Sustainable Grazing Management for Temporal and Spatial Variability in North Australian Rangelands–A Synthesis of the Latest Evidence and Recommendations

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Sustainable grazing management for temporal and spatial variability in north Australian rangelands – a synthesis of the latest evidence and recommendations

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Abstract. Rainfall variability is a major challenge to sustainable grazing management in northern Australia, with management often complicated further by large, spatially heterogeneous paddocks. This paper presents the latest grazing research and associated bio-economic modeling from northern Australia and assesses the extent to which current recommendations to manage for these issues are supported. Overall, stocking at around the safe long term carrying capacity will maintain land condition and maximize long term profitability. However, stocking rates should be varied in a risk-averse manner as pasture availability varies between years. Periodic wet season spelling is also essential to maintain pasture condition and allow recovery of overgrazed areas. Uneven grazing distributions can be partially managed through fencing, providing additional waters and in some cases patch burning, although the economics of infrastructure development are extremely context dependent. Overall, multipaddock grazing systems do not appear justified in northern Australia. Provided the key management principles outlined above are applied in an active, adaptive manner, acceptable economic and environmental outcomes will be achieved irrespective of the grazing system applied.

Keywords: Rainfall variability, stocking rates, spelling, grazing distribution, grazing trials, simulation modelling, water points, paddock size, burning.

Introduction

The rangelands of northern Australia occupy a vast area stretching from Queensland to Western Australia with the majority of these lands used for extensive beef production (Mott *et al.* 1984). How these rangelands are managed thus has important ecological, economic and social implications. Poor water quality emanating from grazing lands for example has been identified as a major threat to the Great Barrier Reef and associated fishing and tourism industries (Furnas 2003).

A major challenge for the sustainable and profitable management of all rangelands is that of inter-annual rainfall variability. In Australia, rainfall variability is extreme and occurs at annual, decadal and generational time scales (McKeon *et al.* 1990). This leads to major temporal variability in forage supply, with significant risks of resource degradation and economic loss in below average rainfall years if not managed appropriately. Eight major regional degradation events have been documented in Australia: all followed a similar pattern of above-average rainfall years followed by drought and overstocking, leading to catastrophic overgrazing, degradation and a shift to lower, less productive rangeland states (McKeon *et al.* 2009). Since the 1960's the introduction of improved supplementation, hardier *Bos indicus* cattle, the provision of new water points and the ability to truck cattle rapidly over long distances have significantly increased the capacity of graziers to manage for drought (Gardner *et al.* 1990). However, these changes have also allowed high grazing pressures to be maintained both during and after droughts, increasing the risk of severe resource degradation.

Spatial variability is a further complicating factor for sustainable management in northern Australia. Properties and paddocks are generally very large, have few watering points and are often spatially heterogeneous. In the Northern Territory and Western Australia for example, paddocks can be 13000 – 16000 ha with only two or three water points (Oxley 2006). Despite low paddock stocking rates, area-selective overgrazing is thus common around water points or in the most productive parts of the landscape, with other distant or less preferred areas seldom utilized (Andrew 1988).

The challenges of managing for a variable environment are not new: for example, the legendary Australian grazier Sir Sidney Kidman utilised spatial variability via an extensive network of grazing properties to both integrate breeding and fattening operations and buffer temporal variability in forage supply (Dobes 2012). This strategy is still successfully employed by large cattle companies but most graziers are restricted to using agistment (leased grazing) to cope with rainfall variability (McAllister 2012).

While the use of spatial variability may buffer localised or regional droughts, it is of little use for droughts at state or national scales (Dobes 2012).

The inherent nature of the grazing industry in northern Australia also makes managing for variability difficult. Most properties have limited fencing and water points, labour is expensive and returns on investment extremely low (McCosker *et al.* 2010). Large distances, limited markets, and the seasonal inaccessibility of many roads also restrict the ability of managers to respond rapidly to changing conditions. Most systems accordingly have to be relatively simple and inexpensive, which tends to preclude more intensive grazing management systems.

The challenges of managing for temporal and spatial variability in Australian rangelands have been addressed previously, notably by McKeon *et al.* (1990) and Stafford-Smith and Foran (1993). Since then a significant amount of research involving both grazing trials and modelling has been conducted. The objective of this paper is to review the latest evidence available and the extent to which it supports current grazing management recommendations to manage for variability in northern Australia, highlight deficiencies in knowledge and practical difficulties in their application and synthesize the latest findings into an updated set of recommendations for managing temporal and spatial variability.

