Figure 5a: Change in frequency of *B. ewartiana* in different treatments between 1998 and 2014. Note the change in treatments post 2010.

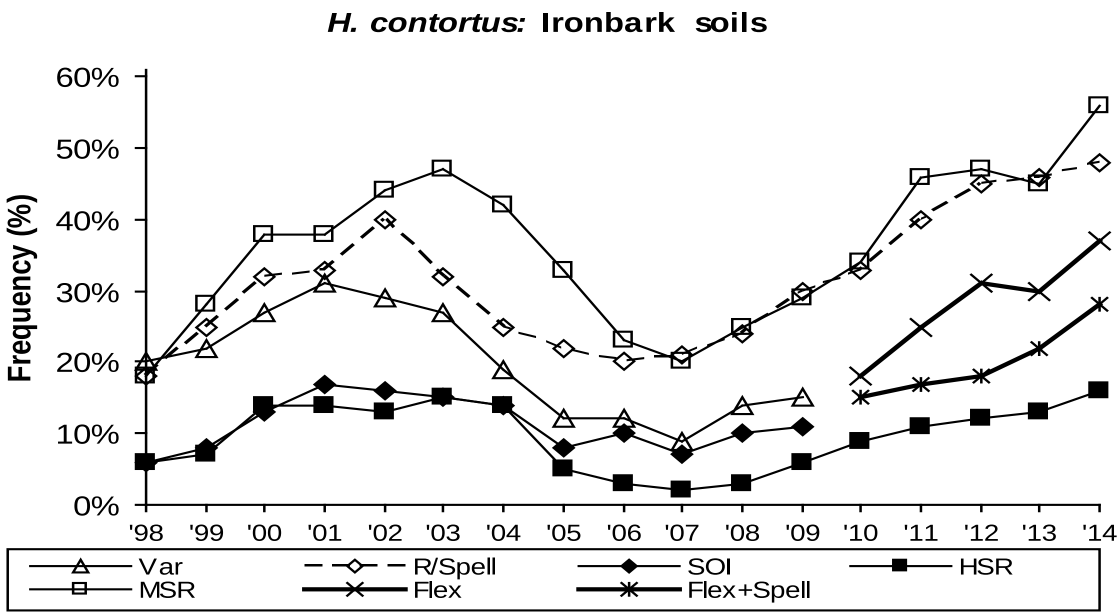


Figure 5b: Change in frequency of *H. contortus* in different treatments between 1998 and 2014. Note the change in treatments post 2010.

In contrast to these 3-P species, the annual fire grasses (*Schizachyrium and Mnesithea* sp.) were highest in the HSR, followed by the Flex and Flex+S treatments, with frequencies lowest in the R/Spell and MSR (Figure 5c). Although the abundance of these annual species fluctuates considerably with rainfall, they are clearly favoured by the lower ground cover in the HSR, and to a lesser extent in the Flex and Flex+S strategies.

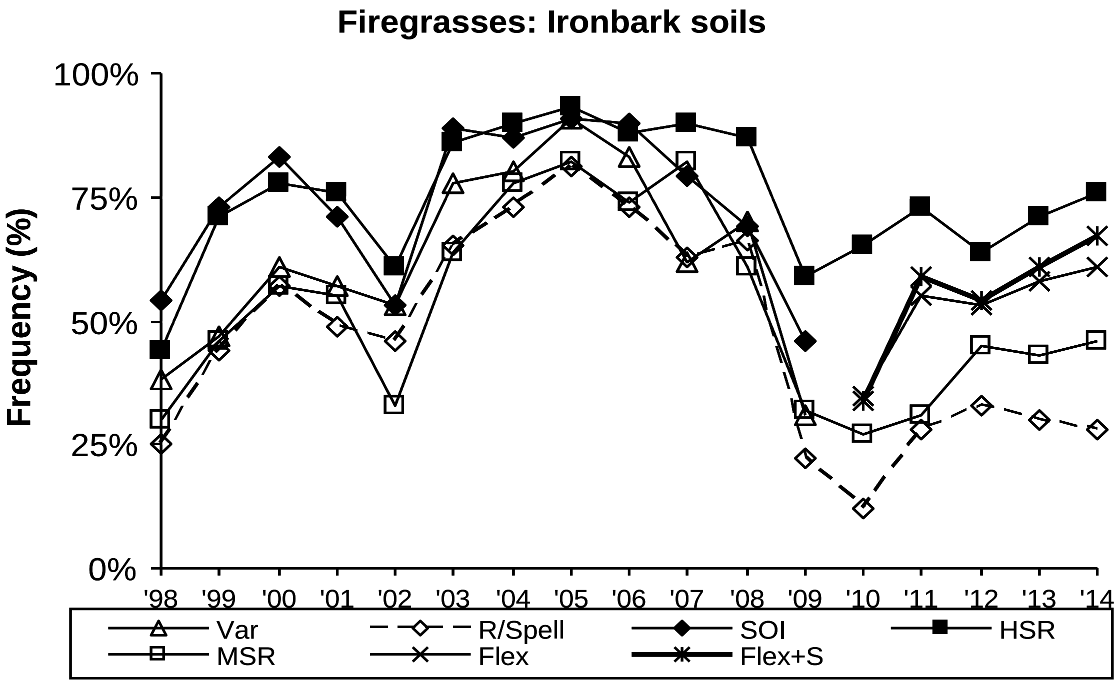


Figure 5c: Change in frequency of *Firegrass* spp. in different treatments between 1998 and 2014. Note the change in treatments post 2010.

The most striking change however, has been the explosion of *B. pertusa* at the site, particularly on the box soils, since 2006 (Figure 5d). Although *B. pertusa* has increased dramatically in all treatments, the greatest increase has been in the HSR with *B. pertusa* frequency increasing exponentially from just 1% in 2005 to nearly 60% in 2014. In contrast, the increase in *B. pertusa* in the more lightly stocked MSR (27%) and R/Spell (31%) has been only half that in the HSR. *B. pertusa* has also increased in the two Flexible strategies. Note that although the increase in *B. pertusa appears* greater in the Flex than in the Flex+S, the actual magnitude of change since both treatments started in 2010 is identical (+20%).

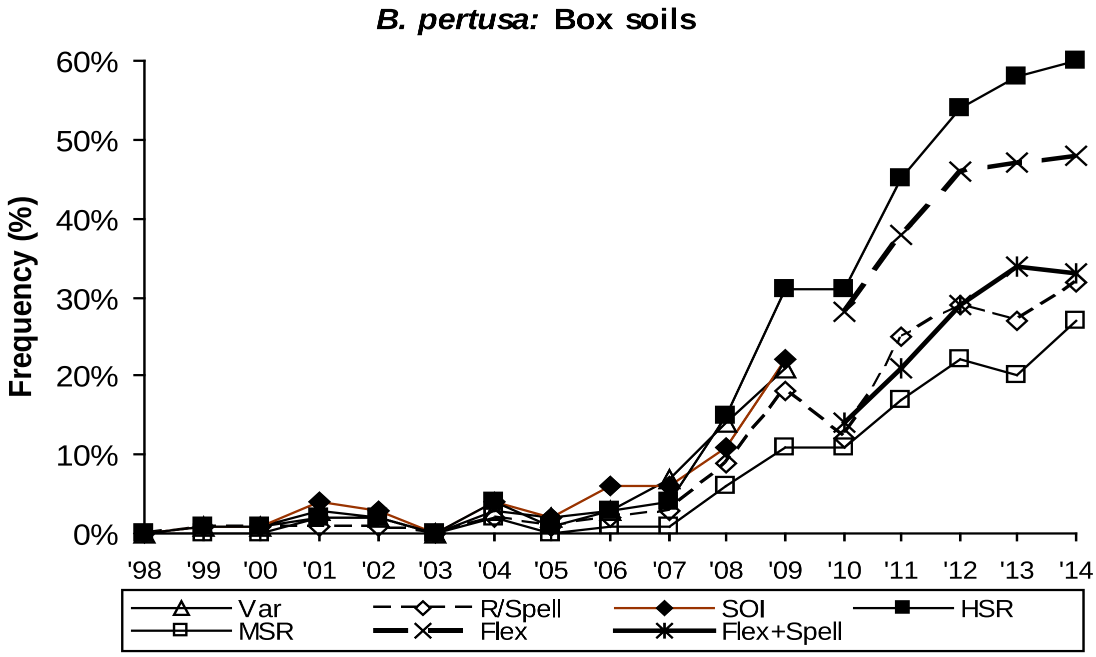


Figure 5d: Change in frequency of *B. pertusa* in different treatments between 1998 and 2014. Note the change in treatments post 2010.

4.3.4 3-P Tussock Density

In 2014, 3-P tussock densities were markedly higher in the MSR and R/Spell paddocks (mean: 8/m^2) than in the Flex and Flex+S (mean: 5/m^2). Tussock densities in the HSR (2/m^2) were by far the lowest of all strategies, indicating that despite the relatively good rainfall in the last eight years, significant recovery in pasture condition has not occurred (Table 2). The remaining 3-P tussocks in the HSR are also far smaller and weaker than those in other treatments, particularly the MSR and R/Spell (*pers. obs*.) As before, 3-P densities in the Flex+S would be expected to increase in coming years with ongoing spelling.

Table 2. Average density of 3-P tussocks for the different grazing treatments from 2010/11 onwards. Data averaged across all soil types.

	3-P density (tussocks/m^2)			
Treatment	**2010/11**	**2011/12**	**2012/13**	**2013/14**
HSR	1.8	2.0	2.3	2.3
MSR	6.0	8.9	7.8	8.4
R/Spell	5.5	11.4	6.9	7.7
Flex	3.7	5.0	5.1	5.4
Flex+Spell	3.8	5.4	5.3	5.7

4.3.5 Changes in *Carissa ovata* cover

Carissa ovata (currant bush) cover on the box soils, estimated by the percentage of 0.25 m^2 frequency quadrats with any *Carissa* cover present, increased by between 10 and 22 percentage units between 2000 (immediately after the 1999 fire) and 2011 (Figure 6). The most rapid increases occurred from 2005 onwards in conjunction with good dry season rainfall in a number of subsequent years. Overall, the increase in *Carissa* cover was lowest on the Ironbark (1-4 %) followed by the Brigalow (8-15 %) and highest on the box soils (10-22 %). For the box, the magnitude of the increase was greatest in the HSR (22 %) followed by the MSR
(15 %). However this data requires more detailed analysis before these differences can be deemed to be statistically significant. The 2011 fire caused a sharp, but temporary decline in *Carissa* cover across all soils with *Carissa* cover bouncing back thereafter (see Appendix 2 for more detail).

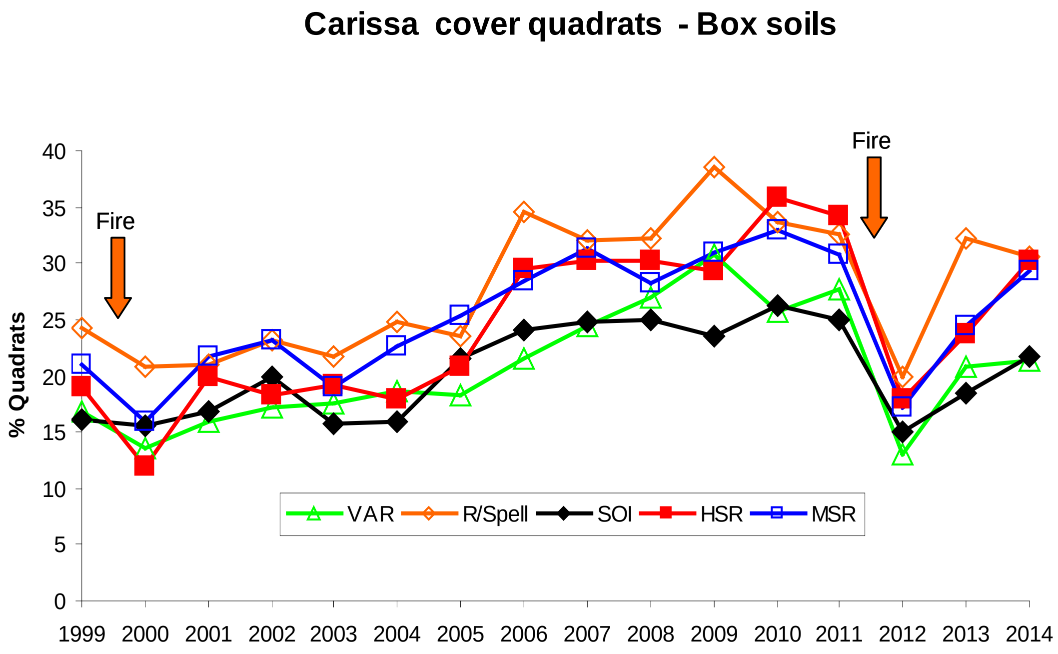


Figure 6. Change in % of 0.25 m^2 frequency quadrats with *Carissa ovata* cover on box soils between 1999 and 2014 under five grazing strategies at the Wambiana grazing trial.

4.3.6 Has carrying capacity declined with land condition?

To assess the effects of any change in pasture condition on carrying capacity, the potential carrying capacity (CC) of each treatment was estimated from end-of-wet season pasture TSDM averaged over several years. CC was calculated using an approximate daily dry matter requirement of 10 kg/AE (about 2% of body weight) and a 'safe' annual pasture utilisation rate (20%). To assess the change in CC, two periods were compared i.e. 1998 to 2003 (early years) and 2010 to 2014 (later years). Average annual rainfall was relatively high for both the early (822 mm) and late periods (777 mm).

Table 3: Estimated carrying capacity for the periods 1998-2003 and 2010-2014.

