Final report

Feedbase and Pastures

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Mitchell grass death in Qld: extent, economic impact and potential for recovery

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Abstract

Severe drought conditions from 2001 to 2007 have resulted in poor land condition across 53% of the Mitchell grasslands. Poor (or 'C') condition was associated with the dieback of Mitchell grass plants, leading to a dominance of annual plants or bare ground instead of the desirable perennial Mitchell grass. However, dieback did not occur uniformly across the landscape and this appeared to be associated with variation in recent management and rainfall history. Mitchell grass pastures usually support productive cattle and sheep grazing enterprises throughout 33,800,000 ha of Queensland. It is estimated that this dieback will cost industry $58.5 to $92.4 million per annum through reduced carrying capacity. Low recorded soil seed reserves suggest that recovery to full productivity will occur slowly over the next 3-5 years. Measurements at key sites suggest alternative management practices, such as wet season spelling and burning, may have a role in reducing susceptibility of Mitchell grass pastures to dieback in the future. Further research is needed to confirm these possibilities and to then refine viable future management strategies.

Executive summary

Mitchell grass pastures support cattle and sheep grazing enterprises throughout 33,800,000 ha of western Queensland. The Mitchell grasslands are generally regarded as resilient to grazing and rainfall variability. The drought conditions of 2001-2007, however, have challenged this notion. Across some areas Mitchell grassland, between 40 and 60% of Mitchell grass plants have suffered dieback during this period. Plants appeared to be dead, with blackened tillers. Concern heightened when affected Mitchell grass plants generally failed to respond to good (> 250 mm) summer rains in early 2004.

There was evidence that the high levels of tussock mortality and dieback during the drought, and resultant poor pasture condition, were not a simple case of conditions having been too dry for too long. Fence-line and fire-line contrasts within the central-west show areas of pasture in good condition within a ‘sea’ of dead Mitchell grass. There was also large variation in the amount of Mitchell grass seed present in the soil seed bank.

This project evolved in consultation with industry to assess the extent and economic impact of Mitchell grass dieback, and the potential for pasture recovery. We also sought evidence of management regimes that either exacerbated or attenuated dieback. An industry based steering committee guided the conduct of the project and its effective communication to producers.

The project conducted the first comprehensive assessment of the health of Mitchell grass pastures during drought. The results were not encouraging. Compared with published historical information, the Mitchell grasslands are in worse condition in 2006 than in 1992 or 1978. The major decline appears to have occurred between winter 2005 and winter 2006, with condition in 2005 similar to that of 1992. However, Mitchell grass tussocks which had low vigour in 2005 did not appear to have survived into 2006 leading to a general decline in land condition. It is estimated that this reduced land condition across the Mitchell grasslands of central western Queensland costs industry between $5.7 and 10.4 million in lost productivity per annum.

Extended periods of below average rainfall, coupled with high evaporation, are the major factors leading to dieback. It may not be as simple as more rain equating to better Mitchell grass survival, as it is likely that there is a critical duration of soil moisture remaining below wilting point which leads to plant death. There is evidence to suggest that timing of rain is also critical, with early summer rains potentially promoting survival but winter rain potentially promoting mortality, depending on the timing in relation to summer rain.

Surveys of key sites of contrasting Mitchell grass survival suggest that management also has a significant influence on the occurrence of dieback, and that continuous grazing practices may exacerbate dieback even with light grazing pressure.

Research to date suggests that the impact of drought can be attenuated by:

- high grazing pressure for a short period in the dry, coupled with wet season spelling
- occasional burning, under the right circumstances
- high grazing pressure with cattle at particular times,

but exacerbated by:

- grazing with sheep at particular times
- kangaroo grazing at particular times
- burning, under the wrong circumstances.

Management practices, such as wet season spelling or burning, may therefore have a role in minimising future dieback events. However, the mechanisms involved in promoting Mitchell grass survival are unclear and further research is needed to understand and test management strategies.

The project has achieved the stated aims of assessing the severity and extent of Mitchell grass dieback, estimating economic costs associated with dieback, identifying likely causes of contrasting high and low levels of Mitchell grass survival and promoting management guidelines to industry based on current knowledge.

This information will contribute to restoring the condition of the Mitchell grasslands through influencing current management techniques. Individual graziers will benefit from these management techniques, and also by being challenged to contemplate the adequacy or otherwise of their current drought management. Industry as a whole will benefit through an improved understanding of the impact of drought on land condition, and knowledge of alternative management strategies to reduce the impact of future droughts.

Improvements in land condition may be apparent by the 2008-09 summer should new management practices based on current knowledge, such as wet season spelling, begin to be implemented over the 2007-08 summer. Improvement in land condition based on contemporary management practices is likely within the next five years, provided there are at least two summers of above average rainfall within that period.

Wide-scale dieback of Mitchell grass may be alleviated during future droughts through alternative management practices, based on experimental strategies such as burning or short periods of heavy grazing.

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1 Background

Queensland's Mitchell grasslands represent 19% of the state's native pasture area – some 33,800,000 ha – and support approximately 15% of the cattle herd and more than 40% of the Merino sheep flock in Queensland. Between 2500-3000 people depend on employment generated by the production of beef, sheep meat and wool based on Mitchell grass country (ABS 2005).

Rainfall variability is high within the Mitchell grasslands, as in most arid and semi-arid rangelands of the world, and droughts occur frequently. The soils of the Mitchell grasslands are heavy cracking clays which become extremely dry (moisture levels of 4-5%) by the end of the winter dry season and during drought. The high water holding capacity of these soils coupled with the low soil moisture levels mean that initial rains of at least 100 mm are needed to wet the soils to 30 cm depth. Such rainfall events occur infrequently, suggesting a generally slow recovery from drought. Deep (>60 cm) soil moisture can be replenished through rain water flowing down the vertical cracks of the soil, although this process is not well understood.

Mitchell grass is a tropical (summer growing) tussock grass with adaptations to dry conditions. Tussocks become drought dormant to escape desiccation and death during extended dry periods (Whalley and Davidson 1968; 1969), and roots extend beyond 100 cm to tap into deeper soil moisture reserves (Everist 1964). However, the mechanisms involved in the breaking of drought dormancy are poorly understood, and only one published account of Mitchell grass root structure exists (Everist 1964).

The Mitchell grasslands are generally open, treeless plains, meaning that there is little or no browse available from tress and shrubs to supplement pasture forage (Weston 1988a; 1988b). During drought, the lack of browse encourages graziers to either de-stock through selling or agistment, or import feed supplements and substitutes. Mitchell grasses provide the bulk of the pasture yield under most conditions (Orr and Holmes 1984; Weston 1988a). When the option of substitution feeding is chosen, the grazier is generally locked into feeding for the duration of the drought. This leads to increasingly high feed costs and may erode the capital of the business. Furthermore, substitution feeding generally results in retention of sufficient sheep and/or cattle to maintain high grazing pressure on tussocks during drought. This may increase the risk of Mitchell grass mortality.

The most recent drought began in 2001, with 17 of the 20 shires in western Queensland progressively drought declared under Queensland and Australian Government legislation. It has been colloquially termed the 'millennium drought'. Large areas of Mitchell grass tussocks have been observed to have died during this drought, apparently through a combination of extended moisture stress and management practices. These areas are now much less productive than prior to the drought, in both the short-term due to a lack of available feed and in the long-term through a lack of Mitchell grass capable of responding to drought breaking rains. The most severely affected area appears to be the central-west, especially the northern half of the Ilfracombe and Longreach Shires, the western portion of the Aramac shire, the eastern portion of the Winton Shire and the southern portions of the Flinders and McKinlay shires. There are also large areas affected within the Barcoo and the southern portion of the Longreach shire. In these areas, discussions with industry and informal observations suggest tussock mortality to be as high as 90% across entire properties. For these areas to recover, Mitchell grass density will have to increase through seedling recruitment.

Wide-scale death and dieback of Mitchell grass tussocks has previously been recorded on three occasions: the 1900s, 1930s and 1960s (e.g. Forrest 1988). Of these occurrences, only the 1930s is well documented (e.g. Everist 1935; 1939). It seems that pastures eventually recovered from seedlings, but there is no information on the extent of tussock mortality or the speed of recovery. The onus is now on us to ensure the current event is studied well enough to indicate management strategies that will reduce future wide-scale mortality events in the Mitchell grasslands.

Dieback refers to the death (either progressive or sudden) of the above ground components of the Mitchell grass tussock. Generally, Mitchell grass tillers retain a hayed-off appearance during dry conditions and a proportion of leaf is retained. Many tillers remain green along the lower 2-15 cm section arising from the crown during dry conditions. This portion is presumably alive and capable of photosynthesising. During dieback, all leaf is shed and tillers turn grey to black in colour. This dead material is rarely, if ever, grazed by cattle or sheep.

Dieback does not necessarily mean that the crown, rhizomes or roots have died. Mitchell grass dieback should not be confused with dieback diseases e.g. the fungal dieback of buffel grass reported in central Queensland in the early 2000s. However, fungal causes of dieback in Mitchell grass cannot yet be ruled out.

There is ample evidence that the high levels of tussock mortality and dieback during the millennium drought, and resultant poor pasture condition, are not a simple case of conditions having been too dry for too long. Fence-line and fire-line contrasts within the central-west show areas of pasture in good condition within a ‘sea’ of dead Mitchell grass. One property in the Augathella district reported a superior pasture response compared to neighbouring properties apparently due to modified grazing management during the drought. The timing and amount of rainfall across these properties was similar. There is some mention of similarly resilient areas existing in the 1930s (Everist 1935), but no hints as to how management may have contributed to the lower Mitchell grass tussock mortality.

Of particular concern for the long-term productivity of the Mitchell grasslands, and hence to industry, was the failure of Mitchell grass tussocks to respond following reasonable summer rains over the 2003-04 wet season.

If global change models are correct, drought frequency is likely to increase. The current situation presents an invaluable opportunity to begin to understand how to better manage the Mitchell grasslands for increased resilience to drought. This would increase future production and reduce the risk of land degradation.

2 Project objectives

By completion of the first phase of the project, in April 2007:

1. Completed an assessment of the severity and extent of Mitchell grass dieback throughout the Mitchell grasslands of central-western Queensland and used this information to target extension and research efforts.
2. Estimated the impact of Mitchell grass dieback on individual farm profitability and the region’s economy, and used this information to encourage action by landholders and other stakeholders.
3. Assessed the potential for recovery of land condition on a representative sample of affected properties, via measurement of soil seed reserves, and used this information to tailor the management options for these landholders.
4. Identified the likely causes of contrasting high and low levels of Mitchell grass mortality.

5. Assessed the benefit to industry from additional research to identify and evaluate strategies for reducing the risk of future dieback events, as well as the additional resources required to conduct this research.
6. Achieved general awareness amongst landholders in affected areas about the problem, its cost to production, and the current best practices to accelerate pasture recovery.
7. Produced a publication documenting the project findings for distribution in the Mitchell grass region.

3 Methodology

There were five main components to this project:

- assessing the condition of the Mitchell grasslands
- assessing the potential for recovery through soil seed banks on a sample of paddocks and tailoring recovery options
- estimating the economic cost of the current decline in land condition
- conducting measurements at paired sites with contrasting levels of dieback
- increasing awareness amongst producers about the problem.

Each aspect of the project had separate research or extension methods which are detailed in the following sections.

3.1 Condition of the Mitchell grasslands

A rapid appraisal technique (Hassett *et al.* 2000) and CIGS data collection software (Anon. 2000-2002) was modified to assess Land Condition using the ABCD framework (Chilcott *et al.* 2004). The CIGS software automatically records latitude and longitude for each data entry point, and is fully configurable to allow for fast and efficient data entry and to rapidly transfer large volumes of data into GIS based applications. Two trained operators assessed Land Condition on the basis of pasture condition, soil condition and woodland condition.

3.1.1 Pasture condition

Pasture condition was assessed using the criteria outlined by Phelps and Bosch 2002). Mitchell grass tussock density (relative to expected, number/m^2), tussock viability (estimated % alive) and tussock response (relative growth response compared with the potential following good summer rains) were critical parameters of the assessment. Where rains had not been received, response was nil, but tussock viability was estimated using evidence of anchorage, evidence from a response pot trial conducted during 2004 and evidence of response from similar areas which had received rain. Species composition and weed prevalence were also key parameters.

3.1.2 Soil condition

Soil condition was assessed on evidence of rill, gully, sheet or wind erosion, but not pedestalling, due to the potential for tussock grasses to be pushed upwards in clays.

3.1.3 Woodland condition

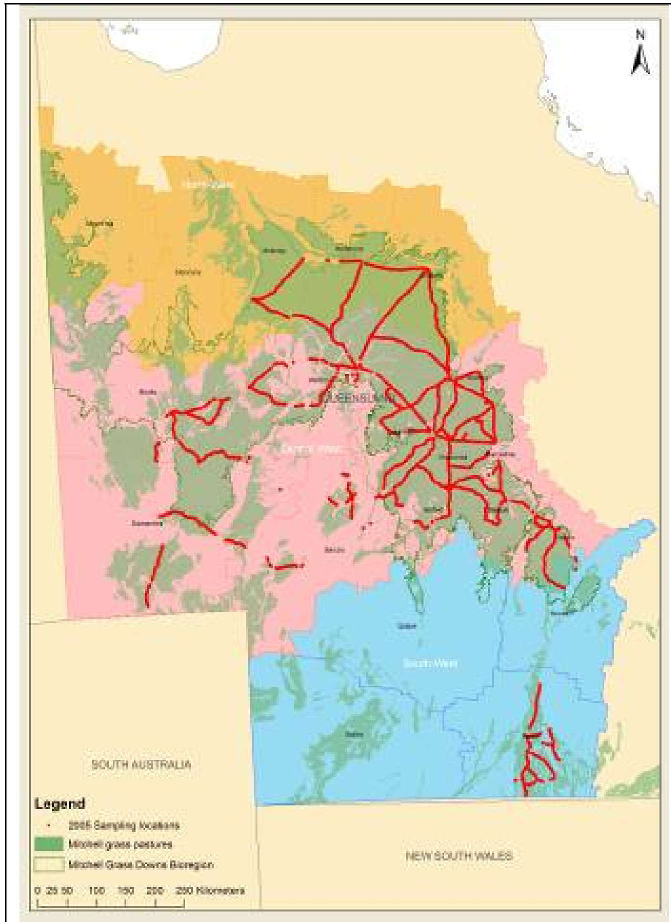
Woodland condition was generally unimportant within the sample area, but where present woodlands were assessed for unusually high rates of thickening (e.g. signs of invasive seedling spread), tree death or a lack of regeneration.

3.1.4 Sampling area and intensity

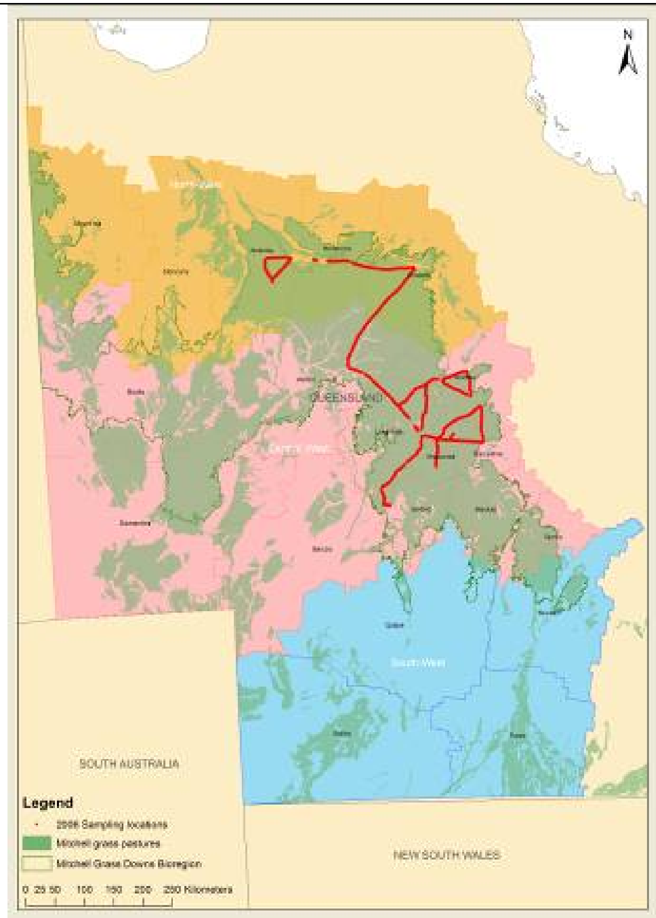
The modified Rapid Appraisal technique allowed for approximately 4000 sampling points to be assessed from a moving vehicle throughout the central-west, north-west and south-west of Queensland over a 4 week period in mid-2005. Further assessments were conducted in the shires of Diamantina and Barcoo in November 2005 and the shire of Paroo in January 2006, prior to wet-season rains (Figure 1a). Routes within the shires of Barcoo, Ilfracombe, Longreach, Barcaldine, Richmond, Winton and McKinlay were reassessed after rain in 2006 (Figure 1b).