In Section 1 the key recommendations and associated research for managing temporal variability in northern Australia are presented. Section 2 addresses strategies for managing spatial variability, while Section 3 presents new evidence on the contentious issue of multi-paddock grazing systems. Section 4 summarises the key recommendations for managing temporal and spatial variability based on the available grazing trial and modelling evidence.

Managing for temporal variability in forage supply

Temporal variability in forage supply occurs at two scales: in the shorter term, *intra-annual* variability in supply (and particularly quality) occurs due to the pronounced seasonal distribution of rainfall in northern Australia (Ash *et al.* 1997). Although a major constraint on animal production, such seasonal variation is fairly predictable and thus relatively easy to manage (Danckwerts *et al.* 1993). In the longer term, *inter-annual* variability in forage supply occurs in response to rainfall fluctuations between years. Although the coefficient of variation in annual rainfall can be up to 40 % or more for some areas (Ash *et al.* 1997) the actual variability in forage supply can be far higher, varying by up to twelve fold between years even under moderate stocking rates (O'Reagain *unpublished data*).

This paper focuses on the problem of inter-annual variability of forage supply which is far less predictable and hence far more difficult to manage than that at the intra-annual scale. The three major recommendations for managing for inter-annual variability in forage supply are to stock at long term carrying capacity, to match stocking rates with forage supply and to apply wet season spelling. These recommendations are discussed below.

Stock at long *term carrying capacity*

The most basic recommendation to manage for rainfall variability is stocking at the long-term carrying capacity (LTCC). Depending upon vegetation type, this is defined as an average annual utilisation of 15-30 % of the pasture growth expected in most years with the level of 'safe' utilisation increasing with rainfall and soil fertility (Scanlan *et al.* 1994). Stocking at LTCC should ensure sufficient forage in all but the driest years and maintain resource condition, ensuring long term profitability (Wilson and MacLeod 1991). In northern Australia, the GRASP model has been used extensively to estimate the LTCC of individual landtypes (McKeon *et al.* 2009; Walsh and Cowley 2011). Although the most objective method of estimating LTCC currently available, given the complexity of the systems and landscapes involved, these, and indeed all, estimates of LTCC are not infallible and hence must be applied with caution.

Empirical evidence for stocking at LTCC

There is substantial evidence that low to moderate pasture utilisation rates maintain or improve land condition (McKeon *et al.* 2009). For example in a 26 year study on *Astrebla* grasslands, pasture condition was maintained at a 30 % utilisation rate of dry season standing forage while 50 % utilisation proved unsustainable with a marked decline in pasture condition after 20 years (Orr and Phelps 2013). There is however, a lack of direct empirical evidence showing that stocking at LTCC is more profitable in the longer term than heavy stocking. Most grazing studies have focused on pasture dynamics, been relatively short term, and/or used small, uniform paddocks restricting the relevance of their results to commercial management. The extent to which relationships derived from steers and wethers extend to breeding animals has also been questioned (Ash and Stafford-Smith 1996). This basic lack of evidence of relevance to the grazing industry has limited the adoption of lighter, more sustainable stocking rates in northern Australia.

Results from a 13-year stocking rate experiment using paddock sizes of 10 – 40 ha in central Queensland showed that profitability was greatest at the heaviest stocking rate with an average pasture utilisation rate of about 61 % (Burrows *et al.* 2010). Although rainfall over the trial period was generally well below average, no major pasture composition change occurred. Nevertheless, some preliminary degradation was recorded indicating that the highest stocking rates were not sustainable (Orr *et al.* 2010).

Conversely, in a trial using larger (~100 ha), spatially heterogeneous paddocks over 15 years in north Queensland (O'Reagain *et al.* 2009; O'Reagain and Bushell 2011), constant moderate stocking at LTCC maintained pasture condition, gave better live weight gain per head (LWG/hd) and was far more profitable than heavy stocking. Although heavy stocking gave the highest overall LWG/ha and was very profitable in the initial good rainfall years, pasture condition declined markedly in the first drought. In the long term, profitability was severely reduced relative to stocking at LTCC due to higher interest and drought feeding costs and reduced product value in drier years. Importantly, this difference in overall profitability and pasture condition was not reversed despite five later above-average rainfall years.

