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Herbage mass thresholds rather than plant phenology are a more useful cue for grazing management decisions in the mid-north region of South Australia

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Abstract. Research was conducted in the mid-north of South Australia over the period 2000–05 to evaluate the effects of different grazing management cues on composition and production of a grassland. The management cues were based on calendar, plant phenology or herbage mass thresholds using grazing exclusion as a control. There were five grazing treatments: (i) regional practice (RP), where sheep grazed continuously for the period April–December; (ii) autumn rest, where sheep grazing was restricted to June–December; (iii) spring rest, where sheep grazing was restricted to April–August; (iv) high density and short duration (HDSD), where herbage mass thresholds determined when grazing occurred and for what duration; and (v) nil (NIL) grazing by domestic herbivores. Mean annual estimates of herbage mass were highest for NIL and HDSD and inclusion of the estimate of herbage consumption by sheep resulted in greatest primary plant production in HDSD. The contribution of perennial grasses to herbage mass declined with RP and seasonal grazing treatments. Frequency of perennial grasses was unaffected by grazing treatment but the number of perennial grass plants increased over time in RP and seasonal treatments. HDSD allowed maintenance of basal cover whereas bare ground increased with RP and seasonal treatments. Litter accumulated in NIL but this was associated with a decline in perennial basal cover. Seasonal grazing treatments did not provide an advantage over RP and there appeared to be no benefit from including phenology in management decisions. In contrast, HDSD resulted in a stable and productive grassland ecosystem, with stocking rate estimated at 78% greater than other treatments. These features offer a desirable mix for future industry adoption in the mid-north of South Australia.

Additional keywords: grazing exclusion, management cues, perennial grasses, seasonal grazing, short duration and high intensity grazing.

Introduction

More than 500 000 ha of grasslands in the mid-north of South Australia (32°25′–34°21′S) are grazed by livestock (Nicholls 1999). Annual rainfall in this region varies from 250 to 600 mm and occurs mostly in the period May–October. Grazed pastures tend to be largely confined to non-arable areas and are strongly annual-dominant, with wild oats (*Avena barbata*) and brome grasses (e.g. *Bromus diandrus* and *B. molliformis*) contributing heavily to herbage mass [botanical nomenclature according to Harden (1993)]. Grasslands have traditionally been grazed continuously from the autumn break in May until harvest in December when animals are removed to graze crop stubbles. The long period of continuous grazing associated with largely invariable stocking rates has been associated with a transition from perennial to annual dominance (Westoby *et al*. 1989; Nicholls 1999).

Debate exists as to the relative merits of grazing management practices, using different cues for introducing and removing livestock, on grassland composition and productivity and the direct and flow-on effects of such practices on animal production (Hart *et al*. 1988; Kirkman and Moore 1995; Heitschmidt and Walker 1996; Norton 1998). Long periods of continuous grazing using only the historical ‘stocking rate’ to determine livestock numbers and commonly referred to as set stocking, is the legacy of most pastoral regions of Australia and is still commonly employed. Forty-eight percent of respondents ($n = 2292$) to a National Benchmark Survey (Reeves and Thompson 2005) indicated they practised set stocking while 38% practised rotational grazing. Within the definition of rotational grazing, several cues have been suggested to guide decisions about the timing of introduction, the number of livestock and their removal from a paddock. The common element among approaches is periods where grazing does not occur or stocking rate or density is varied. Management cues can include herbage mass (Dowling *et al*. 1996; McKenzie and Tainton 1996), length of time of grazing events (Taylor *et al*. 1993; Earl and Jones 1996), length of time between grazing events (Taylor *et al*. 1993; Earl and Jones 1996; Bowman *et al*. 2009), number of leaves per tiller (Fulkerson and Donaghy 2001) and phenology of designated desirable and/or undesirable plant

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species (Whalley *et al*. 1978; Lodge and Whalley 1985; Garden *et al*. 2000).

Seasonal grazing management based on plant phenology targets the mechanisms used by plants to regulate population size, including seed production, dispersal and germination and seedling recruitment (Whalley 1994) as a means of effecting compositional change in pastures. In temperate regions, a relaxation of grazing pressure in autumn will encourage seedling recruitment of cool season annual and perennial species. Relaxation of grazing pressure in spring will encourage seed dispersal of these same groups and so it is difficult to envisage a selective advantage to perenniality arising from these practices. In contrast, management of grazing to more tightly control utilisation of herbage and minimum and maximum amounts of herbage mass throughout the year may better regulate population dynamics and hence compositional change in pastures towards perennial grasses. The aim of this experiment was to evaluate the effects of calendar-based, plant phenology-based and herbage mass threshold-based grazing treatments on pasture composition and production and relate the measured changes to a grazing exclusion control treatment.

Method

Experimental design

An experiment was conducted over the period September 2000 to November 2005 at the property 'Anama', located 15 km north of Clare, South Australia (33°50′22.59″S, 138°36′13.32″E; 385 m a.s.l.). The research area had historically been used for grazing by sheep and had not been cropped. A 26.5-ha area within a pre-existing paddock was subdivided into 5 treatment areas (3 × 6.2 ha; 1 × 5.0 ha; 1 × 3.0 ha). There were five different grazing management treatments including exclusion of domestic herbivores (i.e. nil grazing). Nil grazing (NIL) was allocated to the smallest treatment area but the other grazing treatments were allocated at random.