Assessments of each side of the road were made by the driver and passenger, with data entry conducted by the passenger. Sampling frequency was approximately once per minute, providing an intensity of one observation every 2-3 km from a vehicle moving at 80 km per hour. An area of approximately 1 ha was observed and assessed by each operator, with the area influenced by road-side verges (e.g. road run-off areas, grader lines) excluded from the assessment. Wherever possible, only grazed paddocks were assessed. Similarly, stock routes and town common areas were generally excluded.

Stationary field inspections were conducted at every major change in condition, or once condition became difficult to ascertain from a moving vehicle. The minimum data set was a recording of general observations (e.g. ground cover and tussock density) with photographs. Belt transect (50 m by 1 m) recordings of tussock and seedling density, ground cover, yield and species composition were conducted at least twice daily. Field inspection locations were recorded as part of the overall dataset (Table 1).



a) 2005



b) 2006

Figure 1. The rapid appraisal sampling routes (red lines) in relation to amalgamated shire areas (north-west, central-west and south-west) and the Mitchell grassland bioregion a) initial assessment conducted in winter 2005 and (Paroo only) early 2006 b) routes reassessed in winter 2006.

Table 1. Major parameters recorded through the CIGS data collection software

Parameter	Description	Options
Operator	Operator name	Alpha-numeric entry
Location	The location of the observation in relation approximate compass bearing	categories of North, South, East, West, or Average of both sides of the road
Biomass	Pasture yield (including dead/inert material)	Dry Matter kg/ha (numeric)
%Biomass dead	The proportion of the biomass estimated as dead/inert tussock	% (numeric)
%Cover	Estimated ground cover (excluding rock cover)	% (numeric)
Green cover	The proportion of the cover estimated to as green	categories of None, Quarter, Half, Three-quarter or All
Tussock density	The density of tussocks in relation that expected for the area	categories of None, Very low, Low, Medium, High, Very high
Tussock viability	The estimated proportion of tussocks actually living	categories of None, Very low, Low, Medium, High, Very high, All
Tussock response	The estimated vigour of tussock response	categories of None, Very low, Low, Medium, High, Very high
Major spp	The major species comprising the pasture (abundance)	categories of Undesirable perennial grasses, other perennial grasses, annual grasses, Legumes, Forbs, Undesirable Forbs, Lilies, Wildflowers
Minor spp	The minor species comprising the pasture (abundance)	categories of Undesirable perennial grasses, other perennial grasses, annual grasses, Legumes, Forbs, Undesirable Forbs, Lilies, Wildflowers
Condition	Land Condition rating	A, B, C, or D (including +/- categories and ability to mix e.g. “AB”)

3.2 Potential for recovery through soil seed reserves

Industry members were encouraged to provide locations for the collection of soil seed bank samples through field days, newsletters and the media. Paddocks, or areas within paddocks, of interest to the graziers were selected and 10 samples each comprised of four individual soil cores (5 cm diameter and 5 cm deep) were collected from representative areas to provide sufficient sampling intensity (Jones and Bunch 1988). A total of 110 soil samples from 11 paddocks and seven properties were collected in winter 2004 or 2005.

Samples were germinated for species identification at the start of the following summer to allow seed dormancy to be broken (Watt 1982). In February 2005 or 2006, individual soil samples were spread as a 2 cm thick layer on top of coarse sand in 15 cm diameter pots and watered daily by overhead sprinkler until wet (approximately 15 minutes). The samples were allowed to dry before the next daily watering, maximising the germination of the summer growing plants found in the Mitchell grass lands (Orr *et al.* 1996). Individual plants were identified, counted and removed over a 12 week period.

Plant species were combined into categories of Mitchell grass (any *Astrebla* spp.), other perennial grasses, annual grasses, palatable forbs or unpalatable forbs for reporting back to graziers. The land condition and management implications of the composition of the soil seed bank samples were reported to the cooperating graziers.

3.3 Economic impact of reduced pasture condition

The economic impact of reduced pasture condition was based on both biological and economic estimates. The assessment of land condition (previous section) provided an estimate of the proportion of the Mitchell grasslands in A, B, C or D land condition while estimates of reduced carrying capacity resulting from land in reduced pasture condition were taken from the Mitchell grass gazing land management (GLM) package (Chilcott *et al.* 2004). Economic data and modelling assumptions were sourced from land-holders and published information. The economic modelling thus provides robust estimates of the relative changes resulting from changes in land condition during the current drought. However, more detailed data and surveying of on-farm costs and income would be required to determine actual on-farm and regional gross margins and profit. The collection of such data was outside the scope of this project. As such, this analysis should be treated as preliminary, but nevertheless provides a guide to the likely economic impacts of drought. Economic impacts were explored at the regional and property scales.

3.3.1 Regional scale

A static gross margin (GM) approach was taken to explore regional scale impacts. The key assumptions used in the modelling were:

- stocking rates are best practice
- carrying capacity is 100% in A condition; 85% in B condition; 45% in C and 25% in D condition (Cobon and Peart 1995; Phelps and Orr 1998; Phelps and Bosch 2002)
- 3% of land in 2005 was in A condition, 65% in B condition, 32% in C condition and <1% in D condition (see Results section)
- carrying capacities are at these potential levels, not at further drought-reduced levels
- a baseline level of 70-80% of land in A condition, 12.5% in B condition, 12.5% in C condition and 5% in D condition was assumed from a previous assessment (Tothill and Gillies 1992)
- the area of land in B condition under Tothill and Gillies 1992 (25%) is spread evenly between B and C condition of the current framework (i.e. 12.5% into each of B and C condition classes)
- a contemporary ratio of 75% cattle to 25% sheep in central-western Queensland (ABS 2005)
- average cattle, sheep, and wool prices are used and variable costs are current based on information sourced from local producers and contemporary reports (MLA 2006)

The area of Mitchell grass country for each of the shires of Longreach, Barcaldine, Ilfracombe and Isisford was calculated from shire boundaries and pasture community mapping (Weston 1988a, Table 2). Individual shire Mitchell grass areas were then totalled and the area of Mitchell grass pastures in A, B, C or D condition class calculated from assessed values (Figure 2).

Table 2. The area (ha) of Mitchell grass pasture within the central-western shires of Longreach, Barcaldine, Ilfracombe and Isisford

Shire	Mitchell grass area (ha)
Longreach	1,844,976
Ilfracombe	657,645
Isisford	723,951
Barcaldine	440,213
TOTAL	3,666,785

3.3.2 Property scale

Statistics and information from producers and grazing land scientists were obtained to derive the parameters, costs, and prices of a representative cattle enterprise in northern Australia (Puangsumalee *et al.* 2005).

The method involved calculating annual GM, operating profit, net (accounting) profit, economic profit, cash flow, and yearly changes on the farm balance sheet, where:

- GM is total farm income minus variable costs
- operating profit is the difference between total farm income and farm operating costs (variable + fixed costs)
- net profit is accounting profit, which is operating profit minus depreciation, bank interest, family labour and tax
- economic profit is operating profit minus the change in market value of farm capital, and the opportunity costs of farm labour, land and capital. A negative economic profit means that the return on labour, land, and capital is lower than other forms of investment- in this case ten-year government bonds
- the balance sheet includes assets, liabilities, and owners equity.

The key assumptions used in the modelling were:

- inflation rate of 2.5% per annum is set on variable and fixed costs, and labour.
- present value is discounted at 5% - comparable with lower risk assets
- cattle saleyard prices decrease annually as forecast (Drum *et al.* 2006)
- the cattle enterprise uses average parameters, farm costs, labour, assets and liabilities similar to an enterprise of this scale operating in the CWQ region (Shafron *et al.* 2001; Puangsumalee *et al.* 2005)
- depreciation is calculated using the straight-line method and effective life of assets (ATO 2006)
- tax is calculated at company rate of 30%
- land size = 42,000ha
- land condition is condition B (85% carrying capacity) in the first two years and then declines to condition C (45% carrying capacity)
- average steer sold at 430 kg @ $1.9/kg; average steer / heifer purchased at 330kg @$2/kg. Average value per head = 380kgs @$1.95
- stocking rate AE/ ha = 1:13
- mortality rate = 3%
- weaning rate = 70%. All breeders are kept, and mostly steers are sold over the five years
- value of land remains constant over the next five years. Also liabilities, are constant, although value of assets change annually through accumulative cash reserves and change in livestock assets and accumulative depreciation.

3.4 Sites of contrast

Adjacent sites demonstrating contrasting Mitchell grass response were identified through the assessment of land condition, remote sensing techniques, discussions with the steering committee, industry liaison; and discussions with GLM workshop participants. Broad criteria for site selection were allowed, with the data set to be used for the identification and exploration of trends and hypothesis generation. The criteria were that sites:

- must be within Open Downs, Ashy Downs or Wooded Downs land types
- should visually demonstrate a difference in response
- should primarily be due to management across fencelines, burn lines or along an identifiable grazing or rainfall gradient.

A total of 49 sites (22 paired sites and one set of 5 sites within a long-term grazing experiment, Orr and Phelps 2004) of contrasting response were selected between June and December 2006. Pasture yield, botanical composition (Tothill *et al.* 1992) and *Astrebla* spp. density, vigour and basal area (Orr 1998) were measured within 30 quadrats of 1x1 m^2 size along two 75 m transects for each site. Tussock density and basal area was grouped into dead and living categories, to allow previous and current basal area to be assessed. Photographs were taken of general site conditions and each quadrat.

The ability to link to remote sensing data in the future was made by ensuring:

- recording of site waypoints to an accuracy of +/- 5m
- that sites were within an area representative of the aspect being measured (e.g. burnt or unburnt areas)
- each site would cut across at least two LandSat pixels (by having two 75m long transects, at 45 degree angles, with their respective starting point spaced 40m apart)
- paired sites were between 200 and 1000m distance from each other to avoid sites overlapping within pixels.

Potential botanical composition was estimated through soil seed bank surveys. Ten soil samples, each comprising four cores of 5 cm diameter and 5 cm depth, were collected along the same 75 m transects providing sufficient sampling intensity for small plots (Jones and Bunch 1988). Samples were germinated in a shade-house at Longreach and counts conducted as each species became identifiable (Orr *et al.* 1996).

General observations of grazing pressure, pasture response, pasture condition and land type were recorded, and site history (grazing, burning and site specific rainfall) was obtained through semi-structured interviews with the owner/manager of each property. Rainfall data were estimated for each site using Silo DataDrill (Jeffrey *et al.* 2001) and validated against property records.

A rainfall/evaporation ratio (R/E index, see Hodgkinson and Müller 2005) was used as a guide to the severity of soil moisture deficit, with any summer period (October-March) where the moving average of the ratio failed to exceed 0.15 (15%) deemed to be a failed summer.

Raw data were analysed through correlation and multiple regression to identify major trends. Square root transformed data were then analysed through Principal Components Analysis (PCA) using a correlation matrix approach to identify major groupings (GenStat 2007). Land condition change was used to guide group selection, with prior land condition estimated through total *Astrebla* spp. tussock density, soil seed bank species composition and advice from land managers. Discriminant Analysis (DA) based on the groups identified in PCA was used to determine if difference between paired sites were significant (GenStat 2007).

3.5 Industry engagement

3.5.1 Steering committee

A steering committee comprising industry and scientific representatives was formed in October 2005 (Appendix 9.1). Industry members were invited to join the committee based on their previously demonstrated interest, involvement and direct management of Mitchell grass. Collectively, the industry representatives manage approximately 300,000 ha of Mitchell grass pastures from the northern, central, southern and western extent of the Mitchell grass bioregion. The industry representatives bring a combined experience of 170 years. Scientific members were invited to join the committee based on their involvement in natural resource management research within western Queensland and that they have experience at opposite ends of measurement scales, from plant dynamics at the individual plant scale (Dr Orr) to practical remote sensing applications (Dr Beutel). They bring a combined 40 years of scientific experience.

3.5.2 Industry publications

Three publications aimed at assisting graziers to better manage their Mitchell grass pastures during drought, based on current knowledge, were produced. The first, a Mitchell grass recovery information kit (Phelps and Rolfe 2005b; Phelps *et al.* 2005; Phelps 2005; Phelps and Rolfe 2005a) was mailed to 850 landholders in central-western Queensland in January 2006. These kits were developed in conjunction with the project steering committee to ensure the relevance of the content, and to maximise the impact of the publication. The kits comprised four new and three updated fact sheets and were designed to allow further information sheets to be easily incorporated. The shires identified as worst affected by dieback during the assessment of land condition were targeted for receiving the information kits. Feedback sheets to determine the relevance and usefulness of the information were included with the kits.

The second publication, a grazier booklet to report on this project and to encourage debate on the issue of sustainable grazing management of Mitchell grass pastures during drought will be distributed to all graziers within the Mitchell grasslands (Phelps *et al.* 2007a). Feedback sheets to determine the relevance and usefulness of the information will be included with the booklet.

The third publication, a brief fact sheet on identifying Mitchell grass seedlings and discussing seedling establishment rates, was identified as a need through discussions with industry (Phelps *et al.* 2007b). The fact sheet will be distributed with the grazier booklet. In addition, industry has sought updates on the progress of the project. Updates have been provided through the LeadingSheep e-book drought series and through Department of Primary Industries and Fisheries (DPI&F) newsletters and media releases (Phelps 2007). Copies of these publications are available on request.

3.5.3 Industry training

The latest findings of the project have been incorporated into Mitchell grass GLM (Chilcott *et al.* 2004) training workshops.

3.5.4 Industry advice

Industry members were invited to submit soil seed bank samples as an on-going service, and in meeting objective 4. Samples have been grown out and advice on the levels of seed present and possible management implications provided as feedback.

4 Results and discussion

4.1 Condition of the Mitchell grasslands

Observations within the north and central-western statistical divisions were dominated by B condition in 2005, whilst the south-west was dominated by C condition (Figure 2). Reassessed areas within the north and central-west declined to be dominated by C condition in 2006 (Figure 3) and on average were A 2.5%, B 40.2%, C 53.2%, D 4.1%.

The decline was associated with areas of no to low tussock response (Box 1) in 2005. For instance, over half of the observations in B condition within the Flinders shire in 2005 showed no to low tussock response. Observations in B condition had declined from 80 to 42% by 2006, whilst C condition observations increased from 12 to 46% (Figure 4a, b). There were similar trends in other shires (e.g. Ilfracombe, Aramac and Winton; Figure 4).

When these data are compared with historical observations, an overall declining trend in pasture condition can be inferred. For instance, in 1978-81, 80% of the area of the Mitchell grass pastures in central-western Queensland was estimated in A ("good"), 15% in B/C ("moderate") and 5% in C/D ("poor") condition. In 1991, 70% of the central-west was estimated to be in A condition, 25% in B/C condition and 5% in D condition (Tothill and Gillies 1992, page 84). By comparison, in 2005, <5% was estimated to be in A (or "good") condition, approximately 60% in B (or "moderate"), 30% in C (or "poor") and <5% in D (or "degraded") land condition classes and C condition levels had increased at the expense of B condition by 2006.

Caution should be exercised in comparing the data across different seasonal conditions and frameworks. Observations of condition can be confounded by seasonal conditions in the Mitchell grasslands, even when based on intensive ground measurements (Phelps and Bosch 2002). There appears to be overlap in the definition of B and C condition between the three proposed frameworks, reducing the precision of any comparison. Nevertheless, the dramatic decline in Mitchell grassland regarded as within "good" or "A" condition between 1978 and 2006 is significant cause for concern (from 70-80% prior to the drought to <5% within the millennium drought). The conduct of further assessments over time would strengthen the picture of the overall health of the Mitchell grasslands.

Box 1. Examples of a) no and b) high Mitchell grass response.

a) an example of no response within drought affected B condition Mitchell grassland.

b) an example of high vigour response within A condition Mitchell grassland.