	Estimated carrying capacity (ha/AE)	
Treatment	1998-2003	2010-2014
VAR	5.8	(6.6)*
R/Spell	5.7	5.2
SOI	6.0	(7.4)*
HSR	5.8	11.4
MSR	4.8	5.2
Flex	-	6.9
Flex+Spell	-	7.1

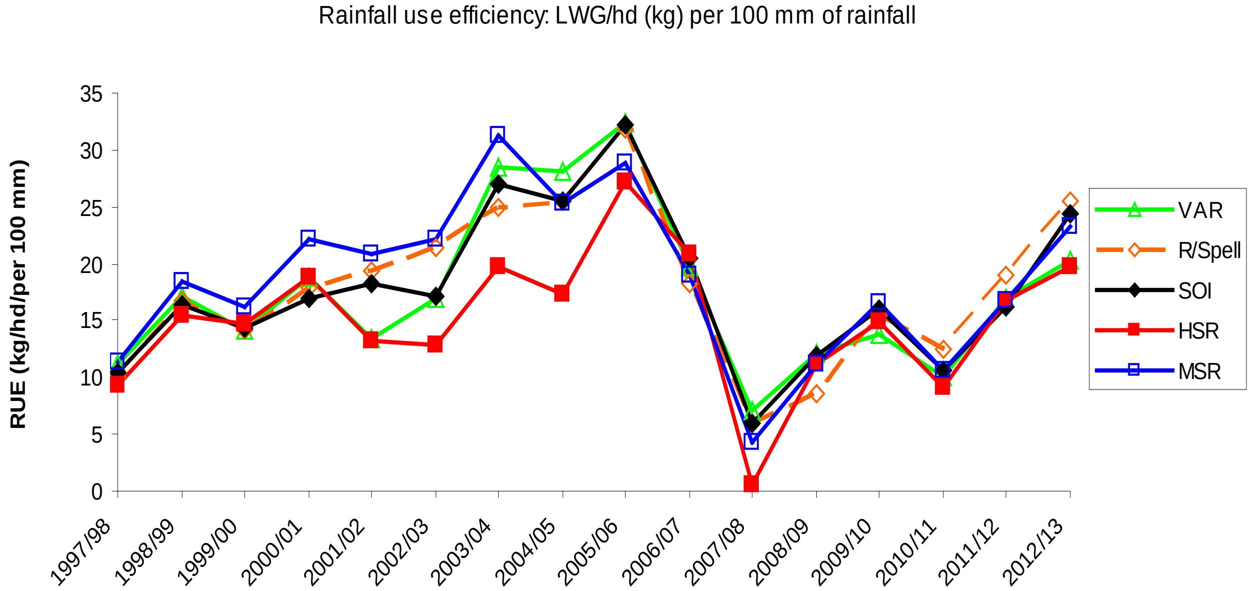
**Based on the original paddocks now in Flex and Flex+S.*

Comparison of the estimated CC for the early years of the trial (1998-2003) showed that there was little difference between treatments with similar CCs in the HSR and MSR (Table 3). This obviously reflects the fact that treatment effects on pasture yield and condition were only emerging at this early stage. In contrast, pronounced differences in CC for the late years were evident with estimated CC in the HSR (11 ha/AE) only half that in the MSR and R/Spell (both 5 ha/AE). Carrying capacities in the Flex and Flex+S were somewhat lower than in the MSR and R/Spell but still far higher than in the HSR. Potential CC in the HSR has thus almost halved as a direct result of a significant decline in land condition associated with a loss of 3-P species, reduced pasture vigour and an increase in less productive grass species in this treatment.

4.3.7 Has rainfall use efficiency changed with land condition?

Rainfall use efficiency (RUE) is a key index of landscape functionality. RUE typically declines as land condition deteriorates due to changes in species composition, lower rainfall infiltration rates and disruption of key biological and physical processes (Le Houerou 1984). RUE is usually expressed as pasture grown/unit of rainfall. Here, RUE was calculated in terms of the kg of beef produced/unit of rainfall by dividing the average annual live weight gain (LWG) per head or per ha for each treatment by the total rainfall for that year.

RUE indexed as LWG/hd/100 mm of rainfall (RUE_{hd}) varied markedly over time with rainfall, as might be expected: in general, treatment differences were most marked in dry years with RUE_{hd} being highest in lighter stocked strategies (Figure 7a). However, treatment differences were less marked or even absent in wetter years. In contrast, RUE indexed as LWG/ha (RUE_{ha}) tended to be highest in the heaviest stocked treatments; this is logical given their generally higher LWG/ha (Figure 7b).



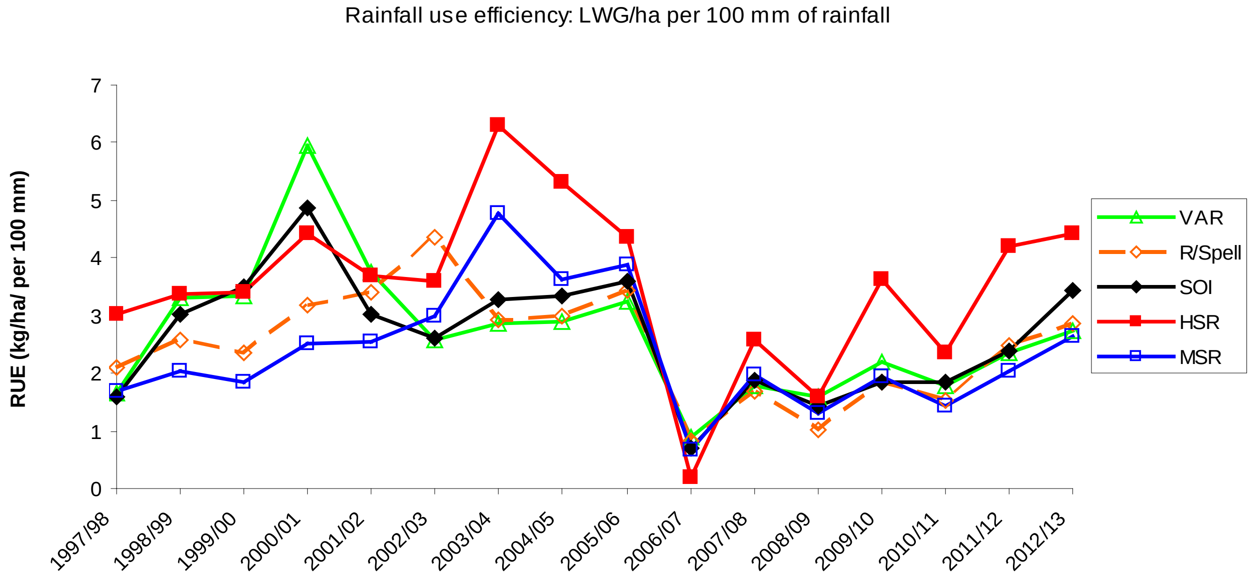


Figure 7a: Change in rainfall use efficiency (RUE) per hd (top) and per ha (bottom) in different treatments from 1998-2014.

The key issue is whether RUE has declined over time, particularly in the HSR where land condition has obviously deteriorated substantially. However, the present data suggest that despite 17 years of heavy grazing, neither RUE_{ha} nor RUE_{hd} have declined in the HSR (Figure 7). This result is significant and contradicts a tenet of rangeland management and a key extension message that the inherent ability of landscapes to produce beef or other secondary products declines with reduced land condition. Although surprising, this may be due to a number of reasons. First, the recent sequence of seven very good to just below average seasons may have buffered any impact of reduced land condition on beef production and hence RUE i.e. under good conditions when moisture is not limiting, efficiency of rainfall use may be of little significance. Second, the rapid spread of *B. pertusa* in the HSR has at least partially filled the void in forage production left by the loss of 3-P grasses. Moreover, given the relatively well distributed rainfall in most of these seasons, the short *B. pertusa* lawns would have provided relatively high quality forage compared to the weak perennials, annuals and forbs that would otherwise probably have dominated under heavy grazing in the HSR.

The real test of the impact of reduced land condition on RUE will however only occur when another sequence of dry years occurs. Until then, the present data do not support the key tenet that secondary production inevitably declines in concert with declining land condition.

4.4 Animal performance

4.4.1 Production per animal

In 2011/12 the cattle spent only four months (February to May) on the trial, having spent the previous eight months on agistment at the Spyglass Research Facility due to the prescribed burn in November 2011. There is thus no dry season (DS) data for this year. Nevertheless, given that all the LWG for 2011/12 occurred in the time that they were on the trial site, the total LWGs for this year are presented. Treatment differences in total LWG in 2011/12 should obviously however be interpreted with caution.

Table 4: Individual live weight gain (LWG) for the dry season (DS) and total LWG for the year for different treatments from 2010/11 onwards.

	Dry season LWG (kg)				Total LWG (kg)			
Treatment	2010/11	2011/12	2012/13	2013/14	2010/11	2011/12	2012/13	2013/14
HSR	48	N/A	9	-44 *a*	111	125 *bc*	117	91 *a*
MSR	59	N/A	28	-6 *b*	125	126 *bc*	137	144 *b*
R/Spell	72	N/A	36	3 *b*	148	131 *b*	151	162 *c*
Flex	64	N/A	30	-15 *b*	124	142 *a*	128	142 *b*
Flex+Spell	59[1]	N/A	29	-1 *b*	132[1]	117 *c*	136	137 *b*
P-value	*0.531*	-	*0.111*	***0.027***	*0.124*	*0.014*	*0.489*	***0.001***

[1] *Flex+S not fully in operational in 2010/11*; N/A= *Animals on agistment*; *Within years, means followed by the same letter are not significantly different (P<0.05).*

There were marked differences between treatments in all years with dry season LWG and total LWG generally highest in the R/Spell, followed by the MSR, Flex and Flex+S treatments (Table 4). Individual LWG/hd was lowest in the HSR in most years (excluding 2011/12) but treatment differences were only significant in 2013/14 *(P<0.001).* The lack of significance 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. Nevertheless, these results are consistent with data from previous years and add more weight to the finding that individual animal performance is better in lighter stocked strategies.

The consistently higher LWG in the R/Spell relative to the MSR in the last four years (Table 4) is interesting and a reversal of previous trends when LWGs were generally higher in the MSR (O'Reagain & Bushell 2011). This change is noteworthy because although both treatments are stocked at the same rate, wet season spelling in the R/Spell 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/Spell thus suggest that spelling has improved pasture condition in the R/Spell, possibly buffering the effects of these increased wet season stocking rates on animal production. If this trend continues, it will provide some of the first quantitative data showing the positive effects of wet season spelling on animal production and profitability.

4.4.2 Carcass characteristics

In all years carcass mass, price/kg and hence total carcass price were highest (or equal highest: 2012/13) in the R/Spell, with carcass values generally second highest in the MSR (Figure 8). In contrast, carcass price and price/kg were lowest in the HSR in most years. Interestingly, this included 2011/12 when steers were only on the trial for four months. Overall, both price/kg and carcass price in the Flex and Flex+S were intermediate between the HSR and R/Spell. These results provide further confirmation of previous findings at the trial that individual animal production and hence carcass grades and values are highest under lighter stocking rates.

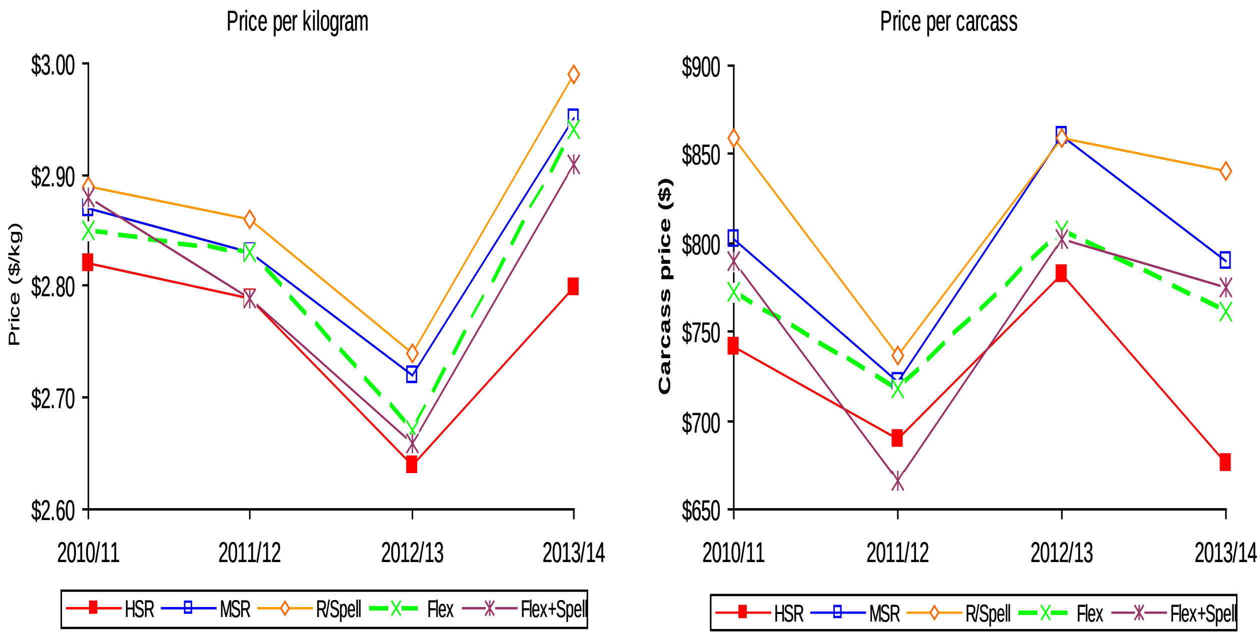


Figure 8. Meatworks price per kg (left) and total carcass price (right) between 2010/11 and 2013/14. NB: Animals were only on the trial for four months in 2011/12.

The poor animal performance in the Flex+S in 2011/12 is unexpected given that the overall stocking rates in this treatment were lighter than in the HSR. However, the poor LWG and low carcass price in the Flex+S possibly reflects the relatively high *effective* stocking rates in this treatment with a third of the paddock area spelled in this wet season. Although wet season stocking rates were also high in the R/Spell, this treatment is in better condition than the Flex+S due to the R/Spell's long history of wet season spelling.

4.4.3 Production per unit area

As in all previous years, annual LWG/ha was by far the highest in the HSR reflecting the high stocking rate in this treatment (Figure 9). The slightly heavier stocking rates run in the Flex and Flex+S strategies compared to the MSR did give higher LWG/ha in most years, but this appeared to be off-set by reduced LWG/hd in some years in the Flex treatment. It is noteworthy that total LWG/ha was consistently higher in the R/Spell than in the MSR despite having the same stocking rate. This obviously reflects the superior LWG/hd in the R/Spell treatment and again, suggests an emerging benefit of wet season spelling on animal production.

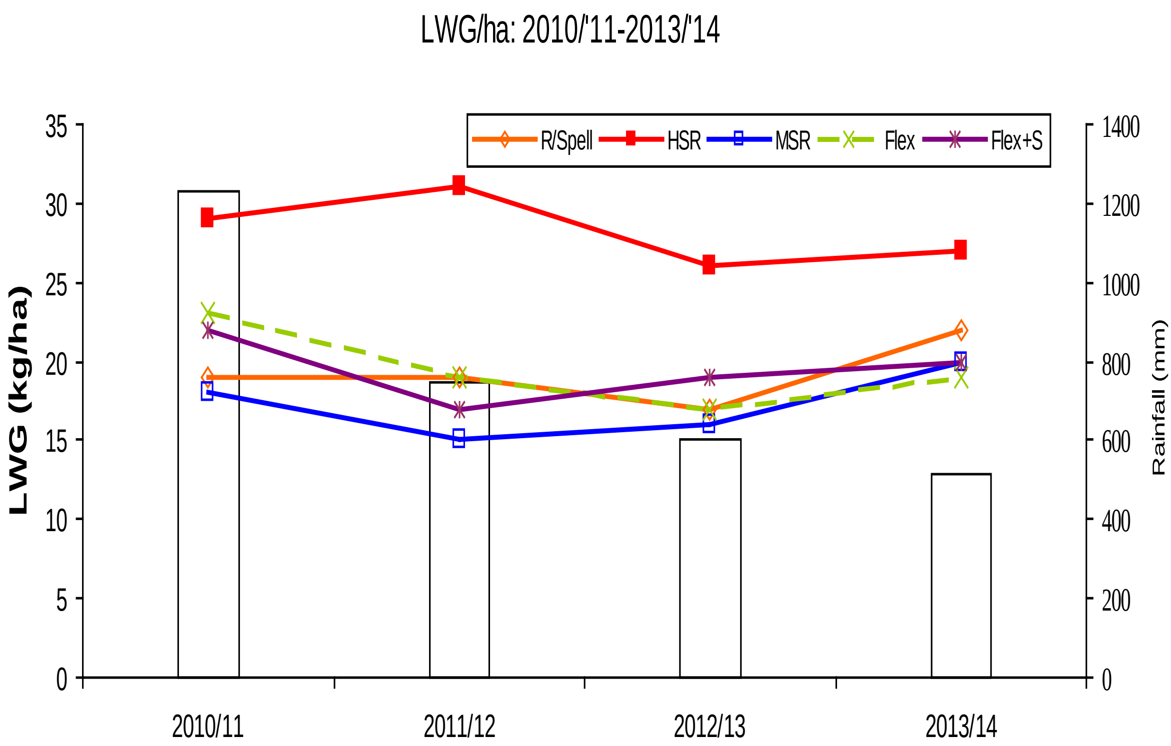


Figure 9. Total liveweight gain (LWG) per ha and rainfall between 2010/11 and 2013/14. NB: Animals were only on the trial for four months in 2011/12.