Grazing treatments

The five grazing treatments compared two different approaches to planning the grazing process with regional practice (RP) and NIL (Table 1). The first approach to planning the grazing system (two seasonal grazing treatments) was structured on the key phenological events of seed set and germination and required that the timing of grazing and rest periods be guided by the notion of phenological season. The four phenological seasons were defined according to observation (M. Nicholls, pers. comm.) of the phenological stages of the predominant perennial native grasses present in the pastures, *Austrostipa* spp., *Austrodanthonia* spp. and *Aristida behriana*. The timing and length of each season were as follows: (i) summer, 14 December–16 April; (ii) autumn, 17 April–16 June; (iii) winter, 17 June–24 August; and (iv) spring, 25 August–13 December. The second approach to planning the grazing system (one grazing treatment) was based on herbage mass and plant growth rate; grazing and rest periods were irrespective of phenological season.

The rationale for the grazing treatments was as follows. RP (6.2 ha) represented the control treatment as practised in the region with annual stocking rate set to the regional mean of 2.5 dry sheep equivalent (DSE)/ha; autumn rest (AUT rest; 6.2 ha) from grazing would allow for improved germination and seedling survival of cool season perennial grass species; and spring rest (SPR rest; 6.2 ha) from grazing would allow for improved seeding of cool season perennial grasses.

High density and short duration grazing (HDSD; 5.0 ha) had grazing events and stocking rate determined by herbage mass and rest periods determined by plant growth rate and both were unrestricted by season. Herbage mass was typically in the range 1500–3000 kg DM/ha before grazing and 750–2000 kg DM/ha after the grazing event. The range in herbage mass values before grazing reflected two factors. First, that grazing of HDSD would (i) not occur until herbage mass attained a value of at least 1500 kg DM/ha; and (ii) occur before herbage mass exceeded 3000 kg DM/ha. The second factor contributing to the range in herbage mass values was seasonal conditions, with higher values of herbage mass associated with better conditions. The range in herbage mass after grazing events was directly related to starting values. The mean rest period was 122 days but the range was from 25 to 308 days and was inversely related to pasture growth rate. The shortest rest period occurred from October to November 2004 and the longest from November 2004 to September 2005. Over the 5 years of the experiment, grazing events occurred in January (1), June (1), July (2), August (1), September (2), October (3), November (3) and December (2). During grazing events, the treatment paddock was further subdivided into four areas of equal size (1.25 ha) and animals grazed sequentially in the subdivisions, according to herbage mass cues, to comprise a single grazing event. The subdivisions were used to increase the number of animals to ~350/ha and minimise the required length of the grazing event. NIL of domestic herbivores represented the typical management regime philosophy for grassland conservation reserves in South Australia at the time.

Within the two seasonal grazing treatments, grazing events commenced at the start of each relevant period and when there were two grazing events within the period available for grazing,

Table 1. Details of the five grazing treatments

Grazing treatment	Period when able to be grazed	Graze period (events × days)	Period without grazing (days/year)	Number of animals[A] (No./ha)
Regional practice	17 Apr.–13 Dec.	1 × 241	124	3.3
Autumn rest	17 June–13 Dec.	2 × 40	285	9.6
Spring rest	17 Apr.–24 Aug.	2 × 40	285	10.3
High density and short duration	All year	3 × 5	350	360.0[B]
Nil grazing	Nil	0	365	0.0

[A]During the period of grazing; values are means for the period 2001–05.
[B]Calculated on the basis of the paddock being grazed in four subdivisions each of 1.25 ha.

a 50-day rest period intervened. For example, grazing events in AUT rest occurred 17 June–27 July and 15 September–25 October inclusive.

Grassland assessment

Five permanent transects (50 m) were established within each treatment paddock to proportionally sample variation in soil type and position of slope. In the HDSD treatment paddock, a single transect was established in each of three subdivisions and two transects established in the fourth subdivision. Monitoring of vegetation was undertaken on an annual basis, starting in September 2000 and then November in 2001–05.

Herbage mass and the contribution of the dominant plant species were assessed in $10 \times 0.25\text{-m}^2$ quadrats along each transect. At these quadrats, the presence or absence of plant species was recorded and used to calculate species frequency. Prior definition of the plant species area curve based on five nested quadrats ranging in area from 0.04 to 25 m^2 was conducted. This indicated that sampling 2.5 m^2 along each transect would sample 69% of the number of species likely to be sampled in a 25-m^2 area. Allowing for five transects in each paddock increased sampling to 88% of species.

The number of native perennial grass plants was also recorded within each quadrat along two transects per treatment paddock. Individual plants were defined as having a distinct perimeter which was not in contact with another perennial grass plant of the same species. Basal cover was determined using a 100-point quadrat (1 m^2) at fixed locations 5 m from the western end of three transects within each treatment paddock.

Animal measurements

Treatment paddocks were grazed by non-reproductive Merino sheep. The mean number of animals grazing RP, AUT rest and SPR rest was 21, 59 and 61, respectively. The number of sheep grazed in the seasonal grazing treatments was based on the number in RP and adjustment for a shorter period of grazing throughout the year (Table 1). Animals were weighed at the start and end of each grazing period and animals in RP were also weighed at these times. Change in liveweight was used to calculate the DSE on the basis that a non-reproductive 50-kg sheep maintaining liveweight was equivalent to 1 DSE (Russell 2009). A gain of liveweight was equivalent to an additional 0.005 DSE per gram. A loss of liveweight was equivalent to a subtraction of 0.003 DSE per gram. Because graze periods in HDSD were of a few days duration this prevented the use of liveweight change data to calculate stocking rates. Therefore, a DSE was estimated for these periods based on herbage mass, estimated herbage quality and liveweight changes in other grazing treatments around the same time.