Limitations of the application of the latter results to commercial properties include the relatively small scale of the experimental relative to commercial paddocks and the use of steers as opposed to breeders (Ash and Stafford-Smith 1996). The results are also somewhat place and time specific with different outcomes potentially possible given a different sequence of rainfall years. Despite this, these results are the first empirical evidence in northern Australia showing that in the longer term (>8 years) stocking at LTCC is more profitable than heavy stocking.

Bio-economic modelling of different stocking rates

Simulation modelling provides a means to overcome some of the limitations of grazing trials and has been widely used to compare the performance of different management strategies *e.g.* Buxton and Stafford-Smith (1996). Recent models simulate grazing systems far more realistically than previous versions, but significant progress has also been made in simulating property level outcomes with breeders (MacLeod and Ash 2001; Scanlan and McIvor 2010).

In a recent study, different grazing management strategies were simulated for nine regions across northern Australia using historic rainfall data (Scanlan and McIvor 2010). In each region a 'typical' model property was developed to simulate a beef breeder herd with followers and fattening stock grazing up to 20 paddocks. Simulated properties contained a representative mix of the relevant regional land types but paddocks contained only one landtype.

Results across all nine regions indicated that pasture condition declined as stocking rates increased above LTCC, eventually resulting in reduced LWG/ha at high stocking rates. Over 25 years, stocking at LTCC was more profitable than heavy stocking, although the length of time that this took to occur varied with region, starting conditions and the sequence of rainfall years encountered (Scanlan and McIvor 2010).

Simulations have also been run to extend the grazing trial outcomes of O'Reagain *et al.* (2009; 2011) to a representative commercial property in the same area with breeders (Scanlan *et al.* 2013). Increasing stocking rates up to nine 450 kg animal equivalents (AE)/100 ha had little adverse impact on pasture condition or individual animal performance, leading to an improvement in overall LWG/ha and economic return (Fig. 1). However, at stocking rates above 12 AE/100 ha, there were adverse impacts on soil loss, pasture growth, land condition and LWG/hd, leading to an overall reduction in LWG/ha, increased supplementary feeding and an associated decline in profit. While economic returns peaked at stocking rates between 9 and 12 AE/100 ha, at higher stocking rates LWG/hd began to decline and there were potentially large impacts on pasture condition, both of which increase risk and vulnerability in a variable climate. Accordingly, it would be prudent to operate at stocking rates below those that yield maximum economic returns. Importantly, these outcomes suggest that the overall principles elucidated with steers at the grazing trial level (O'Reagain *et al.* 2009, 2011) may also hold with breeder animals at a commercial scale.

One weakness of these simulations is the assumption of a single soil or land type in each paddock. However, realistically modelling the performance of different management strategies in large paddocks is a major challenge given the interactions between foraging behaviour, spatial heterogeneity and vegetation dynamics that occur in a complex and highly variable environment.

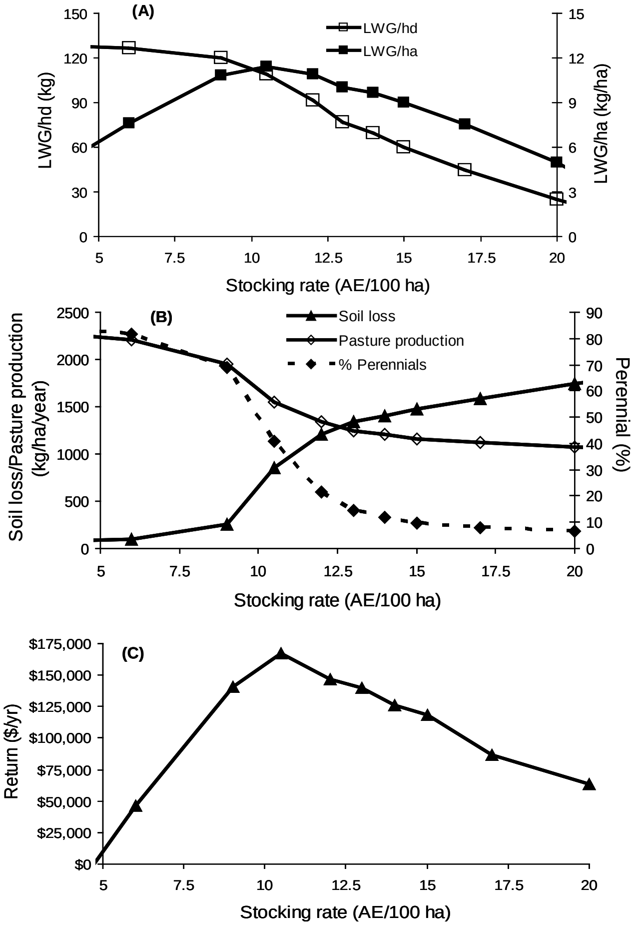

Fig. 1. Simulated effect of increasing stocking rate on (A) live weight gain per head (LWG/hd) and LWG/ha, (B) soil loss, pasture growth and percent desirable perennials in the pasture and (C) return on capital, labour and management for a *Eucalyptus brownii* woodland in north Queensland.