Despite the large differences in LWG/ha between the HSR and the other strategies, treatment differences were only significant in two of the four years (Table 5). However, given the general consistency of this result over nearly all years of the trial, their significance for management are obvious i.e. heavy stocking rates maximise total production per unit area, at least in the moderate term (17 years). Whether this continues in the longer term and with another run of dry years is one of the major reasons the trial needs to be continued.

Table 5: Total live weight gain per ha (LWG/ha) for different treatments from 2010/11 onwards.

Treatment	2010/11	2011/12	2012/13	2013/14
HSR	29 *b*	31 *c*	26	27
MSR	18 *a*	15 *a*	15	20
R/Spell	19 *a*	19 *b*	17	22
Flex	23 *a*	19 *b*	17	19
Flex+Spell	22 *a*	17 *ab*	19	20
P-value	***0.024***	***<0.001***	*0.167*	*0.413*

Within years, means followed by the same letter are not significantly different (P<0.05).

4.5 Economic performance of different strategies

4.5.1 Gross margins

Annual gross margins were calculated based on the value of beef produced (total mass by price/kg) less total costs (interest on livestock capital @ 7.5% plus supplementation and vaccination costs). As in previous years a price differential of $1.30, $1.40 or $1.50 was used based on meatworks grades (2004-2014) or body condition (1998-2003).

Gross margins varied between years but were lowest in the Flex and HSR in 2012/13. In 2013/14, gross margins in the HSR were negative (-$594/100ha) and by far the lowest of all treatments (Figure 10). This outcome is a direct reflection of the lower individual LWGs in the HSR (Table 4) and the subsequent penalties incurred at the meatworks due to reduced body condition (Figure 8).

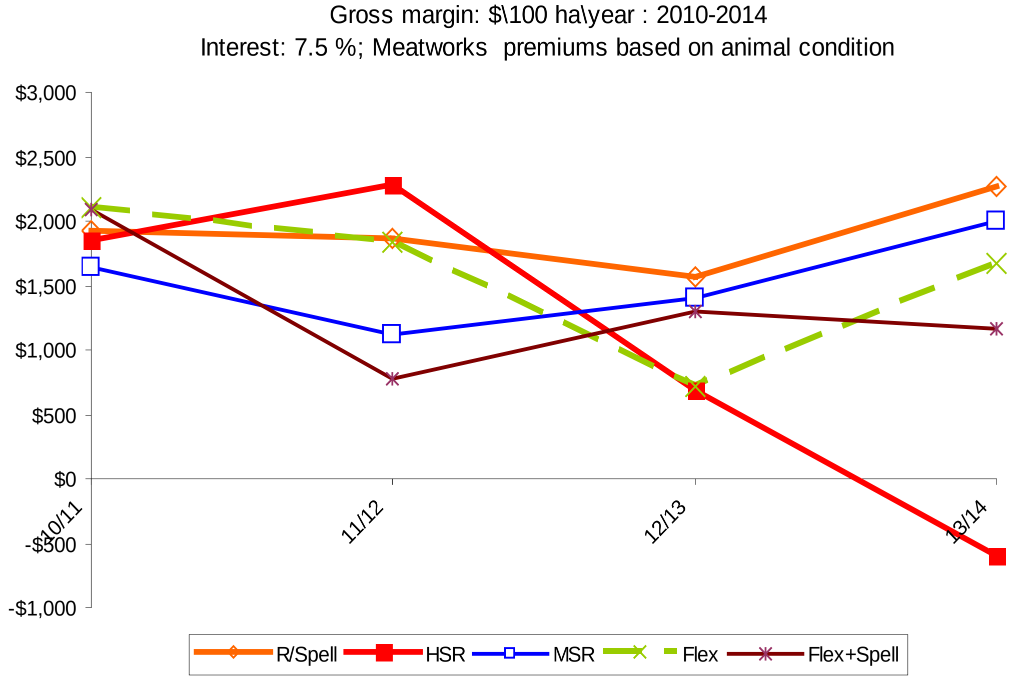


Figure 10. Gross margins between 2010/11 and 2013/14. NB: Animals were only on the trial for 4 months in 2011/12.

Examination of accumulated gross margins (AGM) over the 17 years of the trial show that despite the last seven relatively favourable seasons, AGM in the HSR in 2013/14 is still some $10000/100 ha lower than in the other strategies (Figure 11). This outcome is however, strongly dependent on a market where prices are related to body condition. Where little, if any, premium is paid for body condition e.g. the live export market, the HSR strategy would be the most profitable, at least in a steer-only scenario.

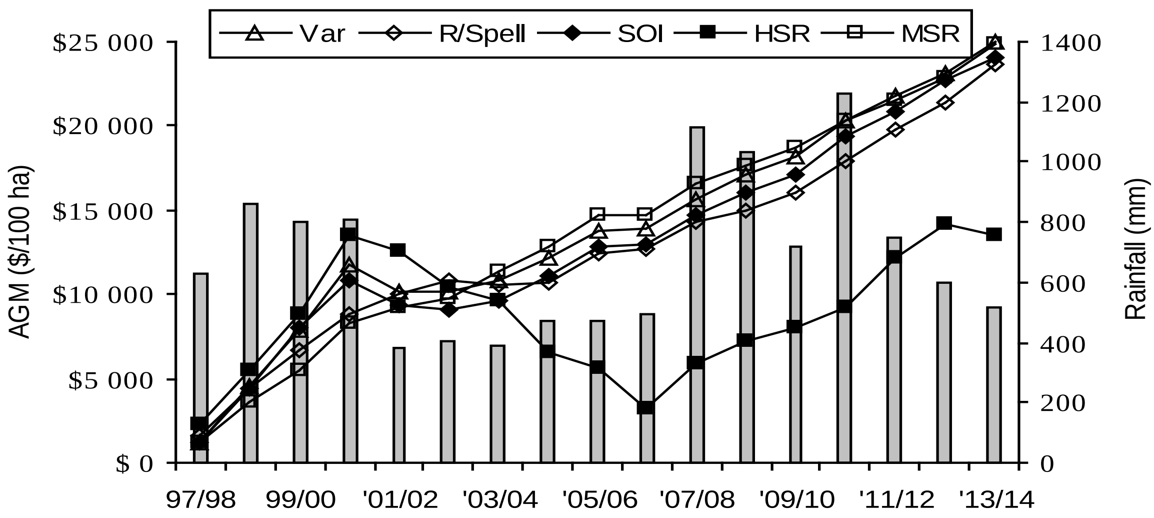


Figure 11. Accumulated gross margin (AGM) for five grazing strategies at the Wambiana grazing trial from 1997/98 to 2013/14. Interest at 7.5% and a price differential of $1.30, $1.40 or $1.50 used based on condition score. NB: For continuity, VAR and SOI treatment designations used.

4.6 Discussion

All strategies were far superior to the HSR in terms of their effects on pasture condition, individual animal production and profitability. However, the present results show no clear advantage in applying a flexible stocking strategy with or without spelling, versus simply stocking at long term carrying capacity as was done in the MSR and R/Spell. In theory, a flexible strategy should be more profitable than constant stocking as closer tracking of stocking rates with forage supply should avoid the losses of dry years but also take advantage of the extra forage produced in wet years. In Phase 1 (1998-2010) there was evidence that the former occurred in drier years with animal production higher in the VAR and SOI that were stocked more lightly than the MSR. However, while attempting to take advantage of the early good years with very high stocking rates in the VAR and Flex was initially successful, the sudden change to dry years post 2001 graphically demonstrated the risks associated with unconstrained, 'variable' stocking.

Flexible stocking strategies should also presumably result in similar or better land condition than constant stocking at LTCC as lower stocking rates in drought years should avoid overgrazing when pastures are particularly sensitive to overuse. Conversely, flexible strategies should be able to run relatively high stocking rates in wetter years without causing pasture degradation. Again, earlier experience with the VAR and SOI strategies partly supported this argument but also highlighted the long lasting damage to pasture condition that can occur if stocking rates are excessive and/or not promptly reduced with the approach of drier years.

The lack of a clear advantage to the new flexible strategies in Phase 2 is not surprising for a number of reasons. First, the treatments have only been running for a relatively short period with implementation delayed due to wet conditions and the controlled burn in 2011. Both flexible treatments were only fully implemented for two years (2012/13 and 2013/14) and any real impact on animal production or pasture condition would be unlikely.

Second, the carryover effects of previous management in these paddocks will persist for some time. In particular, the adverse effects of the very heavy stocking in the VAR and SOI strategies leading into the millennium (2002-2006) drought are still obvious (Table 2) in these 'new' treatments. Third, the average to well above average rainfall experienced over the last seven years, including the wettest La Nina year in 50 years (2011), undoubtedly affected treatment outcomes. In particular, these conditions undoubtedly allowed the continuation of heavy stocking rates in the HSR without any major impact on total LWG/ha or the need for drought feeding. Any adverse effects of heavy stocking on pasture condition will also have been at least partially ameliorated, in part by the rapid spread of *B. pertusa*.

Given these good seasonal conditions, it is also noteworthy that the response to spelling in the Flex+S strategy has been relatively subdued: although ground cover and pasture TSDM responded well to spelling in some areas (*pers. obs*.), the overall response to spelling was very patchy and varied strongly with soil type and pasture condition. However, given the slow response to spelling observed both in the R/Spell in Phase 1 and the MLA Spelling Strategies project (B.NBP.0555) on the Wambiana site (P. Jones *pers. comm*.), the current results are not surprising. This supports the conclusion previously noted in this project (O'Reagain & Bushell 2011) and elsewhere (McIvor 2001) that the response to wet season spelling is generally slow and often erratic. Despite this, spelling does nevertheless appear to be essential in any long term strategy for maintaining and improving pasture condition.

4.7 Unanswered questions

1. Can more sophisticated, 'optimal' management strategies i.e. flexible stocking+/-spelling, increase productivity and profitability without adversely impacting pasture condition? Are they any better than simpler systems such as constant moderate stocking at LTCC?
2. Results to date suggest that continuous stocking at long term carrying capacity is sustainable. However, pasture condition and productivity may ultimately decline due to patch grazing, a lack of spelling and overstocking in drought years. The present monitoring methodology (permanent monitoring sites; long linear transects) may possibly be missing very small, localised patches or areas of repeated overgrazing and hence potential degradation, that may be occurring. Detailed spatial analyses of satellite images may hopefully address this issue in the near future.
3. 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 recent 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 with an inevitable return to low rainfall years?
4. Once *B. pertusa* is a significant pasture component, are the 'better' 3-P species able to return with good management? If not, what management guidelines are necessary to maintain *B. pertusa* dominated pastures and prevent further declines in land condition?

5 Simulation modelling of different management strategies

5.1 Validating and improving the reliability of bioeconomic modelling

5.1.1 Procedure

Trial data collected at the plot, land-type and paddock level were used to calibrate the GRASP model for the site, which was then linked to the Enterprise economic model as shown in the analytical schema in Figure 12 (see Scanlan *et al.* 2013 for more detail). First, GRASP was parameterised for the Box land-type using detailed data collected over seven growing seasons (1998 - 2005) on replicated small (30 x 30 m) plots within the box land type using the SWYFTSTYND methodology (Day and Philp 1997). This was done to provide suitable parameters for running GRASP for further simulations as described by Scanlan *et al.* (2008). GRASP was then run at the paddock level: a simplifying assumption was that the entire paddock consisted of the box land type; in reality this land-type made up only 55 % of trial paddocks. GRASP outputs were then assessed against BOTANAL paddock data (1998-2011) on pasture total standing dry matter (TSDM) and species composition. The observed data for 3P (palatable, productive, perennial) grasses were used to compare with the modelled percentage pasture composition of these grasses

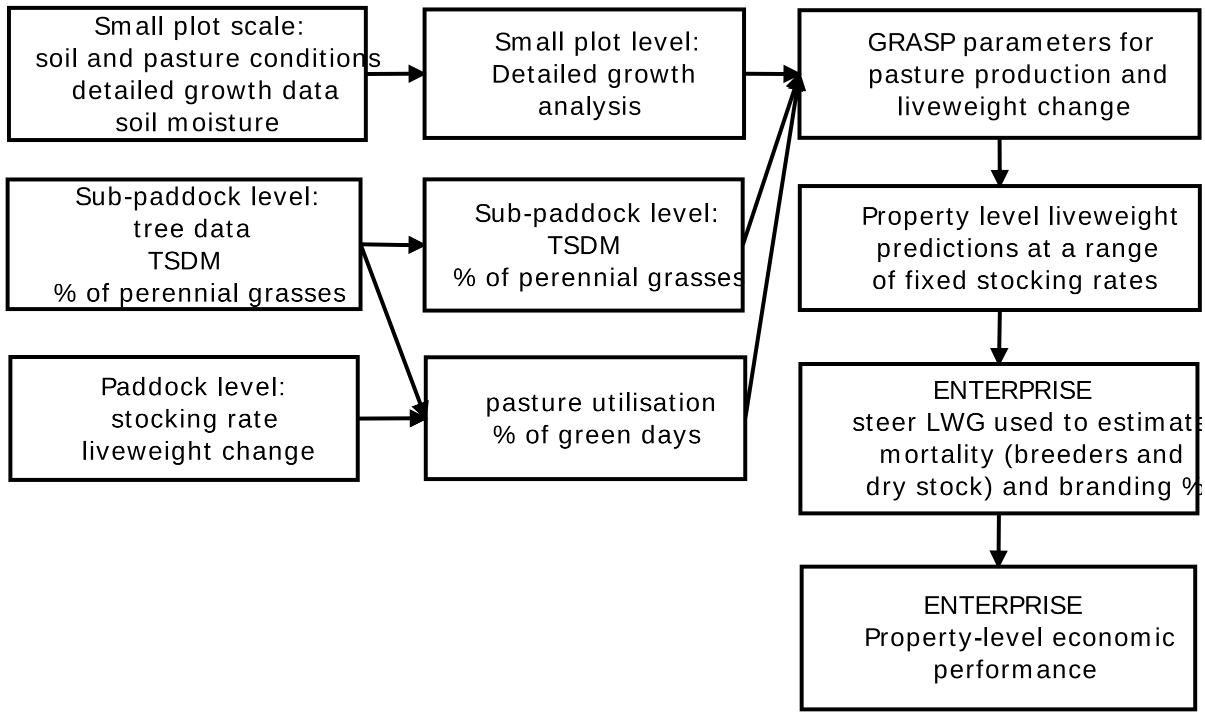


Figure 12. Key steps in the modelling process in evaluating the effect of stocking rate on property-level biophysical and economic performance.

