Wambiana Grazing Trial: Water Quality Update to Burdekin Dry Tropics NRM

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1. Introduction

Aside from the obvious issues of animal production, pasture condition and economic performance, a key issue in savanna management is that of soil loss and runoff. Increased sediment and nutrient inputs from grazing lands have been identified as major threats to the Great Barrier Reef (GBR) lagoon and water quality is obviously of major relevance to the grazing industry. However, an aspect usually given lesser prominence is that excessive loss of runoff and nutrients will inevitably compromise long term pasture and animal production.

Previous studies conducted on grano-diorite and sedimentary landscapes in the Burdekin catchment showed that runoff and sediment loss increased sharply as cover declined (McIvor et al., 1995; Scanlan et al., 1996). However, neither study addressed the issue of nutrient loss from these systems. Furthermore, both studies were conducted on relatively small plots: under these conditions much of the sediment moved is likely to be re-deposited before entering water ways, making it difficult to extrapolate sediment losses to larger catchment scales.

Major knowledge gaps thus exist concerning the relationship between management and runoff in extensive grazing lands. These are firstly, how runoff and water quality are affected by grazing management on the relatively flat, infertile, tertiary sediments, which make up *c.* 20% of the Burdekin catchment. Secondly, how grazing management affects water quality. And thirdly, the extent (if any) of the trade-off between reduced soil loss and economic productivity in grazing management.

To test the effects of grazing management on soil and nutrient loss, five 1 ha mini-catchments were established in December 1997 under different grazing strategies on a sedimentary landscape near Charters Towers. The objectives of the trial are to:

1. Assess the relative ability of different grazing strategies to cope with rainfall variability in terms of their effects on animal production, economics and resource condition.

2. Develop new and practical sustainable management strategies based on seasonal climate forecasting to cope with present and future rainfall variability, and

3. Promote the adoption of these strategies through direct demonstration of the benefits of sustainable management.

2. Methods

2.1. Trial site description

The trial is located on Wambiana, 70 km SW of Charters Towers (20° 34’ S, 146° 07’ E), north Queensland. Long term (90 year) mean annual precipitation for the nearest Bureau of Meteorology rainfall station at Trafalgar, 17 km NW of the trial is 652 mm (C.V. = 40%). Rainfall is generally highly seasonal with most (70 %) falling between December and March and a long dry season occurring in intervening months (Clewett et al., 2003). Soils are derived from tertiary sediments and are relatively infertile (De Corte et al., 1996) and include kandosols, sodosols, chromosols and vertosols (Isbell 1996). The trial was sited on these tertiary sediments because of the prevalence of similar, low fertility land types in northern Australia. The study area is located in the *Aristida-Bothriochloa* pasture community (Tothill and Gillies 1992) and is an open savanna dominated by *Eucalypt*, and to a lesser extent, *Acacia*, woodland species, overlying C_4 tropical grasses.

Paddocks were laid out to ensure that experimental paddocks contained similar percentages (%) of the 3 main soil–vegetation associations (Fig. 1). These associations and their % of total paddock area are firstly, a *Eucalyptus melanophloia* community on yellow/red kandosols (23%). These relatively well drained, low fertility soils are dominated by unpalatable grasses like *Eriachne mucronata* and *Aristida spp.* but may also contain appreciable quantities of *Chrysopogon fallax* and *Heteropogon contortus*. Secondly, an *Acacia harpophylla – Eucalyptus brownii* community on grey vertosols (22 %). These more fertile areas are largely dominated by *Dicanthium sericeum*, *Bothriochloa ewartiana* and *Eulalia aurea*. Thirdly, a *E. brownii* community on brown sodosols and chromosols (55%). These soils are relatively shallow (30-40 cm), of moderate fertility and are commonly dominated by a *Chrysopogon fallax - Bothriochloa ewartiana* pasture layer.

Experimental paddocks are *c.* 100 ha in size, with the stocking strategies being tested as follows: (i) constant *light stocking* (LSR), stocked at the long term carrying capacity (LTCC) of 8 ha/animal equivalent (AE= 450 kg steer) to achieve the recommended ‘safe’ average pasture utilisation rate of 20-25 %; (ii) constant *heavy stocking* (HSR): run at twice LTCC (4 ha/AE) to achieve an average of 40-50 % utilisation of pasture; (iii) *variable stocking* (VAR) - stock numbers adjusted annually in May at the end of the wet season (range: 3-10 ha/AE) according to available pasture; (iv) a *Southern Oscillation Index (SOI)-Variable* (SOI) strategy – stock number adjusted annually in October based on the SOI and available pasture; and (v) Rotational wet season spelling *(R/Spell)*, with one third of the paddock spelled annually.

Animal production is measured using Brahman-cross steers, supplemented with wet-season phosphorous and dry season urea. Molasses and urea drought feeding was provided in extreme circumstances. Accumulated cash surplus (ACS) was calculated from annual gross margins (GM) i.e. the value of beef produced minus variable and interest (10%) costs. Pasture total standing dry matter (TSDM) and species contribution to yield are assessed annually in May. Species data is grouped into 5 functional groups i.e. 3-P and 2-P (palatable, productive and/or perennial) grasses, wiregrasses (*Aristida* and *Eriachne* spp.), annual grasses and 'other'. 3-P tussock densities are derived from tussock counts in 0.25 m^2 quadrats measured in May 2007. Pasture utilisation rates were calculated retrospectively using the GRASP model (McKeon et al., 1990) calibrated for the site.

