CSIRO PUBLISHING

The Rangeland Journal, 2017, **39**, 227–243
http://dx.doi.org/10.1071/RJ16126

Grazing pressure impacts on two *Aristida/Bothriochloa* native pasture communities of central Queensland

Trevor J. Hall[A,E], *Paul Jones*[B], *Richard G. Silcock*[C] and *Piet G. Filet*[D]

[A]Department of Agriculture and Fisheries (DAF), Toowoomba, Qld 4350, Australia.
[B]DAF, Emerald, Qld 4720, Australia.
[C]Formerly DAF, Brisbane, Qld 4102, Australia.
[D]Formerly Queensland Department of Primary Industries, Emerald, Qld 4720, Australia.
[E]Corresponding author. Email: trevor.hall@daf.qld.gov.au

Abstract. Managing native pastures for sustainable and economic production requires a good understanding of grazing effects on pasture dynamics. The *Aristida*/*Bothriochloa* pastures of north-eastern Australia are important for cattle production but little data on grazing pressure impacts on pastures are available to guide management decisions of producers, for land management education programs, or for predictive modelling. To address this deficiency, four different continuous grazing intensities were imposed on woodland communities over 7 or 8 years at two sites: a *Eucalyptus populnea* (poplar box) and a *E. melanophloia* (silver-leaved ironbark) community. Both sites had replicated paddocks grazed at a low, medium or high grazing pressure by +/− tree killing using herbicide (12 paddocks), and 12 ungrazed (nil grazing pressure) 1-ha plots subjected to the same tree-killing contrasts. Grazed paddock areas were fixed and varied between 3.5 and 21.5 ha. Differential grazing pressures were reset each autumn, by adjusting cattle numbers to consume over the next year the equivalent of 0%, 25%, 50% or 75% of the standing pasture mass available.

Pasture grasses suitable as indicators of grazing pressure were identified for both communities. Under low grazing pressure, *Themeda triandra* (kangaroo grass) was the only desirable grass to show a significant increase in total contribution over time at both sites, although *Dichanthium sericeum* (Queensland bluegrass) also increased its contribution at the poplar box site. *Chloris* species increased their contribution as grazing pressure increased. The proportion of less palatable *Aristida* spp. (wiregrasses) in the pasture was not affected by high grazing pressure, although they increased at low grazing pressure in the poplar box community. There were no consistent changes in native legumes or weedy forb species to any treatment. Increasing grazing pressure had a greater negative effect on pasture mass, ground cover and pasture crown cover area than on changing species composition. Most changes in composition due to grazing pressure were smaller than those associated with variable seasonal rainfall, and were greater in the poplar box community. In above-average rainfall years grazing up to 50% of autumn standing pasture mass had no detrimental effect on composition in treeless poplar box country in the short term. The pastures remained stable or improved in both communities when grazing pressure was set annually to utilise 25% of the standing autumn forage.

Additional keywords: 3P grass, crown basal area, *Dichanthium sericeum*, eucalypt woodlands, pasture composition, *Themeda triandra*, utilisation rate.

Received 19 December 2016, accepted 13 May 2017, published online 9 June 2017

Introduction

Successful pasture management requires controlling grazing pressure to preserve the dominance of the desirable perennial, palatable and productive grasses (the 3P species), while preserving the ability of the soil resource to maintain economically viable cattle production. The 3P grasses provide persistent ground cover, preserve the soil surface and produce the bulk of forage in beef production systems in central Queensland. The diverse *Aristida*/*Bothriochloa* native pasture community (*A*/*B* pasture type) of Queensland (Weston *et al*. 1981) is dominated by C_4 tussock grasses, mainly *Bothriochloa ewartiana* (Domin) C.E. Hubb. (desert bluegrass), *Heteropogon contortus* (L.) P.Beauv. ex Roem. & Schult. (black speargrass), *Themeda triandra* Forssk. (kangaroo grass), *Dichanthium sericeum* (R. Br.) A. Camus (Queensland bluegrass), *Bothriochloa decipiens* (Hack.) C.E. Hubb. (pitted bluegrass) and *Bothriochloa bladhii* (Retz.) S.T. Blake (forest bluegrass). The useful perennial *Chrysopogon fallax* S.T. Blake (golden beard grass) is widespread, as is a range of perennial tussock *Aristida* spp. (wiregrasses) of low palatability and low leafiness. The botanical plant names used in this paper are from Henderson (1997).

The *A*/*B* community occurs in open woodlands dominated by eucalypt trees on infertile or poorly structured soils (Tothill and Gillies 1992). It occurs on over half the lands running north–south adjacent to either side of the Great Dividing Range in central Queensland (Silcock *et al*. 1996). Detailed floristics have been published by Schefe *et al*. (1993) and Silcock *et al*. (2015*a*), and the soil–pasture interactions by Silcock *et al*. (2015*b*). The main perennial grasses relate mainly to soil types and not the dominant eucalypt species. For example, *B. ewartiana*, although dominant in some northern *Eucalyptus melanophloia* F. Muell. (silver-leaved ironbark) and *E. populnea* F. Muell. (poplar box) communities (Story 1967), is rare in the southern *A*/*B* region where *E. populnea* is dominant.

Little was known of the grazing responses of these important pasture species in these communities. Hall *et al*. (2016) showed grass production can double without tree competition in some eucalypt communities, along with an increase in desirable grasses such as *D. sericeum* and *T. triandra*. However, appreciable soil erosion occurs in this pasture type when ground cover is severely reduced (Silburn *et al*. 2011) and must be prevented. Provided the soil resource has not been severely degraded, temporary species and ground cover decline in stressed pastures may be reversed in a period of better rainfall years when the grazing stress is removed (Orr and Phelps 2013). To date, identifying indicator pasture plants and quantifying their responses to grazing pressure in the *A*/*B* community have not been reported beyond suggestions of the dominant 3P grasses. However, the pasture responses in two *A*/*B* communities to tree competition have been reported by Hall *et al*. (2016) and burning responses have been reported by Silcock *et al*. (2005).

The two main commercial options for managing grazing pressure, pasture utilisation or grazing use rate, in extensive rangelands are adjusting stocking rates and periodic spelling. Other common land management practices in these communities are tree competition control and burning. Effective management of stocking rates requires knowledge of the sensitivity of key species to grazing pressure and their seasonal responses, and thus an ecologically based understanding is needed of which changes in species composition are indicators of grazing pressure impact. A good condition pasture also provides habitats for wildlife and valuable 'ecosystem services', such as surface soil stabilisation and lower soil temperatures (Teague *et al*. 2011), and protects fungi and burrowing insects that create soil pores for enhanced rainfall absorption (Lobry de Bruyn and Conacher 1990).

Research and anecdotal information shows that persistent high grazing pressure can lead to detrimental changes in pasture composition and reduced ground cover, with a consequent decline in productive capacity, especially in the semiarid rangelands (Moore 1953; Wilson *et al*. 1969; Ash *et al*. 2002). However, current grazing management advice in the *A*/*B* community comes from theoretical frameworks provided by State and Transition models (Hall *et al*. 1994; McIvor and Scanlan 1994) or from models of pasture production estimates by GRASP (McKeon *et al*. 1990), as there are no measured grazing responses on which to base such recommendations.

Some studies of perennial grasslands in northern Australia have failed to demonstrate that heavy grazing pressure over many years will automatically induce a major permanent shift in pasture composition (Orr *et al*. 2010; O'Reagain and Bushell 2011; Orr and Phelps 2013). In one example, pasture dominated by long-lived *Astrebla* species (Mitchell grasses) growing on a moderate fertility, self-mulching, heavy clay soil recovered composition in good seasons (Orr and Silcock 2010). Allen *et al*. (2013) found a weak negative association between grazing pressure and soil organic carbon. This association was influenced by standing herbage mass, soil type, and the dominant grass species. Hall *et al*. (2014) report that for several pastures, including *A*/*B* communities, the production, composition and frequency of the dominant pasture species were not consistently affected by the stocking method, but that there were significant changes between seasons depending on summer rainfall.

On *A*/*B* pastures in north Queensland, O'Reagain and Bushell (2011) found that heavy grazing pressure and seasonal rest both produced large fluctuations in pasture mass, related to seasonal conditions, but no initial major changes in native species composition. However, heavy grazing caused an ingress of a less desirable exotic grass, *Bothriochloa pertusa* (L) A. Camus (Indian couch), and an increase in the native woody shrub *Carissa lanceolata* R. Br. (conkerberry currant bush). Therefore, the permanency of any change may be related to soil fertility, the longevity of individual plants, seasonal conditions, and the recruitment capacity of the major pasture species.

To identify potential grazing indicator plants, to quantify grazing pressure impacts on common species, and to develop evidence-based grazing management recommendations, four experiments were conducted in two woodland communities of the *A*/*B* pasture type in central Queensland. This paper reports on pasture composition and stability, and on species responses to four grazing pressures over a 7 or 8-year period between 1994 and 2002, and identifies potential grazing pressure indicator species related to grazing management.

Methods

Two pasture communities

Two locations 270 km apart with different tree and herbaceous vegetation within the broad *A*/*B* native pasture land type of central Queensland were selected on commercial cattle properties for grazing pressure experiments. The sites were in *E. populnea* (poplar box site) west of Injune at lat. 25°45′23'S, long. 148°24′56'E, at 480 m elevation, and *E. melanophloia* (ironbark site) near Rubyvale at lat. 23°22′30'S, long. 147°35′15'E, at 325 m elevation (Fig. 1). Both sites had two similar grazed and ungrazed experiments, providing four grazing pressure treatments, and the same pasture parameter measurements were recorded between 1994 and 2002.

Details of the two sites, the multi-faceted experiment designs, and treatments are described in Hall *et al*. (2016). Essentially, there were two experiments: one had three grazing pressures (low, medium, and high), in 12 grazed paddocks. It also included treeless and treed competition treatments, by two replications. The second experiment had 12 ungrazed plots, and also included the same two tree competition treatments plus two burning regimes (spring burns and no burning), by three replications. The treeless treatments were created by poisoning all trees using registered herbicides and commercial practices. These treatments of grazing pressures, tree competition and burning were selected because they are common commercial management practices for

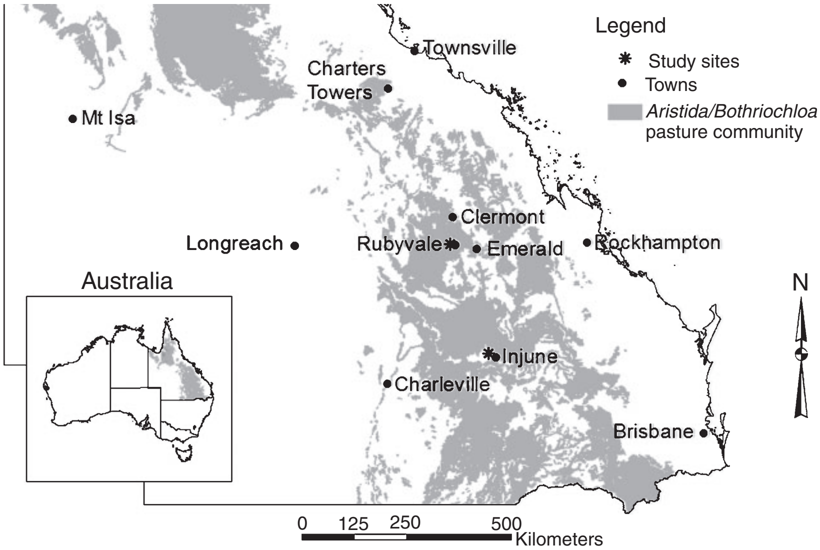

Fig. 1. Location of the two research sites and their nearest towns: poplar box (Injune) and silver-leaved ironbark (Rubyvale) in the *Aristida*/*Bothriochloa* native pasture community of eastern Queensland. The insert shows the location within Australia.

cattle production across the *A*/*B* communities. All treatments commenced in 1994.