Matching stocking rates to seasonal forage supply

Varying stocking rates to match forage supply is another key recommendation for managing rainfall variability *e.g.* Ash *et al.* (2000). Variable stocking should minimise overgrazing and feed shortages in poor years while taking advantage of good years. Closer coupling of stocking rates with forage supply might thus potentially give greater total production than constant stocking at LTCC, without causing pasture degradation. In northern Australia, the logical time to adjust stock numbers is at the end of the wet season (April/May) as further pasture growth is unlikely for the next 6-9 months. Stocking rates may be set to utilise a percentage of standing pasture e.g. 20-30 % (Hunt 2008), or adjusted using a forage budgeting system like Stocktake (Aisthorpe *et al.* 2004). The use of seasonal climate forecasts like the Southern Oscillation Index (SOI) are also sometimes recommended to inform stocking rate decisions and make adjustments more proactive (McKeon *et al.* 1993).

Empirical evidence for variable stocking

The only long term empirical evidence on the relative performance of variable relative to constant stocking at LTCC is that of O’Reagain *et al.* (2009; 2011). Here stocking rates were varied over 15 years based on either (1) end-of-wet standing pasture or (2) end-of-dry season standing pasture and an SOI based climate forecast for the approaching wet season. Stocking rates in these two treatments varied threefold over the trial period in response to large variations in rainfall. Over 15 years, the overall profitability of both variable strategies was slightly better but more variable than constant stocking at LTCC. However, pasture condition was significantly poorer after 15 years under variable- relative to constant-stocking at LTCC (O'Reagain and Bushell 2011). This occurred due to the carryover of high stocking rates in the variable strategy into a drought period after a sequence of previous wet years. Despite a rapid cut in stocking rates in these dry years, the adverse effects of this short-term overgrazing on pasture condition were still evident years later. Similar effects have also been observed with simulation modelling of variable stocking (Scanlan *et al.* 2011).

The use of the SOI in combination with standing pasture to adjust stocking rates at the start of an extended dry period in 2002 did result in stocking rates being reduced six to seven months earlier than would otherwise have happened. However, this had no discernable effect on pasture condition relative to simply adjusting numbers based on standing pasture alone. This indicates that the reduction in stocking rates was too late in both strategies to prevent degradation in the subsequent drought. The timing of the reduction in stock numbers in the SOI strategy (late in the dry season) also resulted in an economic loss through the sale of poor condition cattle. Both factors indicate the need for seasonal forecasts with a longer lead time i.e. >6 months, to allow stocking rate adjustments earlier in the season.

These results indicate that while variable stocking is a valid strategy in managing for rainfall variability, stocking rate changes need to be made in a risk averse manner (*i.e.* decreases faster than increases and with upper limits set on the maximum stocking rate allowed in even the best years e.g. 1.5 times LTCC). Although the end of the wet season should be the primary stocking rate adjustment point, other secondary adjustment points such as the end of the dry season, or mid-wet season, should also be used (O'Reagain and Scanlan 2013). These recommendations are currently being tested in ongoing work at this trial site (O’Reagain and Bushell 2011).

Two large scale but relatively short term (<6 years) assessments of variable stocking with breeders were also conducted in the Northern Territory at Mount Sanford and Pigeon Hole cattle stations (Cowley *et al.* 2007; Hunt *et al.* 2013). Here stocking rates were adjusted annually based on end-of-wet season standing pasture to achieve target pasture utilisation levels of between 12 and 40% depending on treatment. Importantly, conditions at both sites were comparable to commercial breeder properties; with 5000 cattle grazing a combined area of 35 000 ha, the Pigeon Hole trial is one of the largest grazing trials ever conducted.