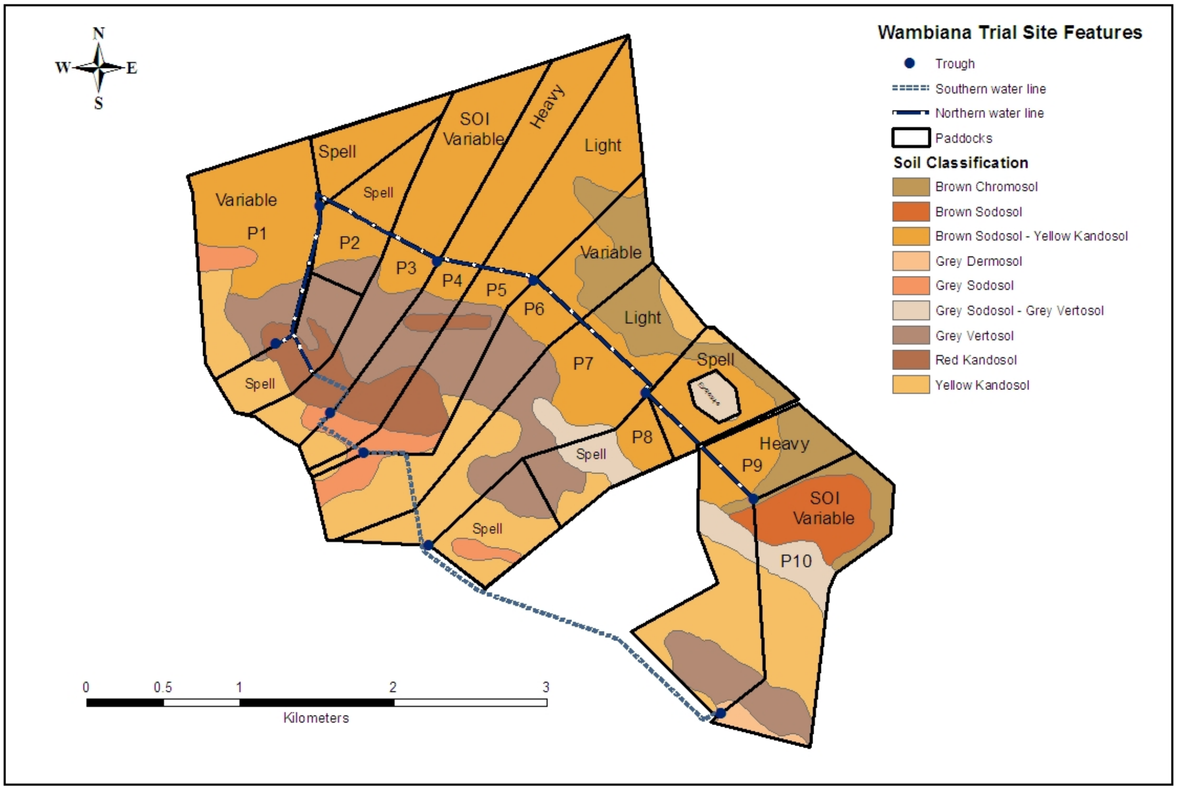

Figure 1. Wambiana grazing trial paddock layout and other features.

2.2. *Soil loss and runoff*

Runoff and soil loss are measured in a 1 ha bounded catchment using San-Dimas flumes (O'Reagain et al. 2005). Runoff was collected at the bottom of catchments by wing-walls which funnel runoff towards a sediment trap (1 x 1 x 0.2m) and San-Dimas flume (2.5 x 0.5 x 0.5m). Flow height and duration through the flume were recorded at one-minute intervals using Macquarie borehole loggers (Windstream technologies, Mona Vale, NSW, Australia), allowing quantification of runoff rates and volumes. Rainfall quantities and intensities were recorded at one minute intervals using tipping-bucket pluviometers.

Water samples were automatically collected from flumes using Macquarie (1999-2001) or refrigerated ISCO 3700 (2002 onwards) auto-samplers (ISCO, Lincoln, Nebraska, U.S.A.). To minimise expense, samplers were initially only fitted to the 'heavy' and 'variable' treatments but in November 2002 ISCO samplers were installed at all sites. Samplers were programmed to extract 500 ml samples with the first flush of water through the flume and thereafter at every 10 mm change in flow height. Depending upon site accessibility (a function of localised flooding), water samples were generally collected within 24 hours of a runoff event. Samples were returned to Charters Towers on ice where they were sub-sampled for nutrient analyses, which included filtration using pre-rinsed Sartorius Minisart filter modules (0.45µm pore size). All samples were stored on ice prior to their transfer to the Water Quality Laboratory, Australian Centre for Tropical Freshwater Research (ACTFR), James Cook University, Townsville.

3. Results

3.1. Rainfall

Rainfall was initially above average but declined sharply in later years with the period from 2001 to 2006 being within or close to the lowest 20 % of rainfall years (Fig. 2). Pasture TSDM consequently changed profoundly from a high of *c.* 4500 – 5000 kg/ha in 1999 to average only 500 kg/ha in 2007. Differences in TSDM between grazing strategies were most pronounced in later years, with the HSR being virtually devoid of forage in the dry season of some years. Stocking rates in the VAR were set very high in the early wetter years (*c.* 4 ha/AE) but were halved in 2002 due to poor yields, and then progressively reduced as available pasture declined. In the HSR, drought feeding was needed in 3 consecutive dry-seasons to sustain animals, but stocking rates were eventually cut by 30 % in May 2005 due to continued forage shortages (TSDM < 400 kg/ha). Pasture utilisation rates were thus initially low (< 20 %) but increased sharply in 2002 as rainfall declined, particularly in the VAR (64 %) which was very heavily stocked due to previous good seasons. As stocking rates were subsequently reduced in the VAR, utilisation rates dropped sharply to slightly below that in the LSR. Pasture utilisation rates in the HSR in contrast, remained high due to continued heavy stocking (O'Reagain et al., 2008).