Grazing treatments

Four consistent grazing pressure treatments were set as pasture use rates of the autumn standing herbage mass (kg ha^{-1} dry matter). The rates were: ungrazed (0% pasture use), low (~25%), medium (50%) and high (75%). Estimated average annual pasture growth was calculated from the GRASP model (McKeon *et al*. 1990) to set the initially paddock sizes. The animals' expected consumption over a year was calculated at 10-day intervals from the daily intake equation (Eqn 1) of Minson and McDonald (1987), assuming the growth rates of young steers estimated by local producers on that land type throughout the year. These growth rates varied in a sigmoidal pattern between potential daily gains of 1 kg $head^{-1}$ day^{-1} in mid-summer to losses in late winter of 0.3 kg $head^{-1}$ day^{-1}.

$$\text{Daily intake (kg DM)} = 1.185 + 0.00454\text{L} - 0.0000026\text{L}^2 + 0.315\text{G}^2 \quad (1)$$

where: L = current liveweight (kg) and G = daily liveweight gain (kg $head^{-1}$ day^{-1}).

This method of setting grazing pressure is based on autumn feed-budgeting, which can be used by land managers, and forms a basis of best management practice education packages for cattle producers (Queensland Government 2016). It differs from computer-modelled pasture utilisation assessments based on calculating annual new pasture growth from long-term climatic data and the soil type characteristics (Scanlan *et al*. 1994; Johnston *et al*. 1996). Their methods estimate a grazing pressure for strategic long-term planning for pasture sustainability, whereas our research method is designed for shorter-term tactical management decisions. Our method incorporates recent seasonal conditions, grazing history and carry-over forage, but not new growth in the upcoming year. Dry-season nutritional supplements or seasonal climate forecasting (O'Reagain *et al*. 2009; O'Reagain and Bushell 2013) did not influence our stocking rate calculations.

The 12 grazed paddocks at each site varied in size from 4 to 18 ha at the poplar box site and 3.5 to 21.5 ha at the ironbark site, depending on the expected pasture response from killing trees and on the potential to initially carry three 200-kg weaner steers (brahman cross) at the planned grazing pressure for a 1-year period, with a residual 150 kg ha^{-1} of pasture. The 12 ungrazed plots were each 1 ha in area. A new herd of weaner steers weighing 175–250 kg was introduced to the grazed paddocks annually after the autumn pasture recording and remained until after the next autumn assessment. Grazing pressure was adjusted annually by changing animal numbers and/or total initial animal liveweight. There were 8 and 7 herds at the poplar box and ironbark sites respectively. Usually no stock adjustments were made later during a year as seasonal conditions changed. However, one steer was removed from both high grazing pressure paddocks for welfare reasons as pasture quantity declined below an estimated 500 kg ha^{-1} in spring 1999 at the poplar box site and in the summer of 1996 at the ironbark site. These animals were returned to the treatment when summer rain produced new pasture growth.

At the poplar box site, trees were poisoned in July 1994, the first cattle herd was introduced on 30 November 1994, and the first pasture assessment was conducted in January 1995. At the ironbark site in 1994, trees were poisoned in March, an initial pasture assessment was recorded in July, and cattle were first introduced on 4 November.

Pasture response to grazing pressure

In the four treatments, the pastures and their response to grazing pressure and seasonal conditions were measured annually by:

- Composition (%) of total herbage mass contributed by each species or species functional group,
- Frequency (%) of pasture species (measured as occurrence in the recording quadrats),
- Herbage mass (kg ha^{-1}) of total standing pasture (dry matter yield),
- Ground cover (%) by plants and litter (permanent/semi-permanent organic matter),
- Pasture crown cover (%) of the ground covered by live pasture plant crowns (basal area), and
- Plant density (number per square metre) of grass species.

Species composition, species frequency, standing herbage mass, and ground cover were determined in April–May (autumn) each year after the summer growing season using the BOTANAL protocol (Tothill *et al*. 1992). Data were recorded on a grid pattern using 0.25-m^2 quadrats. Ranked standing pasture herbage mass (dry matter), percentage contribution by the main species (up to 6 per quadrat), and total ground cover percentage were recorded in each quadrat to calculate total herbage mass, individual species mass contribution (% composition), and species frequency (% occurrence). The pastures were recorded for eight consecutive years: 1995–2002 in the poplar box community, and 1994–2001 at the ironbark site.

Pasture crown cover (%) of species was recorded each winter using the point-frame technique (Rangelands West 2014) along three 150 m-long permanent transects in each grazed treatment and two 100 m-long permanent transects in each ungrazed treatment. Five pins in each frame were 15 cm apart and frames were laid end-on-end along the transect length. Any species struck at its base on the soil surface by a pin was recorded.

Population dynamics of the main perennial grasses, recorded as plant density, were assessed each winter in fixed, permanently marked quadrats in all treatments using the charting technique of Jones *et al*. (2009). At the poplar box site there were 27 quadrats of 1 m × 0.5 m in each grazed treatment, and nine equivalent quadrats in each ungrazed treatment, whereas the ironbark site had 15 quadrats of 1 m × 1 m per grazed paddock, and three similar quadrats in each ungrazed plot. In every quadrat, the basal dimensions of each live grass, as well as that of new recruits, were measured, while the loss of plants was also recorded. From this population data, the fluctuating numbers and density of key grasses in response to grazing pressure were calculated.

Statistical analyses

Statistical analyses of the data were performed with the GENSTAT package (GENSTAT 2015), mainly using ANOVA and the REML protocol for handling repeat time-series data. The two sites and experiments were analysed separately. For each pasture parameter, the 'grazed treatments' model was the main effects of three grazing pressures (low, medium and high) by years, meaned across the two tree treatments and two replications. The 'ungrazed treatment' model was the pasture parameter mean of the 12 plots by years, across the two tree treatments, two burning regimes and three replications. A probability level of 5% ($P < 0.05$) or lower was accepted as a statistically significant grazing pressure main effect. Although data are presented graphically in figures for grazed and ungrazed effects over time, they are not statistically analysed together due to the multi-faceted experimental design. The statistical differences (l.s.d.) shown in Figs 3 to 6 relate only to the three grazed treatments.

Results

Rainfall

The two sites shared a similar range of growing seasons. Both experienced high rainfall (decile 8 or 9) summers as well as low rainfall (decile 1 or 2) years. The sites averaged slightly below (20–60 mm) their long-term annual mean rainfall with 573 mm at the poplar box site and 639 mm at the ironbark site. The summer rainfall pasture growing season, October–March, during the experiments and for the previous year 1993–1994 (decile 4 at both sites) are shown in Table 1. Both sites experienced three dry growing seasons (summer deciles 2 or 3) and annual totals that were equally low. Contrasting rainfall between sites occurred in the 1997–1998 summer with a high decile 8 summer at the poplar box site and a low decile 2 season at the ironbark site, and again in 1999–2000, when the poplar box site had

Table 1. Annual (July–June) and summer (October–March) rainfall (mm) and decile values at each site during both the experimental period and the previous year

Decile values are the ranking of each season relative to the long-term district average

Year	Poplar box site				Ironbark site			
	Annual (July–June)	Decile	Summer (Oct.–Mar.)	Decile	Annual (July–June)	Decile	Summer (Oct.–Mar.)	Decile
1993–1994	557	4	414	5	526	4	352	3
1994–1995	392	1	314	2	472	3	378	4
1995–1996	571	5	439	6	460	2	321	3
1996–1997	654	7	475	7	829	7	717	9
1997–1998	707	7	506	8	483	3	296	2
1998–1999	844	9	527	8	852	9	602	8
1999–2000	391	1	288	2	632	6	398	5
2000–2001	569	5	501	7	745	7	670	9
2001–2002[A]	456	2	270	2	–	–	–	–
Long-term[B]	634	–	425	–	658	–	481	–

[A]Ironbark site was not recorded in 2002.

[B]Poplar box site rainfall from 'Westgrove', Injune recording station; Ironbark site from Anakie town records.

a dry year (decile 1) and the ironbark site had above-average rainfall (decile 6).

There were summer rainfall events each year that produced pasture growth periods at both sites. However, there were also extreme year-to-year fluctuations in summer rainfall at the two sites, for example, over the 3 years from 1996–1997 to 1998–1999 the ironbark site received 717, 296 and 602 mm respectively. An unusually wet winter (June–August) at both sites in 1998, 402 mm and 376 mm at the poplar box and ironbark sites respectively, kept more green leaf in the pastures and grew more winter-active forbs than were present in average rainfall years. However, this higher winter rainfall impacted negatively on perennial tussock grasses in the ungrazed treatment at the poplar box site.

Pasture response to grazing pressure

Pasture composition (species dry matter yield as % of total standing herbage mass)

The pasture was dominated by different perennial tussock native grasses at the two sites. *Bothriochloa decipiens* and *Enteropogon ramosus* (twirly windmill grass) were prominent at the poplar box site, but were rare in the ironbark pastures, whereas *B. ewartiana* and *H. contortus* were prominent at the ironbark site but not common at the poplar box site. Two desirable 3P native grasses, *T. triandra* and *D. sericeum* occurred in both communities, as did a range of 2P grasses (perennial and palatable or perennial and productive) such as *Chloris* (windmill grasses), *Enneapogon* (bottlewasher grasses) and *Eragrostis* (love grasses) species. A range of undesirable *Aristida* spp. (wiregrasses) were present also in both communities. The main forage species and minor species groups at these two sites have been described by Hall *et al.* (2016).

Poplar box pastures

No perennial grasses were dominant across the poplar box site, where a range of species contributed individually 6–15% of the pasture mass. A mean of 24 grass and 18 forb species were recorded annually in the grazed paddocks out of the total of 74 herbaceous species recorded during the experiments. There was a decrease in *D. sericeum* composition to increasing grazing pressure, from an 8-year mean annual contribution of over 9% at low and medium grazing pressure to 4% at high grazing pressure, where it had declined to 1.6% by 2002. There was a similar trend for the desirable, but uncommon *H. contortus* as grazing pressure increased, at an annual mean of 3.3%, 0.6% and 0% at the low, medium and high pressures respectively. Grasses that increased their percent composition with increasing grazing pressure over 8 years, included:

- *B. decipiens*, which had a mean annual contribution of 7.4% at low compared with 13.8% at high grazing pressure,
- *Chloris divaricata* (slender chloris or windmill grass) a short-lived perennial, from 1% at low to 7% at high grazing pressure, compared with no change when ungrazed, and
- *C. fallax*, *Eragrostis* spp., particularly *Eragrostis molybdea* (granite lovegrass), and *Tripogon loliiformis* (five-minute grass).

The contribution of *Sclerolaena birchii* (galvanised burr), a common indicator of overgrazing and drought, declined under all grazing pressures, but by 2002 had its highest composition (3%) under high grazing pressure.

There were inconsistent grazing pressure responses from the abundant grasses *E. ramosus*, *Aristida ramosa* (purple wiregrass), and *Enneapogon* spp., and also from the 'other broadleaf forbs' group. *Tragus australianus* (small burrgrass) increased its contribution marginally at high grazing pressure, but was less than 1% in all treatments after 8 years. Grazing pressure did not appreciably alter the contribution of the perennial tussock grass *Panicum effusum* (hairy panic) nor that of the forb species *Fimbristylis dichotoma* (fringe sedge), *Brunoniella australis* (blue trumpet), *Calotis* spp. (daisy burrs) and *Verbena tenuisecta* (Mayne's pest).