At both Pigeon Hole and Mount Sanford, land condition was unaffected by increasing pasture utilisation rate. Although unexpected, this undoubtedly reflects the relatively short study period, the robust, productive land types involved and the good seasons encountered. In some good rainfall years the intended higher pasture utilisation rates were also not achieved (Hunt *et al.* 2013).

The Mount Sanford and Pigeon Hole results appear to suggest that profitability is maximised at high rates of pasture utilisation. However, although LWG/ha increased with utilisation rate, at the Mount Sanford site reproductive indices like inter-calving interval and cow condition began declining at higher utilisation rates (Cowley *et al.* 2007). In the longer term, given the droughts associated with a variable climate, the adverse effects of higher utilisation rates would undoubtedly emerge, as observed in the Queensland trials. Importantly, the maximum pasture utilisation rates at both sites were also relatively low compared to those sometimes observed in practice. The Pigeon Hole and Mount Sanford results thus cannot be interpreted as contradicting the general principle that high utilisation rates lead to pasture degradation and an associated decline in profitability.

Both Pigeon Hole and Mount Sanford highlighted the practical difficulties in varying stock numbers to achieve set pasture utilisation targets. For example, to achieve 20% utilisation at Pigeon Hole, stocking rates had to be varied from 10-20 AE/100 ha between years. This would be almost impossible to achieve in commercial practice, especially with breeders. Recommended pasture utilisation rates should thus be considered a long-term target *average* rather than attempting to achieve a specific rate each year by sharply varying livestock numbers (Hunt *et al.* 2013).

Bio-economic modelling of variable stocking

Scanlan and McIvor (2010) compared a range of annual stocking rate changes from 0%, *i.e.* constant stocking to fully flexible stocking to match forage supply. Only one stocking rate change was allowed each year based on end-of-wet-season standing pasture. In most regions, variable strategies that allowed relatively small (10-20%) stocking rate increases in good years relative to larger decreases (30-40%) in poor years out-performed set stocking at LTCC. However, highly variable strategies with large fluctuations in stocking rate had a large number of years with negative gross margins. Importantly, when heavy stocking rates were carried into a dry year following good seasons, pasture condition invariably declined leading to a long term decline in animal and pasture productivity.

Wet season spelling

Although secondary to stocking rates management, wet season spelling (resting) is a key principle of sustainable pasture management (Ash *et al.* 1997), and is also important for managing rainfall variability. In the short term, spelling can buffer intra- and inter-annual variations in feed supply by providing a bank of ungrazed fodder (Danckwerts *et al.* 1993). However, this depends upon forage persistence, weather and potential losses to other herbivores. In the longer term, periodic wet season spelling maintains land in good condition which, by definition, has a high proportion of perennial grasses. Perennials directly reduce inter-annual variability in forage supply due to their superior productivity and longevity (Orr and O'Reagain 2011). Perennial grass patches also have higher rainfall infiltration rates and hence rainfall use efficiency than those patches dominated by annuals or shorter-lived perennial grasses (Roth 2004).

Empirical evidence for wet season spelling

Although there is extensive anecdotal evidence on the benefits of wet season spelling *e.g.* Landsberg *et al.* (1998) there are relatively few empirical studies where its effects have been assessed. In particular, there is very little evidence to assess the economic costs or benefits of spelling. This is a significant impediment to adoption: although most managers recognise the benefits of spelling for pasture condition, many regard spelling as an expensive loss of grazeable forage (Walsh and Cowley 2013).

In a recent smaller scale study over 8 years on three land types in north Queensland (Ash *et al.* 2011) good condition pastures were maintained at a 25% pasture utilisation rate without spelling. However, with annual early-wet season spelling 50% utilisation was possible without pasture degradation occurring. More importantly, poor condition pastures improved with annual spelling and a 50% utilisation rate (Ash *et al.* 2011). Annual early-wet season spelling thus buffered the effects of higher utilisation rates on pasture condition. Although annual spelling of a commercial paddock is impractical, these results suggest that pasture utilisation rates could be increased slightly above recommended levels, provided regular spelling occurred. However, a limitation of the trial was that the impact of these treatments on animal production was not assessed.

There appears to be only one study where the long term effects of spelling on animal production and profitability were also quantified (O'Reagain *et al.* 2009; 2011). Here constant, moderate stocking at LTCC without spelling was compared to moderate–heavy stocking with a third of the pasture spelled annually. In contrast to Ash *et al.* (2011), spelling did not appear to buffer the impacts of higher stocking rates on either pasture condition or animal production, necessitating a reduction in stocking rate after seven years to moderate levels. This suggests that the detrimental effects of increased stocking rates on the grazed (non-spelled) areas during the wet season may outweigh the benefits of spelling if overall stocking rates are not close to LTCC.