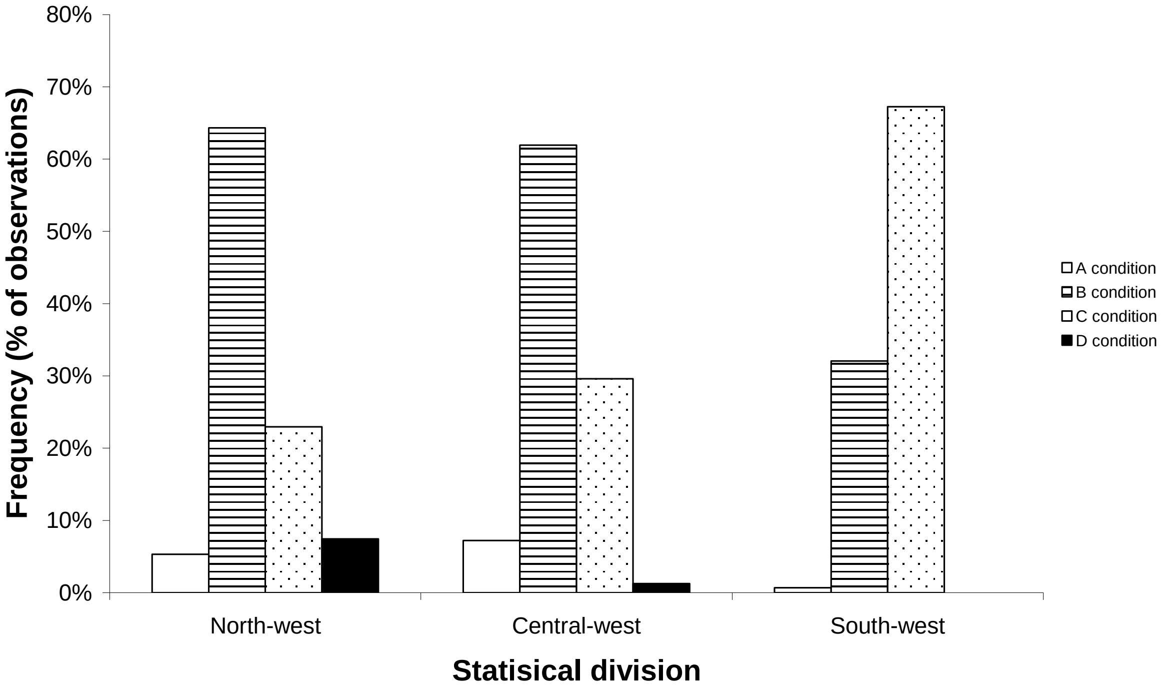


Figure 2. Proportion of A, B, C or D condition classes in 2005 within the amalgamated shire divisions of western Queensland.

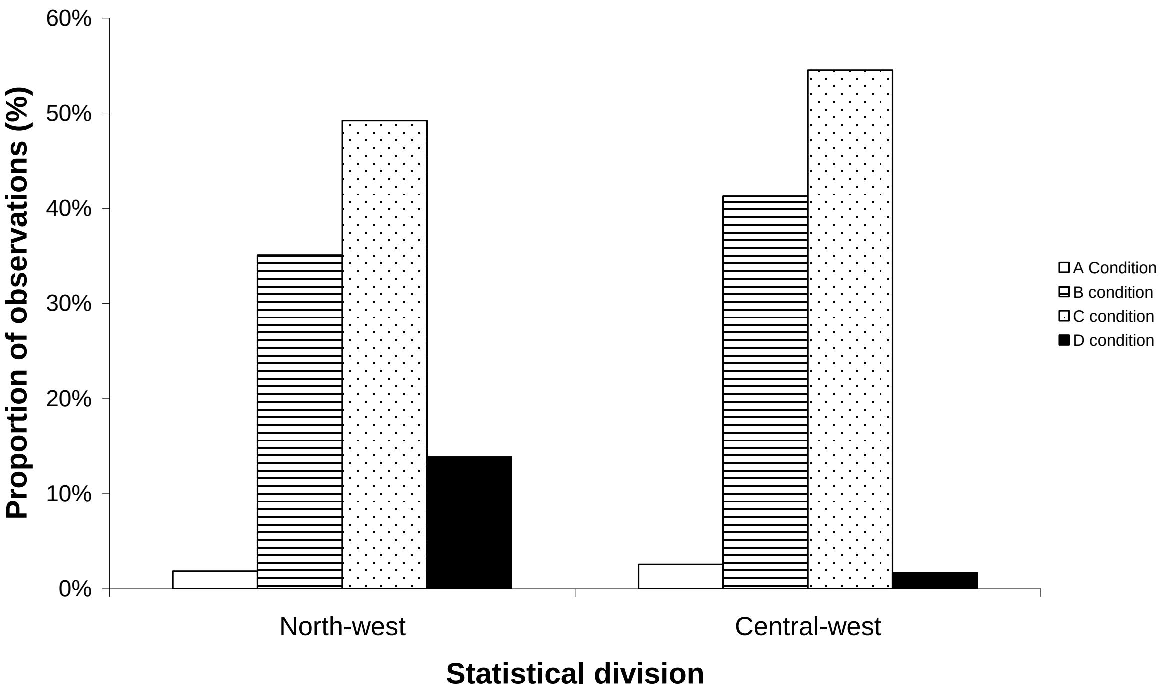
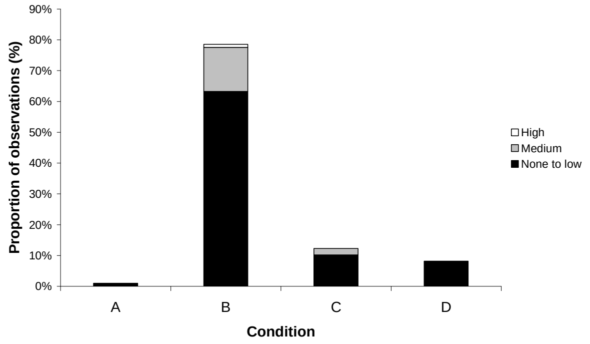
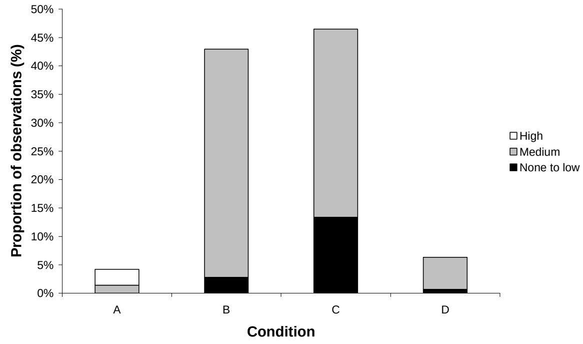


Figure 3. Proportion of A, B, C or D condition classes in 2006 within the north and central-western amalgamated shire divisions.

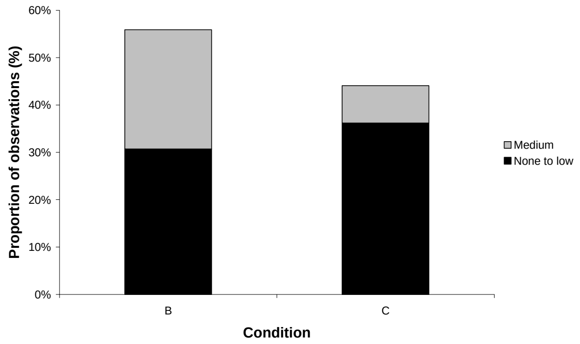
a) Flinders shire in 2005



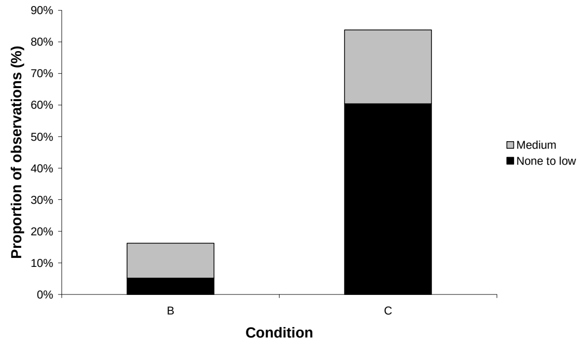
b) Flinders shire in 2006



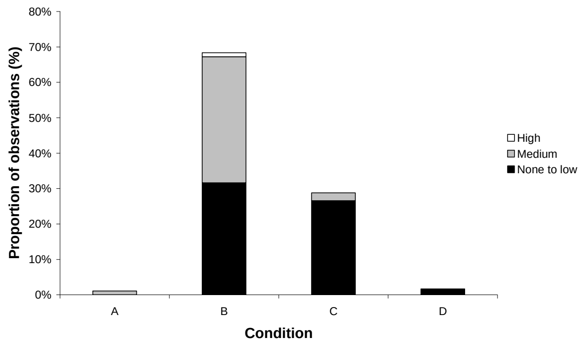
c) Ilfracombe shire in 2005



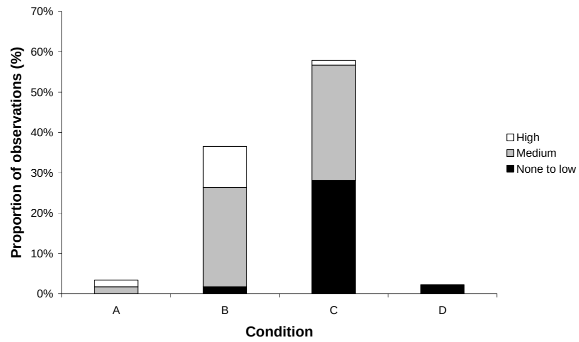
d) Ilfracombe shire in 2006



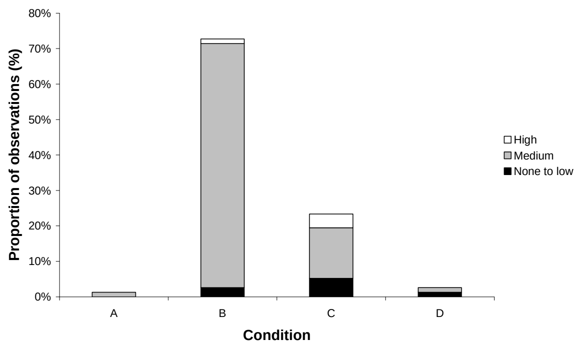
e) Aramac shire in 2005



f) Aramac shire in 2006



g) Winton in 2005



h) Winton in 2006

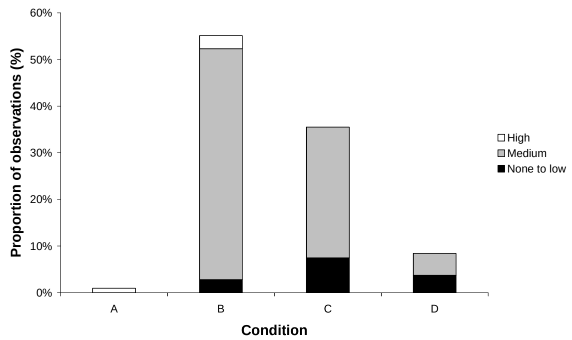


Figure 4. Example shires, showing the distribution of condition classes in relation to Mitchell grass tussock response in 2005 and 2006.

A total of 223 field sites were assessed in 2005 and 91 in 2006, representing 5.0% of the 4310 mobile observations in 2005 and 6.1% of the 1470 mobile observations in 2006. Of these field sites, 77 were belt transects recording *Astrebla* spp. tussock density and response. The remaining 146 were photographic sites, with general pasture observations recorded (e.g. overall tussock density and health, dominant plant species).

The belt transects demonstrated a close association between condition rating and live *Astrebla* tussock density. In both years sites rated in C condition had lower responsive tussock density, with 0.69 and 0.91 responsive tussocks per m^2 in 2005 and 2006 respectively. In contrast, A condition sites had 1.92 and 2.69 responsive tussocks per m^2 in 2005 and 2006 (data not graphed). Sites rated in C condition also had a lower overall tussock density than A or B condition sites (Figure 5).

These measured data support the rapid assessment data which demonstrated lower *Astrebla* response within C condition sites. The data infer similar tussock densities within the A, B and C condition scores for the mobile assessments as the belt transects.

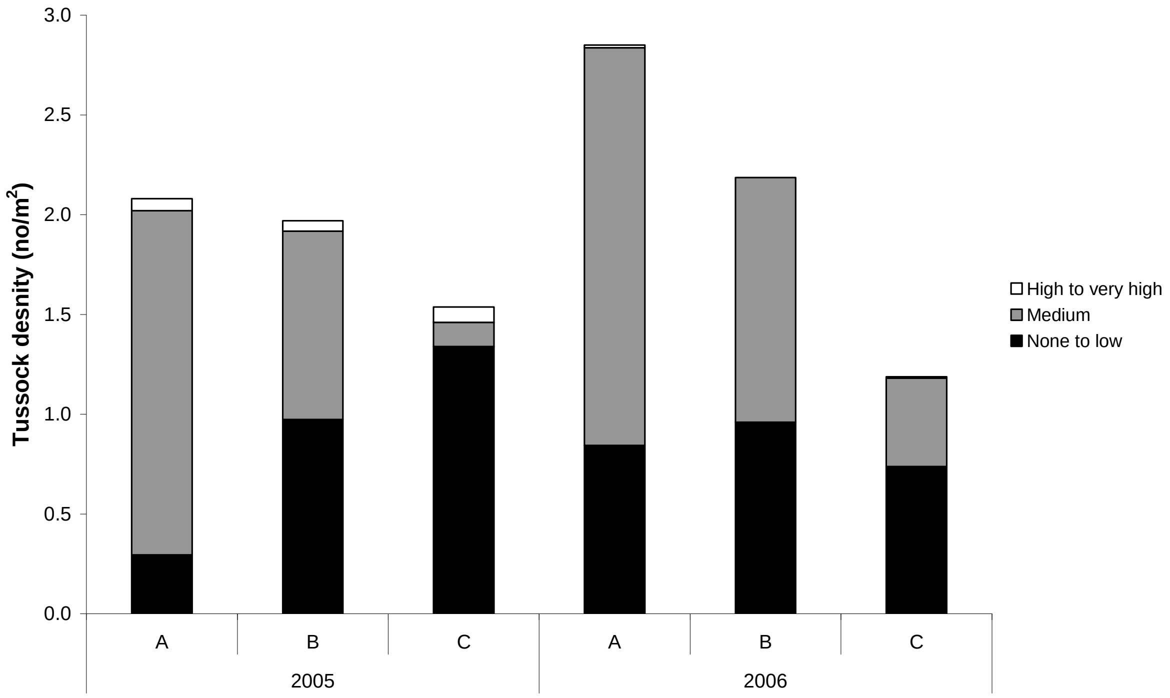


Figure 5. The density of *Astrebla* spp. tussocks showing none to low response, moderate response or high to very high response within A, B or C condition classes in 2005 and 2006 across all areas sampled.

4.1.1 Potential to link with remote sensing tools

The data collected during the rapid appraisal process (both mobile points and validation transects) and from the sites of contrast can be linked to remote sensing tools, such as Landsat or MODIS satellite imagery based cover trend analysis. The inclusion of these key parameters allows point based cover and biomass data to be related to pixels within an image (e.g. Karfs and Saunders 2004). Specifically, these parameters were:

- location (latitude and longitude)
- ground cover (%)
- biomass (kg/ha)
- location of bare areas
- a coarse estimate of tree and shrub cover.

The recording technique, where each side of the road is assessed separately, allows for the identification of fence-line contrasts for further exploration within remotely sensed data. A large volume of cover trend analysis data has been compiled for the Queensland section of the Lake Eyre Basin. The way in which the rapid appraisal data has been collected provides the capacity to link with this data set and value add to both.

4.1.2 Potential to link with GRASP

The data collection includes parameters to allow linkages to be made with GRASP (Park *et al.* 2003) modelling. Specifically, these parameters are:

- location (latitude and longitude)
- green cover (%)
- biomass (kg/ha)
- old growth biomass (% of biomass)
- grazing animal (where apparent)
- a coarse estimate of tree and shrub cover
- an estimate of grass basal area (assigned within condition classes).

The inclusion of these key parameters allows for site-specific rainfall data (such as SILO data) to be modelled through the Mitchell grassland’s parameter file for GRASP, producing site-specific pasture growth data which can then be compared with the observed biomass and green cover values for validation. The lack of detailed grazing pressure data for specific sites would be a limitation of this approach.

In theory, regional rainfall data from Rainman (Clewett *et al.* 2003) could also be used to produce regional pasture growth, as tested by Park *et al.* 2003. At this stage the linkages are conceptual, as modelling has not been conducted to test the data.

4.2 Potential for recovery through soil seed reserves

Mitchell grass soil seed density was low (<10 seeds/m^2) in seven of the 11 paddocks sampled. Mitchell grass soil seed density was high in only two paddocks with one paddock at Morella with 356 seeds/m^2, and one at Ilfracombe with 267 seeds/m^2 (Figure 6). These densities are comparable with maximum values recorded in other field experiments (Orr 1991; Phelps and Orr 1998; Phelps 2006). The high Mitchell grass seed density at Ilfracombe was recorded in a laneway which receives regular wet season spelling, and was in contrast with a low seed density (38 seeds/m^2) in the adjacent continuously grazed paddock (paddock 6). There was also a contrast in Mitchell grass seed density between paddock 8 (a burnt and subsequently ungrazed area, with 102 seeds/m^2) and paddock 9 (a recently ungrazed and unburnt area, with 25 seeds/m^2). Other perennial grass was generally present as low seed density, whilst annual grass reached as high as 2482 seeds/m^2. Both palatable and unpalatable forbs reached moderate densities in the soil seed bank.