The percentage composition of the *Aristida* spp. group increased at low grazing pressure (+10.1%) and declined under high grazing pressure (–2.5%) by 2002. There was a relative decrease in *A. ramosa* during the wetter summers with an increase again in the drier final years to be near its original mass proportion. The native legumes, including species of *Rhynchosia*, *Desmodium*, *Glycine*, *Indigofera*, *Tephrosia*, and *Zornia*, fluctuated between 0.1% and 1% composition and were not significantly affected by grazing pressure, but increased in higher rainfall years.

Silver-leaved ironbark pastures

The two dominant grasses, *B. ewartiana* and *H. contortus*, contributed over 70% of the total autumn pasture mass at high grazing pressure late in the experiment. The other grass species, forbs, and native legumes group, many being the same genera as those present at the poplar box site, contributed individually less than 5% of total pasture mass. Of the major desirable grasses, *T. triandra* and *D. sericeum* had the greatest composition decrease at high grazing pressure, whereas the undesirable *Aristida* spp. had negligible change from a low base. The mass of the common *T. australianus* never exceeded 4% of the total pasture, and declined in 1999 and 2001. Increaser trends, based on the concepts of Dyksterhuis (1948), were shown by *C. divaricata*, and possibly by *H. contortus*. *Bothriochloa ewartiana* is rated as a 'mid' reactor as it tended to contribute greatest proportions at medium grazing pressure.

The strongly perennial grass *Eulalia aurea* (silky browntop) initially contributed 7% of herbage mass but it declined to 1% by 2001, irrespective of the grazing pressure. Between 1994 and 2001, there was no consistent grazing pressure effect on the common grasses *C. fallax*, declining from 14% to 5%, and *Enneapogon* spp., declining from 4% to 1%. Other common species that showed no strong response to grazing pressure were *Eragrostis* spp., *Panicum* spp. (panic or millet grasses), *T. loliiformis*, native legumes, the sedges (*Cyperus* spp. and *Fimbristylis* spp.), and the 'other broadleaf forbs' group.

Pasture community species comparison

The reaction to grazing pressure of species common to both sites is shown in Fig. 2 as mean annual percentage composition recorded over 8 years. Similar response trends mostly occurred at the two sites, but the rate of change often differed. For example, *D. sericeum* increased steadily up to the 50% use rate at the poplar box site, before a rapid decline at the 75% rate,

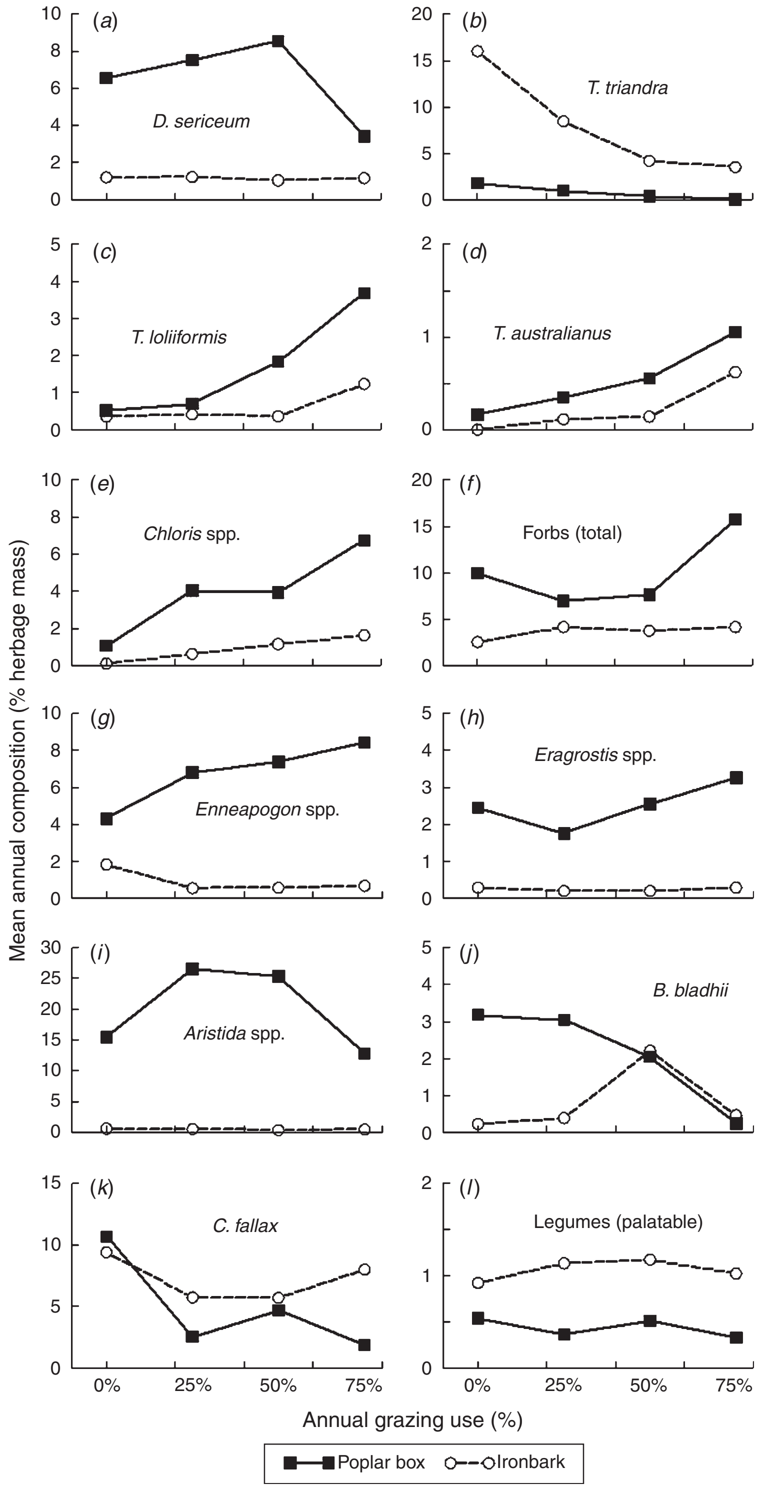

Fig. 2. Eight-year annual mean composition (as % of total standing herbage mass in autumn) of common pasture species and species groups in response to four grazing pressures (ungrazed, low, medium, and high), set as a percent of the autumn pasture to be grazed over the coming year (0%, 25%, 50%, and 75% respectively), at the poplar box site between 1995 and 2002 and at the ironbark site between 1994 and 2001. Species: *Dichanthium sericeum*, *Themeda triandra*, *Tripogon loliiformis*, *Tragus australianus*, *Chloris* spp., native forb species, *Enneapogon* spp., *Eragrostis* spp., *Aristida* spp., *Bothriochloa bladhii*, *Chrysopogon fallax*, and palatable native legumes. Note the different composition scales.

whereas in the ironbark community, where its contribution was less, there was not a similar decline (Fig. 2*a*). There was a steady decline in composition of *T. triandra* as grazing pressure increased at both sites, although from a much greater level in the ironbark community (Fig. 2*b*). As grazing pressure increased, small-statured species such as *T. loliiformis* (Fig. 2*c*), *T. australianus* (Fig. 2*d*), *Chloris* spp., predominantly *C. divaricata* (Fig. 2*e*) and the common forbs group (Fig. 2*f*) also increased their percentage composition, but at varying degrees, especially at the high grazing pressure. Notably, the *Sida* spp. (flannel weeds) at the poplar box site tripled their composition to 2.7% at high grazing pressure compared with that at low pressure. There was a greater grazing pressure response by the 2P species at the poplar box site than in the ironbark pasture, with *Enneapogon* spp. (Fig. 2*g*) and *Eragrostis* spp. (Fig. 2*h*) having their highest composition at the 75% use rate. *Aristida* species had a negligible contribution at the ironbark site, but had a much reduced contribution where grazed at the poplar box site, from 26.5% at low to 13% at the high grazing pressure (Fig. 2*i*). There was a steady decline in the proportion of the desirable grass *B. bladhii* as grazing pressure increased at the poplar box site, whereas spatial variability coupled with a low presence produced an unclear result at the ironbark site (Fig. 2*j*). *Chrysopogon fallax* made its greatest contribution at both sites when ungrazed and it had a differing response between the 50% and 75% use rates, increasing in the ironbark pastures and declining at the poplar box site (Fig. 2*k*). The proportion of palatable legumes was double in the ironbark site pastures (1.2%) compared with in the poplar box pastures, but grazing pressure had no major impact on legume composition at either site (Fig. 2*l*). The annual mean composition of *H. contortus* was similar and over 22% for all treatments at the ironbark site, but never reached 2.5% in any treatment at the poplar box site where its contribution declined with increasing grazing pressure to an annual mean of 0.14%.

Species frequency (%)

Poplar box pastures

After 8 years, high grazing pressure had a significant impact on *D. sericeum* frequency, which was 25% in the low grazing pressure pasture, but only 7% under prolonged high grazing pressure (Table 2). The species' mean autumn frequency over the 8 years was 24.5%, 23.1% and 10.9% for the low, medium and high grazing pressures respectively. The frequency of *H. contortus* was a better indicator of grazing pressure than its contribution to the pasture when measured as dry matter composition. By 2002, its frequency was 7.9%, 3.3% and 0.5%

Table 2. Frequency percent changes of key pasture species in autumn in response to four grazing pressures at the poplar box and ironbark sites between 1994 and 2002

Negative differences indicate the frequency has declined since 1994 or 1995. (Sorted by grazing impact rating)

Site	Plant species	Grazing pressure (annual pasture use %) Frequency %								
		Ungrazed (0%)		Low (25%)		Medium (50%)		High (75%)		
Poplar box	(1995–2002)	1995	*diff*[A]	1995	*diff*	1995	*diff*	1995	*diff*	Grazing impact
	Chloris divaricata	4.1	*3.2*	8.2	*22.4*	1.5	*28.4*	2.5	*29.8*	Increase
	Chrysopogon fallax	52.7	*–22.0*	30.1	*–7.3*	33.0	*1.8*	15.9	*2.9*	Increase
	Tripogon loliiformis	16.5	*–13.6*	7.1	*3.2*	1.0	*21.8*	2.5	*29.9*	Increase
	Dichanthium sericeum	8.3	*2.6*	9.7	*15.3*	16.3	*4.5*	7.0	*–0.1*	Decrease
	Verbena tenuisecta	0.0	*11.8*	0.0	*5.1*	0.0	*7.2*	0.0	*2.9*	Decrease
	Enteropogon ramosus	3.3	*3.4*	18.2	*1.2*	6.9	*1.1*	26.9	*–9.1*	Unclear
	Aristida ramosa	30.4	*12.7*	3.2	*32.6*	3.0	*32.8*	2.5	*20.7*	Nil
	Enneapogon spp.	22.4	*0.5*	38.0	*7.3*	39.0	*1.7*	39.1	*4.5*	Nil
	Tragus australianus	6.6	*–6.3*	21.6	*–19.2*	23.7	*–22.7*	25.3	*–22.7*	Nil
	Brunoniella australis	18.2	*–14.3*	32.3	*–12.4*	43.9	*–25.0*	22.8	*–11.1*	Nil
	Native legumes	19.6	*–5.4*	12.0	*1.1*	24.0	*–4.5*	12.0	*–1.8*	Nil
Ironbark	(1994–2001)	1994	*diff*	1994	*diff*	1994	*diff*	1994	*diff*	–
	Chloris divaricata	1.9	*–1.9*	0.0	*13.6*	0.0	*29.0*	0.0	*35.4*	Increase
	Chrysopogon fallax	48.5	*–12.8*	41.1	*–5.3*	43.4	*–5.4*	38.9	*–1.0*	Increase
	Heteropogon contortus	28.4	*18.0*	24.3	*28.6*	25.1	*29.0*	22.8	*32.3*	Increase
	Tripogon loliiformis	21.4	*–19.8*	14.1	*–1.9*	10.2	*12.0*	12.1	*17.0*	Increase
	Sedges	42.0	*–35.0*	30.9	*–22.8*	24.5	*–15.8*	19.4	*–8.4*	Increase
	Other broadleaf forbs	82.8	*–37.4*	74.00	*–22.2*	73.3	*–7.6*	71.1	*–2.6*	Increase
	Enneapogon spp.	18.9	*–7.5*	14.8	*1.8*	16.9	*5.7*	19.9	*–7.8*	Mid[B]
	Themeda triandra	14.1	*37.7*	16.3	*10.6*	19.0	*–5.7*	17.2	*–7.7*	Decrease
	Dichanthium sericeum	2.6	*3.9*	4.1	*1.2*	6.4	*1.2*	5.2	*–2.1*	Decrease
	Bothriochloa ewartiana	42.3	*21.5*	32.1	*27.5*	36.1	*28.7*	31.7	*25.2*	Nil
	Aristida spp.	26.3	*–10.5*	21.5	*–17.5*	21.3	*–14.9*	16.8	*–9.1*	Nil
	Eulalia aurea	11.5	*–9.5*	14.2	*–9.6*	12.9	*–7.5*	13.8	*–11.2*	Nil
	Native legumes	71.3	*–13.5*	60.3	*–18.1*	68.7	*–19.6*	57.3	*–5.9*	Nil