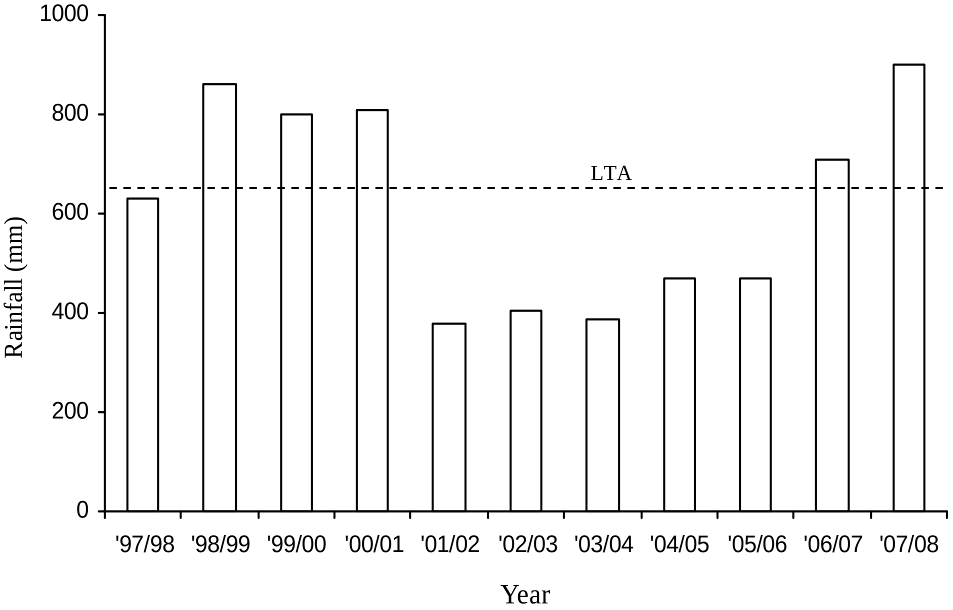

Figure 2. Annual rainfall (1st July - 30 June) between 1997 and 2007 at the Wambiana grazing trial. Note 2006/07 rainfall included 200 mm that fell in June 2007.

3.2. Pasture composition

After ten years, pasture TSDM was far greater in the LSR and VAR than in the HSR strategy (Fig.3). Total 3-P (palatable, productive, perennial) grass yield was also 8 to 10 fold greater in the former strategies. In terms of pasture condition, 3-P tussock density was 3 to 4 fold greater in the VAR and LSR than in the HSR. The slightly greater 3-P density in the LSR than in the VAR reflects the high utilisation rates inflicted on the VAR immediately preceding and leading into the dry years.