Statistical analysis

The experimental design had each grazing treatment in a single paddock and as such lacked replication at the paddock scale. There were several reasons for this design, the main being the desire to use a scale of hectares to better represent the commercial grazing context of the region. We propose that the five transects in each paddock be considered as the experimental units for grassland assessment and hence provide replication. Strictly the transects are pseudo-replicates but we suggest that they sampled variation within a paddock as a paddock replicate would sample variation across the landscape. We advance this argument only for the analysis of treatment effects on vegetation variables but not for treatment effects on stocking rate. The reader can assess the validity of the conclusions reported in this paper on the basis of this information.

Data collected from the experimental site were subjected to ANOVA, ANCOVA or repeated-measures ANOVA depending on the measured variable using the SAS Institute statistical software (SAS 2003). Differences in percentage contribution of herbaceous species to herbage mass and species herbage mass among grazing treatments were tested using several species or functional species groups. Presence and absence data and ground cover estimates were converted to percentage frequency for analysis of grazing treatment effects. Assumptions of normality were tested for all variables and transformations were made where required. The suitability of transformations was assessed by reference to the Shapiro–Wilks statistic. Least-squares (l.s.) means ± standard error (s.e.) or back-transformed l.s. means ± 68% confidence intervals are presented. These confidence intervals give a close approximation to the s.e. which cannot be back-transformed as they are asymmetric about the mean. Solutions to the normal equations were used to generate parameter estimates to determine the effect of time within each grazing treatment on the measured variable.

Results

Climate

Description of the rainfall and temperature at Clare (Bureau of Meteorology Station Number 21131) and open pan evaporation at Nuriootpa (Bureau of Meteorology Station Number 23373), South Australia, for the period November 2000–November 2005 is provided in Fig. 1*a* (Bureau of Meteorology, pers. comm.). Rainfall was dominant over the months May–October when 74% of the annual rainfall and 71% of the annual rain days occurred. Mean annual rainfall was 561 mm and was greatest in 2000 (708 mm) and least in 2002 (383 mm) (Fig. 1*b*). Mean daily maximum temperature of 30.0°C occurred in January and on average, the daily maximum exceeded 35°C on 20 days each year. Mean daily minimum temperature of 4.1°C occurred in July and on average, the daily minimum was below 0°C on 8 days each year. Mean minimum and maximum daily pan evaporation of 1.6 and 9.2 mm occurred in July and January, respectively.

Herbage mass

Herbage mass (Fig. 2) was estimated at each sampling event and sampling in November probably represented the maximum or near maximum level of herbage throughout the year. There were no differences among treatment paddocks at the initial measure, but by 2001 differences ($P < 0.001$) had emerged among treatments such that herbage mass was least in RP and AUT rest and greatest in HDSD and NIL. These differences broadly continued throughout the following 4 years, with the exception of 2004 when herbage mass of all paddocks converged to a similar value. When averaged over the 5-year measurement period (Fig. 2), herbage mass varied among grazing treatments

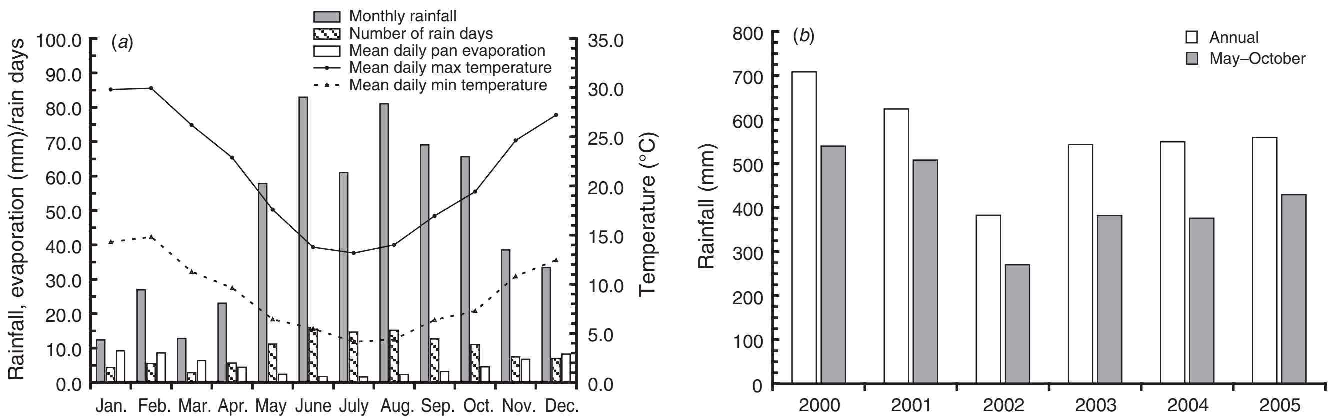

Fig. 1. (*a*) Mean monthly rainfall, number of rain days, mean daily maximum and minimum temperatures and (*b*) annual rainfall during the period 2000–05 for Clare, South Australia. Open pan evaporation was obtained from Nuriootpa, South Australia (Bureau of Meteorology, pers. comm.).

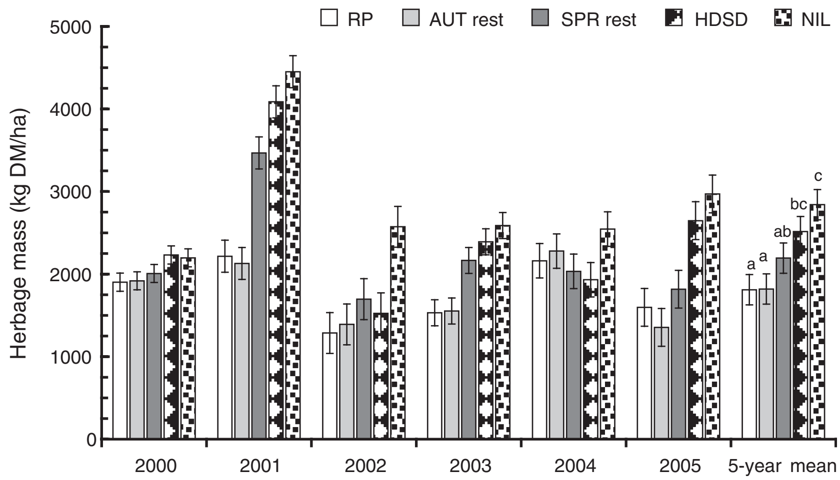

Fig. 2. Herbage mass (±s.e.) over the period September 2000–November 2005 for the grazing treatments of regional practice (RP), autumn rest (AUT rest), spring rest (SPR rest), high density and short duration grazing (HDSD) and nil grazing (NIL). Five-year mean values with different superscripts differ significantly ($P < 0.001$).