Simulations were then run for the HSR and MSR trial paddocks to estimate annual pasture utilisation rates and the percentage of green days in the year (days when the growth index exceeded 0.05) using paddock stocking rates and rainfall records. Pasture utilisation rates and the percentage of green days were then used as inputs to estimate annual LWG of steers. Liveweight data for 2004-5 and 2006-7 were excluded from the analysis as the HSR paddocks had additional energy supplementation (molasses and urea) or were destocked (2004) during parts of these years.

5.1.2 Results

General model performance

Parameterisation of GRASP using the SWIFTSYND data collected at the small plot level trial was very good with 94% of pasture TSDM variation at the this level explained (Scanlan *et al.* 2013). When these parameters were then applied to the whole paddock the model explained 82% of observed variation in paddock TSDM (Figure 13). This is comparable to the general fit for GRASP against observations in other studies. In addition, the model gave a reasonable fit against the observed proportion of 3P grasses for the whole paddock. While the model explained only 53% of the variation in the observed proportion of 3P grasses, this is reasonable and was considered sufficient to use in further modelling. The perennial grass model in GRASP is quite simple and the whole issue of representing perennial grass composition in native pastures is extremely difficult. Few other models make any attempt to model perennial grass composition and none have been successfully used in northern Australia (Scanlan *et al.* 2013).

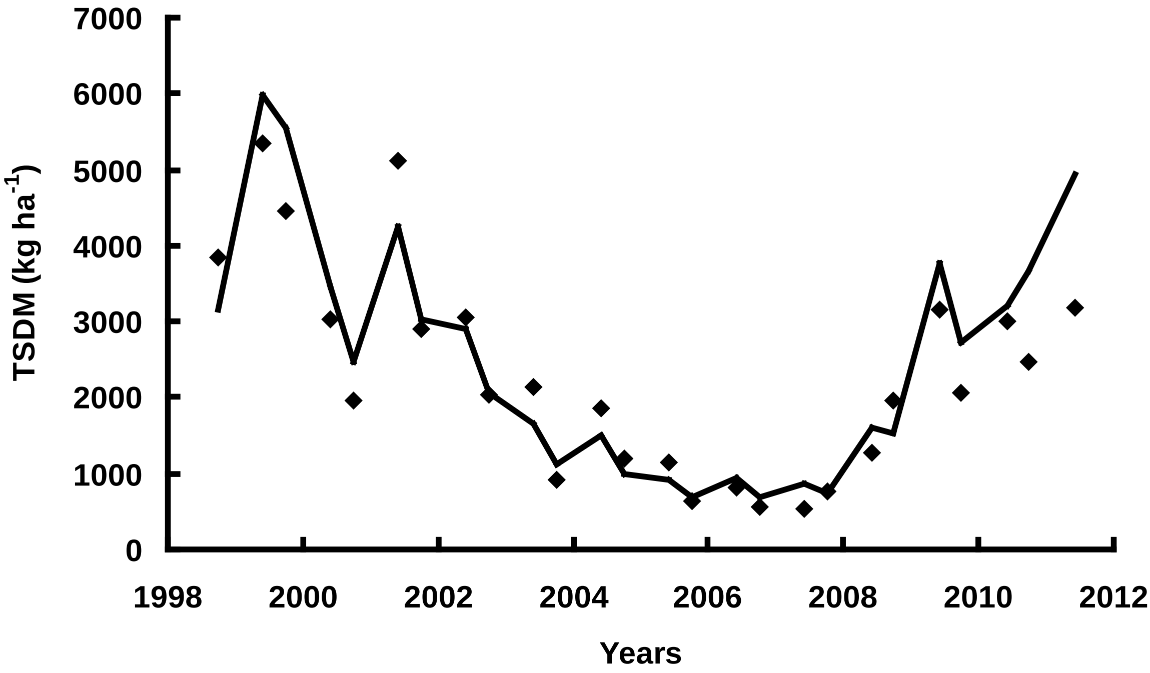


Figure 13. Predicted (——) and observed (◆) pasture total standing dry matter (TSDM) for one of the two MSR paddocks from 1998 to 2012.

Predicted versus observed LWGs are shown in Figure 14. When trial data for 2004/5 and 2006/7 are excluded (Scanlan *et al.* 2013), the match between observed and modelled LW change was reasonable (64%). The two years for which data were excluded were years when pasture TSDM was very low (<600 kg ha^{-1}). In these years the actual LW changes for the calculated utilisation and green days % were very different from other years with similar values of these estimates. The reason for this is unknown but could be related to impacts of other land types within the paddocks on the actual utilisation and green days %. Nevertheless, given the coarseness of the LW change model, this was an acceptable result and was sufficient to progress to the whole-property modelling.

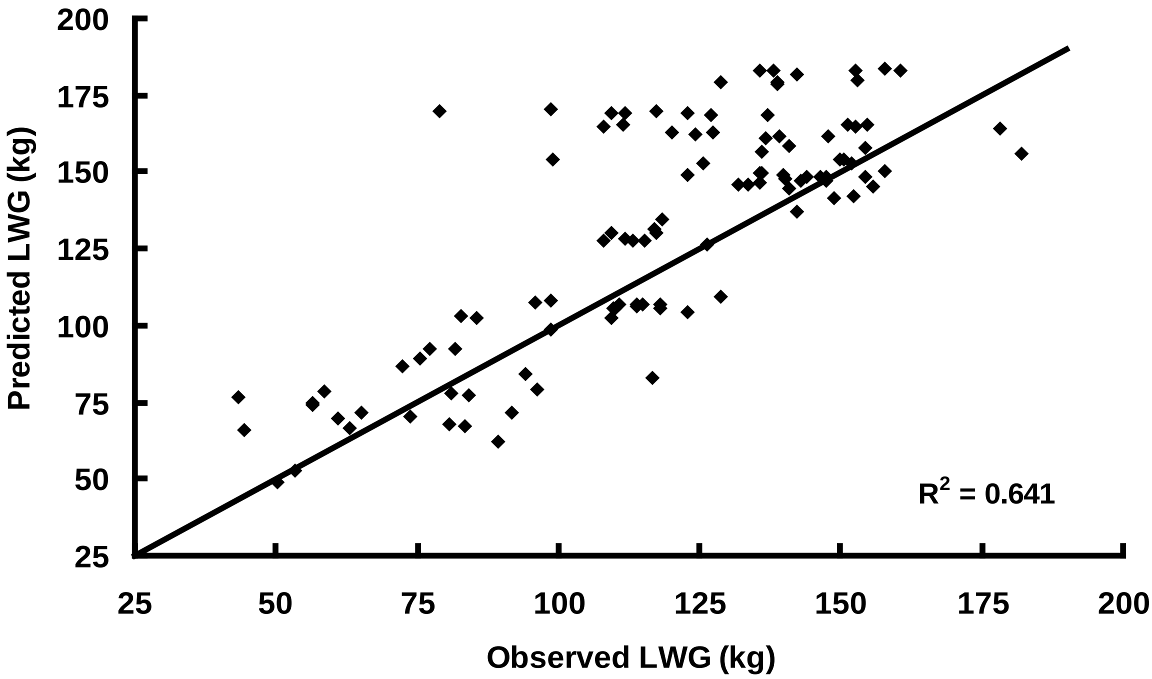


Figure 14. Predicted (——) and observed (◆) individual annual liveweight gain for all MSR and HSR paddocks for all years except 2004/05 and 2006/07.

5.2 Property level modelling

5.2.1 Procedure

The ENTERPRISE model was used to examine property-level economic performance of a breeding-finishing business (Scanlan *et al.* 2013). The property was 23 500 ha composed of the box land type with $750 000 debt and $168 500 annual overhead costs. Steers were sold at 590 kg liveweight or at three years of age and excess females were also sold. Drought feeding was initiated if projected annual LWG of steers was less than 40 kg. GRASP simulations were then run to generate the percentage (by weight) of perennial grasses in the pasture and annual LWGs of steers for 30 year (June-May) climate windows for three stocking rate strategies with a very wide range of initial stocking rates (from 3 AE 100 ha^{-1} to 35 AE 100 ha^{-1}). Strategies were:

- *Fixed* stocking rate (3 - 30 AE 100 ha^{-1})
- *Low flexibility* - stocking rates varied by up to +/- 15% annually in response to end of wet season pasture TSDM.
- *Moderate flexibility* -stocking rates varied by up to +/- 40% annually in response to end of wet season pasture TSDM.

These GRASP outputs were then fed into ENTERPRISE to simulate the property-level economic impacts of these stocking strategies (Scanlan *et al.* 2013). Modelled paddocks consisted entirely of the box (grey/brown sodosol) land-type, the dominant trial soil type. To account for the effects of climate variability models were run over six 30-year climate sequences for Charters Towers since 1956 (Figure 15 and Table 9).

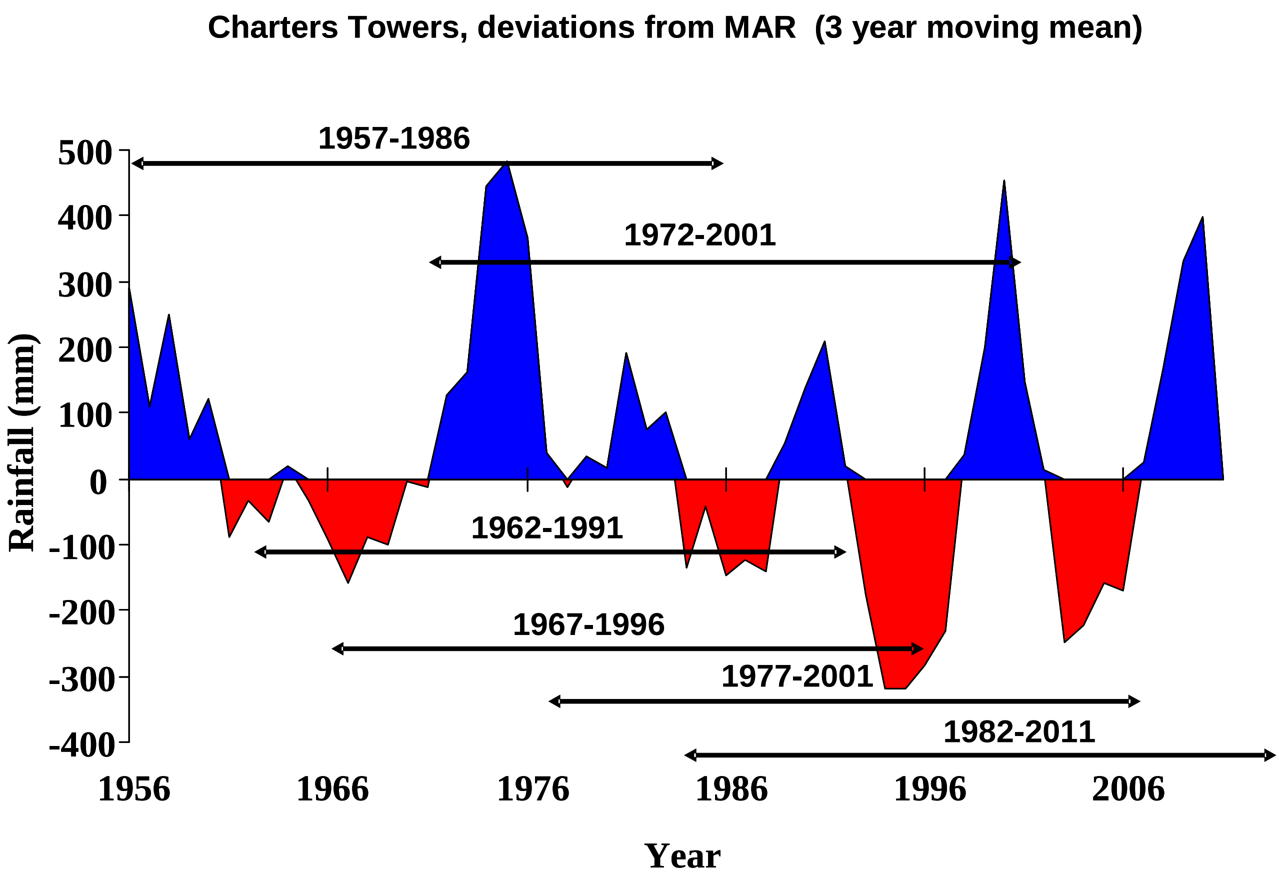


Figure 15. Graphical representation of the sequence of rainfall years in the six climate windows used in the GRASP-Enterprise modelling. Data shows the three year moving mean of deviations from mean annual rainfall (MAR).

Data from the these six climate windows is summarised below (Table 6)

Table 6. Summary annual rainfall statistics for the six historical climate windows used in the GRASP-Enterprise simulations.

Variable	**Climate window**					
	1957-86	**1962-91**	**1967-96**	**1972-01**	**1977-01**	**1982-11**
Average (mm)	694	711	670	699	621	658
Highest (mm)	1633	1633	1633	1633	1287	1287
Lowest (mm)	344	344	263	263	263	263
Years <500 mm	6	4	8	8	12	12
Years <400 mm	4	4	8	8	9	9
Years >650 mm	15	17	15	15	12	13

5.2.2 Results

5.2.3 Effect of climate window on profitability

For the fixed stocking strategy the maximum average return on capital, labour and machinery (ROCLM) varied substantially with the climate window used (Figure 16). ROCLM thus varied from only $160 000/yr. (1982-2011) to more than $380 000/yr. (1957-1986). Interestingly, while average rainfall was similar for both windows (658 mm vs. 694 mm respectively) there were more than twice the number of years with rainfall <400 mm in 1982-2011 compared to the 1957-1986 window. The stocking rate at which the maximum return occurs also varied from 10.5 to 15 AE/100 ha depending upon the window (Figure 16).

5.2.4 Effect of stocking rate on economic performance

For both fixed and flexible stocking the ‘optimum’ stocking rate (SR) at which enterprise level ROCLM was maximised occurred within a band from 11-16 AEs/100 ha; this roughly corresponds with ‘light’ to ‘moderate’ (9 - 6.25 ha/AE) stocking for the box land-type. Stocking rates above and below this level resulted in reduced ROCLM. As noted above there was considerable variation between climate windows in terms of the SR where the maximum economic return occurred.

A major factor driving enterprise level economic performance at different stocking rates is the cost of supplementary feeding in years when cattle do not gain sufficient live weight, increasing mortality and decreasing reproductive rates. Simulations show that once a threshold stocking rate is crossed of about (~12 AE/100 ha), the percentage of years in which supplementary feeding is required increases sharply (Figure 17). Thus at a stocking rate of ~17 AE/100 ha, drought or emergency feeding is required in almost 40% of years. At such high levels of feeding, the simulated economic performance is driven by the assumptions made in the supplementary feeding component of the ENTERPRISE model. This model is not designed to deal with what is essentially a ‘drought-feeding’ regime, and hence provides only limited economic insights at such high stocking rates.