[A]Species frequency (% occurrence in quadrats) diff. is the change from the initial to final recordings.
[B]A 'Mid' is a plant that is less common at both high and low grazing pressure (Silcock *et al*. 2005).

at low, medium and high grazing pressure respectively, compared with its highest annual mean composition, by weight, of 2.3% at low grazing pressure. Conversely, the frequency of *T. loliiformis* was 32% under high grazing pressure and 10% with low grazing pressure (Table 2). Its 8–year annual means were 12%, 21% and 28% for the three increasing grazing pressures respectively. The most frequent taxon was *Enneapogon* spp. with a similar frequency of 41% under the three grazing pressures. The next most common species, *C. divaricata*, increased over time from a mean of 4–26% and had a marginally higher final frequency at high grazing pressure (32%) (Table 2). There were fluctuations over time in frequency of both desirable and undesirable forage species, but there was no extensive weed species invasion caused by the grazing treatments, although *Sida* spp. increased in patches to a frequency of 21.5% at high grazing pressure by 2002.

Other notable frequency responses to grazing pressure were:

- *Calotis* spp., predominantly *C. lappulacea* (yellow daisy burr), fluctuated seasonally with a strong response to higher winter rainfall in all treatments, for example from 6.1% to 21.1% frequency between 1998 and 1999 when grazed. By 2002 its frequency increased with increasing grazing pressure with a mean of 9.9%, 11.9% and 17.6% at the low, medium and high grazing pressure respectively,
- *B. bladhii* frequency was 5.7% under low grazing pressure compared with 0.2% at high grazing pressure after 8 years,
- *V. tenuisecta*, a moderately palatable forb, had the lowest frequency when heavily grazed. The 8-year means were 5.1%, 7.2% and 2.9% for low, medium and high grazing pressure respectively,
- Forb species (non-legumes) of low palatability, such as *Malvastrum americanum* (malvastrum), *Portulaca* spp. (pigweeds) and *S. birchii* increased slightly over time under high grazing pressure.

The frequency of some common species fluctuated during the experiments, independent of grazing pressure. For example, the unidentified *Aristida* species group increased in all grazed treatments from a mean of 1% to 9.5%, *T. australianus* declined from 22% to 1.6%, but with high annual variability, and *B. australis* frequency fell from 33% to 20% by 2002.

The legumes and broad-leafed forbs had a high frequency of occurrence (Table 2) but low total mass, and showed no consistent response to grazing pressure. In contrast to the ironbark site where the soil was spatially very consistent, there were species preferences to soil types in the poplar box community. *Bothriochloa bladhii* was more frequent on the heavier textured, clay soils (Vertosol) of the creek flats, whereas *B. decipiens* preferred the lighter textured, loam soil types (Sodosols) of the hill slopes. *Cenchrus ciliaris* (buffel grass) was the only exotic pasture species present, occurring in isolated disturbed microsites such as along firebreaks. It did not spread in any treatment.

Silver-leaved ironbark pastures

The autumn frequency of the dominant grasses better reflected their composition percent by weight at this site. For example, *B. ewartiana* had an 8-year mean annual frequency between 46% and 52% with a mean composition between 34% and 46%, and *H. contortus* mean frequency was between 36% and 40% at a mean composition of between 22% and 25% for the four grazing pressures. However, *H. contortus* increased most in frequency under high grazing pressure from 32% to 55% (Table 2), although there was no similar change in its percent composition (mean 23.1%).Increasing grazing pressure caused a decrease in frequency of *T. triandra* from 52% ungrazed to 9.5% at high grazing pressure (Table 2), and had no significant effect on *B. ewartiana* frequency which increased under all four treatments from an initial mean of 36–61%. The high grazing pressure significantly ($P < 0.05$) increased the frequency of *C. divaricata* (to 35%) and *Digitaria* spp. (windmill or finger grasses) where differences were significant in 1999 and 2000, and *T. loliiformis*, to 29% by 2001. The frequency of *C. fallax* was roughly maintained at all grazing pressures. Although the broadleaf forb group and sedges declined under all grazing pressures over 8 years, they had the smallest change at high grazing pressure. Frequency of many species fluctuated in response to seasonal conditions and not in response to grazing pressure. For example, *Panicum effusum* decreased by 20%, whereas *B. ewartiana* increased by over 20%, but from a different starting frequency. Native legume frequency was high with annual fluctuations correlated with grazing pressure in some years and with seasonal conditions in others. As in the poplar box pastures, small-statured, minor pasture components, such as the native legumes, often had a high frequency of occurrence, disproportionate to their low mass contribution.

Increasing grazing pressure increased the frequency of the annual grass *T. australianus* in most years, with a peak of 15% at high grazing pressure in 1998. However, in 2001 its frequency declined to a mean of 2% over all grazing pressures despite above-average rainfall the previous summer and a trend of increasing total herbage mass. There was no grazing pressure effect on *Aristida* spp. frequency which declined generally over 7 years, and frequency changes in *Enneapogon* spp. were also more related to seasonal rainfall than to grazing pressure. Other minor pasture components, many of which are short-lived perennials, had minimal responses to grazing pressure.

Herbage mass in autumn

Low pasture herbage mass (dry matter yield) at the start of the experiments, 500 kg ha^{-1} at both sites, reflected the prior low rainfall and commercial grazing practices over the previous 2–3 years. With higher summer rainfall in subsequent years, yields increased markedly, particularly in the ungrazed and low grazing pressure treatments, to 3000 kg ha^{-1} in the poplar box community and to 5000 kg ha^{-1} at the ironbark site. For the first few years, the differing grazing pressures steadily increased the gap in autumn herbage mass between grazing pressure treatments at both sites. Cattle grazed all grasses at the high grazing pressure, including the less palatable species, with the result that standing autumn herbage mass fell below an estimated 500 kg ha^{-1} on two occasions in spring at both sites.

Herbage mass increased rapidly at the poplar box site (Fig. 3*a*), reaching a maximum in 1997 and 1998 before declining, whereas the initial increase was ongoing at the ironbark site (Fig. 3*b*). This site produced up to 2000 kg ha^{-1} greater pasture mass than the poplar box site in the ungrazed and low grazing pressure

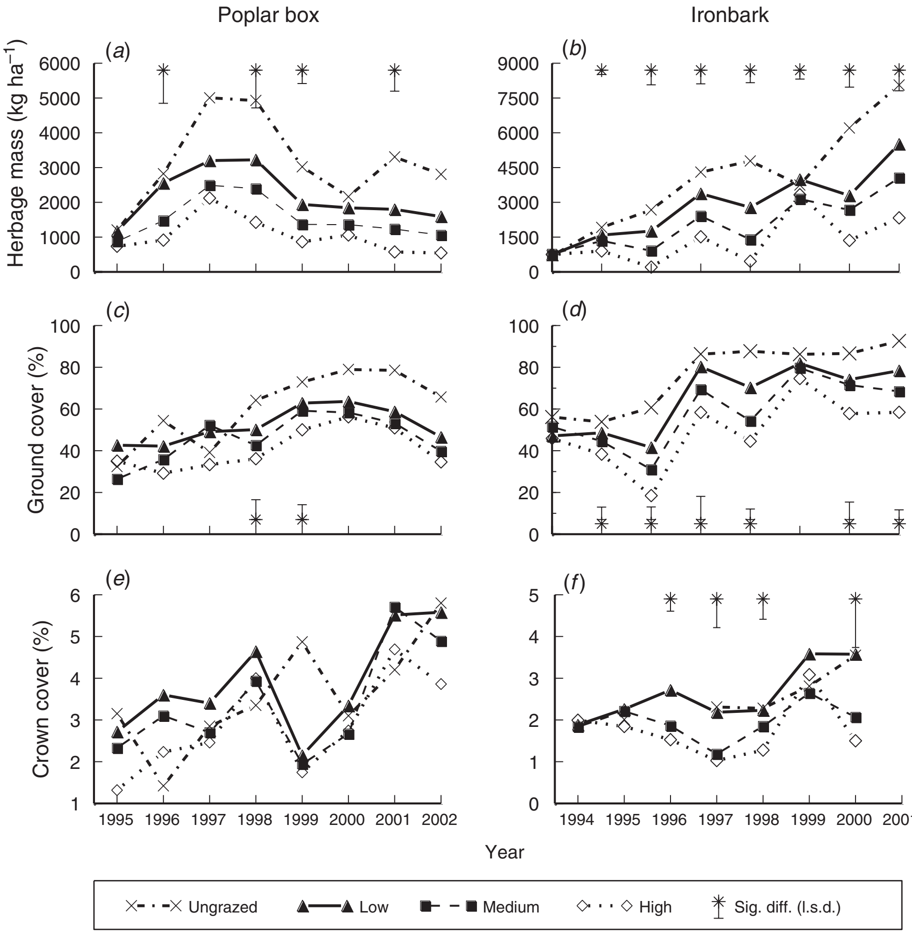

Fig. 3. Impact of four grazing pressures (ungrazed, low, medium, and high) on total pasture herbage mass (kg DM ha^{-1}) (*a* and *b*), ground cover (%) (*c* and *d*), and pasture crown cover (%) (*e* and *f*) between 1994 and 2002 at the poplar box and ironbark sites respectively. Vertical bars show significant l.s.d. ($P = 0.05$) between the three grazed treatments only. Note the different herbage mass and crown cover scales.

treatments from similar summer rainfall. However, the ironbark pasture had less winter and spring greenness due to a combination of fewer cool season rainfall events and a paucity of species capable of responding to the small winter falls, for example *Chenopodium* species.

Poplar box pastures

In the poplar box pastures, the mean annual herbage mass was 3350, 2670, 2230 and 1240 kg ha^{-1} for the ungrazed, low, medium and high grazing pressures respectively. Of these means, 280, 120, 105 and 160 kg ha^{-1} respectively were contributed by forb species. These pastures did not sustain the herbage mass reached in 1998 because summer rainfall was well below average (decile 2) in the 1999–2000 and 2001–2002 summers. The effect of the grazing pressures on herbage mass was consistent over time and, where ungrazed, autumn pasture mass was often over 1000 kg ha^{-1} greater than in the low grazing pressure pastures (Fig. 3*a*). The common grasses *B. decipiens*, *A. ramosa* and *E. ramosus*, contributed an average of 370, 220, and 170 kg ha^{-1} respectively, whereas five other perennial grasses, *D. sericeum*, *C. divaricata*, *Aristida calycina* (branched wiregrass), *Enneapogon* spp. and *C. fallax*, each contributed up to 140 kg ha^{-1} in some years.