($P < 0.001$) and was least in RP, AUT rest and SPR rest and greatest in HDSD and NIL.

Contribution to herbage mass

The contribution of perennial grasses to herbage mass averaged 28.7% and was composed of variable contributions of *Austrostipa blackii*, *A. trichophylla*, *A. gibbosa*, *A. behriana*, *Austrodanthonia* spp, *Themeda australis* and *Dicanthium sericeum*. These genera contributed 13.8% (combination of all *Austrostipa* spp.), 10.6, 1.4, and 2.9% (combination of *T. australis* and *D. sericeum*), respectively, to the perennial grass contribution.

Significant differences existed among treatment paddocks before application of grazing treatments but were confined to lower ($P < 0.05$) perennial grass contribution in HDSD relative to RP and SPR rest (Fig. 3). Lower ($P < 0.01$) contribution in HDSD relative to all other treatments continued in 2001 but differences among treatments were not evident again until 2004 when perennial contribution in NIL was greater than in RP, AUT rest and HDSD. Examination of the change in contribution from perennial grasses over time indicated differences among treatments ($P < 0.001$) with a declining and significant trend for RP (–4.3% perennial contribution per annum; $P < 0.05$), AUT rest (–5.3% per annum; $P < 0.001$) and SPR rest (–4.1% per annum; $P < 0.05$). In contrast, the trends for perennial contribution over time in HDSD and NIL did not differ significantly from zero but were numerically positive (mean 1.6% per annum).

No significant differences existed among treatment paddocks in the initial contribution of *Austrostipa* spp. to herbage mass. Percentage contribution of *Austrostipa* spp. declined ($P < 0.05$) over time in RP (–2.0% contribution per annum), AUT rest (–3.7% per annum) and SPR rest (–2.1% per annum) whereas there were positive but not significant changes in HDSD and NIL. The percentage contribution of *A. behriana* over time was variable and changes did not vary significantly among treatments.

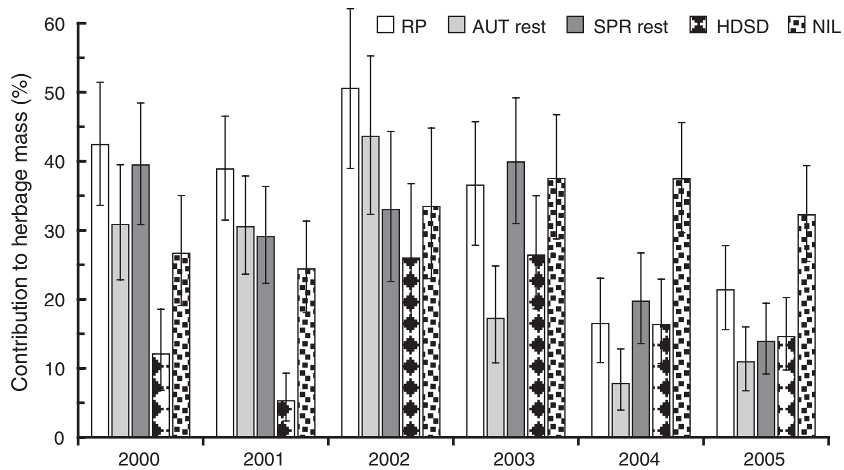

Fig. 3. Percentage contribution to herbage mass (±68% c.i.) of native perennial grasses over the period September 2000–November 2005 for each grazing treatment. See caption of Fig. 2 for description of grazing treatments.

The contribution of annual grasses to herbage mass averaged 39.3% and was composed of variable contributions of *Brachypodium distichum*, *A. barbata*, *Vulpia myuros*, *Bromus diandrus*, *B. rubens* and *B. molliformis*. These genera contributed 18.1, 13.0, 4.7 and 3.5% (combination of all *Bromus* spp.), respectively, to the annual grass contribution. Percentage contribution of annual grasses to herbage mass did not differ among treatment paddocks at the initial measure and differences among paddocks in response to grazing treatment did not emerge until 2004. Contribution in NIL during 2004 and 2005 was less ($P < 0.05$) than all other treatments (Fig. 4). In 2005, contribution of annual grasses in SPR rest was less ($P < 0.05$) than in RP and AUT rest. Change in percentage contribution of annual grasses over time was variable but there was a suggestion ($P = 0.08$) that the contribution in NIL had declined (–5.2% contribution per annum) over time.

Percentage contribution of *B. distichum* and *A. barbata* did not differ among treatment paddocks at the initial measure. The change in contribution of *B. distichum* varied ($P < 0.001$) among grazing treatments over the 5-year period. A significant decline in contribution was recorded in AUT rest (–2.8% contribution per annum; $P < 0.05$) and NIL (–3.7% per annum; $P < 0.01$). In contrast, a significant increase in contribution was restricted to HDSD (1.9% per annum; $P < 0.05$). The change in contribution of *A. barbata* varied ($P < 0.001$) among grazing treatments over the 5-year period but a significant decline in contribution was only recorded in HDSD (–4.5% contribution per annum).