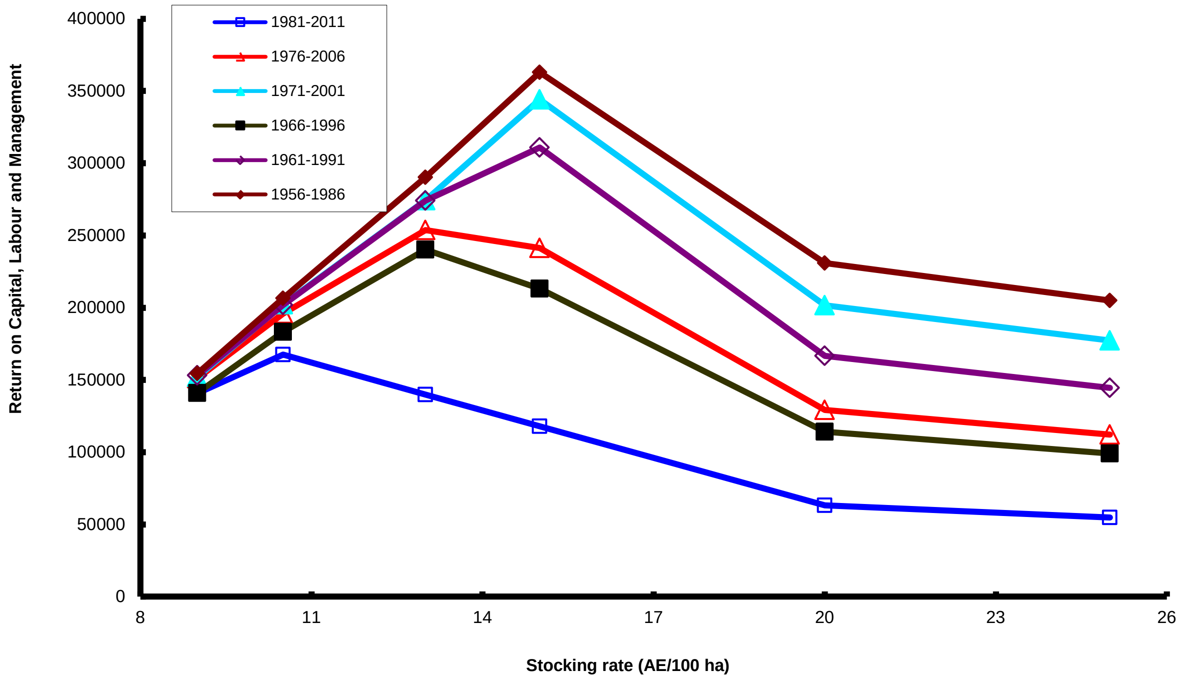


Figure 16. The return on investment (capital, labour and management) for a property composed of the box land type during six different 30-year climate windows for fixed stocking rates from 9 to 25 AE/100 ha.

The increase in the number of years in which drought or emergency feeding is required will obviously be paralleled by a decline in economic performance as stocking rates increase (Figure 17). Similar results occurred in the grazing trial with drought feeding dramatically increasing costs and hence reducing profitability in the HSR.

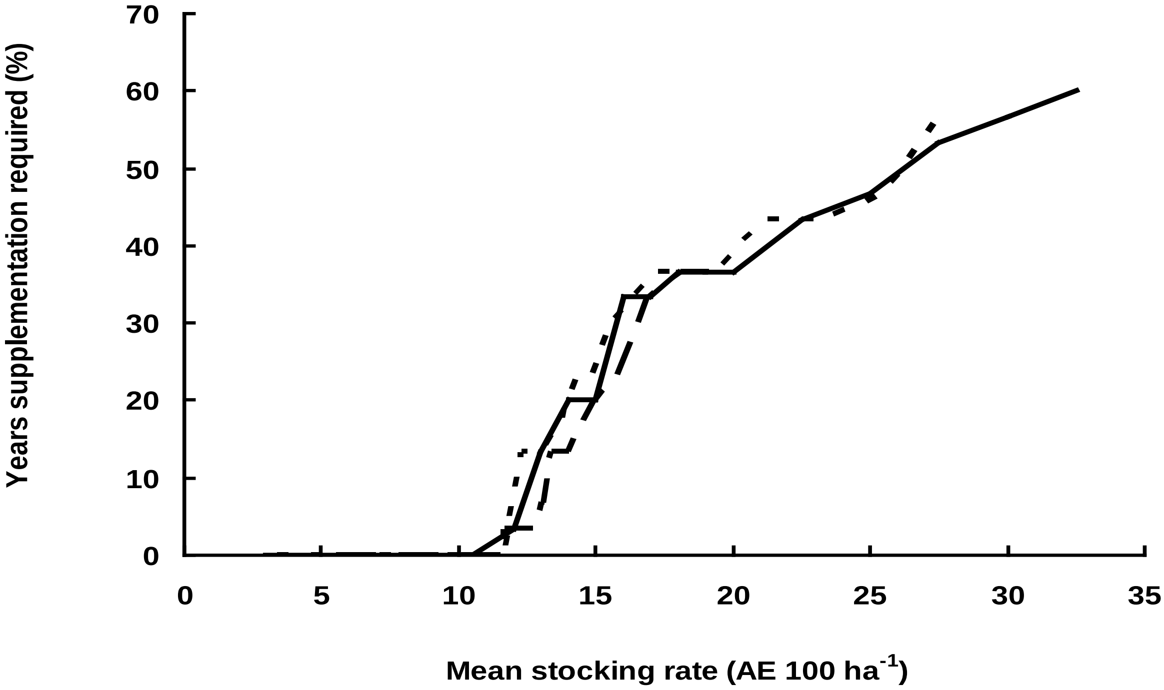


Figure 17. Percentage of years when drought/emergency feeding was required due to lack of feed available from simulation of a range of average stocking rates with fixed (solid line), moderate (dashed) and low flexibility (short dashed) stocking rate strategies from 1981-2011 for a property composed of the box land system.

5.2.5 Fixed vs. Flexible stocking

For all climate windows, the 'fixed' and 'low flexibility' strategies either outperformed (3 or 6 periods) or performed as well at the 'optimum' SR of about 11-16 AEs/100 ha rate, as the 'high flexibility' strategy (Figure 18). This indicates that there is no economic advantage or indeed an increased risk of an economic loss associated with highly flexible strategies i.e. the fixed stocking strategy is generally at least as good as the two flexible strategies.

There was also an apparent strategy by SR by climate window interaction in determining outcomes i.e. at high stocking rates, ROCLM appeared to decline faster in the 'low flexibility' than in the fixed stocking strategy. This decline also appeared to be sharper in some windows e.g. 1982-2011 than in others e.g. 1967-1996.

The maximum stocking rate that could be carried at which ROCLM was still positive also varied between climate windows. Thus, in the 1982-2011 window ROCLM became negative at a SR of 26 AEs/100 ha but in 1972-2001 remained positive up to SRs of 35 AEs/100 ha.

In the 'high flexibility' strategy, the response of ROCLM to SR appeared to double back above a certain SR in some climate windows e.g. 1967-1996 (Figure 18). This is an obvious model artefact with these higher SRs possibly causing a sudden shift in pasture condition and thus economic return.

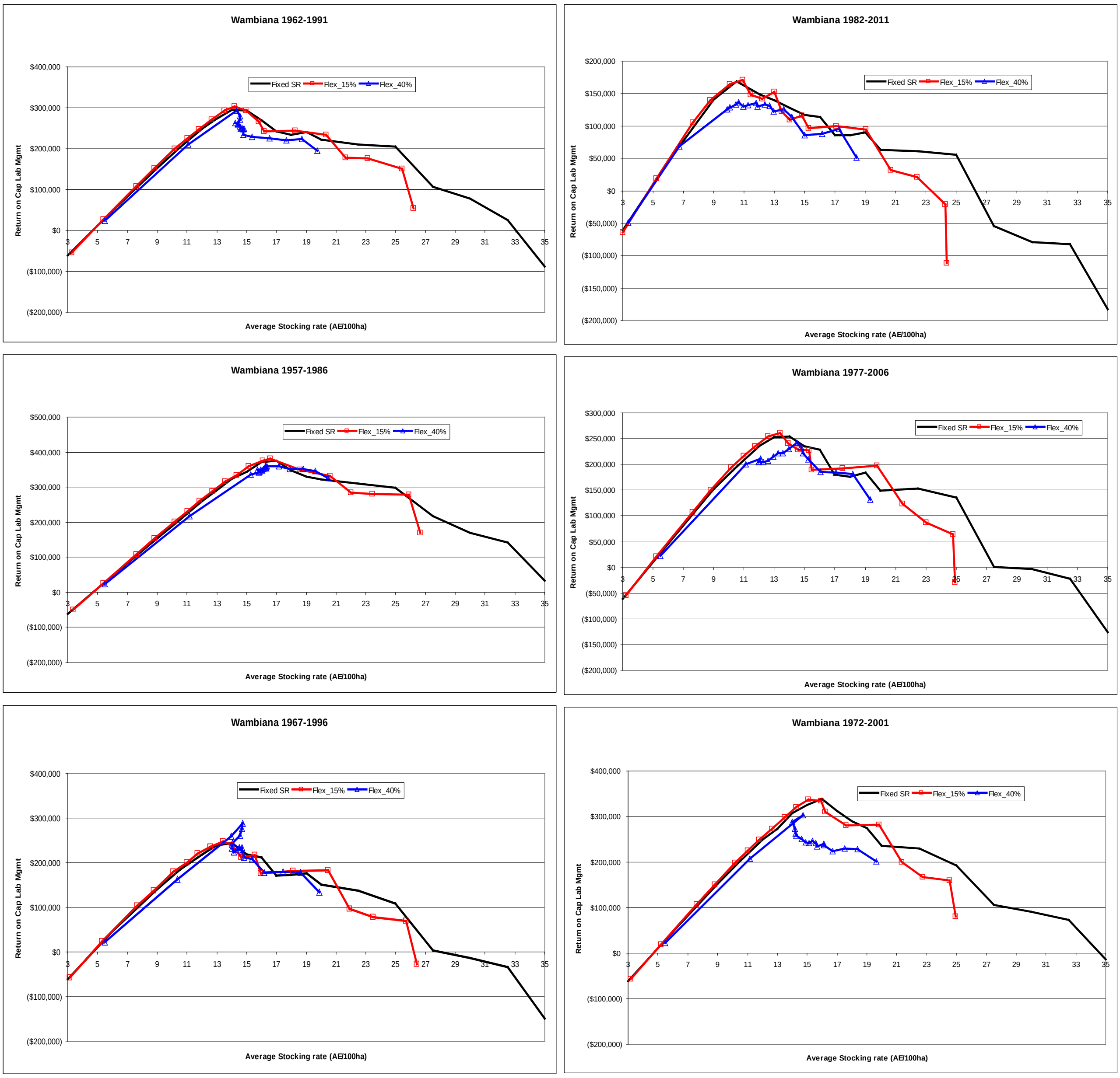


Figure 18. Average return on capital, labour and machinery (ROCLM) with increasing stocking rate for six climate windows under (a) fixed-, (b) low (15%) flexibility and (c) a high (40%) –flexibility stocking strategy.

Effect on pasture condition

For all three stocking strategies, good pasture condition (defined here as 3-P % > 70% pasture yield i.e. composition) could be maintained, provided SRs did not exceed threshold levels of about 8 to 15 AEs/100 ha (Figure 19). Increasing SRs above these levels resulted in a precipitous drop in condition with the 3-P% declining below 10 % and forming an insignificant proportion of the pasture at very high SRs of 13 to 21 AEs/100ha.

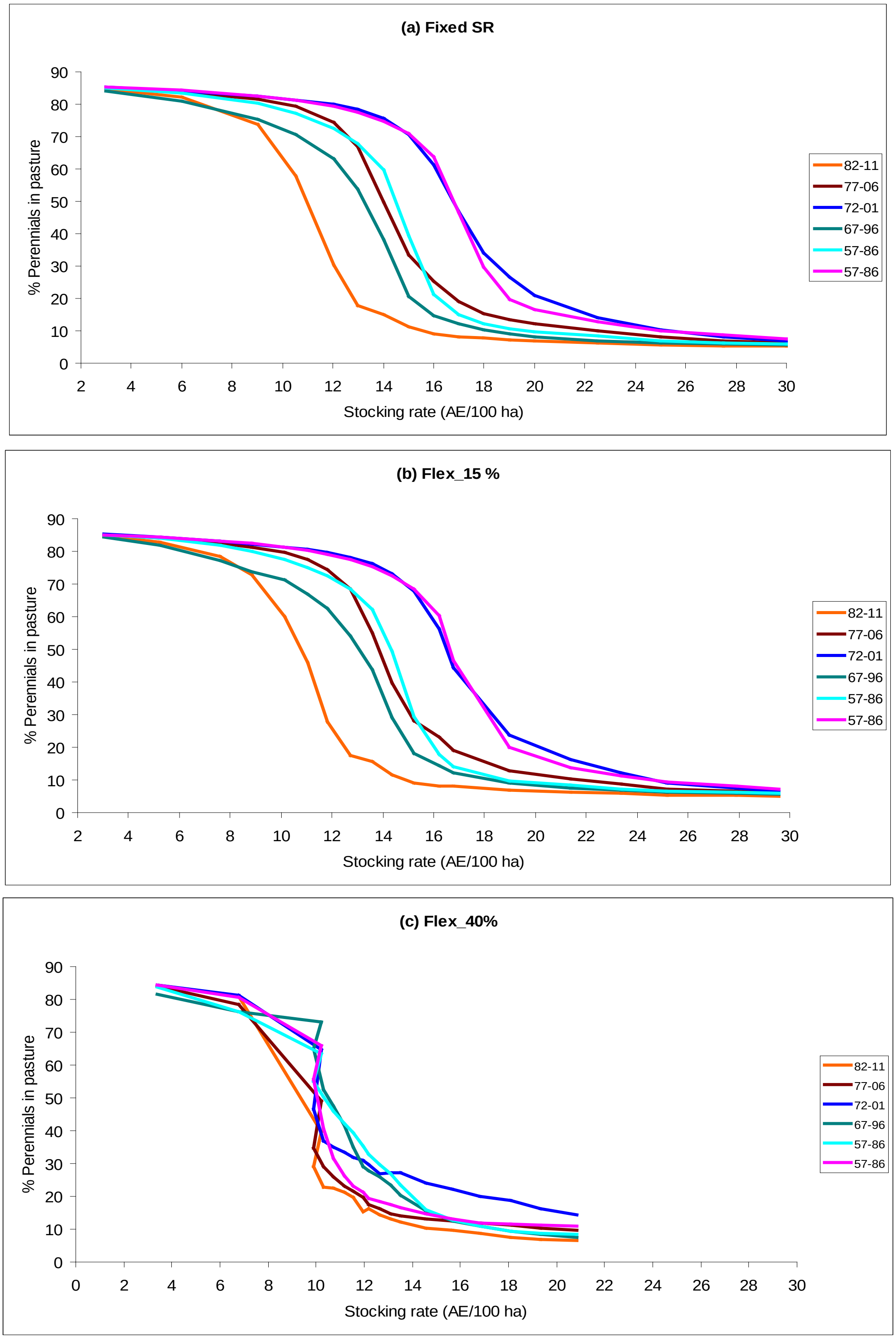


Figure 19. Change in the % of perennial grasses in the pasture with increasing stocking rate for six climate windows under (a) fixed-, (b) low (15%) flexibility- and (c) a high (40%) -flexibility stocking strategy.