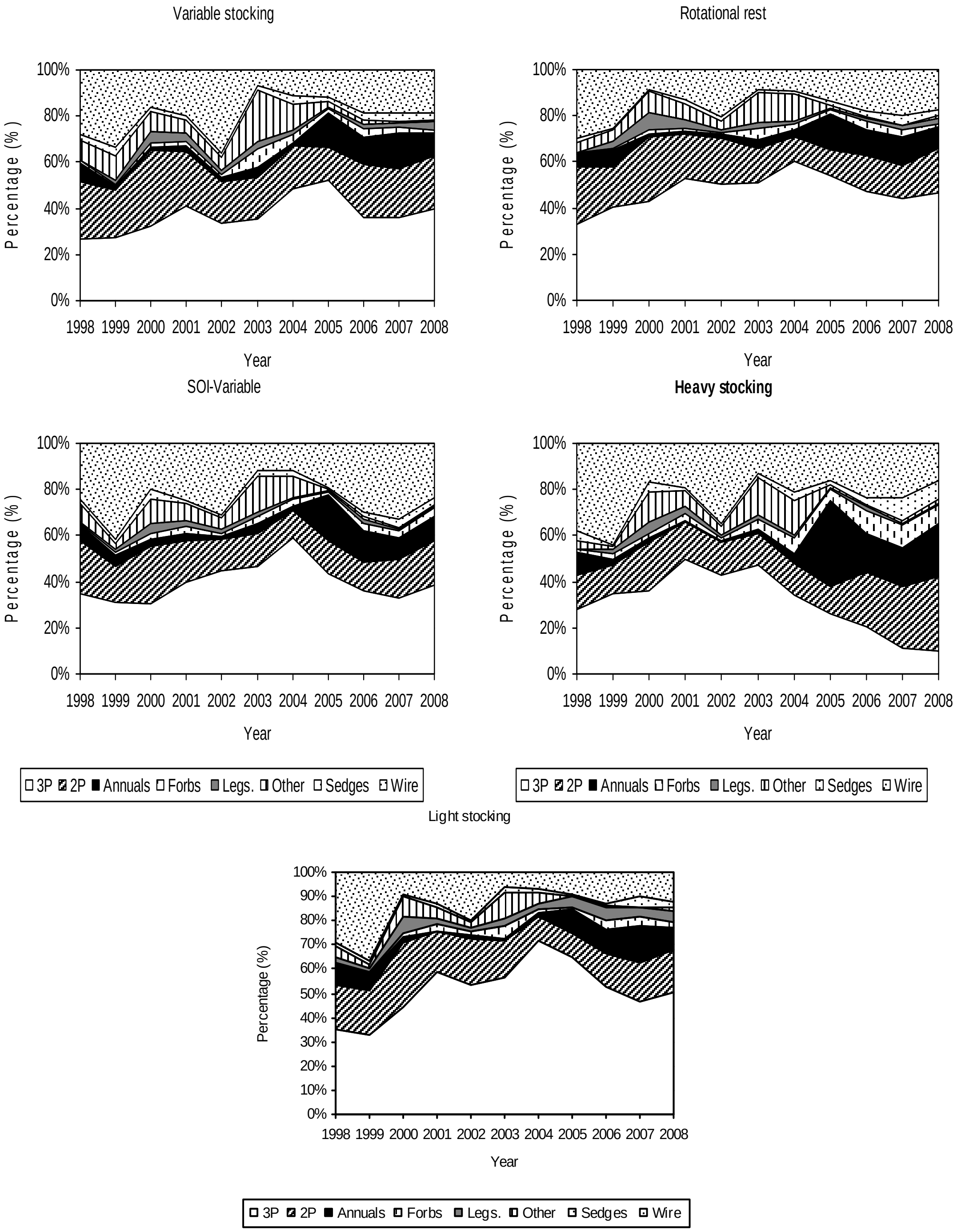

Figure 3. Change in the % contribution to pasture TSDM of different species groups between 1998 and 2008 for five grazing treatments at Wambiana. Data meaned over treatment replicates (n=2).

3.3. Runoff and soil loss

Initially, there were few differences in runoff between strategies due to high ground cover in early, high rainfall years. In later years however, the number and intensity of runoff events was markedly greater in the HSR compared to the LSR. This occurred particularly with early wet season storms in November and December, leading to increased sediment and nutrient loss. Overall, loss of nutrients, sediment and bedload increased with increasing long-term pasture utilisation rate (O'Reagain et al. 2008). The increased runoff was a direct consequence of the reduced soil macro-faunal activity and soil infiltration rates under heavy, constant stocking (Dawes-Gromadzki et al., 2007).

3.3.1. Treatment differences in runoff events

There were no clear differences between treatments in percentage runoff, particularly through the initial good seasons (data not shown). The lack of a treatment effect is not surprising considering the high cover levels in all treatments through the first five years of the trial (Table 1). These cover levels in turn reflect the good seasons and the relatively short period over which the grazing treatments had to express themselves.

Table 1. Average ground cover (%) for each treatment prior to wet season commencement i.e. end of dry, for each year of the trial.

Percentage ground cover for each treatment					
Date	**Treatment name**				
	HSR	***LSR***	***R/Spell***	***SOI***	***VAR***
1998 Oct	56	56	51	56	55
1999 Oct	65	70	64	67	63
2000 Oct	58	56	57	53	54
2001 Oct	66	71	62	64	59
2002 Oct	63	70	57	57	44
2003 Oct	36	54	43	45	41
2004 Oct	20	36	33	30	28
2005 Oct	18	29	32	29	24
2006 Oct	10	19	26	22	23
2007 Oct	24	32	36	30	29

However, major differences in the frequency and nature of runoff events are beginning to emerge, at least in the HSR and LSR: while flumes in both treatments had similar amounts and intensities of rainfall between 29 November 2004 and 19 January 2005, five runoff events occurred in the HSR compared to only two in the LSR (Fig. 4). Runoff events were also larger and of shorter and sharper intensity in HSR treatment. For example, on the 8 January 2005, more than twice as much runoff occurred under heavy compared to light stocking (9 cm vs. 4 cm): the duration of this runoff event was also shorter and sharper than in the latter treatment.

In a similar fashion, three flows occurred in the 2005-2006 season in the HSR compared to only a single flow in the LSR (Fig. 4). What is of interest in both treatments is that relatively small amounts of rain are now triggering runoff events. This contrasts sharply with the earlier years when runoff generally only occurred in conjunction with very large rainfall events.

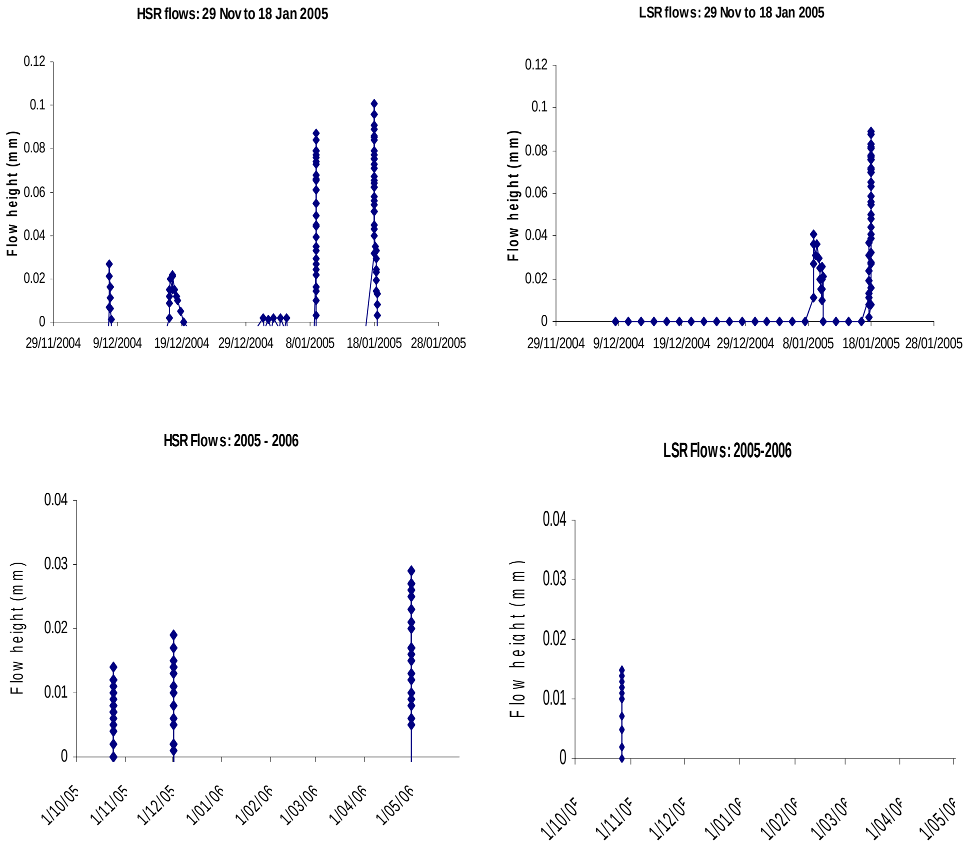

Figure 4. Runoff events and flow heights for the flumes located in the heavy and light stocking rates (top) between 29/11/04 – 18/01/05 and (bottom) over the 2005/06 wet season.