Contribution of the undesirable *Homeria flaccida* averaged 7.6%, varied considerably among years (range of mean values 0.9–12.0%) and was unaffected by grazing treatment. Contribution of the undesirable *Scabiosa atropurpurea* averaged 2.9%. Over time, differences in the contrast between grazed treatments with NIL emerged and reached statistical significance

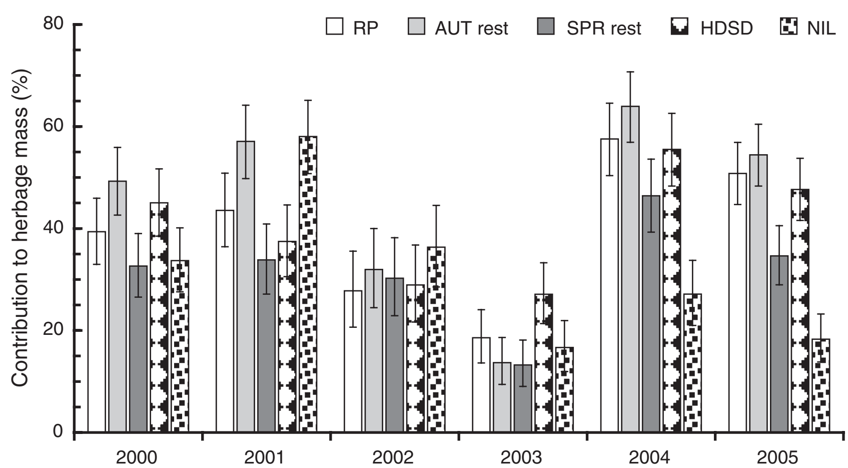

Fig. 4. Percentage contribution to herbage mass (±68% c.i.) of annual grasses over the period September 2000–November 2005 for each grazing treatment. See caption of Fig. 2 for description of grazing treatments.

($P < 0.05$) in 2003–05 (mean of *S. atropurpurea* contribution in grazed treatments was 0.8% and in NIL was 10.9%).

Species frequency

A total of 92 species were recorded across the grazing treatments. Of the total number of species, six species had a mean species frequency of greater than 50%. The species were *A. barbata* (90.6%), *H. flaccida* (83.7%), *Brachypodium distachyon* (83.3%), *Trifolium angustifolium* (74.7%), *A. behriana* (68.1%) and *A. blackii* (58.2%).

A. blackii was the most frequently recorded species from the genus and was used as an indicator of change in species frequency. Mean frequency of *A. blackii* at the initial and final measures was 56.9 and 66.0%. No differences in frequency emerged among grazing treatments over time. The frequency of *A. behriana* at the initial and final measures was 68.9 and 74.7%. The change in species frequency over time did not vary among grazing treatments.

Mean frequency of *B. distichum* at initial and final measures was 77.1 and 82.8% and frequency did not vary among grazing treatments over time. The frequency of *A. barbata* did not vary significantly among grazing treatments and was 87.8 and 98.3% at the first and final measure.

The frequency of *H. flaccida* at the initial and final measures was 79.5 and 95.4%. A significant ($P < 0.001$) increase in the frequency of *H. flaccida* over time was recorded in RP (6.1% contribution per annum). Changes in frequency in the other grazing treatments were also positive but did not differ significantly from zero, and were lowest in NIL (0.3% per annum). Frequency of *S. atropurpurea* did not vary significantly among grazing treatments and averaged 20.9 and 38.5% at the first and final measure, respectively.

Number of native perennial grass plants

The mean number of native perennial grass plants per transect did not differ significantly among treatment paddocks at the initial measure (Fig. 5) and averaged (l.s. mean ± s.e.) 51.4 ± 13.94 plants per 2.5 m^2. By 2003 the number of native perennial grass plants per transect was described by two groupings ($P < 0.01$) namely, greater numbers in RP and AUT rest than other grazing treatments. By 2004 the number of perennial grass plants in AUT rest was greater ($P < 0.05$) than in SPR rest, HDSD and NIL. The number of native perennial grass plants increased over time in RP (10.5 plants/2.5 m^2 per annum; $P < 0.01$) and AUT rest (12.9 plants/2.5 m^2 per annum; $P < 0.001$) with the same trend in SPR rest (6.5 plants/2.5 m^2 per annum; $P = 0.07$). In general, areas with very low herbage mass and a soil surface that was largely immovable to tactile pressure (i.e. hard and solid to the touch rather than soft and/or crumbly) had a greater count of perennial grasses.

Basal cover

Total plant basal cover did not differ significantly among treatment paddocks at the first measure in 2000 and averaged 14.0%. By 2001, total plant basal cover was greatest ($P < 0.01$) in HDSD (17.7%) and NIL (18.0%) and least in RP (8.2%) and AUT rest (10.3%). Total basal cover declined in all treatments during 2002, but cover in HDSD was greater ($P < 0.05$) than in RP, AUT rest and NIL. By 2004, plant basal cover continued to differ ($P < 0.01$) significantly among grazing treatments and was lowest in RP and AUT rest with no differences among the other treatments. At the final measure in 2005, differences among treatments were not significant but total plant basal cover was 21.6% in HDSD and averaged 14.9% in the other treatments.

Perennial grass basal cover did not differ among treatments at the first measure and averaged 3.8%, which comprised 27% of total basal cover (Fig. 6*a*). Perennial grass basal cover differed among grazing treatments in 2003 ($P < 0.05$) and again in 2005 ($P < 0.05$). In 2003, perennial basal cover in HDSD was greater ($P < 0.01$) than in all other treatments. In 2005, perennial cover in RP and HDSD was greater ($P < 0.05$) than SPR rest and NIL. Changes in perennial grass basal cover differed among treatments over time ($P < 0.05$) with perennial cover decreasing ($P < 0.01$) by 0.8% per annum in NIL.