In most instances, low seed density was coupled with low *Astrebla* spp. tussock density and hence poor land condition. Graziers were advised that low seed and tussock density created a high risk of further decline in pasture productivity, and that very low grazing pressure and/or wet season spelling was required to encourage the existing Mitchell grass tussocks to set seed. Building the seed bank was promoted as one way of reducing the risk of further land condition decline, especially when annual grass or unpalatable forb densities were high.

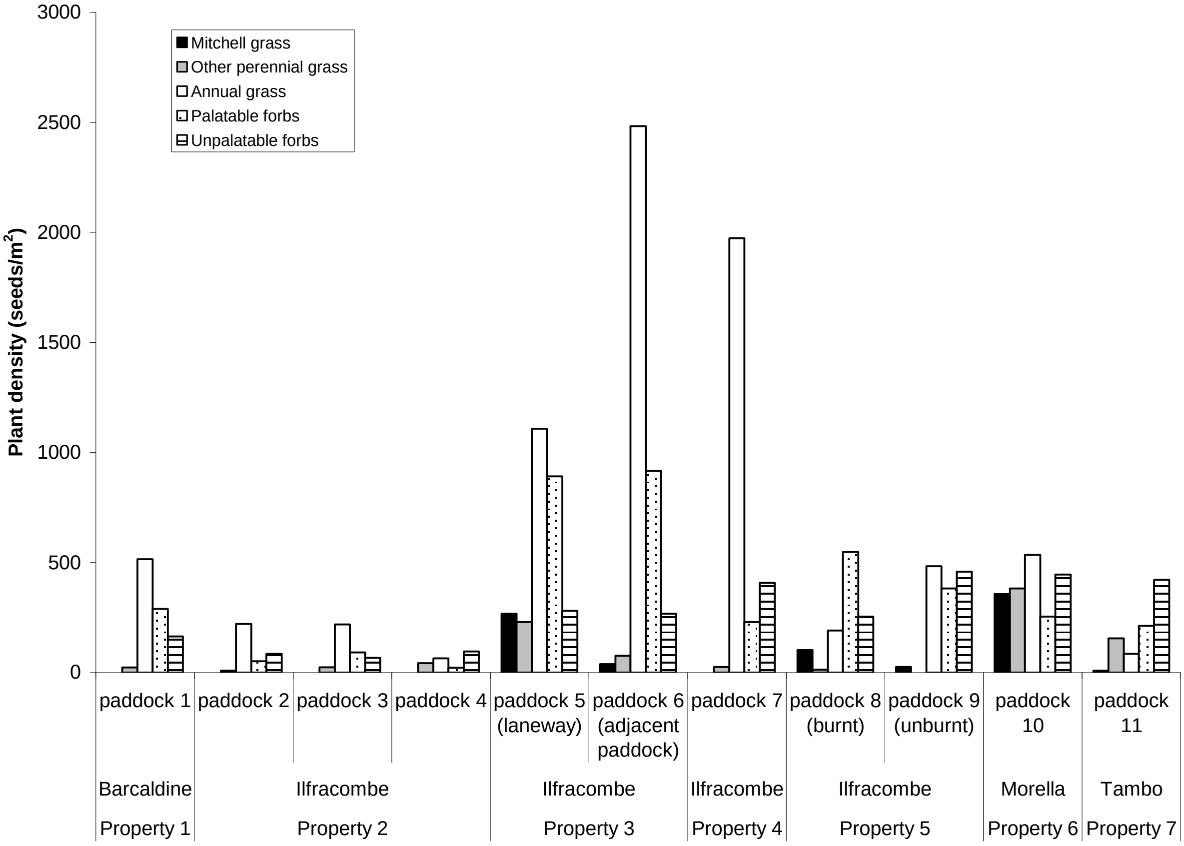


Figure 6. The density of Mitchell grass, other perennial grass, annual grass, palatable forbs and unpalatable fobs in the soil seed bank in 11 paddocks in the Barcaldine, Ilfracombe, Morella and Tambo districts of central-western Queensland.

4.3 Economic impact of reduced pasture condition

4.3.1 Regional scale

The proportion of Mitchell grassland assessed to be in A, B, C, or D condition (Section 4.1, Figure 2, Figure 3) was coupled with estimates of the gross value of primary production (GM basis) within the central-western shires of Longreach, Ilfracombe, Barcaldine and Isisford. It was assumed that carrying capacity is 100% in A condition; 85% in B condition; 45% in C and 25% in D condition (Cobon and Peart 1995; Phelps and Orr 1998; Phelps and Bosch 2002; Chilcott *et al.* 2004).

When land condition in 1991 is used as a baseline, the value of production in 2005 within the central-west was reduced by $5.7 million per annum (Table 3a, b). This value is based on the reduced capacity to carry livestock and does not account for:

- direct costs associated with increased risk through increased livestock trading
- direct costs of additional supplementary feeding
- any other drought related costs
- any flow-on effects of primary production into the surrounding towns of Longreach, Ilfracombe, Barcaldine or Isisford.

The incremental reduction in GM through the broad regional modelling approach was the equivalent to the reductions in carrying capacity. For example, as carrying capacity declines to 85% as land condition declines from A to B, GM also declines to 85% of the potential within the modelling approach taken. The estimates are based on properties carrying their maximum potential within each land condition category, and does not account for the likelihood that carrying capacities are further reduced under continuing drought conditions.

The value of production in 2006 within the central-west was reduced by $10.4 million compared with 1991, based on the estimated increase in C condition land (Table 3c). Assuming the same GM reduction across Queensland, a total loss of $92.4 million is predicted for 2006 based on estimated condition classes (A 2.5%, B 40.2%, C 53.2%, D 4.1%) for the 33.8M ha of Mitchell grass pastures. A total loss of $58.5 million was estimated for 2005. These values represent a 26 and 16% reduction from the total annual GM of $356.9 million from 1991 (Table 3a). These values also represent the potential gains to be made by returning country to A and B condition dominance through drought recovery strategies.

4.3.2 Property scale

A property scale GM analysis was conducted for a cattle scenario only, given the high proportion of cattle in central-western Queensland (75% of livestock), and to represent a property across northern Australia. However, the principles and relative changes will be similar for a sheep based enterprise.

Property scale GM analysis demonstrates a large increase in income in year 2, due to the forced sale of cattle as land condition declines from B to C condition. Subsequently, however, GM is halved as a new ‘steady state’ income level is reached from year 3 onwards (Figure 7).

Further property scale modelling of profit and cash flow suggest that the enterprise becomes unprofitable once land condition declines from B to C, with negative operating, net and economic profit eroding the capital base (Table 4). This would lead to longer term problems should land condition not improve, and potentially result in the forced sale of the business.

The GM analysis fails to capture this negative profit and the subsequent erosion of capital, suggesting the regional GM analysis may also fail to capture these key aspects and hence fail to demonstrate the true severity of the impacts of drought and reduced land condition within the central-west. Such a detailed analysis was outside the scope of this report. GM analysis does not capture changing equity levels and these often impact on tradability and forced property sales.

Table 3. Total, cattle and sheep Gross Margin (GM) values of primary production in central western Queensland within a) each condition class in 1991 (Tothill and Gillies 1992) b) under estimates of land condition in 2005 c) under estimates of land condition in 2006

a) the value of production within each condition class in 1991

Condition class	% in each class	area in class (ha)	GM cattle ($)	GM sheep ($)	GM total ($)
A	70.00%	2,565,980	21,109,481.86	5,982,358.77	27,091,841
B	12.50%	458,210	3,204,810.71	908,483.58	4,113,294
C	12.50%	458,210	1,694,218.85	480,501.77	2,174,721
D	5.00%	183,280	376,955.03	106,827.84	483,783
Total		3,665,680	26,385,466	7,478,172	33,863,638

b) the value of production under estimates of land condition in 2005

Condition class	% in each class	area in class (ha)	GM cattle ($)	GM sheep ($)	GM total ($)
A	3.24%	118,804	977,361	276,981	1,254,341
B	65.01%	2,383,777	16,672,581	4,726,259	21,398,841
C	31.50%	1,155,037	4,270,713	1,211,228	5,481,941
D	0.22%	8,067	16,591	4,702	21,293
Total		3,665,685	21,937,246	6,219,170	28,156,415

c) the value of production under estimates of land condition in 2006

Condition class	% in each class	area in class (ha)	GM cattle ($)	GM sheep ($)	GM total ($)
A	3.24%	118,768	977,067	276,897	1,253,965
B	35.00%	1,282,990	8,973,470	2,543,754	11,517,224
C	61.50%	2,254,396	8,335,556	2,364,068	10,699,625
D	0.22%	8,065	16,586.02	4,700.42	21,286
Total		3,664,219	18,302,680	5,189,421	23,492,101

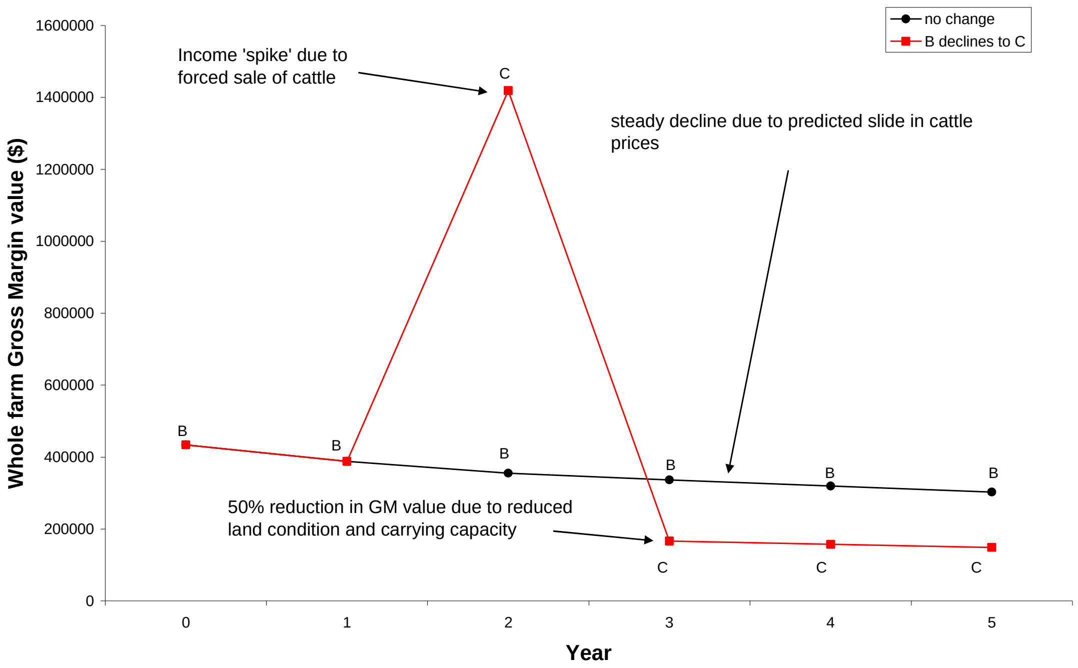


Figure 7. Whole farm Gross Margin (GM, $) analysis for a representative northern Australian cattle property with Mitchell grass pastures, with land condition held constant at B, or declining to C in year 2. Annotations indicate key GM changes.

Table 4. Detailed whole Gross Margin (GM, $), profit, cash flow and balance sheet analysis for a representative northern Australian cattle property with Mitchell grass pastures, with land condition declining from B to C in year 2.

Year	**0**	**1**	**2**	**3**	**4**	**5**
Land Condition (class)	B	B	C	C	C	C
Carrying capacity (AE)	3231	3231	3232	1711	1711	1711
Closing no.	3231	3232	1711	1711	1711	1711
Activity gross margin ($)	434,043	388,353	1,419,003	166,387	157,503	148,905
Profit ($)						
Operating profit (PV)	253,840	196,985	1,053,587	2,494	-7,259	-15,943
Net profit (PV)	100,032	63,151	665,570	-96,447	-102,525	-105,685
Change in trading stock	363	-213,017	-1,107,059	-60,077	-41,249	-39,530
Economic profit (PV)*	-94,560	-316,825	-488,798	-282,570	-256,113	-242,485
Cash Flow						
net increase in cash (PV)	133,271	94,807	695,719	-67,734	-75,180	-79,642
Balance sheet						
Total assets	4,371,327	4,191,379	3,784,872	3,579,907	3,380,993	3,173,526
Total liabilities	472,229	472,229	472,229	472,229	472,229	472,229
Owners equity	3,899,098	3,719,150	3,312,643	3,107,678	2,908,764	2,701,297

4.4 Sites of contrast

4.4.1 Drought impacts

Drought had the strongest influence on *Astrebla* spp. dieback in the 49 paired sites measured, especially record below average rainfall coupled with high evaporation for the 2002/03 summer. Perennial grass mortality in similar Australian climates has been found to increase when the ratio of rainfall to evaporation (R/E) fell below 0.15 for any 3 month period (Hodgkinson and Müller 2005). Soil moisture to 1m depth at the end of the dry season is generally very low (< 5%) in cracking clay soils in western Queensland (Phelps 2003). It may be possible that in cracking clay soils of the Mitchell grasslands the extremely low R/E over the 2002/03 summer would lead to the drying of the soil profile to greater than 1m depth through evaporation to the bottom of the soil cracks. The deep roots of *Astrebla* spp. reach to at least 1.2m depth (Everist 1964) and are critical in keeping the plant alive during drought dormancy (Whalley and Davidson 1969; Phelps and Gregg 1991). Thus the depletion of moisture through the full rooting profile could be assumed to lead to increased mortality during extended periods of soil moisture deficit.

In our study, sites which had been exposed to the longest period of low R/E and had experienced at least one failed summer had significantly lower living *Astrebla* spp. density and basal area (Table 5). A failed summer was defined as a summer where the R/E remained below 0.15 for the entire 6-month period (e.g. Site Ac, Figure 8a). Sites which did not experience a failed summer (e.g. Site Be, Figure 8b) had a high live Mitchell grass basal area (Table 5). Conversely, sites with high dead plant density and basal area had experienced at least one failed summer. There was no difference in total (live plus dead) plant density or in seedling density. Reduced basal area under extended dry conditions is consistent with other published accounts of the dynamics of the pastures of the Mitchell grasslands (Orr and Holmes 1984). Sites on the threshold of a failed summer (e.g. Site Du, Figure 8c) tended towards low *Astrebla* survival (data not presented).

Table 5. The impact of at least one failed summer on *Astrebla* spp. total, dead and live plant density (plants/m^2), dead and live plant basal area (BA, cm/m^2) and seedling density (plants/m^2) at 49 key sites.

Factor	At least one failed summer	No failed summer	significance level*
Live density	1.2	3.1	0.030
Live plant BA	27.8	63.4	0.031
Dead density	1.6	0.7	< 0.001
Dead plant BA	74.4	42.4	0.006
Seedling density	1.7	2.6	0.207
Total density	2.8	3.9	0.165
No. of observations	26	23	

* student's t-test

Multivariate bi-plot analysis of the 49 sites supported the overriding effect of at least failed summer on *Astrebla* spp. dieback. This exploratory multivariate analysis of change in land condition, rainfall, grazing and ecological parameters demonstrated strong associations between declining land condition and:

- failed wet seasons
- dead *Astrebla* spp. density and basal area
- undesirable forbs in the soil seed bank.

There was a weak association between distance to water and declining land condition (Figure 9).