Although the mean annual (1995–2002) herbage mass of *D. sericeum* was 210, 155 and 45 kg ha^{-1} at low, medium and high grazing pressures respectively, at the end of the experiment negligible *D. sericeum* or *B. australis* remained in the high grazing pressure treatment (Fig. 4*a*). The relatively unpalatable, especially when mature, *B. decipiens*, became more prominent under medium grazing pressure (Fig. 4*b*). It flourished initially when ungrazed, but it declined markedly after the wet winter of 1998 when its accumulated dense thatch collapsed and fungi rotted its crowns in this treatment. Under low grazing pressure, bulky 3P grasses like *T. triandra* and *B. bladhii* were more competitive.

The mass of most grasses was reduced by the high grazing pressure treatment, with the exception of *T. loliiformis*, which contributed up to 95 kg ha^{-1}. The aggregate contribution of *Aristida* spp. was always low under high grazing pressure, <200 kg ha^{-1}, but rose to 800 kg ha^{-1} under low grazing pressure (Fig. 4*c*). Although *E. ramosus* reached 590 kg ha^{-1} on 1 year, this

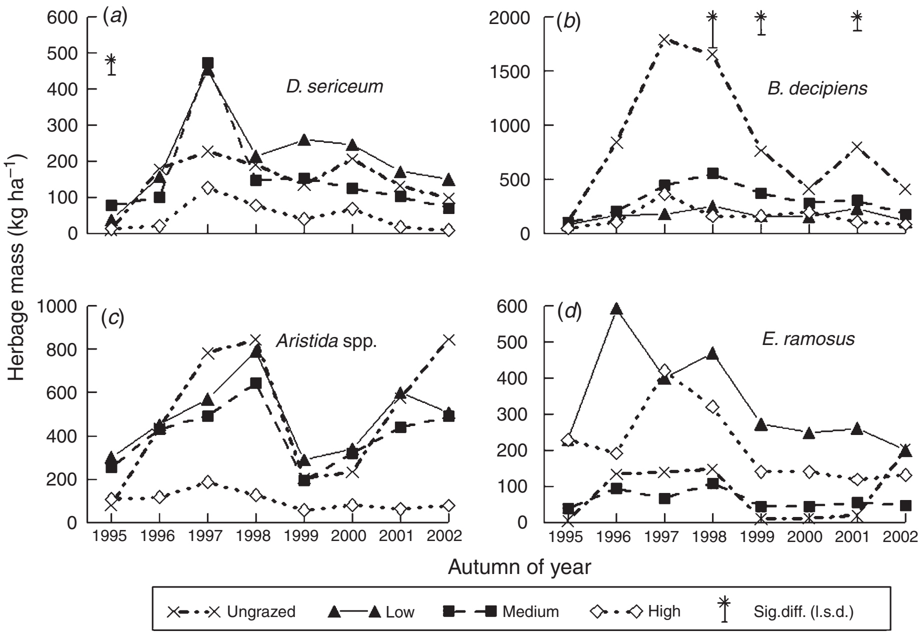

Fig. 4. Poplar box site: Autumn perennial grass species herbage mass (kg DM ha^{-1}) response to four grazing pressures (ungrazed, low, medium, and high) between 1995 and 2002, (*a*) *Dichanthium sericeum*, (*b*) *Bothriochloa decipiens*, (*c*) *Aristida* spp., and (*d*) *Enteropogon ramosus*. Vertical bars show significant l.s.d. ($P = 0.05$) between the three grazed treatments only. Note the different herbage mass scales.

normally low palatability grass had the tops of its tussocks hedge-grazed to less than 50% of its ungrazed height by late spring each year in the high grazing pressure treatment. Its occurrence across the site reflected soil factors, whereas its autumn mass was more affected by rainfall than grazing pressure (Fig. 4*d*). The unpalatable, weed-type forbs, such as *Sida* spp., had their highest standing herbage mass (mean 40 kg ha^{-1}) in the high grazing pressure treatment.

Silver-leaved ironbark pastures

In the ironbark pastures, standing herbage mass differences between the high and low grazing pressures were significant ($P < 0.05$) in all years. These differences also occurred often between the medium grazing pressure and the other two grazed treatments (Fig. 3*b*). The 8-year herbage mass means were 4040, 2880, 2080 and 1350 kg ha^{-1} for the ungrazed, low, medium and high grazing pressures respectively. Peaks in grazed herbage mass (>2500 kg ha^{-1}) in the autumn of 1997, 1999 and 2001 followed above-average summer rainfall (Table 1). Both the ungrazed and low grazing pressures produced high autumn standing herbage mass in all years, reaching >5500 kg ha^{-1} in autumn 2001. The decline in herbage mass of ungrazed pastures in 1999 was due to an unplanned fire in October 1998. The peak in herbage mass under high grazing pressure after a poor 1997–1998 summer was due to there being too few animals de-pastured when well above-average winter, spring and summer rains occurred during 1998.

Autumn herbage mass was driven by summer growth of the three major perennial grasses *B. ewartiana*, *H. contortus* and *T. triandra* (Fig. 5). Their trend of increasing herbage mass during the experiment was in response to improving seasonal condition, with the mass of *B. ewartiana* peaking at 1610 kg ha^{-1} in 1999 under low and medium grazing pressure (Fig. 5*a*). This contrasts with 845 kg ha^{-1} after the dry summer of 1997–1998. Over all treatments, the autumn mass of *B. ewartiana* averaged 1120 kg ha^{-1}, whereas that of *H. contortus*, *T. triandra*, and *C. fallax* was 640, 330 and 160 kg ha^{-1} respectively.

High and medium grazing pressure decreased the autumn mass of *Aristida* spp. and *Enneapogon* spp. in most years. At low grazing pressure, *Aristida* spp. mass increased markedly after above-average summer rainfall in 1996–1997 (210 kg ha^{-1}) and 2000–2001 (250 kg ha^{-1}) (Fig. 5*b*). Ungrazed *Aristida* spp. and *Enneapogon* spp. did not recover herbage mass rapidly after the fire in 1998, compared with the relative increases by *B. ewartiana*, *H. contortus* and *T. triandra* (Fig. 5*a, c, d*).

Ground cover

Ground cover in autumn, a time of relatively high cover, varied at both sites and reflected the four grazing pressures and the total rainfall over the previous summer (Fig. 3*c, d*). Ground cover in poplar box pastures rarely reached 60% when grazed, but it was mostly greater than 40% in all treatments, except under high grazing pressure in the low rainfall years (Fig. 3*c*). This cover included poplar box tree leaf-fall on occasions, to 600 kg ha^{-1} in more densely treed patches after a low rainfall summer. Ground cover at the ironbark site when the experiments commenced after several below average rainfall years was 45–55%, reflecting conservative prior grazing. Thereafter, at this site, increasing grazing pressure resulted in significantly less ($P < 0.05$) autumn ground cover in 6 of the 8 years to 2001. Ground cover after the first few years was generally over 50% under high grazing pressure and over 70% at low grazing pressure. The ground cover

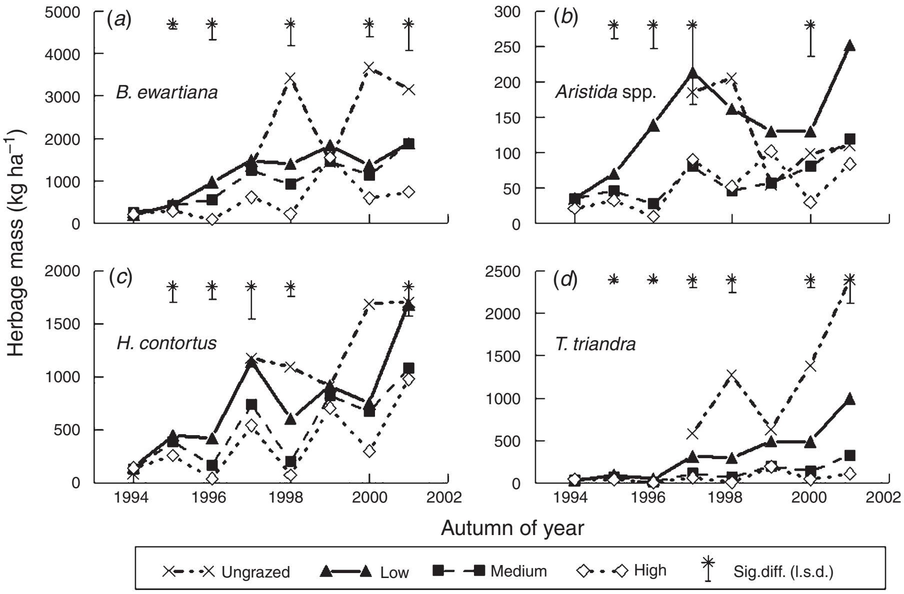

Fig. 5. Ironbark site: autumn perennial grass species herbage mass (kg DM ha^{-1}) response to four grazing pressures (ungrazed, low, medium, and high) between 1994 and 2001, (*a*) *Bothriochloa ewartiana*, (*b*) *Aristida* spp., (*c*) *Heteropogon contortus*, and (*d*) *Themeda triandra*. Vertical bars show significant l.s.d. ($P = 0.05$) between the three grazed treatments only. Note the different herbage mass scales.

in ungrazed ironbark pasture averaged around 90% in later years (Fig. 3*d*) compared with only 70% for the equivalent poplar box site pasture.

Pasture crown cover (basal cover)

There was a trend of increasing pasture crown cover at all grazing pressures at the poplar box site and in the ungrazed and low grazing pressure treatments at the ironbark site, but seasonal effects were marked at both sites. Crown cover was usually highest at low grazing pressure and lowest under high grazing pressure (Fig. 3*e*, *f*). At the poplar box site there was a significant crown cover difference ($P < 0.05$) between high and low grazing pressure when averaged over all years, but it was not significant within any single year. Pasture crown cover ranged from below 2% to almost 6% in the ungrazed, low and medium grazing pressure treatments in the poplar box pastures, with significant ($P < 0.05$) between year differences from 2% in 1995 to 5.3% in 2001. The consistent grazing pressure effect resulted in a greater ($P < 0.05$) average crown cover of 3.9% under low grazing pressure than the mean of 2.9% under high grazing pressure. There is no clear explanation for the crown cover decline in 1999 in the grazed treatments. The ranking of species basal cover contribution under the grazed treatments was, from highest, *C. divaricata*, *Aristida* spp. group, *B. decipiens*, *E. ramosus*, *Enneapogon* spp., *T. loliiformis*, *D. sericeum*, *A. ramosus*, *C. fallax* and *B. bladhii.*

In the ironbark community, increasing grazing pressure significantly reduced pasture crown cover in 4 years, and from near 4% at low and ungrazed, to below 2% at medium and high grazing pressure in 2000. Two years of high grazing pressure elapsed before a significant reduction ($P < 0.05$) occurred in crown cover, despite herbage mass being significantly reduced after 1 year. The species contribution to basal cover throughout the experiments, ranking from highest, was *H. contortus*, *B. ewartiana*, *C. fallax* and *T. triandra*.

Plant density

Population density of the main perennial grasses is the net result of survival and recruitment. At the poplar box site plant density fluctuated slightly with seasons, but plant turnover (total deaths compared with original numbers) was 50% greater at high than at low grazing pressure. Turnover of plants was greatest in *D. sericeum* (240% of the original numbers by 2000), compared with 115% for *A. calycina* and *B. decipiens*, and least for *E. ramosus* (39%) and *C. fallax* (28%). There was a general increase in population density in all treatments between 1998 and 2000, but values were strongly related to the original density at the fixed recording positions. The initial density of the relatively dynamic *D. sericeum* was greatest (3.5 plants m^{-2}) at the high grazing pressure locations and least (1.8 plants m^{-2}) at the ungrazed recording locations. Between 1995 and 2000 those densities ranged between 2.4–4.8 and 1.8–3.6 plants m^{-2} at the high pressure and ungrazed locations respectively. The low and medium grazing treatment recordings began between those initial extremes, but ended as equal highest at 5.0 plants m^{-2} (Fig. 6*a*). The density of the less palatable *B. decipiens* changed less due to grazing pressure than to summer seasons, initially varying among treatments from 3 to 9 plants m^{-2} (Fig. 6*c*).