The threshold SR at which pasture composition declined varied markedly with climate window emphasising the key role of rainfall in mediating management effects like SR (Figure 19). For example, in the 1982-2011 window, pasture condition declined sharply above stocking rates of 9 AEs/100 ha. In contrast, pasture condition was maintained in the wetter 1972-2001 and 1957-1986 windows at far heavier SRs of up to 15 AEs/100 ha. This is an important insight showing that the impact of stocking rate on pasture condition is dependent upon the climatic conditions encountered, giving further support for the recommendation that stocking rates need to be adjusted with seasonal conditions.

There was very little difference between fixed-stocking and the low flexibility strategy in terms of the response of pasture condition to SR and climate: one minor difference was that pasture condition in the 1982-2011 window declined at a slightly lower SR in the low flexibility than in the fixed stocking strategy (8 vs. 9 AEs/100 ha respectively).

There was however, a marked difference in response between the high-flexibility and the fixed and low-flexibility strategies. First, pasture condition was far more sensitive to SR under the high-flexibility strategy with a markedly lower threshold SR at which a decline in 3-P% occurred. Second, in the high flexibility strategy there was little if any difference between climate windows in terms of the response of 3-P species to SR, i.e. the range of SRs that initiated a precipitous decline in 3-P% was far narrower than either the fixed or low-flexibility strategies. Thus, in the high flexibility strategy, a SR of 15 AEs/100 ha resulted in 3-P% of ~20%. In contrast, in the low flexibility strategy depending upon the climate window, the same SR resulted in the 3-P% varying from between 10 and 70 %. This indicates that the *risk* of incurring an adverse change in pasture condition in the high flexibility strategy is far higher than in the fixed or low flexibility strategy and suggests no advantage to a highly flexible stocking strategy over simply applying a constant SR.

Lastly, in the high flexibility strategy the shape of the SR–3-P% response varied markedly depending upon the climate window used (Figure 19c). For example, while some curves declined relatively gradually as SR increased above threshold levels e.g. 1967-1996, other curves dropped almost vertically e.g. 1957-1986. This suggests a large amount of unpredictability in how pasture composition might change under different climate scenarios with a high flexibility strategy.

5.3 Discussion

For fixed stocking, there were major differences in outcomes between the six different 30-year climate windows with both the maximum return and the optimum stocking rate varying with the climate window considered. This highlights the overriding influence of climate, particularly the sequence of rainfall years and its interaction with stocking rate, on pasture and livestock production, and, therefore, economic performance. Given the ~ 50% difference between ‘optimum’ stocking rates observed here (Figure 16), there is an obvious need to consider strategies that allow stocking rate to changes in response to climate signals. These stocking rate changes need to be large enough to take advantage of good years without increasing the risk of pasture degradation if subsequent years are poor; similarly, decreases in animal numbers should not be so large that cash flow is so adversely impacted that herd dynamics and subsequent property viability are put at risk.

With breeders it is unrealistic to adjust animal numbers annually to consume a fixed proportion of available pasture growth as such dramatic changes cause unmanageable fluctuations in breeding herd structure and performance. Accordingly, some form of flexible stocking should be applied with restrained stocking rate changes as the seasons vary. The long term carrying capacity of a site would thus be used to set general stocking rate boundaries with fodder budgeting applied to adjust stocking rates with seasonal variations in forage supply.

In conclusion, further modelling approaches are needed to investigate the potential impact of some key factors on the results obtained, particularly the influence of mixed land types within paddocks on animal distribution, pasture composition, utilisation rates and animal performance.

5.4 Modelling – unanswered questions

How can paddocks with more than one soil type be realistically simulated in a manner that captures spatial grazing and degradation patterns and the interaction of these factors with animal production and profitability?

What effect does starting land condition i.e. A, B, C or D condition, affect the performance (profitability, pasture composition) of different grazing strategies? How does climate window affect these outcomes?

6 Sustainable management

Sustainable and profitable grazing management for a variable environment will thus involve all of the following elements:

1. Use of long term carrying capacity (based on 25 % utilisation of average pasture growth) as the general guidelines for setting sustainable stocking rates for different land-types;
2. *Flexible* stocking rates with numbers adjusted in a risk-averse manner in line with forage availability, seasonal conditions and if appropriate, climate forecasts;
3. Rotational wet season spelling, preferably for a full wet season.
4. The appropriate use of fire that takes into account time since last burning, the resilience of the land-type and climate forecasts for the approaching wet season.

7 Management recommendations

7.1 Managing stocking rate in a variable climate

7.1.1 Guidelines

1. Paddocks should be stocked around the long term carrying capacity (average of 20-25% utilisation of long term pasture production) of the constituent land-types. [*Stocking around LTCC ensures good individual animal production, reduces risk, maintains or improves pasture condition and is more profitable in the longer term (>5-10 years) than heavier utilisation rates].*
2. Stocking rates (SR) should be adjusted in a constrained, flexible manner as seasons vary *[If stocking rates are not adjusted downwards in droughts, stocking at LTCC could still lead to over utilisation, pasture degradation and reduced animal production. Conversely, understocking in very good years may result in foregone animal production and income]*
3. Changes in SR should be made in a risk averse manner i.e. rapid reductions e.g. 20-40% in SR with the approach of poor seasons but gradual increases in SR e.g. 10-15% in good seasons (depending obviously on the current stocking rate, relative to LTCC). In even the best seasons, upper bounds to stocking rates should be set based on LTCC to prevent overgrazing. *[Large increases in stocking rate are extremely risky*

and coupled with unexpectedly dry conditions can lead to significant economic loss and pasture degradation].

4. The primary SR adjustment point should be at the end of the wet season, with other secondary adjustment points in the late dry season and in the early wet season. Adjustments should be based on available pasture, expected time until the first growth and where appropriate, seasonal climate forecasts [*At the end of the wet season, animals are in prime condition and most marketable; certainty is also greatest regarding feed availability and the likelihood of rain (i.e. very low); early destocking also reduces the magnitude of any stocking rate reductions that may be required later in the season. In the late dry season animals are often in poorer condition while the high levels of uncertainty associated with the chance of rainfall (early storms are notoriously patchy and unpredictable) make decision making more difficult]*.
5. While stocking rates may be increased or decreased at the end of wet season adjustment point, the secondary adjustment points at the end of the dry and early wet are essentially correction points to ensure earlier stocking rate adjustments were appropriate. Thus, stocking rates would either only be left unchanged or reduced at these points. [*If understocked, most excess feed will still be available (albeit at a lower quality) at the end of the wet and SRs can then be adjusted accordingly. Underutilising pastures in good wet seasons is also likely to improve pasture condition*].
6. Importantly, all stocking rate estimates are imprecise and serve only as a guide. Irrespective of their derivation, all estimates of stocking rate should be used with caution and applied in an adaptive manner i.e. close monitoring of pastures and animals are important in case further adjustments are required.

7.1.2 Rules of thumb

1. Stocking rates should be adjusted according to a forage budget e.g. *Stocktake*, based on (a) available pasture, (b) expected time until the first significant rains i.e. 50 mm in two days (from *Rainman*) plus a buffer of two months in the event of a late season and (c) expected wet season pasture growth.
2. Expected growth for the approaching wet season can be estimated from GRASP based predictions of pasture growth expected in 70% of years based on land-type, land condition and the SOI. Expected wet season stocking rates can then be calculated using a ‘safe’ pasture utilisation rate.
3. Whatever the expected growth the following season, the SR chosen at the end of the wet season must allow for sufficient pasture DM for 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 e.g. pregnant cows, but should be animals that can be marketed relatively easily e.g. potential live export cattle, in the event of a poor wet season the subsequent year. Obviously, the most appropriate stock will vary enormously depending upon specific conditions.

7.2 Implementing wet season spelling

7.2.1 Guidelines

1. Wet season spelling is secondary to stocking rate in terms of its effects on land condition but nevertheless very important (probably critical) to maintain or improve pasture condition.
2. Spelling does not appear to buffer the effects of higher stocking rates on pasture condition, hence stocking rates should still be maintained around LTCC.
3. When paddocks are spelled, wet season stocking rates on remaining paddocks obviously increase. Grazed (non-spelled) paddocks must hence be monitored closely to prevent overgrazing, particularly if the rains are erratic and pasture growth slow. If

this does not occur, this heavier grazing pressure may outweigh the benefits of spelling ultimately leading to a decline in pasture condition.

7.2.2 Rules of thumb

1. In any season, spell as many paddocks as possible without putting undue grazing pressure on grazed (non-spelled) paddocks i.e. the better the season, the greater the area spelled.
2. The priority for spelling should be based primarily on paddock pasture condition but also time since last spell – even paddocks in good condition need occasional spelling to overcome patch grazing effects, recover vigour etc.
3. In most years start spelling paddocks after about 50 mm of rain in two days after 1 December. If exceptionally good rains occur before December, paddocks can be spelled earlier, provided conditions are warm enough for growth. In both cases if follow up rains are delayed and forage is in short supply, paddocks can be re-opened and spelled later.
4. Spell paddocks for the full wet season if at all possible [*While early wet season spelling is most important, spelling late in the season also appears to be important to allow perennial species to replenish stored reserves]*
5. During spelling, closely monitor grazed paddocks – if these are being over grazed, open up spelled paddocks progressively to reduce grazing pressure. Open lower priority paddocks first and then, if necessary, higher priority paddocks**.**

8 Delivery against objectives

Quantified the impacts and economic cost-benefits of adaptive, flexible stocking and wet season spelling strategies on animal production, carrying capacity and land condition compared to both moderate and heavy set-stocking. Note: full implementation of the new Flexible and Flexible+Spell treatments as well as the R/Spell with six (as opposed to three) sub-paddocks, only occurred in 2012. These treatments were thus only fully assessed over two complete seasons.

Individual animal performance in terms of LWG/hd, carcass grade and meatworks price was consistently higher in the moderately stocked R/Spell and MSR strategies, and to a lesser extent the Flex and Flex+S strategies, than in the HSR. In contrast, total LWG/ha was heaviest in the HSR relative to the other strategies. Gross margins varied between years but were lowest in the Flex and HSR in 2012/13, but negative, and by far the lowest, in the HSR in 2013/14. Despite the last eight relatively favourable seasons, accumulated gross margin in the HSR calculated over the full 17 years of the trial is $10000/100 ha lower than in the remaining strategies.

Land condition as indexed by ground cover, pasture yield, density of 3-P grasses and species composition is best in the R/Spell and MSR but by far the worst in the HSR. Although the exotic grass *Bothriochloa pertusa* has invaded all treatments it has increased exponentially and at twice the rate in the HSR (+60%) compared to the MSR (+27%) or R/Spell (+32 %). Canopy cover of the native woody weed *Carissa ovata* has also increased far more in the HSR than in other treatments. Land condition in the Flex and Flex+S strategies is far superior to that in the HSR but still significantly poorer than in the MSR and R/Spell. This reflects a range of factors including the carry over effects of previous treatments as well as the short time (two years) that these newer treatments have been fully operational.

In summary, both flexible strategies were markedly superior to the HSR in terms of their impacts upon LWG/hd, land condition and in most years, profitability. However, over the short term of the present study, varying stocking rates with available pasture mass, whether applied with (Flex+S) or without (Flex) wet season spelling, conferred no apparent benefit in terms of either animal production, profitability or land condition relative to constant moderate stocking at long term carrying capacity. These benefits will hopefully become more evident as time progresses and a normal run of drier seasons are encountered.

2. Quantified the long-term impacts of reduced land condition on carrying capacity, productivity, profitability and water quality.
The significant decline in land condition in the HSR caused by ongoing heavy grazing pressure has led to a major decline in carrying capacity (CC) relative to other treatments. Based on pasture production and a 20% utilisation rate, estimated CC in the HSR (14 ha/AE) is now less than half that in the MSR (6.8 ha/AE) and R/Spell (6.7 ha/AE). Although CC has apparently declined slightly with time in all treatments, this decline is insignificant compared to the reduction in CC caused by ongoing heavy grazing pressure in the HSR.

Despite this, there has been no apparent decline in animal production in terms of either LWG/hd or LWG/ha in the HSR relative to other strategies. Rainfall use efficiency (RUE), indexed as the beef produced per 100 mm of rainfall, is also relatively unchanged in the HSR since the start of the trial. This is surprising but probably reflects the previous eight average to well-above average seasons and, possibly, the massive expansion of *B. pertusa*. Nevertheless, over the longer term, inter-annual variability in LWG has become far more pronounced as land condition has declined in the HSR.

Profitability also appears to have declined with reduced land condition. Thus while the HSR was considerably more profitable than the MSR or R/Spell in *all* of the early wet years (1998-2001), in the later wet period (2008-2011), it was only more profitable than the other strategies in one year (2008), and then by a relatively modest amount. Moreover, in 2013/14, which was not a particularly dry year (517 mm), it had a negative gross margin and was markedly less profitable than any of the other strategies.

There has been no major impact of reduced land condition on water quality. However, this largely reflects the relatively flat, low erosivity landforms in the study area. There is, nevertheless, evidence of an increase in the number and intensity of runoff events as land condition has declined. This is important firstly, in terms of its potential impact on gully and stream bank erosion which are major contributors to sediment load. And secondly, its impacts upon pasture and animal productivity, particularly in the late dry season, when cattle are under maximum nutritional stress and reduced infiltration rates can dramatically reduce early season pasture growth.

3. Validated and improved the reliability of bioeconomic modelling using data from the grazing strategies tested at Wambiana in Phase 1 and 2.
The GRASP model was parameterised for the box soil at the trial site using detailed, long term data collected at the plot, land-type and paddock scale. GRASP was then run at the paddock level over 11 years of rainfall and stocking rate data. Model predictions showed good to acceptable agreement with observed values for pasture TSDM, % of 3P species and steer LWG. This parameterisation and calibration of GRASP with data from a range of scales thus validated the modelling and hence improved the reliability of the outputs that feed into the property level Enterprise model. Greater confidence can hence be attached to the resultant bioeconomic simulations of different grazing strategies discussed below.

4. Evaluated the implications of the Wambiana trial findings for a breeder-grower enterprise with bioeconomic modelling.
Bioeconomic modelling was conducted at the property scale using a linked GRASP-Enterprise model parameterised and calibrated for the trial site. Simulations compared the

performance of a 23500 ha breeder enterprise at a range of stocking rates under fixed and two flexible stocking regimes, with simulations run over six historical 30 year climate windows. Model results were largely consistent with trial outcomes and showed that: (1) profitability was optimised and pasture condition maintained or improved at moderate stocking rates, (2) fixed and low-flexibility stocking strategies outperformed high-flexibility strategies. High flexibility strategies also had far greater risk of pasture degradation or major economic loss. (3) Model outcomes were strongly influenced by climate, in terms of total economic performance, optimum stocking rate and pasture degradation. These modelled results strongly support the argument for constrained, flexible stocking rates around long term carrying capacity with stocking rates adjusted in line with changing seasonal conditions.