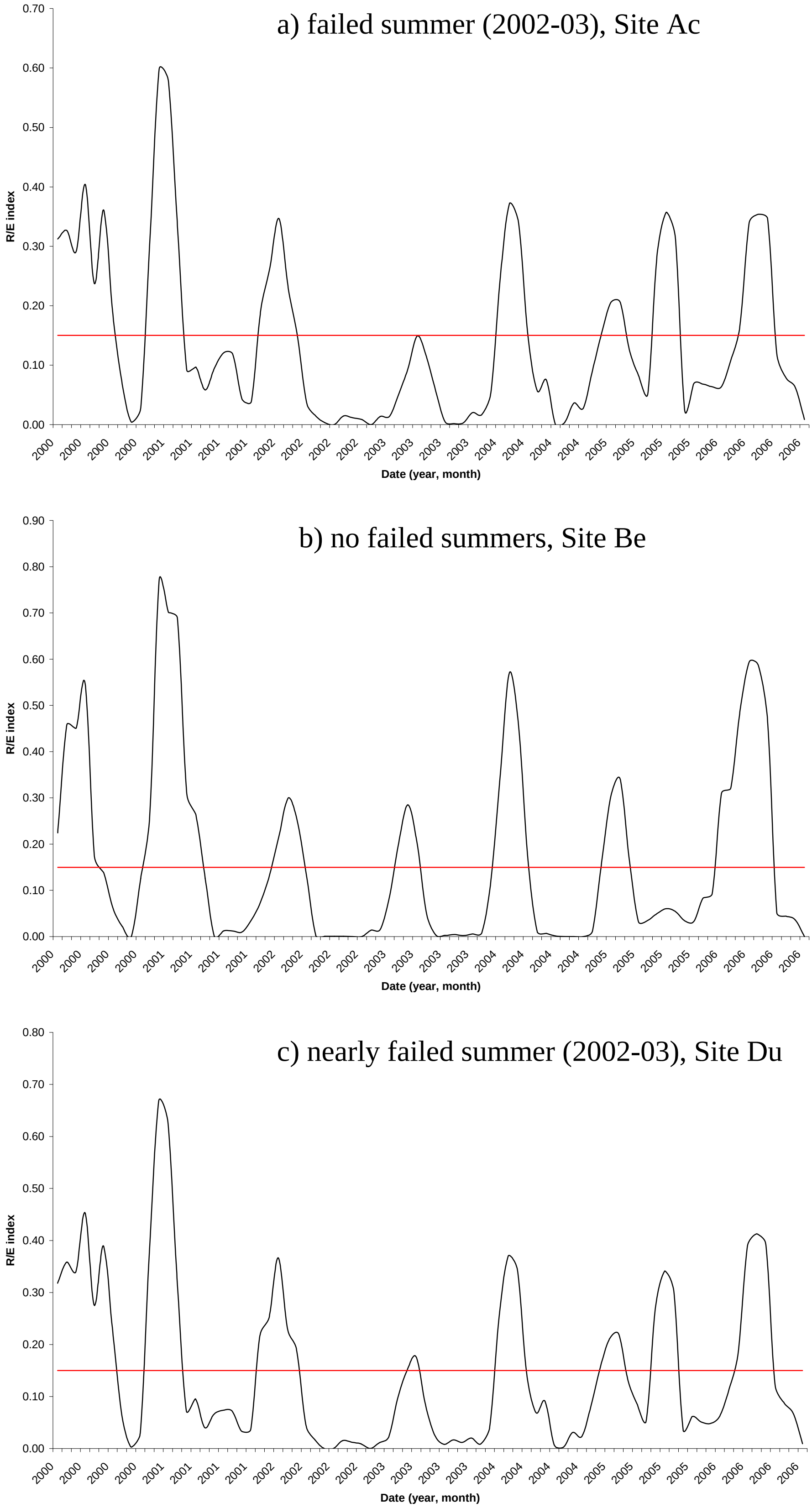


Figure 8. Examples of a) failed b) not-failed and c) nearly failed summers from selected sites. R/E index is the ratio of rainfall to evaporation, derived from SILO data.

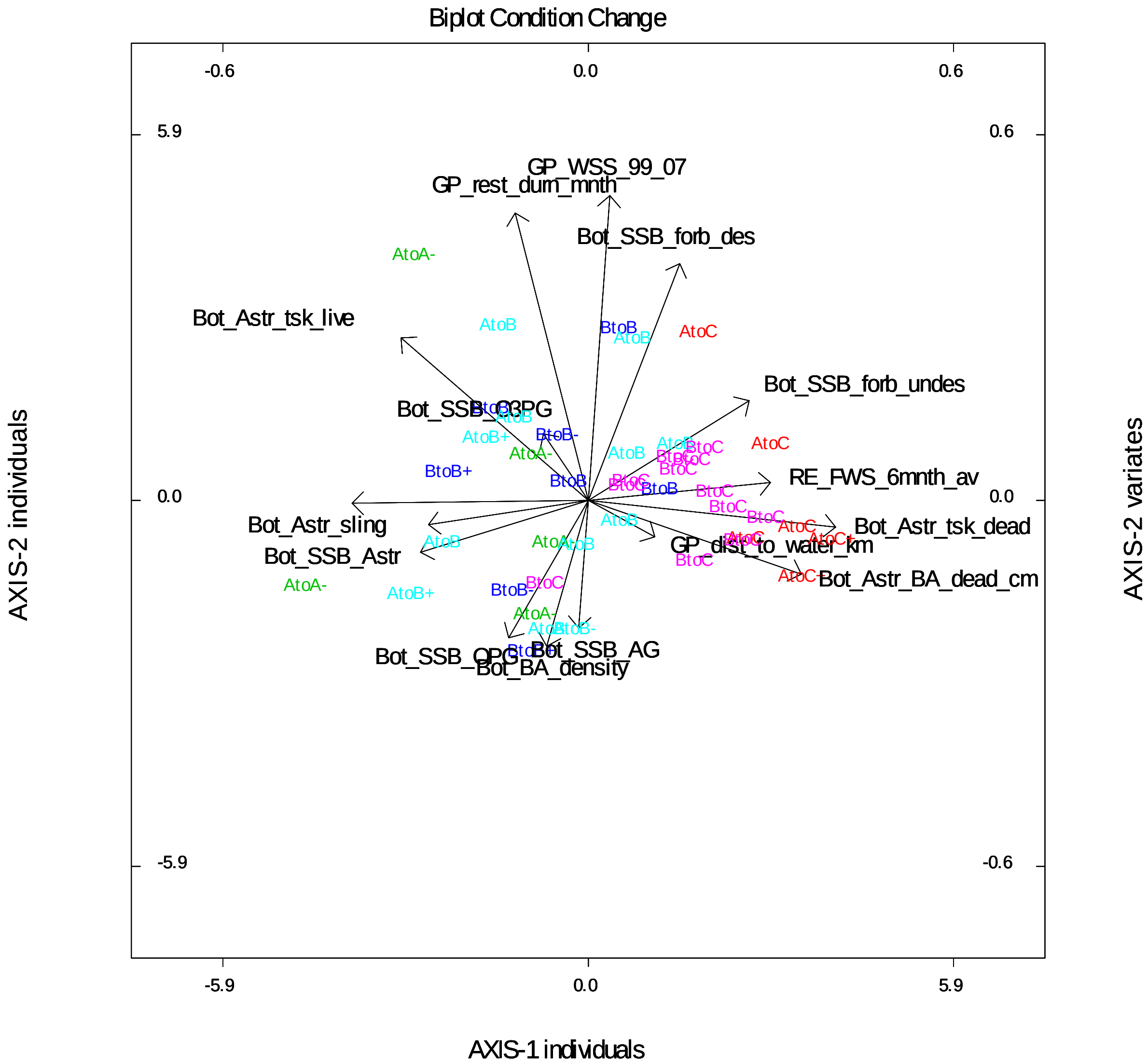


Figure 9. Biplot multivariate analysis of the major botanical (Bot), grazing (GP) and rainfall (RE) factors associated with change in land condition.

Key: SSB indicates density measured through soil seed banks where Astr is *Astrebla* spp., O3PG is 3P grasses other than *Astrebla* spp., OPG is other perennial grasses, AG is annual grasses, forb des is desirable forbs, forbs undes is undesirable forbs; tsk is tussock density, sling is seedling density; GP indicates a grazing pressure variate, where WSS is wet season spell; RE indicates a rainfall and evaporation variate, where FWS is number failed wet seasons using a 6-month rolling average.

4.4.2 Management impacts

Of the 49 sites measured, four pairs showed significantly (P<0.05) enhanced *Astrebla* spp survival due to burning or wet season spelling. One pair had significantly lower *Astrebla* spp survival in the burnt compared with the unburnt site and a further three pairs showed no difference at burnt compared with unburnt sites (Figure 10). The seven paired burnt/unburnt and five paired grazed sites were clustered within five different groups according to change in land condition (see discussion in section 4.4.3).

Three burnt sites were in better (P<0.05) condition than their unburnt pairs, three were not different and one burnt site was in worse condition than its unburnt pair (Figure 10). The only recorded wet season spell site was in better (P>0.05) condition than its paired site which was lightly grazed on a continuous basis. A site grazed to achieve 50% use of end of growing season forage for 24 years was no different to a site grazed to achieve 10% use, whilst a site grazed to achieve 80% use was in better (P<0.05) condition than either the 10 or 50% use site.

The three burnt sites with a superior level of living *Astrebla* spp. tussocks compared with their paired sites were in the Longreach and Winton districts and had all experienced a failed summer over 2002/03 (R/E <0.15, Figure 8a). One site had burnt in March 2001, one in December 2002 and the other in January 2001. Each site was rested over the summer following burning and did not experience high grazing pressure from kangaroos.

Of the three sites where burning made no difference, two were historical burn scars from January 1991 and February 2000 and pre-dated the well above-average summer rains of 2000/01. Neither was de-stocked following the burn. One was a recent burn, from March 2003, which was not de-stocked following the fire.

The single site where burning lead to reduced *Astrebla* spp. survival was an historical fire scar from January 2000 and pre-dated the well above-average rainfall over the summer of 200/001. It was located within 500m of a water point, and whilst de-stocked for 5 months following burning, was reported to be grazed heavily by kangaroos over this time.

Burning can stimulate *Astrebla* spp. tillering, seed production and yield, although it has previously been recorded only following above average rainfall (Scanlan 1980; 1983). In another study, *Astrebla* spp. tillering, basal area and survival was not reduced through burning, even when followed by a summer with below average rainfall (Phelps 2006). It is thus plausible that a single burn could promote *Astrebla* spp. survival during drought, perhaps through the promotion of new tillers. When burning is coupled with high grazing pressure over the subsequent summer, however, the interaction is generally detrimental to perennial grass survival (Orr *et al.* 1991; Orr and Paton 1993; 1997; Orr 2004). The range of responses found in the current study strongly suggests that burning can reduce the impact of drought on *Astrebla* spp. dieback, but the mechanisms are not clear. It appears, however, that spelling was required and that the burn needed to occur once the drought began.

The wet-season spell site which demonstrated superior level of living *Astrebla* spp. tussocks was within a laneway which has been grazed heavily by sheep for 3-6 weeks every winter for at least the last 20 years. The laneway is ungrazed for the rest of the year. Discussions with the land-holder suggest that residual stubble height is generally less that 10cm. The response, even during the height of the drought, was spectacular. Mitchell grass tussocks grew new tillers from the crown, set seed and visual estimates of pasture yield ranged between 800 and 2000 kg/ha of dry matter. In contrast, tussocks in the adjacent paddock failed to tiller, and hence did not set seed, and yields ranged from 150 to 500 kg/ha.

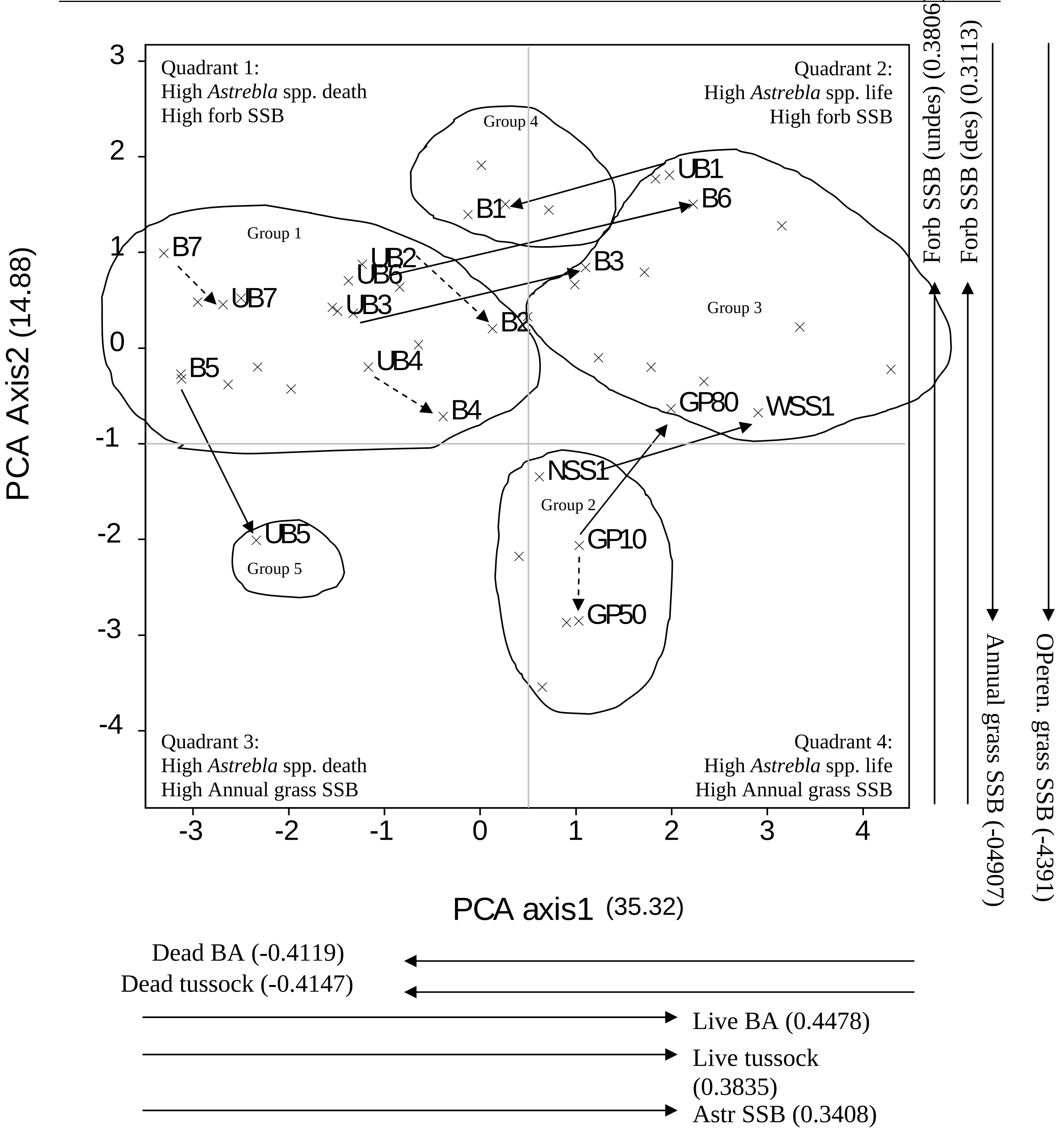


Figure 10. Principle Components Analysis (PCA) of 45 sites of contrasting drought management (grazing, burning) within the Mitchell grasslands.

Solid arrows represent different ($P<0.05$) paired key sites; dashed arrows represent similar ($P>0.05$) key sites where : WSS1 is wet season spell paired with NSS1 (no spell); GP is a grazing pressure gradient (10, 50, 80% annual pasture use); B is burnt (sites 1-7) paired with unburnt (UB) sites 1-7. Annotations indicate: Groups (1-5) identified in ordination space guided by land condition; broad groupings represented by Quadrants 1-4; percentage variation explained by each axis; and the main latent vectors. Analysis based on square root transformed live and dead *Astrebla* spp. tussock density (no/m^2), basal area (BA cm^2/m^2) and soil seed bank (SSB no/m^2) functional groups (*Astrebla* spp. – Astr; desirable perennial grasses, excluding *Astrebla* spp. – O3P grass; undesirable perennial grasses – OPeren. Grass; Annual grasses; desirable forbs – forb des.; undesirable forbs – forbs undes.).

Anecdotal evidence suggests enhanced soil moisture levels within the laneway. A simple push probe was used to determine soil moisture depth following rains in early 2005. The push probe consistently penetrated to a depth of 70-80 cm within the wet season spell site, but to only 40-50 cm in the adjoining paddock. Given that *Astrebla* spp. are deep rooted (to at least 1.2 m, Everist 1964) and drought dormant (Whalley and Davidson 1969), it seems plausible that the greatest gains in future understanding will come from underground. Has Mitchell grass root growth been promoted within the wet season spell site, leading to enhanced infiltration rates (as per Tongway and Ludwig 1995)? What is the relationship between soil moisture depth and the breaking of *Astrebla* spp. drought dormancy? Other studies have demonstrated that *Astrebla* spp. can extract more soil moisture than many other perennial grasses (Phelps and Gregg 1991), yet it has still failed to respond as well as would be expected during the millennium drought. Why should a single burn promote survival? Could enhanced survival be related to the age structure of tillers?