At the ironbark site, density of *H. contortus* fluctuated markedly between 5 and 25 plants m^{-2} and was significantly affected by grazing pressure in 2000 (Fig. 6*b*), with density related inversely to grazing pressure that year. The density of *B. ewartiana* was more stable at 4–8 plants m^{-2} (Fig. 6*d*) and was influenced by the initial location selected. Grazing pressure

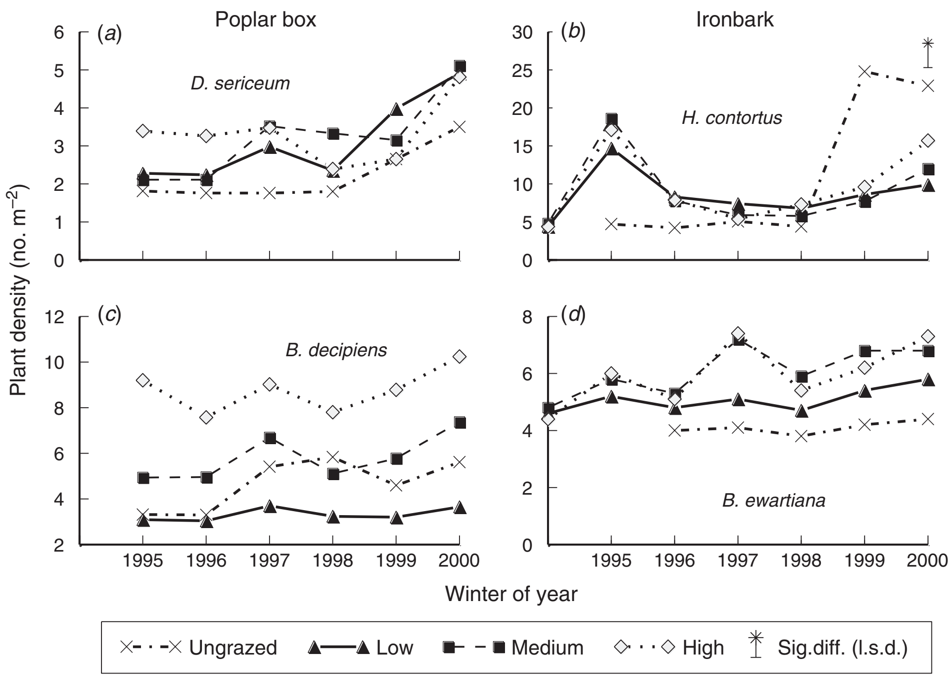

Fig. 6. Perennial grass species density (plants m^{-2}) response to four grazing pressures (ungrazed, low, medium, and high) at the poplar box site between 1995 and 2000, (*a*) *Dichanthium sericeum* and (*c*) *Bothriochloa decipiens*, and at the ironbark site between 1994 and 2000, (*b*) *Heteropogon contortus* and (*d*) *Bothriochloa ewartiana*. Vertical bars show significant l.s.d. ($P = 0.05$) between the three grazed treatments only. Note the different plant density scales.

had no significant effect on this species over the recording period. Density of *C. fallax* plants proved difficult to measure at both sites because of its spread by underground rhizomes and it often appeared as a sparse mat of discreet tillers that may have developed from a single parent plant.

Discussion

Indicator plants for grazing pressure management decisions

Plants are well known as indicators of rangeland condition (Whitehead *et al*. 2001) and ecological factors such as biodiversity (Landsberg and Crowley 2004), but are less well recognised as indicators of grazing management consequences in northern Australia. Ash *et al*. (2002) and Walsh and Cowley (2011) report land managers are seeking advice about plant and pasture indicators that they can use to monitor what effects their grazing pressure management decisions are having on their pastures. Identifying grazing indicator plants can be difficult because of their strong, short-term interaction with seasonal conditions and soil type preferences. These experiments have highlighted a range of indicator pasture species land managers can use to assist their grazing pressure or stocking rate decisions for these poplar box and silver-leaved ironbark *A*/*B* communities. Also, the choice of indicator species can vary with the abundance measure used, such as composition or proportion of standing dry matter, plant frequency or crown cover.

Both the same and different indicator species were identified for these two *A*/*B* communities. For example, a high or increasing herbage mass proportion and an increasing frequency of *T. triandra* is a good indicator of low or sustainable grazing pressure in both communities, while an increasing trend by those measures for *C. divaricata* and *C. truncata* is an indication of increasing, to high, grazing pressure. In the poplar box pastures the latter was not a totally undesirable response, as these *Chloris* spp. responded rapidly to spring rainfall and their high density of small plants provided spring or early summer grazing and soil surface stability at this more susceptible time. Their increase was particularly noticeable in selectively patch-grazed areas. The preferred species at the poplar box site, *D. sericeum*, responded negatively to high grazing pressure, but maintained its production and frequency at medium and low grazing pressure after 8 years, although annual responses in production and density were sensitive to seasonal conditions.

The common 3P grasses at both sites are not always useful indicators of grazing pressure, with *B. ewartiana* in the ironbark community not altering composition, as herbage mass proportion or frequency, due to grazing pressure. Likewise, *C. fallax* remained stable in both communities by all abundance measures, but acted more like an increaser. McIvor (2007) reported a similar non-responsive result to grazing in two environments of north Queensland. *Heteropogon contortus* abundance fluctuated widely with seasons, but it acted more like an increaser based on its frequency and plant density. This is contrary to most other published opinion (McIvor and Scanlan 1994; Rolfe *et al*. 1997) derived from different pasture types. *Bothriochloa bladhii* was a good indicator of grazing pressure, but it is restricted to soil of heavier texture, particularly in the lower parts of the landscape.

Among the 2P grasses few reliable indicator species were identified apart from *C. divaricata*. There was a tendency for *T. loliiformis*, *Eragrostis* spp. and *T. australianus* to act as increasers, but their response was not strong. The common *B. decipiens* had a similar response to the four grazing pressures at the poplar box site. Likewise, *E. aurea* was not a useful indicator. Visually, *E. ramosus* indicates high general grazing pressure when a distinct hedged top develops on most of its tussocks.

Although a high frequency of *Aristida* spp. is often cited as an indicator of over-grazing (Orr *et al*. 1997) they were not reliable indicators during these experiments. The frequency of the common *A. ramosa* increased marginally under all grazing pressures in the poplar box community, but at high grazing pressure it was grazed and had its lowest frequency after 8 years. The short-statured, annual *T. australianus*, usually common on bare ground after droughts in these environments, was an inconsistent indicator of grazing pressure during these experiments. It declined in frequency but increased in herbage composition at both sites under high grazing pressure. The frequency decline may have been from competition and shading by taller perennial grasses which inhibited its spring seed germination or subsequent seedling establishment. Also, reasonable ground cover, offering seedling competition, was maintained in these experiments.

Grazing pressure

The pasture composition changes indicate that removal by cattle grazing over the ensuing year of the equivalent of 25% of standing autumn pasture is a sustainable grazing intensity in the long term for these two pastures. This is a safe grazing rate providing annual grazing pressure which will maintain a desirable pasture composition and land condition. This 25% grazing use metric is within the 10–30% range of annual growth commonly cited for sustainable rangeland use in more marginal environments (Hunt 2008; Walsh and Cowley 2011; Orr and Phelps 2013; Stone *et al*. 2016). Grazing use as high as 50% of autumn forage in the short term in a recently cleared poplar box community in the southern *A*/*B* zone also seems justifiable in above-average rainfall years. This use rate in treeless pastures in the southern poplar box country is higher than calculated utilisation recommendations for other rangelands pastures. However, it did not cause a deterioration of the pasture resource under such seasons. Grazing rates between 25% and 50% use of autumn forage could be imposed by experienced operators.

Pasture composition

Plant deaths occurred in most years particularly in the summers ending in 1998, 2000 and 2001, but the indicator species remained persistent. The known sensitivity of *T. triandra* to high grazing pressure (Coetsee 1975; Snyman *et al*. 2013) became evident after 1 year at the ironbark site and after several years at the poplar box site. This grass combines strong seed dormancy with a tolerance of low fertility soils (Howden 1988) and fires. Periodic wet summers can also inadvertently reduce grazing pressure to low levels during the growth and seedling establishment phases (Daly 1994). Pasture composition fluctuations due to seasonal variation are often more critical to plant persistence than are grazing management differences (Orr and O'Reagain 2011).

The absence of a clear grazing pressure response from *Aristida* spp. and *Enneapogon* spp. is unexpected given that both genera are regarded as increasers under continuous heavy grazing pressure in north Queensland (Rolfe *et al*. 1997). Both groups encompassed a variety of species that differed between sites and in their palatability. For example, fine-stemmed *Aristida* species at the ironbark site, *A. schultzii*, *A. gracilipes* and *A. perniciosa*, were noted as being relatively more palatable than the more common and coarse-stemmed *A. calycina* and *A. ramosa*. In contrast, *T. australianus* did have the expected increased herbage mass under increasing grazing pressure during most years of the experiments. The three taxa are grazed, but they have relatively low grazing value.

Many species present at the poplar box site are widespread on a range of soil types in southern Queensland on other land types (Schefe *et al*. 1993). They are adapted to non-seasonal rainfall environments and survive droughts via strongly perennial crowns, prolific seeding and dormancy of fresh seeds. The lack of major pasture composition change over 8 years due to these grazing pressures does not exclude the possibility that subtle landscape degradation processes may have started at the higher grazing pressures. For example, *Sclerolaena* spp. generally increase in frequency during low rainfall years in this environment, but persist only on degraded surfaces after the drought breaks (NSW DPI 2014).

The high grazing pressure of 75% use kept the tops of *Aristida* spp. as well as other low palatability grasses grazed and standing herbage mass subdued, but it did not kill large numbers of plants. *Cenchrus ciliaris* colonised some disturbed areas such as roadsides and firebreaks, but did not spread into the native pasture. This contrasts with the spread of *C. ciliaris* into poplar box country on red earth soils (Chromosols) in southern inland Queensland (Eyre *et al*. 2009).

At the ironbark site, herbage mass of *B. ewartiana* was reduced by heavier grazing pressure and increased by good summer rainfall at low grazing pressure, probably because cattle have a lower grazing preference for it when other palatable species are present. The slow recovery of the *Aristida* spp. in ungrazed plots after the accidental fire in spring 1998 supports the findings of Orr *et al*. (1997). These authors suggested that *Aristida* spp. abundance was reduced by spring fires in pastures where *H. contortus* was prominent. As in those pastures, *H. contortus* grew vigorously after the fire, as did *B. ewartiana* and *T. triandra*.

The inadvertently low grazing pressure at the ironbark site over the well above-average rainfall 1998–1999 year allowed a strong recovery of herbage mass and crown cover in one good growing season after four consecutive years of high grazing pressure. This shows the capacity of these perennial grasses to recuperate from stress if previously in a healthy condition, similar to the *Astrebla* spp. pastures reported by Orr and Silcock (2010). At lower grazing pressure, fewer tiller buds are grazed, and there is more carry-over ground cover during the dry season with less runoff from the same amount of rainfall (NRW 2006). This may be due to a greater density of plant crowns, more litter and greater root density. Nonetheless, after a setback, recovery of herbage mass generally occurred in one growing season, but it took up to 2 years for the crown cover to increase. The improvement was most marked in one good wet season if there was an early start to that summer's growth.