The increased frequency and magnitude of runoff events occurring in the HSR (and to a limited extent, the LSR) obviously reflects the declining cover, soil surface condition and landscape functionality emerging in all treatments. All these factors are likely to reduce rainfall infiltration and increase the amount and speed of water moving off the landscape. This thesis is supported by soil moisture measurements taken over the same period on grassed and bare patches at these flumes: at all sites, soil moisture increased more and too a greater depth following a rainfall event on grassed compared to bare patches (see also Bartley et al., 2006; Ludwig et al., 2007). These differences obviously have major implications for rainfall use efficiency, and hence potential pasture growth and green-up, particularly in the late dry season when forage quality and quantity are often limiting.

Median and range TSS concentrations for the different treatments from individual runoff events that occurred during the most recent four wet seasons (2004 to 2008) also support this finding (Fig 5). Average ground cover measurements were recorded for each treatment prior to the wet season onset (see Table 1); with the treatments in Figure 5a-d ordered from highest to lowest average ground cover in each of the boxplots. The highest median TSS concentrations were found in the treatments with the lowest ground cover (i.e. heavy stocking), although the concentration range was similar for most treatments (e.g. between 50 and 400 mg/L). Further comparison between treatments at this stage is difficult as data is not available for all treatments over all events due to autosampler failings and severe flooding of the flumes, particularly during the recent 2007/08 wet season.

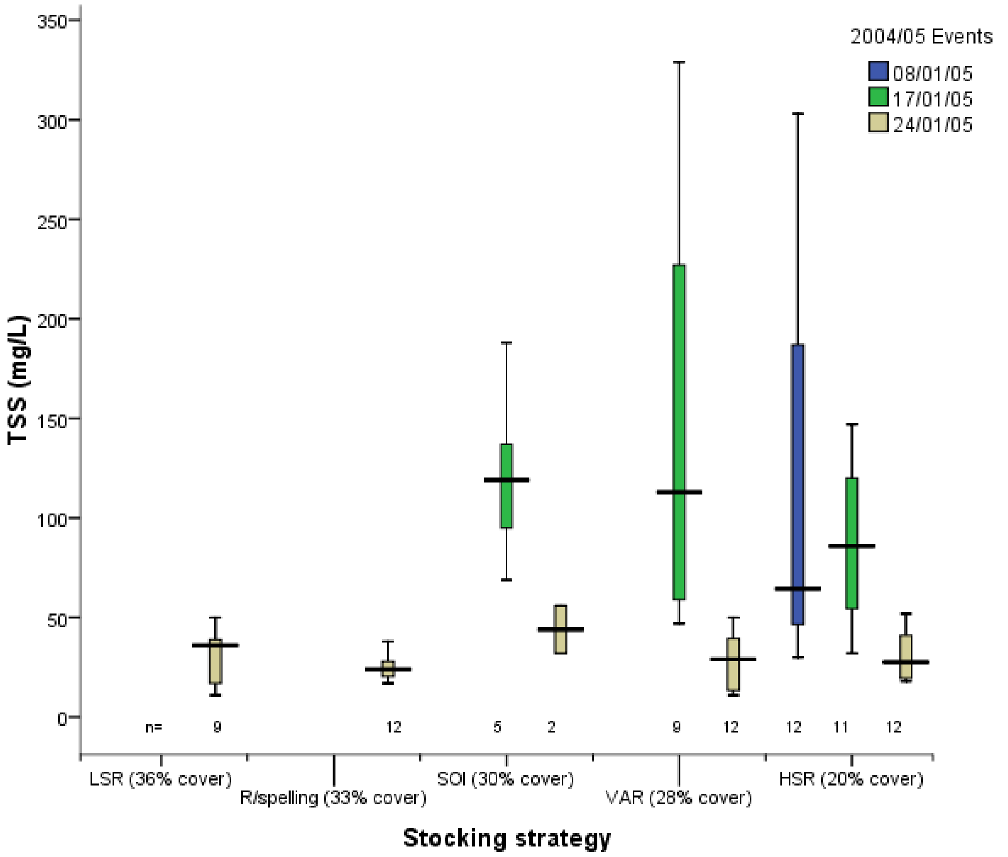

Figure 5*a*. Median and range TSS concentrations (mg/L) for the different stocking strategies during individual runoff events that occurred during the 2004/05 wet season, as collected by the flumes in different treatments. Strategies are ordered by decreasing average paddock ground cover (left to right), as measured at October 2004. All samples collected by flume autosamplers are displayed, however some autosamplers failed to collect samples during some events (e.g. LSR or R/Spell flumes).