A heavily grazed location in the Hughenden district has been observed, but not measured, due to a lack of access. Heavy grazing by sheep during the early wet season appeared to have reduced the competition from *Iseilema* spp. (Flinders grass) and annual forbs, leaving more soil moisture available to promote rapid *Astrebla* spp. growth. Unfortunately, high grazing pressure was maintained for the duration of summer resulting in a pasture dominated by *Pimelea decora* (Flinders poppy) following mid-summer rains. *Pimelea decora* appears to be an indicator of over-grazing (Phelps and Orr 1998; Phelps and Orr 2003). Interestingly, there is a commonly held belief within the grazing community that sheep can be used to compact widely-cracked Mitchell grassland clay soils to reduce moisture loss, especially during drought, by filling in the cracks.

The higher live *Astrebla* spp. density within the heavy grazing pressure (80% use) paddock of the long-term grazing experiment is counter-intuitive. However, this paddock was de-stocked for the 1998/99 growing season, and has been periodically de-stocked towards the end of the dry season when there is insufficient forage available to maintain animals in the paddock (Phelps and Orr 1998). The 1998/99 summer received above-average rain. It appears that the single wet-season spell at this critical time allowed *Astrebla* spp. tussocks to recover.

Discussions with graziers and personal observation identified additional burnt areas and laneways, some of which appear to show contrasting levels of dieback and others which do not. It was not possible to measure every potential site within the current project, but it is apparent that a broader dataset could be investigated. This would allow further hypothesis of factors which exacerbate or alleviate *Astrebla* dieback to be developed.

It is possible that burnt sites which have failed to alleviate Mitchell grass dieback demonstrate more complex interactions between burning and grazing in relation to rainfall events, or represent differences in burning frequency or fire intensity, all of which change the outcome of burning within Mitchell grasslands (Phelps 2006). It is also possible that laneways which exhibit the same high levels of dieback as adjacent paddocks have more complex interactions between the intensity, timing or duration of grazing in relation to rainfall events.

It is apparent that grazing and burning can influence both *Astrebla* spp. survival and land condition change during drought. It had been previously assumed that low rainfall and high evaporation, and the resultant low soil moisture levels and associated plant stress, was the main cause of Mitchell grass dieback. The data suggest that rainfall deficit is not the sole reason for increased *Astrebla* spp. mortality, and that there is the potential for management to alleviate or exacerbate the situation. The underlying mechanisms are not yet understood.

4.4.3 Detailed multivariate analysis

Stable land condition was generally associated with moderate to high live *Astrebla* spp. tussock density, *Astrebla* spp. seedling density, *Astrebla* spp. soil seed bank density and the soil seed bank density of 3P grasses other than *Astrebla* spp. Increasing desirable forb density tended to be associated with wet season spelling and increasing duration of the rest season.

Initial Principal Components Analysis (PCA) using combined rainfall, grazing and ecological parameters lead to weak axes and limited power of explanation. PCA relies on the assumption that data have a normal distribution and generally linear relationships (Kendall 1980; McCune and Grace 2002), which may not have been true for the multiple parameters with different units.

The data set was refined back to ecological data alone, and the assumption of generally linear relationships was confirmed through regression analysis. Individual species soil seed bank data were tested, but refined into functional groups of *Astrebla* spp., desirable perennial grasses other than *Astrebla* spp. (O3P), undesirable perennial grasses (OPG), annual grasses (AG), desirable forbs and undesirable forbs. This data set was successfully combined with field measurements of *Astrebla* spp. basal area, density and seedling density. A correlation matrix approach was used within PCA, as the data had different units of measurement (McCune and Grace 2002).

Five groups were identified within PCA multivariate space. These groups broadly described changes in land condition from estimated prior condition to condition at the time of measurement (Figure 11). *Astrebla* spp. live and dead tussock density, basal area (BA) and seedling density and most functional groupings of soil seed banks (SSB) were different ($P<0.05$) within each of these groups, based on a MANOVA analysis of groups as treatments. The exceptions were O3PG SSB ($P=0.219$) and desirable forbs SSB ($P=0.064$).

The five groups were then used within a Discriminant Analysis (DA) to determine the degree of difference and overlap. Groups 2, 3 and 4 were different ($P<0.05$) from Groups 1 and 5, which overlapped with each other (Figure 12). There was limited overlap between Groups 2 and 3.

Astrebla spp. live and dead tussock density and basal area were the most important parameters on PCA axis 1, demonstrating an inverse relationship. Forb SSB was positively related to PCA axis, whilst AG and OPG SSB were negatively related to PCA axis 2 (Figure 10). These relationships could be summarised into four quadrants within PCA space:

- Quadrant 1 with high *Astrebla* spp. dead tussock density and BA and high forb SSB
- Quadrant 2 with high *Astrebla* spp. live tussock density and BA and high forb SSB
- Quadrant 3 with high *Astrebla* spp. dead tussock density and BA and high AG SSB
- Quadrant 4 with high *Astrebla* spp. live tussock density and BA and high AG SSB.

The parameters related to *Astrebla* spp. density and BA, and hence important drivers of PCA axis 1 were determined through a correlation analysis (Appendix 9.2). In general high live density and BA were associated with:

- higher summer rain and less frequent failed summers
- higher cattle grazing pressure over the summer of 00/01
- lower sheep grazing pressure over the summer of 01/02
- lower kangaroo grazing pressure over the summer of 02/03 and
- lower winter rain over 2003, 04, 05, but higher winter rain over 2006 (Table 6).

It is not clear how winter rain could be both positively and negatively correlated with *Astrebla* spp. tussock survival. Further investigation to determine if this is a real correlation or a mathematical artefact would be useful.

Should predictions of increasing rainfall variability, and possibly increased drought frequency, through climate change (e.g. Gabriel and Willcocks 2004) prove to be correct, it is imperative that we better understand the potential for enhanced drought management into the future.

Specific hypotheses that are worth further investigation based on these findings include:

- young (<2 years old) tillers have a greater probability of surviving drought than old (>2 years old) tillers
- deep root development is enhanced through dry season grazing and wet season spelling
- shallow root development is enhanced through reducing plant competition
- heavy grazing during phase 1 pasture growth reduces root development
- increased root mass increases drought survival
- retarded root development reduces plant vigour
- winter rain can lead to small bursts of phase 1 growth which are very susceptible to overgrazing
- condition change within the Mitchell grasslands is greater underground, than above ground.

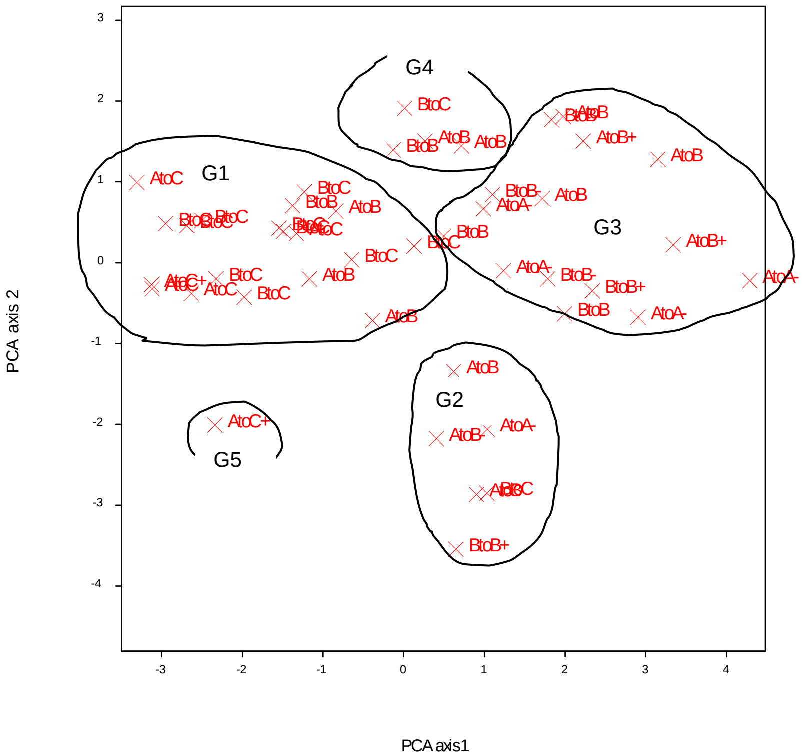


Figure 11. Formation of groups (solid outline) within a) PCA ordination space based on clustering and trends in site condition change (annotations; Group 1 (G1) tended to decline from A or B to C condition; Groups 2-4 (G2-4) tended to be stable, or decline slightly from A to B; Group 5 (G5) was an outlier which declined from A to C condition).

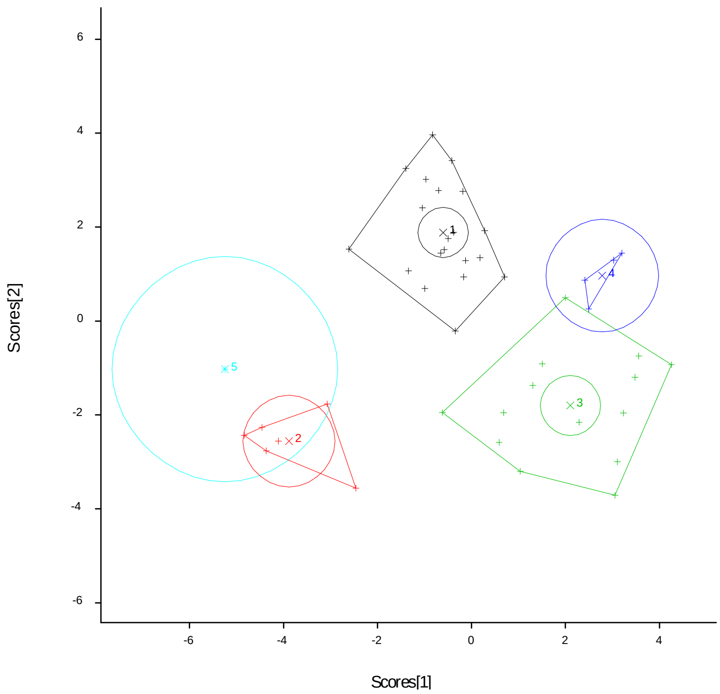


Figure 12. Discriminant analysis (DA) based on five groups identified within Principle Components Analysis (PCA) ordination space. Irregular shapes are the outer bounds of each group; circles are 95% confidence intervals.

Table 6. Main correlation factors associated with live *Astrebla* spp. tussock density or basal area ($P<0.05$).

Negative (detract from survival or live BA)	Positive (promote survival or live BA)
Associated with Quadrants 1 & 3	Associated with Quadrants 2 & 4
a) positively correlated with dead tussock density or BA	b) negatively correlated with dead tussock density or BA
number of failed wet seasons: based on the 3-month moving average of rainfall:evaporation (0.15 threshold) based on the 3-month moving average of rainfall:evaporation (0.20 threshold) based on the 6-month moving average of rainfall:evaporation (0.15 threshold)	rainfall:evaporation ratio (0.15 threshold) in summer of: 2000-01 2003-04 2005-06
kangaroo grazing pressure (Summer of 02-03)	average daily rain (mm from October 1999 to time of site measurement)
sheep grazing pressure (Summer of 01-02)	cattle grazing pressure (Summer of 00-01)
dead *Astrebla* spp. basal area (cm/m^2)	live *Astrebla* spp. basal area (cm/m^2)
dead *Astrebla* spp. tussock density (no/m^2)	live *Astrebla* spp. tussock density (no/m^2)
Change in condition (%)	*Astrebla* spp. seedling density (no/m^2)
	Astrebla spp. SSB (no/m^2)
	Total yield (DM kg/ha)
	Site_condition (A, B, C, D)
c) negatively correlated with live tussock density or BA	d) positively correlated with live tussock density or BA
rainfall:evaporation ratio (0.15 threshold) in winter of: 2003 2004 2005	rainfall:evaporation ratio (0.15 threshold) in winter of: 2006

4.5 Industry engagement

4.5.1 Steering committee

The steering committee met twice formally, with all members in attendance. The committee contributed strongly to the development of the Mitchell grass recovery information kit and to deciding the target areas for distribution. On-going discussions have been held with individual committee members throughout the course of the project, including property visits and the inclusion of committee members' properties in the sites of contrast analysis (Section 4.4).

4.5.2 Industry publications

Feedback on the Mitchell grass drought recovery kit was received from 72 industry members (9% of total recipients). The kit was judged to be both useful and relevant (Figure 13). Some feedback comments made by producers included:

- "Thankyou very much for this booklet, very helpful in managing our grasses and grass productivity."
- "I think that the information on the cycle of the Mitchell grass would be a big benefit to a lot of graziers, as I had no idea of its lifespan."
- "Pictures a good yardstick for assessing condition".
- "Very timely and user friendly."
- "I applaud your effort to educate industry on the management of their Mitchell grass; however I don't believe this pack has answered any of the questions being asked. The majority of the industry is well versed on stocking rates for available pasture."

The final comment suggests industry could be surveyed more widely to determine specific questions that could be addressed in any future research.

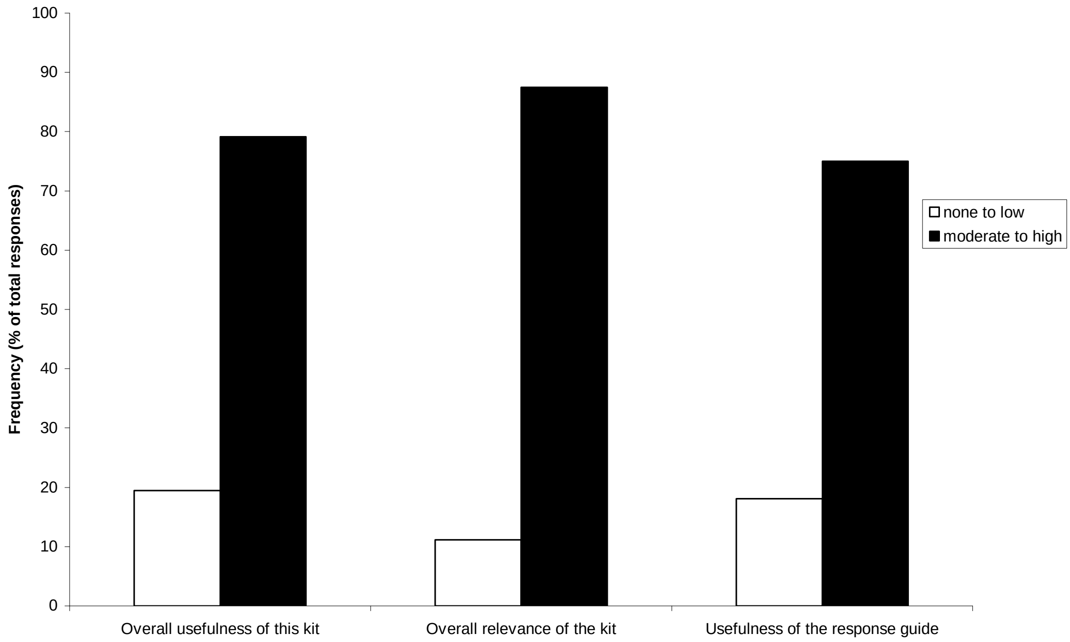


Figure 13. The relevance and usefulness of the information kit as indicated through industry feedback.

4.5.3 Industry training

Industry members who attend training workshops consistently ask for the latest information to assist in managing Mitchell grass during drought. Industry members also request a publication from the long-term grazing study conducted as Toorak Research Station, Julia Creek, which was used within the sites of contrast analysis (Section 4.4).

4.5.4 Industry advice

Soil seed bank samples were provided from three properties. Species were counted individually but combined into functional groups of Mitchell grass, other perennial grass, annual grass, unpalatable forbs and palatable forbs for reporting to cooperating graziers. Mitchell grass seed was limited to one property in the Tambo district, and at relatively low levels (8 seeds/m^2). Co-operators were advised that a slow recovery from the current drought can be expected, as isolated live Mitchell grass plants will be the major source of seed production. The implications of high densities of annual grasses in competing with *Astrebla* spp. seedlings, or undesirable forbs in reducing productivity were discussed with co-operators.

4.5.5 General awareness

A total of 11 related media releases or popular articles were issued since the commencement of the project (four in 2005, four in 2006 and three up to May 2007). These have been taken up by ABC radio (national, Queensland and western Queensland), national media (e.g. The Farm Journal, Feedback and Frontier magazines), Queensland-wide media (the Queensland Country Life and the Courier Mail) and local and regional Queensland newspapers (e.g. Longreach Leader, Charleville Times, and North-west Register). A total of 15 related articles have been published in regional DPI&F newsletters. This high level of interest followed on from National radio and television exposure, a series of three articles in the Queensland Country Life and international exposure through the Range Management Newsletter (Phelps 2004) in 2004.