5. Developed recommendations (including decision rules and/or rules-of-thumb) to (a) manage stocking rate over time and (b) implement wet season spelling for breeding and growing herds that will cost-effectively improve carrying capacity and/or land condition.
Detailed guidelines, recommendations and rules of thumb have been developed for managing stocking rates and implementing wet season spelling to cost effectively improve carrying capacity and land condition. These were developed based on trial results, simulation modelling, grazier feedback as well as results from other research e.g. (Ash *et al.* 2011).

9 Impact on Meat and Livestock Industry

9.1 Improved productivity

Balancing animal forage demand with supply whether through flexible stocking or constant moderate stocking rates gives better live weight gains, increases growth rates and hence reduces turnoff time by a year or more, depending upon the seasons. These animals will be in better condition and in most years will achieve price premiums at the meatworks 5 - 20c/kg. Faster turnoff rates also increase the turnover of animals increasing overall enterprise efficiency.

Bioeconomic modelling as well as industry surveys like 'Cash Cow' show that these benefits also apply to breeder herds with increased branding rates, reduced cow mortality and an overall increase in herd performance.

9.2 Improved profitability

Management strategies like moderate or flexible stocking significantly increase profitability relative to more conventional heavy stocking strategies. This occurs through a reduction in input and interest costs and improved returns at the meatworks. Assuming a property size of 20 000 ha, over the 17 years of the trail the advantage to moderate or flexible stocking equates to an advantage of more than $1.5 million in accumulated gross margin over heavy stocking.

Bioeconomic modelling run over a range of long term climate windows confirms that the superior profitability of moderate stocking rates or low flexibility strategies are not confined to steers but also apply to breeders.

9.3 Improved land condition and sustainability

Better management strategies like moderate or low flexibility stocking also maintain and/or improve land condition, ground cover and hence carrying capacity. This results in greater forage production and importantly, reduces inter-annual variability in forage supply, reducing the risk of forage deficits and the potential for serious economic losses in drought.

Improved land condition and ground cover also directly increase rainfall infiltration and reduce runoff and erosion. Although erosion rates were low on the relatively flat landscape of the study site, increased runoffs rates dramatically increase sediment loss and water quality on more sloping, erosive land-types.

9.4 Maintenance of biodiversity and carbon balance

Moderate stocking rates also improve the abundance of a number of bird species (Kutt *et al.* 2012) and are also likely to favour other faunal groups. A recent carbon budget conducted using trial data also shows that moderate stocking rates have a more favourable CO_2 balance than heavy stocking rates due to lower animal emissions, greater root mass and higher soil C levels (Bray *et al.* 2014).

9.5 Improved social licence

Management systems that maintain acceptable levels of biodiversity, reduce downstream impacts and maintain a neutral or positive C balance improve the social licence of the grazing industry.

9.6 Reduced need for drought assistance

Long term data from the trial, combined with enterprise level modelling clearly show that moderate stocking rates or low flexibility strategies are both more sustainable and more profitable in managing for climate variability than heavy stocking. Adoption of these former strategies would reduce drought risk by first, eliminating management induced droughts caused by overstocking, second, avoiding the costs of drought feeding and potential losses through animal mortality and third, increasing the resilience of both the business and the environment to the inherent climate variability of northern Australia.

10 Conclusions and Recommendations

1. The project continues to deliver long term compelling evidence showing that managers can be substantially more profitable and maintain pastures in good condition by running approximately half the number of animals as those under heavy stocking strategies.
2. Flexible stocking strategies with or without wet season spelling maintain and improves pasture condition and is also far more profitable than strategies run at twice the stocking rate.
3. Due to factors beyond the control of the project team, there has been insufficient time for the new Phase II treatments to fully express themselves and to be objectively assessed.
4. It is accordingly recommended that the project be continued to allow full expression of these new treatments.

11 Scientific and popular publications

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Benvenutti M.A., Bindelle J., O'Reagain, P., Gordon I., Coates D., Mortimore C., Isherwood P. , Poppi D. 2011. The effect of progressive defoliation on forage intake and diet quality of steers grazing a tropical pasture during the dry season. *IX International Rangeland Congress. Rosario. Argentina. April 2011. 462.*

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Kutt, A.S., Vanderduys E.P. and O'Reagain. P.J. 2012, Spatial and temporal effects of grazing management and rainfall on the vertebrate fauna of a tropical savanna. *The Rangelands Journal 34, 173-182.*

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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*

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.*

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. *The Rangelands Journal 35, 193-200.*

12Extension

12.1 Presentations

A total of 26 formal presentations were made between July 2010 and September 2014 to a combined audience size of 1373 people. Presentations included major conferences such as the International Symposium on the Nutrition of Herbivores in Scotland 2012, the International Grasslands Congress in Sydney in September 2013 and the Northern Beef Research Update Conference in Cairns in August 2013.

12.2 Visitors to trial

Thirty two different groups visited the Wambiana trial between July 2010 and September 2014, with a total of 495 visitors. Groups included beef producers, students from James Cook University and the United States of America and staff from different agencies such as the Department of Environment and Heritage Protection.

13References

Ash A. J., McIvor J., Corfield J., Ksiksi T. (2011). Grazing management in tropical savannas: utilization and rest strategies to manipulate rangeland condition. *Rangeland Ecology and Management* **64**, 223-239.

Le Houerou H. N. (1984). Rain-use efficiency: a unifying concept in arid-land ecology. *Journal of Arid Lands* **7**, 213-247.

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

14 Appendices

14.1 Table 1a: Dates and lengths of spelling

Dates and lengths of wet season spelling in different replicates and subsections of relevant treatments: 2011 to 2014 (Rep=replicate)

Treatment/ Year	Spelling priority & period	
	Priority sub-section*	Secondary sub-section
2011/12* **		
Flex+Spell	24 weeks (Rep 1&2)**	24 weeks (Rep 1&2)
R/Spell	24 weeks (Rep 1&2)	24 weeks (Rep 1&2)
2012/13		
Flex+Spell	18 weeks (Rep 1&2)	5 weeks (Rep 1&2)
R/Spell	18 weeks (Rep 1&2)	8 weeks (Rep 1&2)
2013/14		
Flex+Spell	25 weeks (Rep1), 21 weeks (Rep 2)	12 weeks (Rep1), 7 weeks (Rep 2)
R/Spell	25 weeks (Rep1), 21 weeks (Rep 2)	12 weeks (Rep1), 8 weeks (Rep 2)

* *Subsections are spelled based on relative need i.e. priority or secondary.*

***There are 6 sub-sections in both the 'Flex + Spell' and the 'R/Spell' treatments- thus the total area spelled can be varied depending upon seasonal conditions.*

**** In 2011/12 all paddocks spelled post fire to 1 February; spelling period given here is from date of cattle re-introduction post fire to 31 May 2012.*

14.2 Table 1b: Decision point, seasonal conditions and stocking rates

Decision points and stocking rate decisions for the Flex and Flex+Spell strategies in 2012/13 & 2014/15. (AE=Animal equivalent, P=paddock, SOI=Southern Oscillation Index, SR=stocking rate, TSDM=total standing dry matter).

Decision point	Conditions	Stocking rate/Action
End of wet (May 2010)	• Pasture TSDM : average 2000 kg	Set SRs to approx. 6 ha/AE
End of dry (Nov 2010)	• Pasture TSDM: 1700-2300 kg/ha • Good dry season rain (481 mm) • SOI +15 to +19, good wet predicted	No change
Early wet (Feb 2011)	• Very wet: Jan-Feb rainfall =507 mm • Good pasture growth.	No change
End of wet (May 2011)	• Destock trial in preparation for fire in October 2011	Remove steers
Early wet (February 2012)	• Animals return to trial after sufficient post fire growth has occurred	Set SRs to approx. 7 ha/AE
End of wet (May 2012)	• Pasture TSDM: average 2000 kg/ha	Set SRs at 6-7 ha/AE
End of dry (Nov 2012)	• Pasture mass: average 1100-1700 kg/ha • SOI & SPOTA forecast average season	No change
Early wet (Feb 2013)	Cons: • Below average rainfall Dec (43 mm); low rainfall in Feb (51 mm) • Pasture growth slow, autumn approaching Pros: • Jan 150 mm rainfall, soil wet late Jan, early Feb rains • Only 3 months to next adjustment (May) • Stocking rates not excessive (6-7 ha/AE)	No change
End of wet (May 2013)	• Pasture TSDM: average: 1900-2069	Reduce SRs to 7.91 ha/AE (Flex+S) and 7.04 ha/AE (Flex)
End of dry (Nov 2013)	• Pasture TSDM: average 950 kg/ha • Forecasts: average (SOI) slightly above average (SPOTA) season	Reduce SR in rep 2 of Flex (P6) from 6.7 to 8.7 ha/AE; no change other paddocks.
Early wet (Feb 2014)	Cons: • Below average (48 mm) rainfall in Dec, well below (65 mm) average in Feb • Pasture growth slow, autumn approaching Pros: • Average rainfall (150 mm) for Jan, soil wet from Feb rains • Only 3 months to next SR adjustment (May)	No change

	• Stocking rates relatively light (7-8 ha/AE) • Paddocks only moderately grazed	
End of wet (May 2014)	• Pasture TSDM: average 1080 kg/ha	Reduce SRs to approx. 10 ha/AE

14.3 Appendix Two

Fire effects on Carissa ovata-line transect data

The 2011 fire caused extensive top-kill in *C. ovata* but most, if not all, plants resprouted within weeks of being burnt. Although not directly measured, there appeared to be little, if any, plant (as opposed to stem) mortality post-fire. The fire nevertheless had a major impact on *Carissa* cover, with a total reduction in canopy cover of 46 % in the brigalow, 64 % in the box and 80 % in the ironbark (Figure 1). This impact was similar or better than that achieved by the 1999 fire, at least for the box and ironbark soils. For the brigalow, the reduction in canopy cover achieved with the 2011 fire (46 %) was markedly less than that in the 1999 fire (64%).

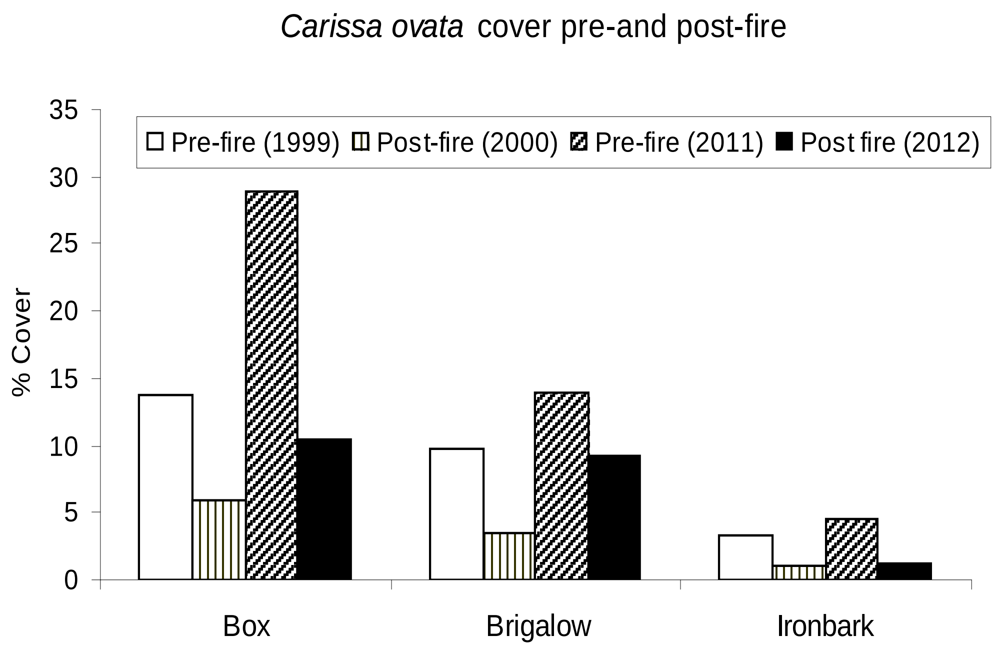


Figure 1. Currant bush (*Carissa ovata*) canopy cover before and after the 1999 and 2011 fires at the Wambiana trial.

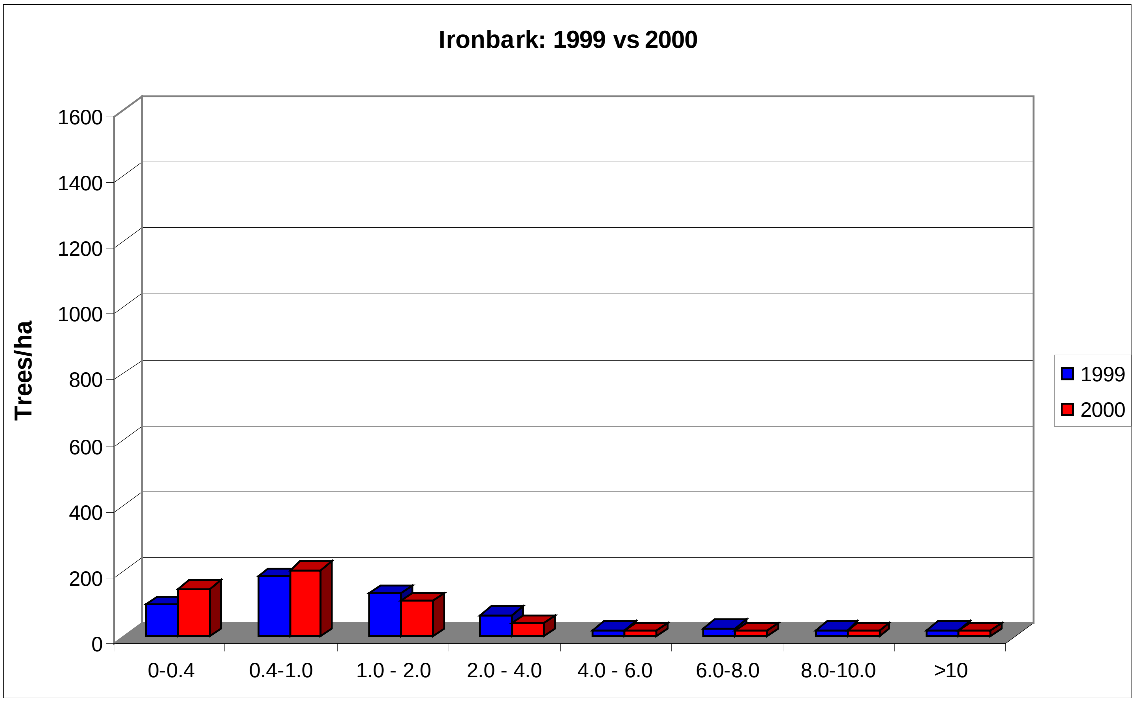
Fire effects on woodland structure and density

Ironbark community

There was massive increase in the number of juvenile Eucalypts in the ironbark areas in later years (2010/12), with numbers in the <0.4 m size class increasing 13 fold from about 100/ha in 2000 to nearly 1300/ha in 2010 (Figure 2). This resulted from the extensive recruitment and establishment of *E. melanophloia* (silver leaved ironbark) and *C. clarksoniana* (bloodwood) during the very wet years post 2008.