Ground cover

Increasing grazing pressure had a direct impact on reducing ground cover, which remained in relative proportion to the grazing pressures throughout the experiments in both communities. The grazed poplar box pastures had lower ground cover, around 40%, than the ironbark pastures, above 50%, irrespective of grazing pressure. This cover also declined to a greater extent in low rainfall summers. Cover at the ironbark site was between 60% and 80% in all treatments by 2001. The potential was demonstrated for large ground cover changes between years at medium to high grazing pressure on these pastures, which could lead to surface condition deterioration.

The recommended ground cover of 60–70% (Harrington *et al*. 1984; Ash *et al*. 2002) was consistently achieved at low and medium grazing pressure at the ironbark site. At the poplar box site, cover levels above 60% were only attained after 1997 when ungrazed. Apart from that year, the relativity of ground cover among the treatments consistently declined as grazing pressure increased. In the poplar box pastures, total ground cover at the end of summer showed less year-to-year variability than pasture crown cover, and being easier to record, was shown to be a measure that producers and regional management groups could potentially use effectively to assess how seasons and management are influencing pasture stability and potential soil conservation outcomes.

Pasture crown cover

By the first crown cover recording at the poplar box site, a ranking was established from 3.2% where ungrazed to 1.3% where heavily grazed. However, the heavy grazing treatment produced a steady increase in crown cover over the next 3 years under improving seasonal conditions. The relative grazing intensities were consistently reflected in the crown cover of grazed paddocks but not of the ungrazed plots, perhaps due to a greater size of individual palatable grass plants, such as *D. sericeum* and *B. bladhii*, in the absence of grazing. After the 1999 decline, crown cover increased for 2 years until the dry year of 2002. The values of 5–6% crown cover at that time would be regarded as productive for Australian savannah woodlands (McIvor 2007; Orr and O'Reagain 2011). The results show the potential for large changes between years, especially at medium to high grazing pressure, and the importance of the multiple small plants of species such as *C. divaricata* for maintaining crown and ground cover. The pattern of these results is similar to that reported by Orr *et al*. (1993), where increasing grazing pressure caused a reduction in pasture crown cover, and also the interaction between grazing pressure and seasonal growing conditions as observed by McKeon *et al*. (1990).

At the ironbark site, crown cover increased under medium and high grazing pressure in response to well above-average rainfall seasons in 1998–1999 before declining again in both treatments in 2000. Even after 7 years of low grazing pressure, the 4% crown cover of these high yielding pastures was relatively low for perennial tussock grasses in a 640-mm rainfall environment, although similar to the basal cover reported from two north Queensland eucalypt communities (McIvor 2007). This may reflect the strong competitive nature of existing *B. ewartiana* plants for readily available resources combined with an inability by *H. contortus* to develop into and persist as large-crowned plants in this environment.

Plant density

The density of discreet plants increased as grazing pressure increased. This is because the larger crowns of established plants were broken apart by trampling and grazing under high grazing pressure, without any appreciable net recruitment from seedling establishment. Heavy grazing pressure by cattle caused a similar break-up of tussocks of *Astrebla* spp. in north-west Queensland (Hall and Lee 1980). The exception to plant density changes due to grazing pressure was by *H. contortus* at the ironbark site where large numbers of seedling plants were recorded in the ungrazed pastures after high rainfall in the 1998–1999 year and a spring fire. Large recruitment events for this species have been documented previously (Shaw 1957; Orr *et al*. 2004).

In the poplar box pastures, total perennial grass plant density was of a similar magnitude to that at the ironbark site, but it was not significantly altered by grazing pressure. However, species changes occurred over time, most significantly for *D. sericeum* in 1998 after numbers had been relatively stable in previous years. Thus density change of individual perennial grasses was not a sensitive measure of grazing pressure in these pastures over this period compared with the large changes in aggregate standing forage mass and crown cover which occurred.

Management implications for Aristida/Bothriochloa communities

Appropriate grazing pressure management to encourage the desirable perennial species differs among these two eucalypt communities. Land managers need to recognise their local indicator pasture species, understand their ecology and seasonal dynamics, and grazing pressure responses. They can use this knowledge to determine the impacts of their grazing pressure decisions and adjust stocking rates accordingly. The pasture composition changes suggest how to devised grazing pressure strategies to suit the specifics of each land type with their differing proportions of the various pasture species. Neither site had any major woody weed shrubs such as *Carissa* spp., *Acacia* spp., *Eremophila* spp. or *Dodonaea* spp. to influence the outcome of the research, but they are an added management complication in other north Australian rangelands, and are usually managed by fire and grazing (Pressland 1982). An awareness of the rapid decline in pasture crown cover at high grazing pressure in below-average rainfall years should provide the incentive to adjust stocking pressure early when such circumstances occur.

Dominant yielding species such as *D. sericeum*, *B. ewartiana* and *E. ramosus* are sometimes not the most palatable species in mid-summer, even if well grazed over a full year, except under heavy grazing pressure. This is a useful trait for ensuring seeding, long-term persistence and spread, similar to the way *Stylosanthes scabra* (shrubby stylo) enhances its position in native pastures by being relatively unpalatable compared with green grass leaf when the legume is green, leafy and growing (Tropical Forages 2014). Reading these responses in pastures, with an understanding of species seasonal responses, can be used to adjust grazing pressures to develop and maintain a desired pasture composition.

Conclusions

This study showed that grazing 25% of standing autumn pasture is sustainable at both sites, although probably underutilising the resource, except in below-average rainfall years. A grazing use rate of 25% is recommended and represents a sustainable long-term carrying capacity for these communities, even though in treeless poplar box pastures the desirable species composition remained stable at 50% use of standing autumn forage in above-average rainfall years. Apart from increasing the preferred *T. triandra* at both sites and *D. sericeum* in the poplar box community, the recommended 25% rate will improve and maintain a desirable pasture composition in the medium term, while accumulating a greater bulk of pasture, and increase both pasture crown cover and total ground cover. Care is needed in quoting safe forage 'grazing use' or 'utilisation' rates without also describing which protocols were used and what objectives are sought, such as for longer-term strategic or shorter-term tactical grazing decisions. In these communities, 7–8 years of sustained high grazing pressure by cattle did not destroy the nature of the pasture composition, despite the significantly reduced herbage mass, ground cover and crown cover, and an increase in some less desirable species. Indications were that this reduced productive capacity could improve subsequently if well managed with low grazing pressure over a period of above-average rainfall years.

These results provide objective data on grazing pressure impacts and pasture species responses affecting the productivity and stability of *Aristida*/*Bothriochloa* native pasture communities in eucalypt woodlands for land holders, land administrators and resource management groups. Some species can be used as indicators of grazing pressure, such as *T. triandra*, *D. sericeum*, *H. contortus*, *B. bladhii*, *Chloris* spp., and to a lesser extent *T. loliiformis* and *T. australianus*. Common grasses such as *B. ewartiana*, *C. fallax*, *E. ramosus B. decipiens* and *Aristida* spp. are less sensitive to the same pressures to be used as indicators. Other plants such as native legumes and many broad-leaved forbs are too dynamic in their seasonal presence and in their response to extremes of grazing pressure for this role. The value of the 2P grass, *C. divaricata*, for early summer grazing and land surface stability was demonstrated. This pasture response knowledge broadens the understanding of grazing management implications and complements the learnings made from other grazing management studies that emphasise differing treatments. The information can also be used directly by property managers and land management education programs to improve both the ecological environment and production capacity of these pasture communities.

Acknowledgements

We thank the Chandler family at Injune for their assistance and access to land, and the Hawkins and Hicks families at Rubyvale for the use of their land, providing cattle and assistance with musters. Peter Knights assisted by sourcing cattle, Kerry Bell and Christina Playford conducted the statistical analyses, Kathy Delaney prepared the figures, and technical expertise was provided by Joff Douglas, Scott Brady, Matthew Hall, David Osten, Ann Sullivan, Jill Aisthorpe and Gavin Peck. Producer consultative committees' provided suggestions on the practical implications and value of our findings. Operating funds were provided by the Australian Meat Research and Development Corporation, and later Meat and Livestock Australia, while Queensland Government field staff conducted the study.

References

Allen, D. E., Pringle, M. J., Bray, S., Hall, T. J., O'Reagain, P., Phelps, D., Cobon, D. H., Bloesch, P. M., and Dalal, R. C. (2013). What determines soil organic carbon stocks in the grazing lands of north-eastern Australia? *Soil Research* **51**, 695–706. doi:10.1071/SR13041

Ash, A., Corfield, J., and Ksiksi, T. (2002). 'The Ecograze Project: Developing Guidelines to Better Manage Grazing Country.' (CSIRO: Townsville, Qld.)

Coetsee, G. (1975). Grazing of *cymbopogon-themeda* veld in the dormant period. *Proceedings of the Annual Congresses of the Grassland Society of Southern Africa* **10**, 147–150. doi:10.1080/00725560.1975.9648763

Daly, J. J. (1994). 'Wet as a Shag. Dry as a Bone.' (Queensland Department of Primary Industries: Brisbane, Qld.)

Dyksterhuis, E. J. (1948). The vegetation of the Western Cross Timbers. *Ecological Monographs* **18**, 325–376. doi:10.2307/1948576

Eyre, T. J., Wang, J., Venz, M. F., Chilcott, C., and Whish, G. (2009). Buffel grass in Queensland's semi-arid woodlands: response to local and landscape scale variables, and relationship with grass, forb and reptile species. *The Rangeland Journal* **31**, 293–305. doi:10.1071/RJ08035

GENSTAT (2015). 'GENSTAT for Windows. Release 16.1.' (VSN International: Oxford, UK.)

Hall, T. J., and Lee, G. R. (1980). Response of an *Astrebla* spp. grassland to heavy grazing by cattle and light grazing by sheep in north-west Queensland. *Australian Rangeland Journal* **2**, 83–93. doi:10.1071/RJ9800083

Hall, T. J., Filet, P. G., Banks, B., and Silcock, R. G. (1994). A State and Transition Model of the *Aristida-Bothriochloa* pasture community of central and southern Queensland. *Tropical Grasslands* **28**, 270–273.

Hall, T. J., McIvor, J. G., Reid, D. J., Jones, P., MacLeod, N. D., McDonald, C. K., and Smith, D. R. (2014). A comparison of stocking methods for beef production in northern Australia: pasture and soil surface condition responses. *The Rangeland Journal* **36**, 161–174. doi:10.1071/RJ13075

Hall, T. J., Jones, P., Silcock, R. G., and Filet, P. G. (2016). Pasture production and composition response to killing Eucalypt trees with herbicides in central Queensland. *The Rangeland Journal* **38**, 427–441. doi:10.1071/RJ16013

Harrington, G. N., Mills, D. M. D., Pressland, A. J., and Hodgkinson, K. C. (1984). Semi-arid woodlands. *In*: 'Management of Australia's Rangelands'. (Eds G. N. Harrington, A. D. Wilson and M. D. Young.) pp. 189–207. (CSIRO: Melbourne, Vic.)

Henderson, R. J. F. (1997). 'Queensland Plants: Names and Distribution.' (Queensland Department of Environment: Brisbane, Qld.)

Howden, S. M. (1988). Some aspects of the ecology of four tropical grasses with emphasis on *Bothriochloa pertusa*. Ph.D. Thesis, Griffith University, Brisbane, Qld, Australia.

Hunt, L. P. (2008). Safe pasture utilisation rates as a grazing management tool in extensively grazed tropical savannas of northern Australia. *The Rangeland Journal* **30**, 305–315. doi:10.1071/RJ07058

Johnston, P. W., McKeon, G. M., and Day, K. A. (1996). Objective 'safe' grazing capacities for south-west Queensland Australia: development of a model for individual properties. *The Rangeland Journal* **18**, 244–258. doi:10.1071/RJ9960244

Jones, P., Filet, P., and Orr, D. M. (2009). Demography of three perennial grasses in a central Queensland eucalypt woodland. *The Rangeland Journal* **31**, 427–437. doi:10.1071/RJ09035

Landsberg, J., and Crowley, G. (2004). Monitoring rangeland biodiversity – plants as indicators. *Austral Ecology* **29**, 59–77. doi:10.1111/j.1442-9993.2004.01357.x

Lobry de Bruyn, L. A., and Conacher, A. J. (1990). The role of termites and ants in soil modification: A review. *Australian Journal of Soil Research* **28**, 55–93.