Nevertheless, after 15 years, the last eight of which involved moderate stocking at LTCC, the profitability of the moderate stocking-spelling treatment was similar to that under constant moderate- or under variable-stocking. Pasture condition was however better than under constant moderate stocking without spelling and markedly superior to the variable treatments (O'Reagain and Bushell 2011).

Bio-economic modelling of wet season spelling

Bioeconomic modelling (Scanlan and McIvor 2010; Scanlan *et al.* 2011) suggested that the percentage of perennial grasses in the pasture increased with the duration and frequency of spelling. However, this response was dependent on stocking rate: even with a full wet season spell every 4 years, land condition declined under heavy stocking (Fig. 2). Again, this occurred because the impact of heavier stocking rates on the grazed areas outweighed the benefits of spelling. Spelling frequency was also important for land condition with a 3 month spell every second year superior to a 6 month spell every 4 years. In terms of animal production, simulations for *Astrebla* grasslands in the Northern Territory for example, suggested that the highest LWG/ha and the fastest land condition recovery occurred with stocking at LTCC with a full wet season spell every fourth year (Walsh and Cowley 2013). This strategy outperformed both light stocking without spelling and heavy stocking with spelling. Spelling thus buffered the effects of a slightly higher stocking rate, allowing greater animal production to be achieved than under light stocking without spelling. Preliminary

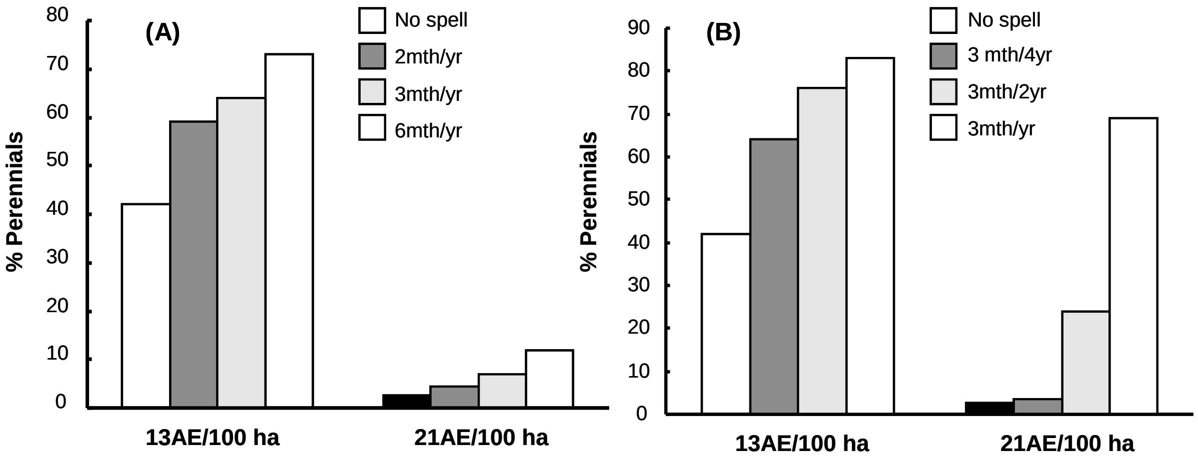

Fig. 2. Simulated mean percent desirable perennials in the pasture showing the influence of (A) stocking rate and length of spell period for a 1 in 4 year rest, and (B) stocking rate and frequency of a 3-month spell for a goldfields land type in north Queensland. (Means are for 20 different climate windows each of 30 years).

modelling suggests that provided regular wet season spelling occurs, stocking rates can be increased by about 10 % without adverse effects on pasture condition (Scanlan *unpublished data*).

Managing for spatial variability

A key management principle for the large, spatially heterogeneous paddocks of northern Australia is to increase evenness of pasture utilisation to improve forage use efficiency and avoid degradation through area selective grazing. Fencing land types, smaller paddocks and more water points are all partial solutions but in extensive, spatially complex paddocks may be impractical and uneconomic. In the Pigeon Hole study, reducing paddock size was the most effective method of improving grazing distribution across the broader landscape (Hunt *et al.* 2007). Establishing additional water points in large paddocks was less effective, partly because cattle still had considerable choice in where they grazed. While reducing paddock size improved the evenness of landscape use, uneven grazing still occurred within paddocks that were small (900 ha) by regional standards (Hunt *et al.* 2007). There were no consistent effects of paddock size on livestock performance or financial returns.