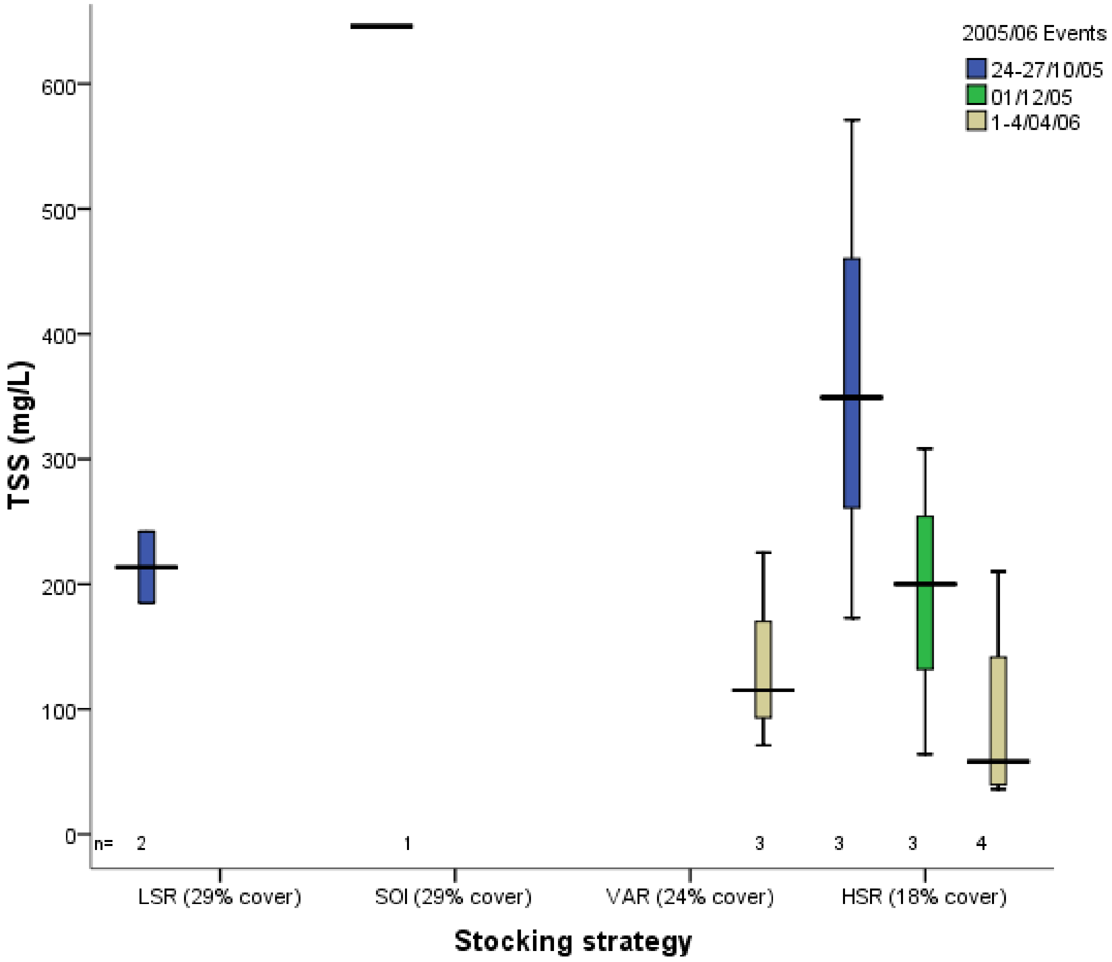

Figure 5*b*. Median and range TSS concentrations (mg/L) for the different stocking strategies during individual runoff events that occurred during the 2005/06 wet season, as collected by the flumes in different treatments. Strategies are ordered by decreasing average paddock ground cover (left to right), as measured at October 2005. All samples collected by flume autosamplers are displayed, however some autosamplers failed to collect samples during some events (e.g. R/Spell flume).