McIvor, J. G. (2007). Pasture management in semi-arid tropical woodlands: dynamics of perennial grasses. *The Rangeland Journal* **29**, 87–100. doi:10.1071/RJ06031

McIvor, J. G., and Scanlan, J. C. (1994). State and Transition Models for rangelands. 8. A State and Transition Model for the northern speargrass zone. *Tropical Grasslands* **28**, 256–259.

McKeon, G. M., Day, K. A., Howden, S. M., Mott, J. J., Orr, D. M., Scattini, W. J., and Weston, E. J. (1990). Northern Australian savannas: Management for pastoral production. *Journal of Biogeography* **17**, 355–372. doi:10.2307/2845365

Minson, D. J., and McDonald, C. K. (1987). Estimating forage intake from the growth of beef cattle. *Tropical Grasslands* **21**, 116–122.

Moore, C. W. E. (1953). The vegetation of the south-eastern Riverina, New South Wales. II. The disclimax communities. *Australian Journal of Botany* **1**, 548–567. doi:10.1071/BT9530548

NRW (2006). 'Erosion Control in Grazing Lands.' Land Series Fact Sheet. (Queensland Department of Natural Resources and Water: Brisbane, Qld.)

NSW DPI (2014). Galvanised burr (*Sclerolaena birchii*). NSW Weedwise. Available at: http://weeds.dpi.nsw.gov.au/Weeds/Details/242 (accessed 20 April 2016).

O'Reagain, P. J., and Bushell, J. J. (2011). 'The Wambiana Grazing Trial. Key Learnings for Sustainable and Profitable Management in a Variable Environment.' (Queensland Department of Employment, Economic Development and Innovation: Brisbane, Qld.)

O'Reagain, P. J., and Bushell, J. J. (2013). Managing for a variable climate: long term results from the Wambiana grazing trial. In 'Throw your hat in the ring and make a difference. Proceedings of the Northern Beef Research Update Conference'. Cairns, Qld, 12–15 August 2013. (Eds E. Charmley and I. Watson.) pp. 55–60. (North Australia Beef Research Council: Cairns, Qld.)

O'Reagain, P., Bushell, J., Holloway, C., and Reid, A. (2009). Managing for rainfall variability: effect of grazing strategy on cattle production in a dry tropical savanna. *Animal Production Science* **49**, 85–99. doi:10.1071/EA07187

Orr, D. M., and O'Reagain, P. J. (2011). Managing for rainfall variability: impacts of grazing strategies on perennial grass dynamics in a dry tropical savannah. *The Rangeland Journal* **33**, 209–220. doi:10.1071/RJ11032

Orr, D. M., and Phelps, D. G. (2013). Impacts of level of utilisation by grazing on an *Astrebla* (Mitchell grass) grassland in north-western Queensland between 1984 and 2010. 1. Herbage mass and population dynamics of *Astrebla* spp. *The Rangeland Journal* **35**, 1–15. doi:10.1071/RJ11068

Orr, D. M., and Silcock, R. (2010). The occurrence and causes of episodic recruitment of *Astrebla* spp. *In*: 'Rain on the Rangelands. Proceedings of the 16th Biennial Conference of the Australian Rangeland Society'. Bourke. (Eds D. J. Eldridge and C. Waters.) pp. 1–6. (Australian Rangeland Society: Perth, WA.)

Orr, D. M., Evenson, C. J., Lehane, J. K., Bowly, P. S., and Cowan, D. C. (1993). Dynamics of perennial grasses with sheep grazing in *Acacia aneura* woodlands in south-west Queensland. *Tropical Grasslands* **27**, 87–93.

Orr, D. M., Paton, C. J., and Lisle, A. T. (1997). Using fire to manage species composition in *Heteropogon contortus* (black speargrass) pastures. 1. Burning regimes. *Australian Journal of Agricultural Research* **48**, 795–802. doi:10.1071/A96130

Orr, D. M., Paton, C. J., and Reid, D. J. (2004). Dynamics of plant populations in *Heteropogon contortus* (black speargrass) pastures on a granite landscape in southern Queensland. 1. Dynamics of *H. contortus* populations. *Tropical Grasslands* **38**, 17–30.

Orr, D. M., Burrows, W. H., Hendricksen, R. E., Clem, R. L., Rutherford, M. T., Conway, M. J., Myles, D. J., Back, P. V., and Paton, C. J. (2010). Impacts of grazing management options on pasture and animal productivity in a *Heteropogon contortus* (black speargrass) pasture in central Queensland. 1. Pasture yield and composition. *Crop & Pasture Science* **61**, 170–181. doi:10.1071/CP09193

Pressland, A. J. (1982). Fire in the management of grazing lands in Queensland. *Tropical Grasslands* **16**, 104–112.

Queensland Government (2016). Grazing and stocking strategies to improve production. Available at: www.business.qld.gov.au/industry/agriculture/crop-growing/grazing-and-pasture-management/improved-production/stocking-strategies (accessed 21 September 2016).

Rangelands West (2014). Point frame method. Available at: http://globalrangelands.org/inventorymonitoring/pointframe (accessed 17 August 2016).

Rolfe, J., Golding, T., and Cowan, D. (1997). 'Is Your Pasture Past it? The Glove Box Guide to Native Pasture Identification in North Queensland.' Queensland Department of Primary Industries Information Series QI97083. (Queensland Department of Primary Industries: Brisbane, Qld.)

Scanlan, J. C., McKeon, G. M., Day, K. A., Mott, J. J., and Hinton, A. W. (1994). Estimating safe carrying capacities of extensive cattle-grazing properties within tropical, semi-arid woodlands of north-eastern Australia. *The Rangeland Journal* **16**, 64–76. doi:10.1071/RJ9940064

Schefe, C. M., Graham, T. W. G., and Hall, T. J. (1993). 'A floristic description of the pasture land types of the Maranoa.' Queensland Department of Primary Industries, Project Report Series QO93003. (Queensland Department of Primary Industries: Brisbane, Qld.)

Shaw, N. H. (1957). Bunch spear grass dominance in burnt pastures in south-eastern Queensland. *Australian Journal of Agricultural Research* **8**, 325–334. doi:10.1071/AR9570325

Silburn, D. M., Carroll, C., Ciesiolka, C. A. A., deVoil, R. C., and Burger, P. (2011). Hillslope runoff and erosion on duplex soils in grazing lands in semi-arid central Queensland. I. Influences of cover, slope, and soil. *Soil Research* **49**, 105–117. doi:10.1071/SR09068

Silcock, R. G., Filet, P. G., Hall, T. J., Thomas, E. C., Day, K. A., Kelly, A. M., Knights, P. T., Robertson, B. A., and Osten, D. (1996). Enhancing pasture stability and profitability for producers in *Aristida/Bothriochloa* woodlands. Final Report 1992–1996, Project DAQ.090 to Meat Research Corporation. (Meat Research Corporation: Sydney, NSW.)

Silcock, R. G., Jones, P., Hall, T. J., and Waters, D. K. (2005). Enhancing pasture stability and profitability for producers in Poplar Box and Silver-leaved Ironbark woodlands. Final Report Project NAP3.208 to Meat and Livestock Australia. (Queensland Department of Primary Industries: Brisbane, Qld.) Available at: www.mla.com.au/research-and-development/search-rd-reports/final-report-details/Productivity-On-Farm/Enhancing-pasture-stability-and-profitability-in-Poplar-Box-and-Silver-leaved-Ironbark-in-*Aristida-Bothriochloa*-Woodlands/2010 (accessed 20 September 2016).

Silcock, R. G., Hall, T. J., Filet, P. G., Kelly, A. M., Osten, D., Schefe, C. M., and Knights, P. T. (2015*a*). Floristic composition and pasture condition of *Aristida/Bothriochloa* pastures in central Queensland. I. Pasture floristics. *The Rangeland Journal* **37**, 199–215. doi:10.1071/RJ14106

Silcock, R. G., Hall, T. J., Filet, P. G., Kelly, A. M., Osten, D., and Graham, T. W. G. (2015*b*). Floristic composition and pasture condition of *Aristida/Bothriochloa* pastures in central Queensland. II. Soil and pasture condition interactions. *The Rangeland Journal* **37**, 217–226. doi:10.1071/RJ14107

Snyman, H. A., Ingram, L. J., and Kirkman, K. P. (2013). *Themeda triandra*: a keystone grass species. *African Journal of Range & Forage Science* **30**, 99–125. doi:10.2989/10220119.2013.831375

Stone, G. S., Fraser, G. W., O'Reagain, P. J., Timmers, P. K., and Bushell, J. J. (2016). A new methodology for the calculation of pasture utilisation for grazing lands. Available at: www.longpaddock.qld.gov.au/about/publications/pdf/Stone_paper.pdf (accessed 1 July 2016).

Story, R. (1967). Vegetation of the Isaac – Comet area. *In*: 'Lands of the Isaac-Comet Area, Queensland'. Land Research Series No. 19. (Eds R. Story, R. W. Galloway, R. H. Gunn and E. A. Fitzpatrick.) pp. 108–128. (CSIRO: Melbourne, Vic.)

Teague, W. R., Dowhower, S. L., Baker, S. A., Haile, N., DeLaune, P. B., and Conover, D. M. (2011). Grazing management impacts on vegetation, soil biota and soil chemical, physical and hydrological properties in tall grass prairie. *Agriculture, Ecosystems & Environment* **141**, 310–322. doi:10.1016/j.agee.2011.03.009

Tothill, J. C., and Gillies, C. (1992). 'The Pasture Lands of Northern Australia. Their Condition, Productivity and Sustainability'. Occasional Publication No. 5, Tropical Grasslands Society of Australia. (Tropical Grasslands Society: Brisbane, Qld.)

Tothill, J. C., Hargreaves, J. N. G., Jones, R. M., and McDonald, C. K. (1992). 'BOTANAL: a comprehensive sampling procedure for estimating pasture yield and composition. I. Field sampling.' Technical Memo. No. 78, CSIRO Division of Tropical Crops and Pastures. (CSIRO: Brisbane, Qld.)

Tropical Forages (2014). *Stylosanthes scabra*. Available at: www.tropicalforages.info/key/Forages/Media/Html/Stylosanthes_scabra.htm (accessed 2 September 2016).

Walsh, D., and Cowley, R. A. (2011). Looking back in time: can safe pasture utilisation rates be determined using commercial paddock data in the Northern Territory? *The Rangeland Journal* **33**, 131–142. doi:10.1071/RJ11003

Weston, E. J., Harbison, J., Leslie, J. K., Rosenthal, K. M., and Mayer, R. J. (1981). Assessment of the agricultural and pastoral potential of Queensland. Agriculture Branch Technical Report No. 27. (Queensland Department of Primary Industries: Brisbane, Qld.)

Whitehead, P., Woinarski, J., Fisher, A., Fensham, R., and Briggs, K. (Eds.) (2001). Developing an analytical framework for monitoring biodiversity in Australia's rangelands. A report by the Tropical Savannas CRC for the National Land and Water Resources Audit. (Tropical Savannas CRC: Darwin, NT.)

Wilson, A. D., Leigh, J. H., and Mulham, W. E. (1969). A study of merino sheep grazing a bladder saltbush (*Atriplex vesicaria*) – cotton-bush (*Kochia aphylla*) community on the Riverine Plain. *Australian Journal of Agricultural Research* **20**, 1123–1136. doi:10.1071/AR9691123