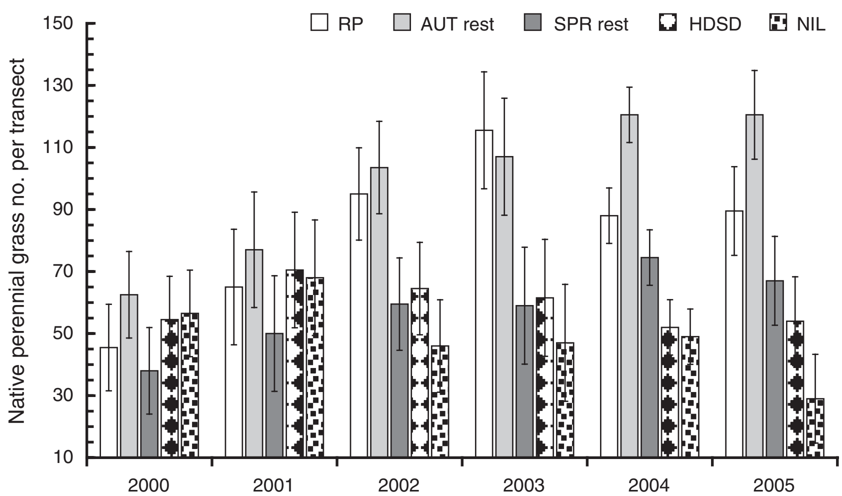

Fig. 5. Number of native perennial grass plants (l.s. mean ± s.e.) over the period September 2000–November 2005 for each grazing treatment. See caption of Fig. 2 for description of grazing treatments.

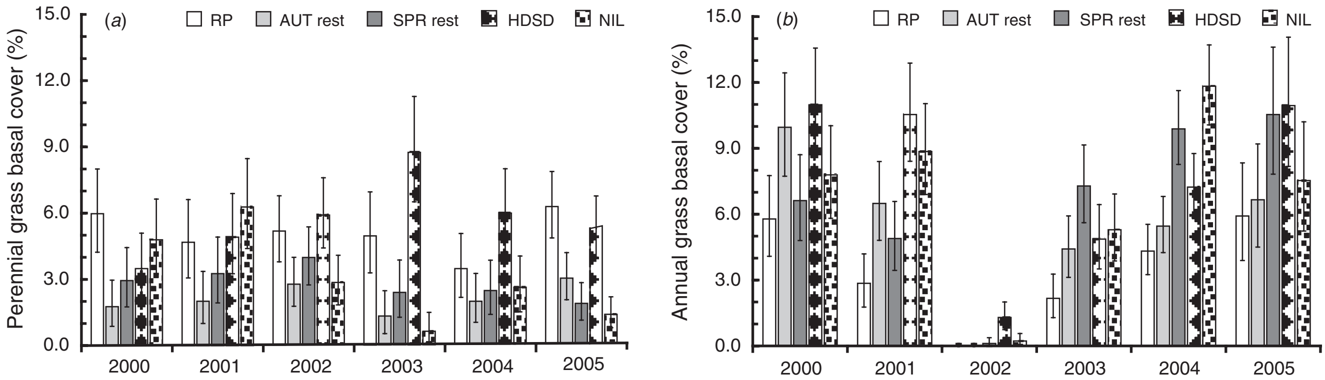

Fig. 6. Basal cover (l.s. mean ± 68% c.i.) of (*a*) perennial and (*b*) annual grasses over the period September 2000–November 2005 for each grazing treatment. See caption of Fig. 2 for description of grazing treatments.

Annual grass basal cover did not differ among treatments at the first measure and averaged 8.2%, which comprised 59% of total plant cover (Fig. 6*b*). Differences ($P < 0.05$) among grazing treatments were apparent in 2004 when annual grass basal cover in SPR rest and NIL was greater than in RP and AUT rest. Changes in annual grass basal cover did not differ among treatments over time.

Basal cover of plants classified as other than annual or perennial grasses did not differ among grazing treatments and averaged 1.9% (equal to 14% of total plant cover), respectively, across all treatments and times.

Bare ground and litter

Bare ground averaged 2.6% at the first measure (Fig. 7*a*) and did not differ among grazing treatments. By 2001, bare ground in RP was greater ($P < 0.05$) than in all other treatments with the exception of AUT rest. Bare ground in RP remained greater ($P < 0.01$) than all other treatments, (other than AUT rest in 2003–04), until 2004 after which differences among treatments remained (RP 25.5%, AUT rest 10.2%, mean of others 2.3%) but were no longer significant. In contrast to RP, bare ground in NIL declined over time and was less ($P < 0.01$) than all other treatments in 2004. The change in percentage of bare ground over time differed among grazing treatments ($P < 0.001$). An increase in bare ground of 7.9% per annum ($P < 0.001$) and 3.0% per annum ($P < 0.05$) was observed in RP and AUT rest, respectively.

Litter cover averaged 65.3% at the first measure (Fig. 7*b*) and did not differ among grazing treatments. Differences among grazing treatments in litter cover emerged in 2002 when values in RP were less ($P < 0.01$) than all other treatments. Low litter cover in RP continued in 2003–04 when litter cover in RP and AUT rest were lower ($P < 0.01$) than all treatments. Conversely, litter cover in NIL over the period 2003–2005, was greater ($P < 0.05$) than all other treatments. Litter cover declined over time in RP (6.3% per annum; $P < 0.001$), AUT rest (4.8% per annum; $P < 0.01$) and SPR rest (4.5% per annum; $P < 0.01$) and in contrast did not change significantly in HDSD and increased in NIL (2.7% per annum; $P < 0.05$).