Despite extensive top-kill, these juveniles were largely unaffected by the 2011 fire with nearly all rapidly resprouting. Indeed, numbers actually *increased* markedly post-fire. This increase cannot be attributed to fire-induced top kill and a shift of trees from the larger- to smaller-size class. Although there was a small shift in the number of trees in the 2-4 m size class down to the 1-2 m size class, this was far less marked than after the 1999 fire.

This increase in juveniles post-fire reflects at least in part further recruitment that occurred between the pre-fire survey in 2010 and post-fire measurements in 2012. At one monitoring site, groups of young seedlings a few months old were also observed in 2012 suggesting recruitment post-fire. Despite the failure of the fire to reduce the number of juvenile *Eucalypts*, previous data indicates that significant mortality should occur with a return to dry years. Ongoing monitoring will be required to determine the fate of these juvenile trees and estimate the transition rates between life-stage (or size) classes e.g. from juveniles to sub-adults, critical for effective modelling of woody plant dynamics.



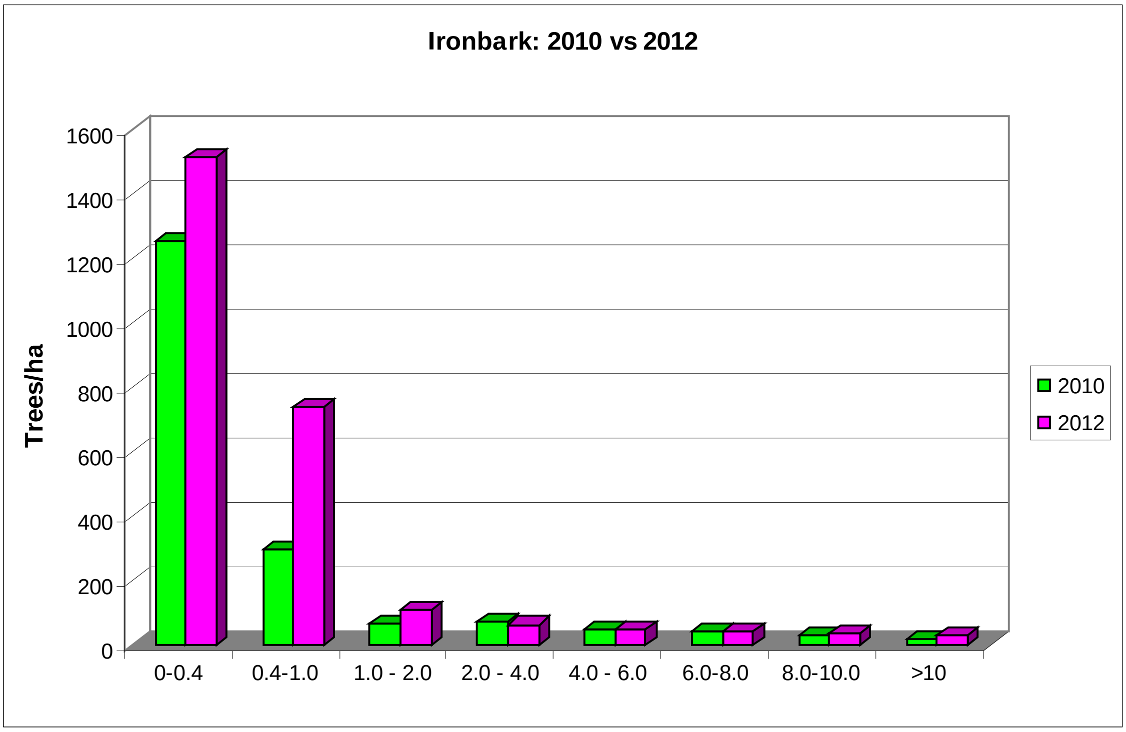
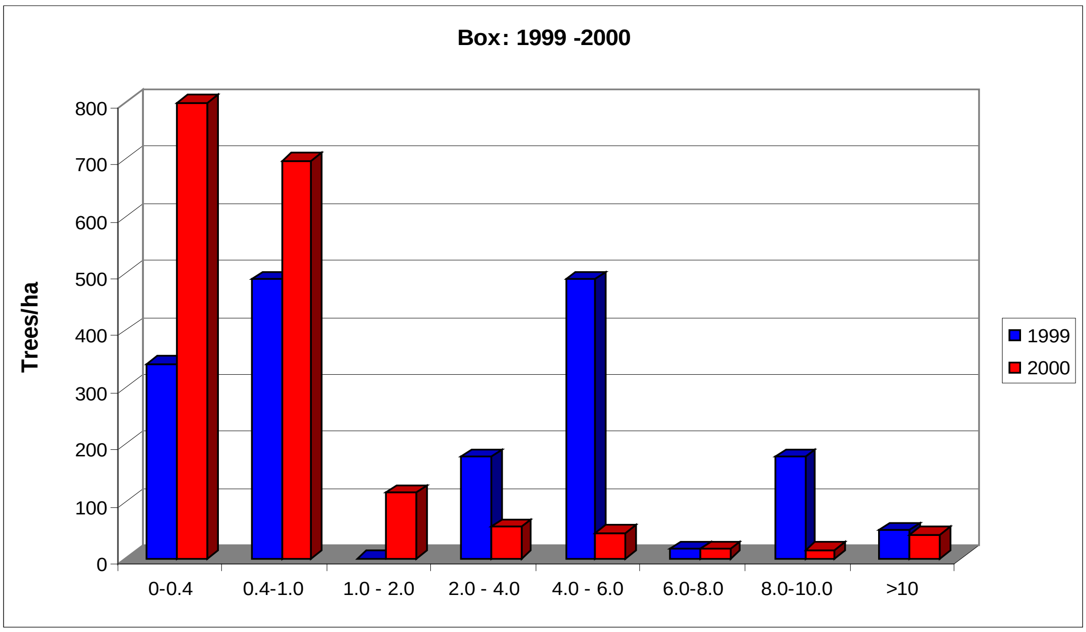


Figure 2. Woody plant density (stems/ha) in the Ironbark community in different size classes pre- and post- fire in 1999 and 2000 (top) and in 2010 and 2012 (bottom).

Box and brigalow communities

Unlike the ironbark, the number of juveniles <1 m in the box and brigalow sites did not increase in the wet years post 2008 (Figure 3). On both soil types, the response to the 2011 fire has been similar to that observed in 2000 with a shift from intermediate to smaller size classes due to top kill. Thus in the box community, the number of trees in the 2-4 m size class for example, declined from 100/ha pre-fire to 40/ha post fire, with the number of trees <0.4 m increasing from 500 to 750/ha. At the same time, there was a slight increase in the number of trees in the largest size classes (>8 m), with this trend being more marked in the box than the brigalow soils. Although unexpected given the fire, close inspection of the data indicated that the height of some trees in the 4-6 m class had increased substantially with the high rainfall between the 2010 (pre-fire) and 2012 (post-fire) surveys.



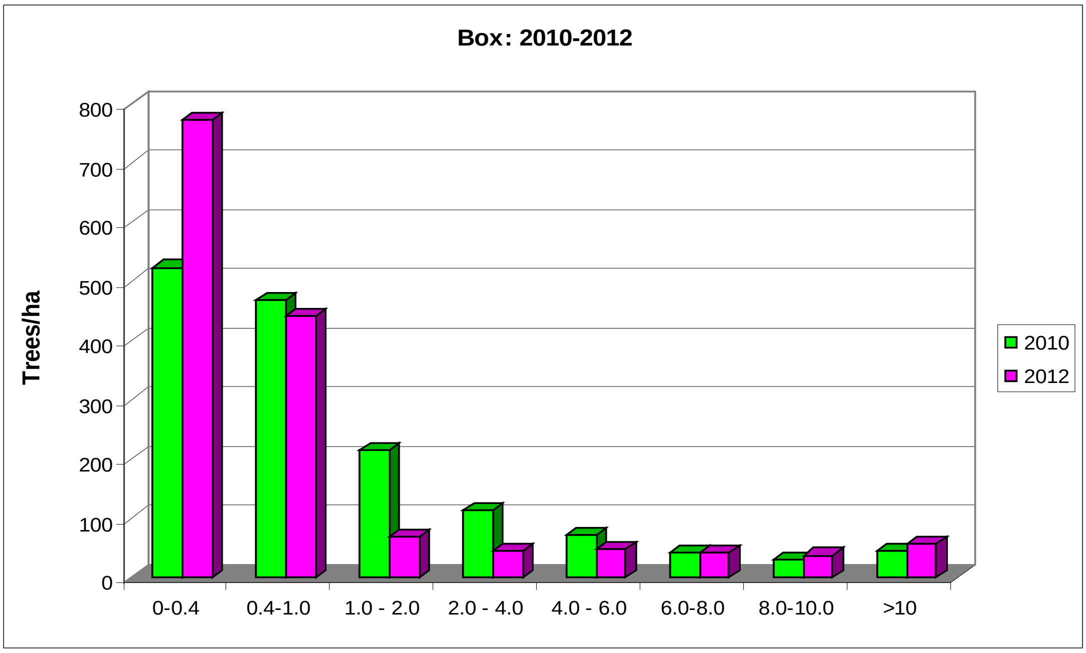
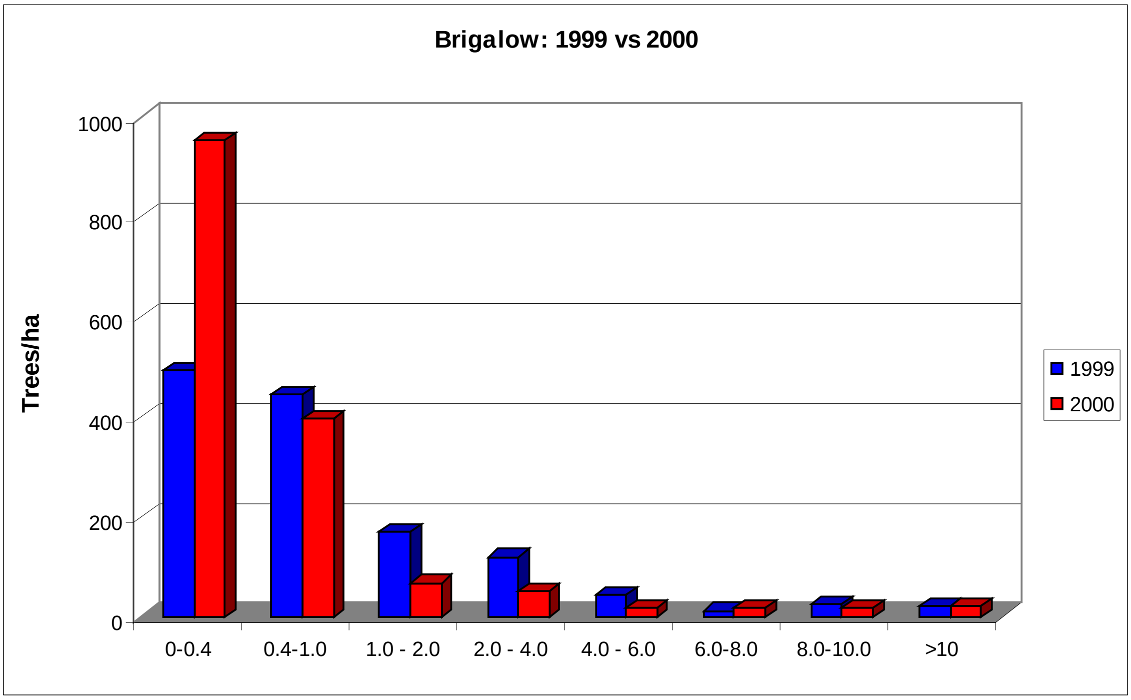


Figure 3a. Woody plant density (stems/ha) in the Box communities in different size classes pre- and post- fire in 1999 and 2000 (top) and in 2010 and 2012 (bottom).



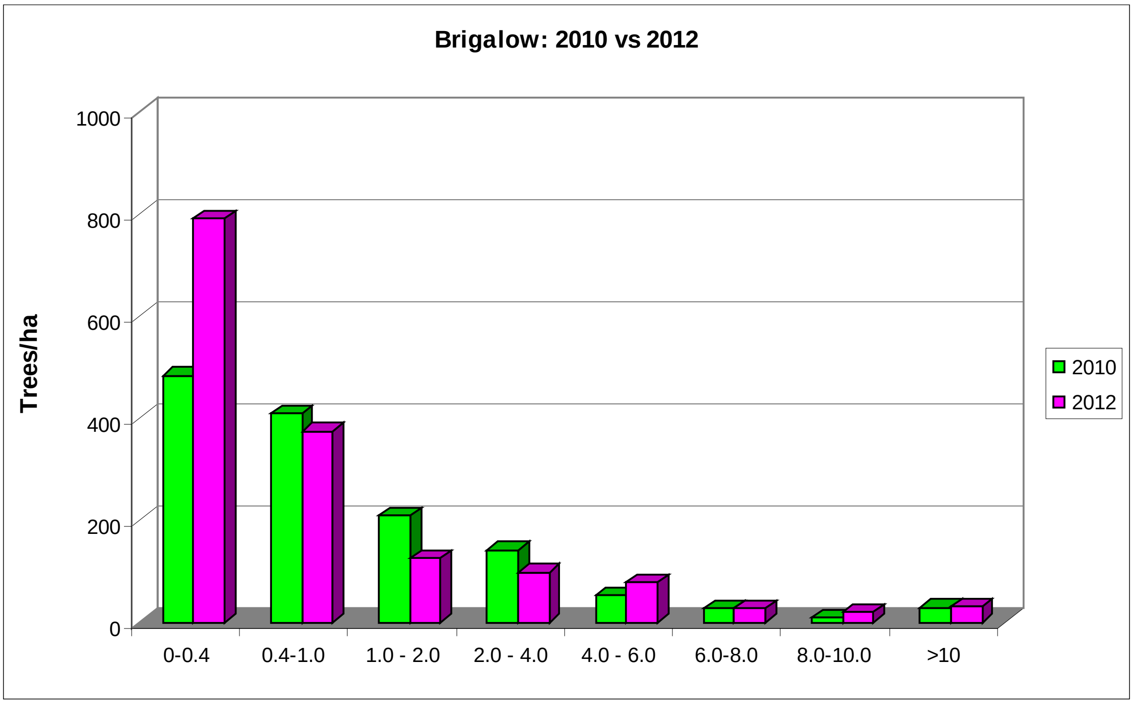


Figure 3b. Woody plant density (stems/ha) in the Brigalow community in different size classes pre- and post- fire in 1999 and 2000 (top) and in 2010 and 2012 (bottom).

Conclusions

These results show that while fire has little impact upon woody density it can change woodland structure by shifting plants to smaller size classes. The rapid regrowth of plants in the years post-burn nevertheless indicate that regular fires are required to prevent plants getting above the height at which they can be suppressed by fire.