Although smaller paddock sizes improve grazing distribution, there is an obvious trade-off against the cost of the additional fences and waters. Overall, these costs per hectare rise disproportionally for paddocks below about 4000 ha in size (Fig. 3). At Pigeon Hole, paddocks smaller than 4000 ha were not justified as they provided no significant improvement in financial return or evenness of use. Optimum paddock size will however vary substantially depending upon carrying capacity and potential improvements in overall production and economic performance. Hence in more productive and intensively managed regions of Queensland, smaller paddocks can be justified (*e.g.* about 2000 ha with 2 water points).

The sequential opening and closing of water points to rotate grazing pressure has also been investigated in a large demonstration paddock (30000 ha) in the Northern Territory. However, a significant number of cattle continued to return to waters that had been turned off (Scott *et al.* 2010). These animals had to be repeatedly herded to the new, open water requiring a significant input of labour. Overall, both cattle and management took two to three years to adjust to the new system. Although an improvement in overall paddock carrying capacity occurred due to the increased number of waters, the effects on animal production and pasture condition were not assessed.

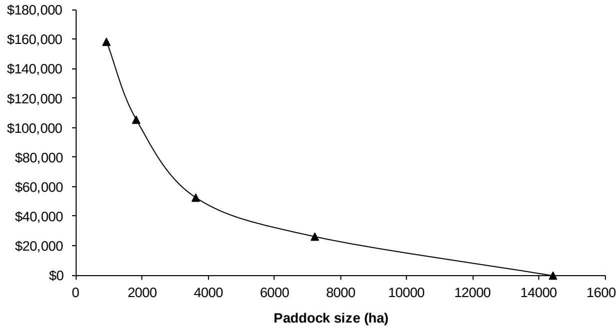

Fig. 3. The infrastructure cost (fencing, waters and roads) of subdividing a 14000 ha paddock into progressively smaller paddocks in the Victoria River District, Northern Territory.

Fire is another suggested tool to change grazing distribution, although its efficacy can vary (Danckwerts *et al.* 1993). In a four year study in the Northern Territory (Dyer *et al.* 2003) rotational burning eliminated or greatly reduced grazing gradients away from water except when burnt areas were located very close to waters or when most of the paddock was burnt. Although unreplicated, these results demonstrate the potential of fire to improve evenness of grazing in large paddocks.

Burning has also been recommended to reduce selective grazing at the patch scale. However, the only long term empirical data available is from a fire-grazing trial near Katherine in the Northern Territory (Andrew 1986). Here, burning alternate paddock halves each year successfully moved cattle off previously overgrazed patches, allowing their recovery. This strategy was sustainable with perennial grass composition and animal LWG maintained over 18 years (Ash *et al.* 1997). However, this region has relatively dependable rainfall and the regular use of fire to improve grazing distribution in drier areas or those with less reliable rainfall requires extreme caution: here the conjunction of patch burning, drought and overgrazing can easily lead to serious degradation. Further research is needed on how and to what extent spelling and fire interact to affect grazing patterns at different spatial and temporal scales and the resultant impacts upon land condition.

Is there a case for multipaddock grazing systems?

Intensive, multi-paddock rotational grazing (MPG) systems are sometimes recommended to improve animal productivity, profitability and land condition in northern Australia (McCosker 2000). This is at variance with evidence from grazing trials (O'Reagain and Turner 1992; Briske *et al.* 2008) which shows little, if any, advantage of MPG over continuous grazing.

The relevance of this grazing trial research for managers has however recently been challenged (Teague *et al.* 2011) with a comparison of ranches in Texas using MPG showing significantly better land condition than those continuously grazed. Importantly, the authors emphasised that the MPG systems were applied *adaptively* with, amongst other things, stocking rates being matched to forage supply. In contrast, a recent Queensland study over four years across a number of regions, showed little if any difference in terms of either pasture or soil surface condition between established MPG and continuously grazed paddocks (Hall *et al.* 2011). Significantly, unlike the Texas study, individual comparisons of MPG and continuous grazing were made *within* rather than *between* properties. Thus both systems were run by the same managers who adjusted stocking rates and grazing periods as conditions changed *i.e.* applied adaptive management. These results and those of Teague *et al.* (2011) appear to suggest that so long as stocking rates are appropriate and adaptive management is applied, acceptable outcomes will be achieved irrespective of the grazing system used.