Animal measurements

The number of animals grazed in each grazing treatment and mean liveweight change during the period of grazing is detailed in Table 2. Animals in SPR rest experienced more frequent liveweight loss than other treatments. Mean annual stocking rate for the 5-year period, 2001–05, is detailed in Table 3. The annual estimated stocking rate of the HDSD treatment was consistently higher than that of the other treatments

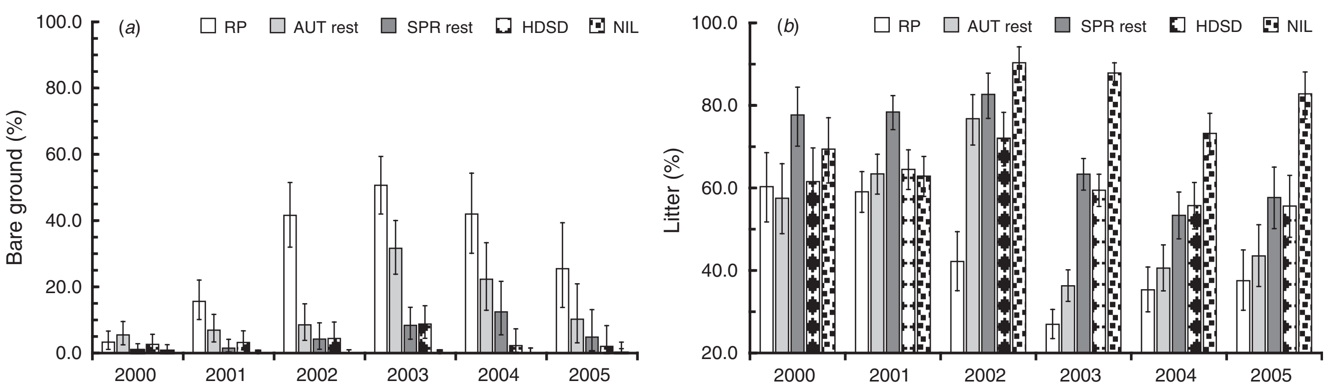

Fig. 7. (*a*) Bare ground and (*b*) litter cover (l.s. mean ± 68% c.i.) over the period September 2000–November 2005 for each grazing treatment. See caption of Fig. 2 for description of grazing treatments.

Table 2. Number of sheep in each grazing event and liveweight change during relevant grazing periods for the five grazing treatments during the period 2001–05

Grazing treatment	Number of sheep in each grazing event					Mean liveweight change for each grazing event (g/day)				
	2001	2002	2003	2004	2005	2001	2002	2003	2004	2005
Regional practice	23	18	22	19	21	18	34	0	29	–17
Autumn rest	70	52	53	50	70	32	15	10	94	–67
Srping rest	70	62	53	52	70	91	–63	8	–10	–14
High density and short duration	465	590	472	302	420	NR[A]	NR	NR	NR	NR
Nil grazing	0	0	0	0	0	NA[B]	NA	NA	NA	NA

[A]NR, not recorded.
[B]NA, not applicable.

Table 3. Mean annual stocking rate (DSE) for the five grazing treatments during the period 2001–05

Grazing treatment	2001 (DSE/ha)	2002 (DSE/ha)	2003 (DSE/ha)	2004 (DSE/ha)	2005 (DSE/ha)	5-year mean (DSE/ha)
Regional practice	2.7	2.2	2.3	2.3	2.1	2.3
Autumn rest	2.9	2.0	2.0	2.3	2.0	2.2
Spring rest	3.6	1.8	2.0	1.8	2.4	2.3
High density and short duration	5.0	4.6	4.3	3.1	3.4	4.1
Nil grazing	0	0	0	0	0	0

(mean 78% higher), but, because of the inherent limitations with the experimental design, it was not possible to assign differences to these values.

Discussion

Herbage mass was greatest with the non-seasonal grazing treatment HDSD and NIL. In contrast RP and AUT rest had the lowest mean herbage mass with SPR rest being intermediate. Continuous grazing for extended periods often results in uneven distribution of grazing pressure resulting in a pasture mosaic observed as areas with vastly contrasting levels of herbage mass (Teague and Dowhower 2003), which was recorded in the current RP treatment paddock. Plants in areas of very low herbage mass will have a lower dry weight of roots and suffer attendant effects on availability of nutrients and water (Thornton and Millard 1996) and reduced growth rate (Dowling *et al*. 1996). In addition to these deleterious patch effects, continuous grazing itself has the capacity to lower plant growth rates (McKenzie and Tainton 1996) when compared with grazing treatments that provide adequate periods of recovery. While these effects may combine to account for the poor productivity of RP it is likely that lower mean herbage mass of AUT rest was associated with lower pasture growth during 2001 when herbage mass of treatments grazed during the phenological season of spring (i.e. RP and AUT rest) were lower (2173 *v.* 4002 kg DM/ha) than for other treatments. This highlights a negative but only occasional effect of grazing during the growing season on pasture growth and suggests that, of the seasonal rest treatments, SPR rest may be superior.