One paper was presented at the 14th Australian Rangeland Conference in Port Augusta, South Australia (Orr and Phelps 2006) and a paper has been invited for presentation at the 2007 National native pasture conference to be held in Mudgee, October 2007.

One project newsletter was produced and distributed electronically to over 100 recipients in 2005.

4.6 General discussion

The Mitchell grasslands are resilient (e.g. Orr and Phelps 2002; 2004), and historically have shown few overt signs of degradation. Whilst the Mitchell grasslands appeared to be in good condition following high summer rains in 1999-2000 and 2000-01, an overall decline in land condition between 1978 and 2006 is inferred from the literature and the data reported here.

In 1978-81, 80% of the Mitchell grassland area was estimated to be in 'good' condition. In 1991, Mitchell grasslands were generally in sustainable (A level) condition (70% in the northern areas, 70% in the central areas and 25% in the southern areas, Tothill and Gillies 1992). Assessments in the north and central-west in 2005 were dominated by A and B condition. If we assume that the Tothill and Gillies sustainable (A level) condition equates to A and B condition under the ABCD framework (Chilcott *et al.* 2004), then condition was relatively stable compared with 1991. However, the dominance of C condition in re-surveyed areas in 2006 suggests that condition has 'flipped' from being dominated by sustainable categories (A and B condition classes) to being dominated by sites in deteriorating (C) condition. It is likely that this is due to the death of low-vigour Mitchell grass tussocks during the 2005-06 summer. The area of Mitchell grasslands in degraded (D condition, or level C in the Tothill and Gillies framework) has altered little.

Further condition assessments after general drought-breaking rains would help to clarify if land condition has 'flipped' over the 2005-06 summer, to a persistent low condition state or if tussock density can return relatively quickly from seed banks or low-vigour rootstock. Anecdotal evidence from the McKinlay district over the summer of 1996-97 suggests that Mitchell grasslands condition can be restored in a single wet season, should sufficient rains fall. In the case of the 1996-97 summer, approximately 600 mm of rain fell between October 1996 and May 1997. *Astrebla* spp. tussock density increased from 5-6 tussocks/ha to 2-3 tussocks/m^2 over this time (unpublished data). It is hence possible that large areas of the Mitchell grasslands could be restored to sustainable condition through well above-average rainfall. It will be important to document this return to sustainable land condition.

The current cost of reduced condition and the resultant reduced productivity is estimated at $58.5 to $92.4 million per annum until land condition is restored. It would be useful to model changing livestock numbers and value of production from the Mitchell grasslands in conjunction with changing land condition. Further cash-flow modelling would reveal other costs associated with drought and declining land condition, such as increased costs of supplementation or increased risks involved in high livestock turnover within C condition country.

It is now clear that management plays a role in promoting *Astrebla* spp. survival, or exacerbating mortality, during drought. High sheep and kangaroo grazing pressure during drought are likely to exacerbate mortality, and lead to declining land condition. The processes involved in such selective grazing pressure have been well documented (e.g. Orr 1975; 1978; 1980a; 1980b; Orr and Holmes 1984; Orr 1998). However, the effects of this grazing may not occur consistently across different seasons, with only one summer's grazing correlated with *Astrebla* spp. death. It is possible that the same grazing pressure can lead to different results in different wet seasons.

Cattle grazing promoted *Astrebla* spp. survival over the 2000-01 summer. This trend is at odds with previous research which has shown that high grazing pressure with cattle during the growing season leads to increased mortality and fragmentation of *Astrebla* spp. tussocks (Hall and Lee 1980; Phelps 2006). This is primarily through portions of tussocks being pulled from the ground during the action of grazing. Once tussocks are fragmented, which may also occur following burning or during drought, cattle grazing over summer will keep tussocks fragmented (Phelps 2006). Fragmented tussocks are less productive than intact tussocks, through reduced basal area and high mortality of small tussock segments. Fragmented tussocks have a high capacity to reform into intact plants. In the absence of grazing, small segments have been found to coalesce into larger, more robust, tussocks with increased basal area and low mortality (Phelps 2006).

Could it be possible that cattle grazing leading into the drought removed old tillers, thus encouraging young growth better able to survive drought? Instead of tillers of two to three years of age dominating tussock tiller composition going into drought, young tillers (<2 years old) may have dominated tussocks. It is plausible that these young tillers, with younger associated rhizomes and root structures, could be better able to survive drought than older tillers with a greater tendency to moribund and old structural material. It is also plausible that it is the same mechanism is involved in burning that encourages *Astrebla* spp. survival.

Reducing competition over the growing season may also advantage *Astrebla* spp. Bushell *et al.* 1993 found that *Astrebla* spp. re-established better in the absence of competition from forbs. High densities of *Iseilema* spp. seedlings are known to out-compete *Astrebla* spp. at the seedling establishment stage (Orr and Evenson 1993). An area of high grazing pressure with sheep in the northern Mitchell grasslands has been observed since the 2005-06 summer. The sheep grazed out the *Iseilema* and forb seedlings, allowing *Astrebla* spp. tussocks to respond quickly during the first 4-6 weeks of the growing season. Unfortunately, we were unable to obtain measurements at this site and it was not included in the sites of contrast dataset.

Whilst plausible, there are no data yet available to validate the speculation that cattle or sheep grazing at critical times may enhance, or diminish, *Astrebla* spp. survival. This lack of data also limits our ability to provide management recommendations.

Given that cattle and sheep are both known to weaken *Astrebla* spp. tussocks during the growing season, it can be assumed that wet season spelling will be advantageous by allowing drought stressed and fragmented *Astrebla* spp. tussocks to regenerate. Incorporating wet season spelling into drought management is thus the only obvious management recommendation at this stage.

The lack of rain, and associated soil moisture deficit, is the major contributor to *Astrebla* spp. mortality during drought (e.g. Orr and Phelps 2002; 2004). As with other perennial grasses (e.g. Hodgkinson and Müller 2005) mortality increases over time as the drying effects of high evaporation compound in conjunction with low rainfall.

However, the details of the soil moisture dynamics are unclear. Above average rain in 2004 wet up the soil profile in the long-term grazing trial at Toorak, but failed to elicit a response from *Astrebla* spp. tussocks (unpublished data). Is it as simple as insufficient moisture to break drought dormancy? Was the moisture penetration of insufficient depth to activate the deep roots – assuming that the deep roots are critical in the breaking of drought dormancy? Anecdotal evidence at the wet season spell contrast site suggests that there was greater depth of moisture penetration under spelled conditions than the surrounding lightly grazed to ungrazed area. Could the wet season spell encourage root growth or soil biological activity which then channel moisture to a greater depth (as per Tongway and Ludwig 1995)?

Members of the project steering committee have expressed their concern over a general decline in productivity within their pastures during the recent drought. Could this decline be related to limited root growth or soil biological activity? The future of Mitchell grass research and management may well be underground.

It is interesting to note that peak periods of research in the Mitchell grasslands have occurred during drought – typically funding has been limited once successive droughts have broken, leaving us no closer to improved drought management. If predictions of climate change leading to greater drought frequency prove to be accurate (Kump 2002; Walsh *et al.* 2002; Gabriel and Willcocks 2004), then enhanced drought management to halt the declining land condition within the Mitchell grasslands is imperative.

We have an opportunity to conduct the necessary research to improve our understanding of the critical factors promoting *Astrebla* spp. survival during drought.

4.6.1 Future research and extension direction

Industry currently stands to lose up to $150 million per annum until land condition and productivity is restored. Further research which leads to improved drought management and land condition will therefore contribute substantially to the long-term future of the red-meat industry in Queensland.

Three broad areas for further work can be identified from the current project:

1. Continued monitoring of the condition of the Mitchell grasslands to alert us to any further declines in land condition, to confirm the rapid decline in land condition between 2005 and 2006, and to monitor any recovery of land condition.
2. Improved economic analysis of the costs associated with declining land condition and drought management.
3. Research to link the ecology and biology of *Astrebla* spp. with high rainfall variability to inform new management practices that will minimise the impact of future droughts.

Continued monitoring of land condition could be conducted through either ground based assessments, or remote sensing applications in conjunction with targeted ground based assessments. Ground-based rapid appraisal assessments conducted in 2005 took two operators 6-8 weeks in total, plus 1-2 weeks of training. A vehicle, laptop, GPS, digital camera, quadrats, shears, bags, drying ovens and scales were the other necessary equipment to conduct the surveys. The abridged re-assessment in 2006 took two operators 2-3 weeks to complete. Rapid appraisals can be conducted relatively cheaply, provided they are part of on-going projects. More resources would be required to integrate rapid appraisal assessments with remote sensing applications. This could be efficiently achieved through collaboration with existing groups with remote sensing expertise and resources.

Improved economic analysis could be conducted through a desk-top exercise coupled with on-farm surveys and tapping into existing surveys of changing livestock numbers. A thorough analysis may take an economist 8-12 weeks to complete over a period of 12-18 months.

Improved understanding of the dynamics of *Astrebla* spp. is needed to devise improved drought management, and reduce the impact of future dieback events. Specific topics include quantifying:

- Mitchell grass root distribution and growth rates from seedlings to mature tussocks, and the impacts of grazing and burning e.g. does wet season spelling encourage root growth
- soil moisture dynamics in relation to Mitchell grass root distribution and the processes involved in the breaking of drought dormancy e.g. are deep roots (>100 cm depth) implicit in the breaking of drought dormancy

- the role of tiller dynamics and age structure in providing vigorous tussocks e.g. do younger tillers (<2 years old) survive soil moisture stress better than old (>2 years old) tillers
- the rate of *Astrebla* spp. vegetative compared with sexual establishment (e.g. from low-vigour rootstock, compared with soil seed banks)
- the fate of seed at depth
- the role of early wet-season competition in retarding *Astrebla* spp. growth.

Research to improve our understanding would be the most resource intensive, but also pay the greatest dividends for industry. Monitoring would inform of actual changes and detailed economic analysis would inform the costs of these changes. Neither, however, would lead to the development of new management tools for future drought management.

Potential approaches to improving our understanding include:

- Multivariate experiments across a large number of commercial sites to determine when burning, wet season spelling, and cattle grazing have succeeded or failed in enhancing *Astrebla* spp. survival. This style of research would require strong liaison with industry, and the need for project staff to be devoted to this aspect of any work in addition to the conduct of scientific studies. Total resources needed would be 3-4 staff plus general operating costs.
- Scenario based modelling (e.g. Hill *et al.* 2005) to further explore the historical pressure points of vegetation change due to rainfall variability and management. The approach could be incorporated into multivariate experimentation. This approach would require liaison with established groups with the necessary skills. Total resources needed would be 1-2 staff plus general operating costs.
- Incorporating remote sensing as an investigative tool within multivariate experiments, to explore historical management with industry. This approach would require liaison with established groups with the necessary skills. Total resources needed would be 1-2 staff plus general operating costs.
- Low cost, permanent rain redistribution plots to mimic drought, current conditions and improved conditions. Such plots could incorporate experimental design to test the interactions between burning, grazing and soil moisture dynamics. The establishment costs may be in the order of $50,000, with on-going commitment from 1-2 staff to measure and maintain the plots.
- Moisture and clipping experiments with Mitchell grass planted into large pots to confirm the impact on root growth. A simple experiment could be completed in a single summer for under $50,000.
- Permanently located soil moisture monitoring equipment could be established in conjunction with either of the first two approaches to monitor soil moisture dynamics in detail, or in targeted locations to take advantage of natural landscape differences. A useful system would cost in the order of $150,000 to establish.
- Negotiating PhD research scholarships (e.g. to look at the details of what conditions are required to break Mitchell grass drought dormancy, especially in relation to plant hormonal controls, root growth and soil moisture depth) with relevant universities, at a cost of $25-30,000 per annum for each scholarship.
- On-farm demonstration sites, based on best-guess management and current knowledge and hypothesis, which incorporate detailed pasture and soil measurements, at a cost of $25-30,000 per site to establish and $5-100,000 per annum to maintain.

A focussed research project may be based around a multivariate experimental approach (McCune and Grace 2002) to take advantage of commercially occurring management differences, coupled with a small number of core sites for detailed experimentation. The existing network of sites of contrast could be expanded by adding sites that have been found subsequent to analysis and refined by honing in on the key questions raised within the exploratory analysis. For instance, additional burning and/or wet season spelling contrast sites could be sought to provide a minimum of five sites where *Astrebla* spp. survival was enhanced, five where mortality was enhanced and five where there was no detectable change. Sampling could be expanded to explore differences in rooting depth and biomass at these core sites, to start to answer questions about the role of root development in drought survival. Measurements to age tillers could also be included. Concurrently, the long-term grazing trial at Toorak could be enhanced through accentuating rainfall variability (e.g. via rainfall reduction/augmentation shelters) and monitoring the soil moisture dynamics under six pre-existing levels of grazing. The grazing within these paddocks have been well documented, including the distribution of grazing pressure (Phelps and Orr 2003), allowing for specific site selection.

Further research may be enhanced by encouraging collaboration and resource sharing between key groups e.g. the DPI&F pasture group at Longreach, the NR&W modelling and remote sensing groups at Indooroopilly and CSIRO Sustainable Ecosystems. Further research could also be enhanced by implementing current knowledge and hypotheses into one or two demonstration sites for testing in practice.

The time is also right to produce an historical book detailing the factual impacts of previous droughts, and the successes and failures of management strategies as a useful industry document. Demographics suggest that most graziers from within Western Queensland will have retired or sold within the next 10-15 years, leaving a gap in the experiential knowledge of managing Mitchell grass.

5 Success in achieving objectives

The objectives of this project have been successfully achieved:

1. The severity and extent of Mitchell grass dieback was assessed throughout the Mitchell grasslands of central, north and south-western Queensland. Overall, about one-third of the Mitchell grasslands are severely affected. This information was used in conjunction with advice from the project steering committee to target extension and research efforts (e.g. the distribution of the drought information kit).
2. The impact of Mitchell grass dieback on individual farm profitability and the economy of central-western Queensland was estimated at up to $15,000,000 per annum, based on reduced carrying capacity alone. This information has been used in media releases and newsletter publications to encourage action by landholders and other stakeholders.
3. The potential for recovery of land condition on a representative sample of affected properties was assessed through the estimation of Mitchell grass soil seed reserves. This information was used to provide direct advice to project co-operators in developing management options.
4. The likely causes of contrasting high and low levels of Mitchell grass mortality have been inferred, but not yet understood. Wet season spelling, coupled with dry season heavy grazing; early wet season heavy grazing with sheep, coupled with wet season spelling; moderate to low intensity burning, coupled with wet season spelling; and early summer rains all appear to reduce Mitchell grass mortality during drought. Overgrazing, or perversely an absence of grazing or burning, coupled with drought

appear to lead to increased Mitchell grass mortality. More research is needed in this area to confirm these inferences and to then devise practical management strategies to minimise the impact of future droughts.

5. The benefit to industry from additional research to identify and evaluate strategies for reducing the risk of future dieback events, as well as the additional resources required to conduct this research have been assessed and reported within this publication.
6. General awareness amongst landholders in affected areas about Mitchell grass death and dieback, its cost to production, and the current best practices to accelerate pasture recovery have been achieved through industry engagement.
7. A publication, which both documents the project findings and challenges industry to consider alternative grazing management strategies for drought has been produced, and will be distributed throughout Queensland's Mitchell grass region.

6 Impact on meat and livestock industry – now & in five years time

Economic modelling suggests that the value of cattle production from Queensland's Mitchell grasslands will be reduced by $58.5 to $92.4 million per annum for each year that the decline in land condition persists. Further research, coupled with a strong extension programme is needed to provide industry with the tools needed to address this issue. The ability for industry to adapt is critical if predictions of declining land condition coupled with climate change are correct.

The first phase of this research has increased industry's understanding of the severity, extent and economic impact of drought dieback in Mitchell grass and encouraged debate over the need to change management practices for sustainability.

This project has identified the potential to develop new management strategies based on the study of sites which showed vigorous Mitchell grass response during drought, when surrounding areas were still drought dormant or dead. However, the project did not seek to develop the strategies required to reduce the impact of future droughts.

Further research and extension may provide the management tools for accelerated recovery from the current drought, and reduce the impact of future droughts. The most widely accepted models of climate change predict that future droughts are likely to occur more frequently, and possibly be more severe. This exposes the Mitchell grasslands to increased risk of persistent declines in land condition, with pastures dominated by annual grasses or forbs instead of productive perennial Mitchell grasses. The potential cost if industry fails to adopt new management strategies is $58.5 to $92.4 million per annum based on declining land condition and reduced carrying capacity. This estimate does not include direct costs associated with drought management, such as increased supplementation of livestock or greater exposure to risk due to increased trading of livestock.