Importantly, neither of the above studies quantified the relative profitability and productivity of MPG relative to continuous grazing. In the Pigeon Hole study the economics and productivity of a large (27 paddock) MPG system was assessed at a commercial scale with cows and calves albeit over only three years (Hunt *et al.* 2013). Overall, the system was less profitable than continuous grazing or a simple 3–paddock spelling system, all of which were adaptively managed (Hunt *et al.* 2013). The MPG system was also labour intensive, logistically difficult, and had no apparent benefits for animal production or land condition. Although the study was unreplicated and only went for three years it was significant because of its large commercial scale. In northern Australia, the economics of MPG systems are thus questionable given the high costs versus the relatively uncertain benefits that may or may not be obtained with these systems.

Key recommendations for managing temporal and spatial variability

Overall, the available evidence shows that in the extensive grazing lands of northern Australia stocking at LTCC will maintain and improve land condition. In the longer term, profitability will also be higher relative to heavy stocking above these levels due to reduced costs and market premiums for better condition cattle. There are, however, some obvious shortcomings of a long term strategy of constant stocking even at LTCC in a variable climate. In particular, overgrazing can occur in dry years depressing LWG and potentially causing longer term resource degradation (O'Reagain and Bushell 2011). Some stocking rate flexibility is thus required as rainfall and pasture availability varies between years. Area selective grazing is also inevitable in heterogeneous paddocks indicating the need for some form of wet season spelling for recovery of preferentially grazed areas.

Modelling and research also suggests that varying stock numbers with pasture availability offers some economic, production and ecological benefits relative to constant stocking at LTCC, but only if managed correctly (O'Reagain and Scanlan 2013). In particular, sudden shifts from wet to dry years can easily result in overgrazing and degradation if stocking rates are not reduced sufficiently early (McKeon *et al.* 1993; Hunt 2008). Variable stocking thus involves greater risk than stocking at LTCC and accordingly requires greater management skill. Important guidelines are that stocking rates should be varied in a risk-averse manner with relatively modest increases in years with abundant forage but far sharper decreases in poorer years with low forage availability. Maximum limits on stocking rates should also be set *e.g.* 1.5 times LTCC, irrespective of how good particular seasons are. As with constant stocking, area selective grazing will also be an issue, requiring some form of spelling as mitigation.

The practical implementation of variable stocking can also be difficult for a number of reasons. These include the timing and extent of stocking rate adjustments and their impacts on herd composition (Diaz-Solis *et al.* 2006). Here, pregnancy testing and foetal aging offers significant potential to appropriately manage and/or market breeders in response to seasonal conditions (Braithwaite and de Witte 1999). Other practical difficulties associated with variable stocking include accurately assessing forage availability in large diverse paddocks and the integration of such information with market and climate signals (O'Reagain and Scanlan 2013).

There is also evidence that wet season spelling improves pasture condition provided overall stocking rates are at or close to LTCC. However, more information is required on the length, frequency and timing of spelling required for improvement and the rainfall conditions under which this occurs. More importantly, there is a lack of data on the long term production and financial implications of spelling versus non-spelling, and its advantages for managing rainfall variability and uneven grazing distribute-ion. These are key issues that need addressing to increase adoption of wet season spelling by managers.

Even use of pastures across paddocks is also important to prevent localised degradation and improve efficiency of forage use particularly in large heterogeneous landscapes. The limited available data indicate that evenness of use can be improved through fencing to land type, smaller paddocks, correct water placement and spacing and, in some areas, the appropriate use of fire. However, the efficacy and economics of all these strategies will vary enormously depending upon circumstances. In reality however, the inherent selective grazing behaviour of animals cannot ever be fully controlled and some form of spelling will probably always be necessary to allow recovery of overgrazed patches and land types.

The available evidence does not support the contention that MPG systems gives superior outcomes for either land condition or animal production. The economics of MPG in northern Australia are also extremely doubtful given the capital and labour costs involved and the nature of the industry. So long as key principles such as stocking at or near LTCC, matching stocking rates to forage availability, ensuring even grazing distributions and wet season spelling are applied and managed adaptively, acceptable outcomes will be largely achieved irrespective of the grazing system applied.

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