Greater mean herbage mass in HDSD indicates that the combined effect of minimum (cue to remove grazing animals) and maximum (cue to introduce grazing animals) herbage mass levels coupled with grazing events that were of short duration and interspersed with adequate periods of rest was superior to the seasonal grazing treatments. That herbage mass in HDSD differed from NIL at only one sampling event (i.e. November 2002) but did not differ in the 5-year mean suggests greater primary plant production when herbage consumed by grazing animals is considered. With a mean annual stocking rate estimate for HDSD of 4.1 DSE/ha, this could account for annual herbage consumption of ~1500 kg DM/ha (Russell 2009). Applying a similar approach to the contrast of NIL with the other grazing treatments was also informative. When an estimate of herbage consumption by grazing animals was combined with the mean herbage mass the difference in herbage mass between NIL and other grazing treatments (RP, AUT rest, SPR rest) reduced from 899 to 73 kg DM/ha. This suggests strongly that most of the difference in herbage mass between these treatments was due to herbage consumption and not greater primary production.

Perennial grasses contributed ~30% of herbage mass with almost equal contributions from cool season or year-long green perennials (*Austrostipa* spp., *Austrodanthonia* spp.) and warm season perennials (*A. behriana*, *T. australis*, *D. sericeum*) grasses. The contribution of perennial grasses to herbage mass declined with RP and seasonal grazing treatments with this effect attributable to a decline in the contribution of cool season perennial grasses. The decline in the contribution of this functional group in both seasonal treatments, and with RP, suggests that the relationship of when grazing and rest occurred with phenological season was unimportant. Robinson (1993) also observed that seasonal rest of phalaris and fescue pastures in the Northern Tablelands of New South Wales provided no benefit over continuous grazing. The intransigence of pasture composition to seasonal rest was also reported by Dowling *et al*. (1996) who suggested that timing of rest to occur during periods of active growth may be more effective. In contrast to the seasonal rest treatments, HDSD generally maintained greater herbage mass and the restricted grazing events would have largely prevented defoliation of new plant growth and improved the stress tolerance of perennial grasses (Sanford *et al*. 2003).

Unlike effects observed for cool season perennial grasses, it was of interest that the contribution of warm season perennial grasses was unaffected by grazing treatment. Both seasonal grazing treatments and RP had grazing excluded during the period 14 December–17 April and this period typically coincides with seed production and dispersal for *A. behriana*. Other species of *Aristida* (e.g. *A. ramosa*) are reported to have a high seed production potential (Harradine and Whalley 1980), which is enhanced (Brown 1987) by the absence of grazing. It may be for this reason that grazing treatment did not affect the contribution of *A. behriana*.

Annual grasses made a variable but important (mean of 39%) contribution to herbage mass, which tended to decline over time with NIL. The contribution of annual grasses was also strongly influenced by year of measurement (Wilson *et al*. 1984) with a large decrease (mean of 11% points) in contribution in all treatments, except HDSD, in 2003. The previous year of 2002 was a low rainfall year (383 mm) with only 68% of the 5-year mean rainfall being recorded. Effects of low rainfall on seed production of annual grasses may account for the lag effect on contribution to herbage mass because the soil seed reserve of naturalised *Avena* spp. is short-lived (Nietschke 1997).

In contrast to effects of grazing on contribution to herbage mass, effects on the frequency of distribution were not evident during the 5 years of observation for any of the functional groups or indicator plant species. This suggests that the number of plants in each grazing treatment remained relatively constant and that changes in contribution to herbage mass arose from effects on the production of existing plants.

The number of perennial grass plants increased over time in RP and seasonal grazing treatments with the annual increase of nearly five plants m^{-2} being recorded for AUT rest. The increased number of perennial grasses could have arisen from two processes, the first being recruitment of new plants and the second from fragmentation of existing tussocks. Fragmentation occurs as the central tillers on existing single tussocks (generally *Austrodanthonia* spp.) die and lateral tillers eventually separate forming 'new' plants. Field observation was that the latter of these processes was most influential and occurred mostly with *Austrodanthonia* spp. plants in areas where the soil surface had no litter and was immovable to tactile pressure. Further support for the notion of fragmentation is evidenced from an unchanged frequency of perennial grass plants. As such, we suggest that increases in the apparent number of perennial grasses were a stress response and is an indication of undesirable change. In contrast, the number of perennial grasses in HDSD was more stable (coefficient of variation among years = 11.1%) when compared with the other grazing treatments (coefficient of variation among years = 29.5%).

The grazing treatments either reduced (RP and seasonal treatment), increased (NIL) or had no effect (HDSD) on litter cover and reciprocal effects were observed for bare ground. Over the years 2002–03, litter cover of RP and AUT rest declined by 32 and 40%, respectively, and bare ground increased by 35% (RP) and 24% (AUT rest). In contrast, litter cover in NIL increased by 25% and there was no bare ground. Associated with these changes was a stability of perennial grass basal cover in RP and seasonal treatments but a decline in NIL from 5.0 to 1.3% over the entire experimental period.

When considered together the data collected from these grazing treatments indicate several processes were at play. First, seasonal grazing treatments did not provide an advantage over RP. These treatments resulted in a loss of litter cover resulting in an increase in bare ground accompanied by increased fragmentation of perennial grasses. These perennial grass plants had lower productivity and it is possible that these are the early signs of a decline in perenniality of a grassland. In contrast, NIL grazing facilitated the accumulation of litter resulting in no bare ground but a decline in the basal cover of perennial grasses suggests that, over time the effect of shading on reducing the recruitment of perennial grasses may be detrimental for grassland composition (Bowman *et al*. 2009). Highest primary plant production from HDSD coupled with more stable litter cover, lower bare ground and no evidence for perennial fragmentation is suggestive of greater soil moisture (Murphy and Lodge 2001) and a stable population containing more robust and productive perennial grasses. The combination of a greater stocking rate with a productive and stable grassland arose from management that combined herbage mass benchmarks with a planned rotation. These features offer a desirable mix for future industry adoption in the mid-north of South Australia.

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