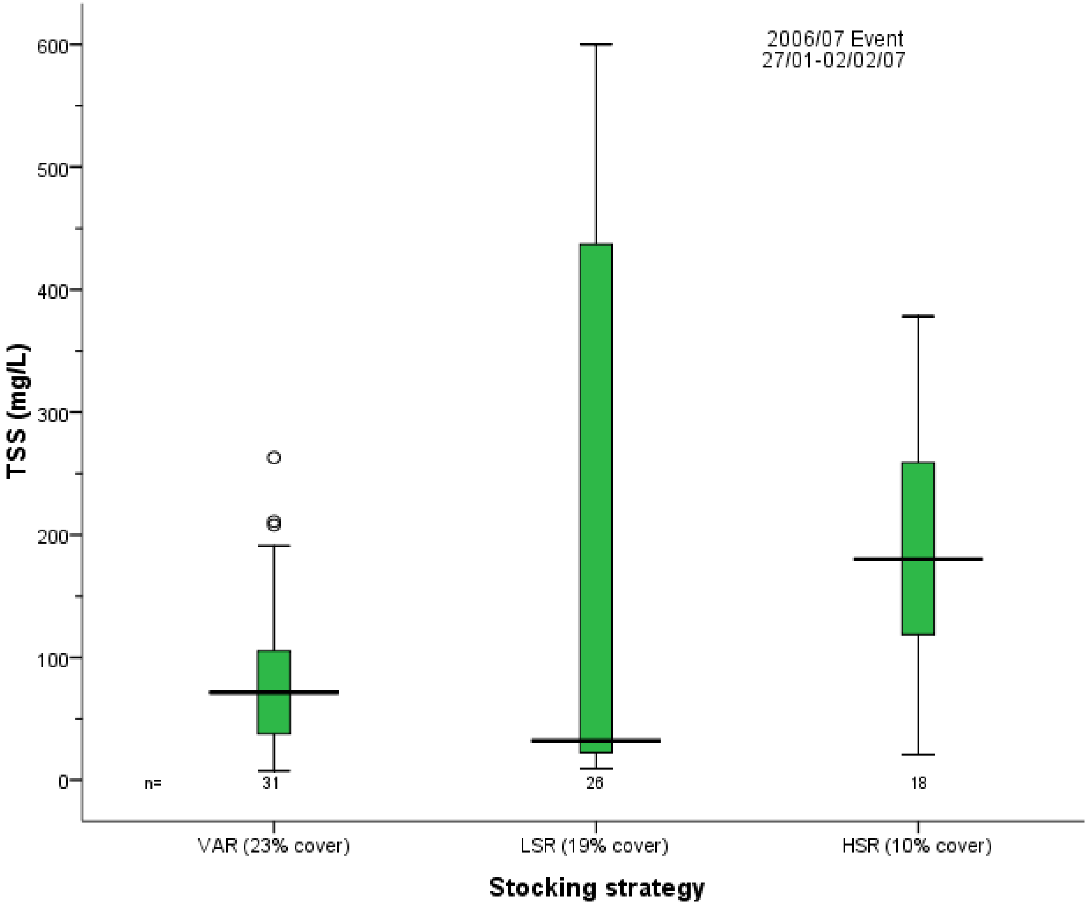

Figure 5*c*. Median and range TSS concentrations (mg/L) for the different stocking strategies during individual runoff events that occurred during the 2006/07 wet season, as collected by the flumes in different treatments. Strategies are ordered by decreasing average paddock ground cover (left to right), as measured at October 2006. All samples collected by flume autosamplers are displayed, however some autosamplers failed to collect samples during some events (e.g. R/Spell flume).

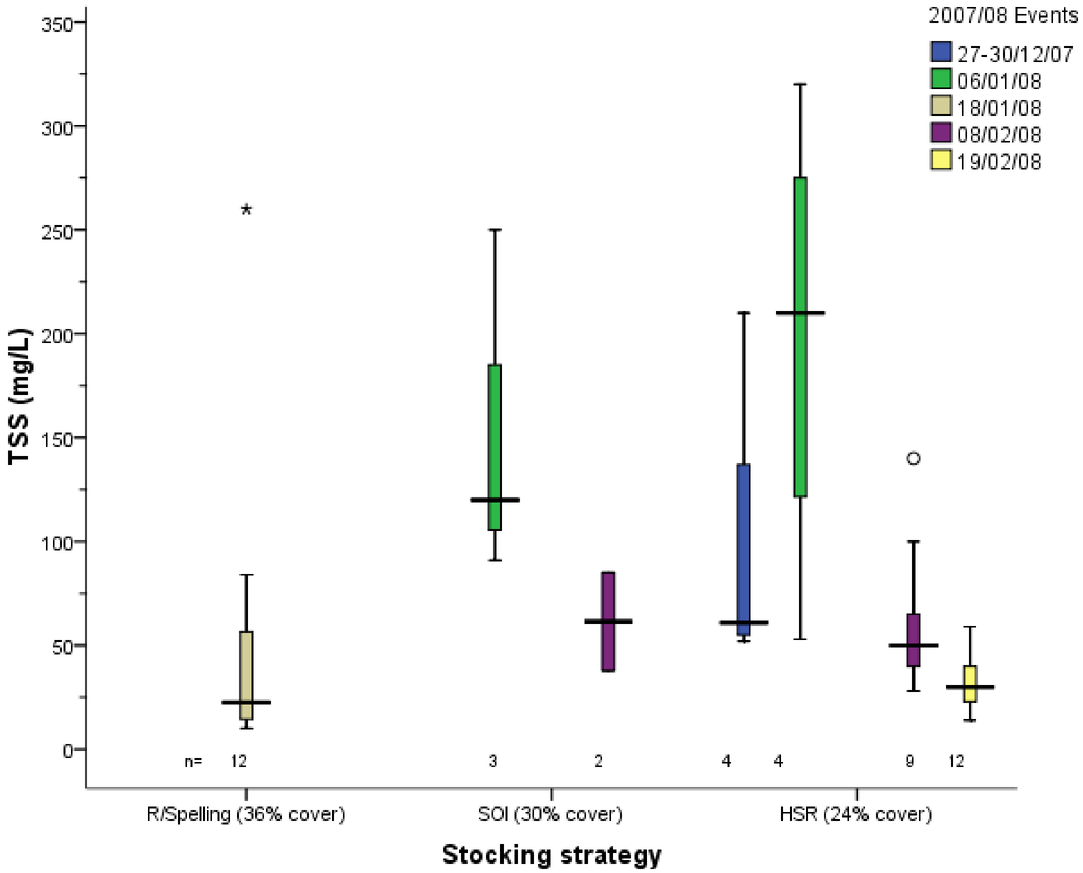

Figure 5*d*. Median and range TSS concentrations (mg/L) for the different stocking strategies during individual runoff events that occurred during the 2007/08 wet season, as collected by the flumes i different treatments. Strategies are ordered by decreasing average paddock ground cover (left to right), as measured at October 2007. All samples collected by flume autosamplers are displayed, however some autosamplers failed to collect samples during some events (e.g. VAR flume).

3.4. Economic performance

The heavily stocked VAR and HSR strategies made rapid initial gains in accumulated cash surplus (ACS) due to relatively high gross margins (GM) in the earlier wetter years (Fig. 6). However, ACS in the HSR dropped sharply in drier years post-2000/01 due to negative GMs arising from drought feeding costs, interest on livestock capital and reduced product value. In the LSR in contrast, ACS increased consistently across all years due to low costs and a higher product value. In the VAR, the initial gain was eroded by losses from reduced LWG and the forced sale of poor condition cattle with the transition to dry years in 2001/02. However, in contrast to the HSR, the rapid reduction in VAR stocking rates allowed ACS to recover in subsequent years. After 10 years, ACS was consequently highest in the LSR and VAR but lowest in the HSR: for a property size of 20 000 ha, this equates to a gross income advantage over the HSR of about AU$1.6 million (O'Reagain et al., 2008).