7 Conclusions and recommendations

Just over half (53%) of the Mitchell grasslands appear to be in poor (C) condition as a result of the 2001-2007 drought, with widespread dieback of mature plants and only patchy recovery. Less than 5% of the areas assessed in 2005 or 2006 were in good (A) condition. This is of concern compared with available historical records which estimated that 80% of the Mitchell grasslands were in good condition in 1981 and 70% in good condition in 1991.

It is estimated that the high proportion of land in poor condition is costing the grazing industry between $58.5 and $92.4 million per annum in lost productivity through reduced carrying capacity. This estimate does not include the increased costs of production during drought.

Soil seed bank data suggest generally low levels of Mitchell grass seed reserves in areas of poor condition. Pasture recovery from poor condition will depend on seedling germination and hence soil seed reserves. It is likely that these reserves will need to be rebuilt over the coming 3-5 years through light grazing pressure or wet season spelling to ensure pasture recovery. Previous experience suggests that well above-average rainfall over a single summer can successfully establish a new cohort of Mitchell grass. However, the probability of such an event is low.

Evidence from sites selected for high survival of Mitchell grass suggest that dry season grazing coupled with wet season spelling, or burning and spelling, can maintain the vigour of Mitchell grass during drought and prevent dieback. Contrasting sites of low survival were generally continuously grazed, but some areas were ungrazed. Overall, extremely low rainfall in 2002 coupled with high evaporation, appears to have caused the dieback.

More research is needed to confirm these initial observations. Management practices that can maintain the health and vigour of Mitchell grass pastures through the predicted increasingly frequent droughts of the coming years will then need to be developed in conjunction with industry. A total investment of 2-3% ($1,500,000) of the lost production per annum over the next 3-5 years could provide management strategies to maximise Mitchell grass root growth and survival. A combination of research to test new hypotheses and development through implementation of current best knowledge and theory may be the optimal way to achieve this outcome.

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9 Appendices

9.1 Mitchell grass project steering committee membership

The project steering committee comprised:

- the project team Dr David Phelps (Chair), Lyndal Rolfe and Ian Houston
- scientific members Dr David Orr and Dr Terry Beutel
- industry members Jim Brodie, David Capel, Peter Douglas, Mac Drysdale, Dan Forster, John Rickertt.

A précis of committee members:

- Dr David Orr has 35 years experience in the ecology of *Astrebla* spp. David has conducted both pasture and animal research in the Mitchell grass region and is initiated the long-term grazing trial Toorak utilisation study.
- Dr Terry Beutel has seven years experience in the mulga lands. His main interest is landscape health with a current focus on using remote sensing tools (e.g. Veg Machine) to assess changes in land condition.
- Jim Brodie has been on 'Redland Park' (between McKinlay and Kynuna) since the 1980s. Redland Park has 30,000 acres of ashy downs country and 20,000 acres of channels and Bull Mitchell flats. It is a breeding, growing and fattening operation aimed at producing animals for the Japanese market. Jim's has a general interest in pastures and has participated in Grazing for Profit (1990), Mitchell Grass regeneration trial (1996) and soil seed bank work. Jim is a founding member of the McKinlay Beef producers group.
- David Capel is the third generation on 'Evesham' (between Longreach and Winton) which is mostly black soil country with some Gidyea and pebbly downs. David is a member of AgForce, and sits on their natural resource management committee.
- Peter Douglas purchased 'Juno Downs' near Jundah in 1978. Juno comprises 70,000 acres of open Mitchell grass downs including 5,000 acres of stunted Gidyea country. After 2004 rains Peter noticed only a 40% strike rate in the Mitchell grass. He is interested in the economic, sustainability and survival issues affecting the Mitchell grass lands. Peter is the Chair of Desert Channels Queensland, the natural resource management regional body which ioversees the Queensland section of the Lake Eyre Basin.
- Mac Drysdale is third generation on 'Perola Park' (Augathella), Peroloa Park comprises 35,000 acres on the southern end of the Augathella/Tambo Mitchell grass downs country. Mac has an organic operation running 7-8000 sheep. He has noticed a general lack of pasture response especially since 2000, which family history has not seen from the 1930s onwards. Mac is interested in the economic and production impacts.
- Dan Forster has been the Overseer at 'Rodney Downs' (between Ilfracombe and Aramac) since 1985. Rodney Downs is 75,000 acres of heavy ashy downs and harder downs country. Dab has noted a general lack of response, with some areas of patchy response. The poor response does not seem to be not specific to soil types.
- John Rickertt managed 'South Galway' (AACo, Windorah) between 1992 and 2006. South Galway has 1000 km^2 of ashy and pebbly Mitchell Grass, which has mostly died during the drought. John's interest is in why the country isn't responding to rain especially when it hasn't been under pressure through grazing.

9.2 Abridged correlation table of major factors at the sites of contrast

Correlation table abridged to show major factors where: Astr = *Astrebla* spp.; BA = basal area (cm^2/m^2); sling=seedling density (no/m^2); tsk = tussock density (no/m^2); SSB = germinable soil seed bank (density no/m^2) functional groups (O3PG = desirable perennial grasses, excluding *Astrebla* spp.; OPG = undesirable perennial grasses; AG = Annual grasses; forb des. = desirable forbs; forbsundes. = undesirable forbs); GP = grazing pressure (C = cattle, K = kangaroo, S = sheep, T = total) for the period or summer (S) or winter (W) periods as indicated; RE index = ratio of rainfall to evaporation. Analysis based on raw data.

Correlation matrix	Astr_BA_dead_cm	Astr_BA_live_cm	Astr_sling	Astr_tsk_dead	Astr_tsk_live	SSB_AG	SSB_Astr	SSB_forb_des	SSB_forb_undes	SSB_O3PG	SSB_OPG	tot_yield	Burning_Status	Condition_change_%
Astr_BA_dead_cm	1													
Astr_BA_live_cm	-0.591	1												
Astr_sling	-0.372	0.379	1											
Astr_tsk_dead	0.519	-0.592	-0.49	1										
Astr_tsk_live	-0.664	0.401	0.357	-0.486	1									
SSB_AG	0.043	-0.038	-0.171	-0.057	0.041	1								
SSB_Astr	-0.312	0.397	0.321	-0.286	0.304	0.248	1							
SSB_forb_des	0.147	-0.199	-0.082	0.089	0.049	-0.114	-0.197	1						
SSB_forb_undes	0.148	-0.283	-0.168	0.529	-0.04	-0.063	-0.333	0.197	1					
SSB_O3PG	0.06	0.038	-0.028	-0.11	0.231	0.188	0.046	-0.059	0.01	1				
SSB_OPG	-0.059	0.097	0.238	-0.162	-0.063	0.105	0.03	-0.261	-0.197	0.251	1			
total yield (DM kg/ha)	-0.525	0.8	0.267	-0.465	0.38	0.008	0.329	-0.457	-0.319	0.018	0.304	1		
Burning_Status	-0.051	-0.075	-0.165	0.298	0.187	-0.084	0.022	0.213	0.297	-0.109	-0.153	-0.007	1	
Condition_change_%	0.613	-0.405	-0.372	0.646	-0.531	-0.093	-0.331	0.227	0.49	-0.064	-0.233	-0.402	0.056	1
GP_dist_to_water_km	0.121	-0.111	0.293	0.07	-0.173	-0.145	-0.048	0.108	0.258	-0.054	0.136	-0.091	0.022	0.282
GPC_site_S00_01	-0.34	0.335	0.072	0.243	0.162	-0.237	0.031	0.068	0.333	-0.22	-0.035	0.296	0.188	0.083
GPK_site_S02_03	0.421	-0.374	-0.149	0.293	-0.239	-0.247	-0.361	0.605	0.373	-0.077	-0.223	-0.567	0.092	0.423
GPS_site_S01_02	0.319	-0.433	0.102	0.367	-0.016	-0.311	-0.312	0.159	0.342	-0.026	-0.297	-0.372	0.098	0.357
GPT_site_99_07	0.179	-0.09	0.077	0.077	0.037	-0.18	-0.343	0.174	0.301	-0.033	-0.033	-0.149	-0.034	0.236
GPT_site_S00_01	0.157	-0.013	0.051	0.304	0.014	-0.432	-0.24	0.131	0.408	-0.053	-0.126	-0.018	0.1	0.355

Correlation matrix	Astr_BA_dead_cm	Astr_BA_live_cm	Astr_sling	Astr_tsk_dead	Astr_tsk_live	SSB_AG	SSB_Astr	SSB_forb_des	SSB_forb_undes	SSB_O3PG	SSB_OPG	tot_yield	Burning_Status	Condition_change_%
GPT_site_S01_02	0.216	0.021	0.12	0.151	-0.03	-0.449	-0.314	0.153	0.329	-0.047	-0.12	-0.03	-0.033	0.346
GPT_site_S02_03	0.173	0.05	0.151	0.109	0.005	-0.44	-0.29	0.156	0.321	-0.074	-0.112	-0.006	-0.018	0.29
GPT_site_S03_04	0.17	0.049	0.158	0.051	0.058	-0.204	-0.334	0.181	0.308	-0.044	-0.117	-0.046	-0.049	0.282
GPT_site_S04_05	0.136	0.043	0.139	-0.187	0.004	-0.225	-0.343	0.33	0.031	-0.097	-0.139	-0.126	-0.076	0.133
GPT_site_S05_06	0.049	-0.019	0.002	-0.04	-0.067	-0.26	-0.385	0.409	0.122	-0.12	0.025	-0.162	0.049	0.166
GPT_site_S06_07	0.16	0.05	-0.074	0.06	-0.175	-0.159	-0.428	0.204	0.22	-0.088	-0.018	-0.084	-0.06	0.291
GPT_site_S99_00	0.24	-0.009	0.085	0.268	-0.071	-0.457	-0.274	0.155	0.385	-0.027	-0.149	-0.06	0.117	0.387
Daily_rain (mm)	-0.342	0.404	-0.159	-0.459	0.292	0.026	0.175	-0.406	-0.406	0.134	0.215	0.498	-0.158	-0.479
RE_FWS_3mnth_av	0.32	-0.387	0.036	0.507	-0.333	-0.173	-0.229	0.483	0.383	-0.27	-0.216	-0.452	0.212	0.512
RE_FWS_3mnth_av0_20	0.342	-0.375	0.059	0.383	-0.343	-0.127	-0.323	0.572	0.328	-0.228	-0.316	-0.536	0.185	0.465
RE_FWS_6mnth_av	0.247	-0.355	-0.031	0.482	-0.27	0.145	-0.224	0.349	0.365	-0.122	-0.285	-0.436	0.166	0.459
RE_index_S00_01	-0.35	0.483	-0.153	-0.464	0.243	0.079	0.283	-0.498	-0.449	0.095	0.244	0.604	-0.167	-0.452
RE_index_S01_02	0.053	0.083	-0.052	-0.516	0.009	0.018	0.14	-0.035	-0.463	0.165	0.09	-0.015	-0.193	-0.288
RE_index_S02_03	-0.296	0.343	0.008	-0.251	0.296	0.147	0.368	-0.665	-0.255	0.228	0.437	0.598	-0.179	-0.381
RE_index_S03_04	-0.332	0.502	-0.174	-0.476	0.126	0.054	0.238	-0.385	-0.47	-0.017	0.118	0.516	-0.211	-0.399
RE_index_S04_05	-0.222	0.204	-0.22	-0.353	0.134	0.171	-0.041	-0.497	-0.327	0.117	0.2	0.384	-0.145	-0.379
RE_index_S05_06	-0.338	0.584	-0.076	-0.362	0.13	0.134	0.215	-0.617	-0.375	0.037	0.306	0.756	-0.194	-0.329
RE_index_W03	0.216	-0.314	0.221	0.389	-0.076	-0.309	-0.15	0.569	0.35	-0.126	-0.173	-0.455	0.168	0.326
RE_index_W04	0.029	-0.34	-0.143	-0.122	0.132	-0.006	-0.307	0.529	-0.003	0.056	-0.281	-0.509	0.145	-0.136
RE_index_W05	0.247	-0.391	0.004	0.246	-0.179	-0.208	-0.506	0.525	0.373	-0.073	-0.352	-0.622	0.125	0.293
RE_index_W06	-0.232	0.332	-0.24	-0.507	0.139	0.235	0.049	-0.382	-0.482	0.134	0.134	0.418	-0.161	-0.422
Site_condition	-0.489	0.608	0.424	-0.656	0.517	0.271	0.507	-0.151	-0.484	0.094	0.125	0.511	-0.032	-0.809

9.3 Listing of CIGS software parameter setup

```
$F1,Op1data,LR,5,5
Location,L,5,North,South,East,West,Average
Biomass,N,5
%Biomass dead,N,3
Cover,N,3
%Green cover,L,5,None,Quater,Half,Three-quater,All
Tussock density,L,6,None,VLow,Low,Medium,High,VHigh
Tussock viability,L,7,None,VLow,Low,Medium,High,VHigh,All
Tussock vigour,L,6,None,VLow,Low,Medium,High,VHigh
Major spp,L,9,3P,UndesP,OtherP,AnnualG,Legumes,Forbs,UndesForb,Lilly,Wildflowers
Minor spp,L,9,3P,UndesP,OtherP,AnnualG,Legumes,Forbs,UndesForb,Lilly,Wildflowers
Condition,A,2
Comments,A,256

$SF1,Op2data,IH,2,5
Location,L,5,North,South,East,West,Average
Biomass,N,5
%Biomass dead,N,3
Cover,N,3
%Green cover,L,5,None,Quater,Half,Three-quater,All
Tussock density,L,6,None,VLow,Low,Medium,High,VHigh
Tussock viability,L,7,None,VLow,Low,Medium,High,VHigh,All
Tussock vigour,L,6,None,VLow,Low,Medium,High,VHigh
Major spp,L,9,3P,UndesP,OtherP,AnnualG,Legumes,Forbs,UndesForb,Lilly,Wildflowers
Minor spp,L,9,3P,UndesP,OtherP,AnnualG,Legumes,Forbs,UndesForb,Lilly,Wildflowers
Condition,A,2
Comments,A,256

$F2,Grazing,8,3
Location,L,5,North,South,East,West,Average
Grazing pressure,L,5,None,Light,Moderate,Heavy,VHeavy
Grazing animal,L,8,Sheep,Cattle,Goats,Horses,Roos,Wallabies,Camels,Other
Comments,A,256

$F3,Weeds,4,3
Location,L,5,North,South,East,West,Average
Exotic weeds,L,6,Prickly acacia,Mexican poppy,Parkinsonia,Ngoora burr,Mesquite,Other
Weed density,L,5,Isolated plants,Isolated clumps,Low,Medium,High
Weed location,L,6,Paddock,Borrow pit,Boredrain,Drainage line,Riparian,Other
Control,L,5,None,Mechanical,Chemical,Both,Unsure
Comments,A,256

$F4,Erosion,6,3
Location,L,5,North,South,East,West,Average
Erosion level,L,3,Slight,Moderate,Abundant
Erosion type,L,6,Sheet,Rill,Gully,Scald,Wind,Other
Comments,A,256

$F5,Fire,0,3
Location,L,5,North,South,East,West,Average
Fire,L,2,Present,Relic
Comments,A,256
```

$F6,Tree&Shrub cover,1,3
Location,L,5,North,South,East,West,Average
Tree cover,L,8,None,Cleared,Isolated clumps,Isolated trees,Very sparse,Sparse,Mid-dense,Dense
Shrub cover,L,8,None,Cleared,Isolated clumps,Isolated shrubs,Very sparse,Sparse,Mid-dense,Dense
Major species,L,13,Gidyea,Boree,Mulga,Whitewood,Vinetree,Bonaree,Coolibah,River red gum,False sandlewood,Turkey bush,Qld bluebush,Lignum,Other
Minor species,L,13,Gidyea,Boree,Mulga,Whitewood,Vinetree,Bonaree,Coolibah,River red gum,False sandlewood,Turkey bush,Qld bluebush,Lignum,Other
Thickening,L,4,None,Some,Moderate,Severe
Tree death,L,4,None,Some,Moderate,Severe
Comments,A,256

$F7,Field assessment,9,3
Location,L,4,North,South,East,West
Type,L,2,Photo,Transect
Waypoint,N,3
Comments,A,1000

$F8,Bare areas,7,3
Bare type,L,6,Road,Airstrip,Water point,Stock camp,Scald,Other
Comments,A,256

$F9,Comments,8,3
Comments,A,1000

$F10,Land type
Land type,L,12,Open downs,Ashy downs,Pebbly downs,Gidyea-hard,Gidyea-soft,Mulga-hard,Mulga-soft,Boree,Alluvial,Floodplain,Jump-up,Other
Comments,A,256

$FnKey,Name,Operator,Colour,MarkerSize
FieldName,FieldType,FieldWidth,ListValues