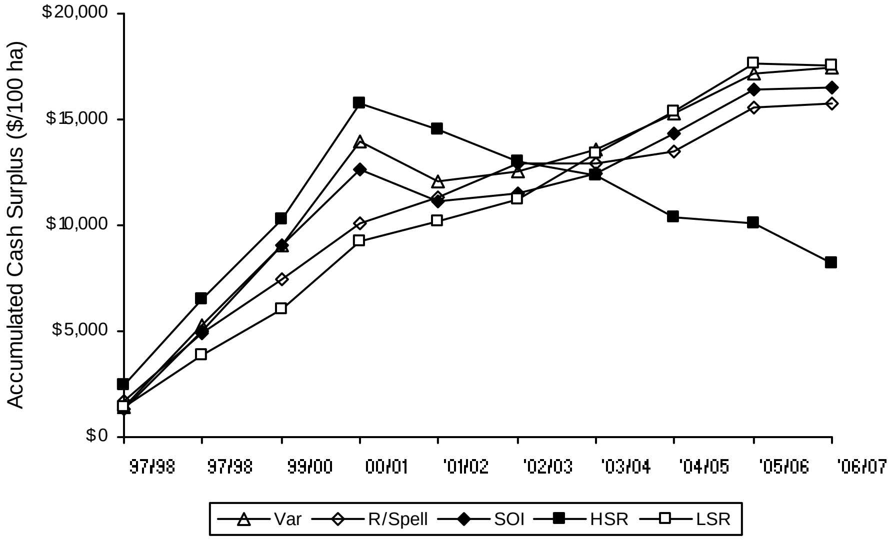

Figure 6. Accumulated cash surplus ($) per 100 ha for five different grazing strategies at Wambiana from 1997/98 to 2006/07.

4. Discussion and Conclusions

Data collected at the Wambiana trial over 10 years and a wide range of seasonal conditions, provide important evidence on the relative ability of the different stocking strategies to cope with rainfall variability. Constant heavy stocking at *c.* twice the long-term carrying capacity of the site, gave good economic and animal performance in the early high rainfall years and initially had no adverse affects upon land condition. However, the heavy stocking strategy suffered major economic loss with the advent of the drier years, and ultimately was far less profitable than either variable or light stocking. Heavy stocking combined with an inevitable sequence of low rainfall years led to a decline in land condition and carrying capacity, reduced soil health and increased the intensity and frequency of runoff events. Runoff water from the heavy stocking strategy also had some of the highest median TSS concentrations of all treatments over a number of monitored wet seasons. In the longer term, the reduced rainfall use efficiency that is likely to occur with reduced infiltration will have obvious negative consequences for pasture and animal production.

In contrast, constant light stocking at long-term carrying capacity gave good individual animal production, minimised costs and importantly was profitable across a range of rainfall years. Light stocking also maintained pasture condition within acceptable limits, maintained soil health, and consequently had a reduced intensity and frequency of runoff events, with lower median TSS concentrations during monitored wet season runoff events. Critically, it was profitable and sustainable over the ten years and showed no evidence of reduced carrying capacity. However, our observations are that the strategy would be improved by (a) inclusion of some form of wet season spelling (and possibly fire) to allow recovery of overgrazed patches or landtypes, (b) judicious adjustments of stocking rate to avoid overgrazing and loss of animal production in very dry years and possibly take some advantage of sequences of above average rainfall seasons.

Lastly, variable or flexible stocking showed some promise as a means of capitalising on good years and avoiding the losses caused by overstocking in low rainfall years. However, it clearly demonstrated the risks and adverse impacts associated with large changes in stocking rate between years. Variable stocking was profitable in most years but incurred significant losses in the transition from good to poor years and appeared to inflict significant and relatively long-lasting damage on pasture condition. Although the sharp downwards adjustment in stocking rate allowed margins to recover, it is significant that after ten years accumulated cash surpluses are nearly identical in the variable and light strategies. It is also noteworthy that pasture condition is still marginally poorer in the variable relative to the light strategy, despite 6 years of relatively light stocking rates in the former.

Variable stocking thus carries much higher risk in terms of land degradation and economic loss than light stocking at long-term carrying capacity. Recent modelling work tends to support this observation (Higgins et al., 2007). Even at very light stocking rates, a variable strategy would also still be vulnerable to area-selective grazing. Tight coupling of stocking rates with rainfall as advocated by some authors would also provide little opportunity for pastures to recover in good seasons, emphasising a need for some form of pasture spelling (Muller et al., 2007). Other practical issues associated with a variable or flexible strategy include (a) difficulties in estimating available forage in large extensive paddocks, (b) problems with calculating the appropriate stocking rate, (c) logistical problems of selling or buying large numbers of animals when required and (d) reconciling stocking rate changes with maintenance of a viable breeding herd (Foran and Stafford-Smith, 1991).

Overall, the water quality trends seen over the most recent wet seasons indicate that there is a relationship between increased suspended sediment runoff and actual ground cover, as measured prior to the onset of each wet season. This is shown over the four wet seasons, which are all ordered from highest to lowest cover, rather than a consistent treatment order. However, in general the heavy stocking strategy does tend to have the lowest cover with the highest median TSS concentrations. The results show clearly that there is a relationship between stocking treatment and cover as well as the relationship between TSS runoff and cover. The complexity of these two relationships means that although we can observe a relationship between stocking treatment and TSS, the relationship is not robust at this stage and further runoff data is required. Given the difficulties in interpreting this relationship at the paddock scale after 10 years of treatment and clear differences in pasture condition, quantifying water quality outcomes of pasture management via water quality monitoring at the larger catchment scale will always be a long-term task.

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