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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

D. M. Orr[A,E], *W. H. Burrows*[A,D], *R. E. Hendricksen*[A,D], *R. L. Clem*[B], *P. V. Back*[A,D], *M. T. Rutherford*[A], *D. J. Myles*[A,D], and *M. J. Conway*[C]

[A]Department of Employment, Economic Development and Innovation, PO Box 6014, Rockhampton Mail Centre, Qld 4702, Australia.
[B]Department of Employment, Economic Development and Innovation, PO Box 395, Gympie, Qld 4625, Australia.
[C]Department of Employment, Economic Development and Innovation, Locked Mail Bag 6, Emerald, Qld 4720, Australia.
[D]Retired.
[E]Corresponding author. Email: david.orr@deedi.qld.gov.au

Abstract. An extensive grazing study was conducted between 1988 and 2001 in a *Heteropogon contortus* (black speargrass) pasture in central Queensland. The study was designed to measure the effects of stocking rate on native pasture, native pasture with legume oversown, and native pasture with animal diet supplement/spring burning on pasture and animal production. Summer rainfall throughout the study was below the long-term mean. Mean annual pasture utilisation ranged from 13% at 8 ha/steer up to 61% at 2 ha/steer. Increasing stocking rate treatments reduced total pasture yields while total yields in legume oversown treatments were similar to those in native pasture at the same stocking rate. When spring burning was possible, total yields were reduced in the subsequent autumn. Increasing stocking rate in native pasture tended to reduce *H. contortus* and *Bothriochloa bladhii*, increased the composition of intermediate species, such as *B. decipiens* and *Chloris divaricata*, and also changed the frequencies of a range of minor species. Oversowing legumes resulted in *Stylosanthes scabra* cv. Seca increasing from <1% of pasture composition in 1988 to 50% in 2000 and was associated with a reduction in *H. contortus* and changes in the frequencies of some minor species. Stocking rates heavier than 4 ha/steer resulted in annual pasture utilisation greater than 30% and were unsustainable because they reduced total yield and resulted in undesirable changes in species composition. It was concluded that pasture production was sustainable when stocking rates were maintained at 4 ha/steer, which equates to 30% annual pasture utilisation, and through the judicious use of spring burning.

Additional keywords: species composition, stocking rate, legume oversowing, burning, *Heteropogon contortus* pastures.

Introduction

The sustainable management of native pastures represents a major challenge for grazing land management. In Queensland, *Heteropogon contortus* (black speargrass) pastures cover 23 Mha and support over 3 M beef cattle. More recently, Bortolussi *et al*. (2005) have highlighted the importance of *H. contortus* pastures for growing and finishing beef cattle in Queensland.

Few ecological studies have examined the inherent pasture and animal productivity of these pastures because most early studies focused on replacing the native grasses with introduced grasses and legumes (Hacker *et al*. 1982). However, the complete replacement of native with exotic species has not been widely adopted because of problems of maintaining sown pastures and the economic sensitivity of the beef industry to export market forces. Consequently, the potential productivity from these native pastures may have been underrated (Burrows *et al*. 1987).

Evidence of deterioration in the condition of native pastures throughout northern Australian has been reported by Tothill and Gillies (1992). For example, in *H. contortus* pastures, the palatable *H. contortus* has been replaced by less palatable grasses in both northern (Pressland *et al*. 1991) and southern Queensland (Orr *et al*. 1997). Much of the change in pasture composition has resulted from increased grazing pressure (fig. 2, Tothill and Gillies 1992), probably as a result of both increased economic pressures on primary producers and the inappropriate adoption of some new technologies. Pasture technologies such as introduced legumes and animal diet supplements (Hendricksen *et al*. 1985) and the introduction of tropically adapted *Bos indicus* cattle (Vercoe and Frisch 1985) have increased dry-season forage utilisation and intensification

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of use of native pastures. The possible role of spring burning in reversing this replacement of palatable by less palatable grasses in southern Queensland was demonstrated by Orr *et al*. (1991).

As a result of concerns regarding the long-term sustainability of *H. contortus* pastures, a large-scale grazing study was conducted in central Queensland (1988–2001) to evaluate the effects of a range of stocking rates on yield and composition of native pasture, legume oversown native pasture, and animal diet supplement/spring burnt native pastures. The study was designed to assess the long-term interactions among soil, plant, and animal parameters in relation to rainfall. A preliminary paper (Orr *et al*. 2001) reported changes in pasture yield and composition between 1988 and 1996 and this current paper reports further changes between 1988 and 2001. Further papers in this series report the dynamics of *H. contortus* and *Stylosanthes scabra* cv. Seca (Orr *et al*. 2010), the diet selected by steers (Hendricksen *et al*. 2010) and the animal liveweight responses (Burrows *et al*. 2010).

Methods

Study site

The grazing study was established in 1988 in a *H. contortus* pasture at Galloway Plains, Calliope (24°10′S, 150°57′E), in central Queensland. Mean annual rainfall for Calliope Station (20 km north of Galloway Plains) is 854 mm based on 97 years of records, and ~70% of this annual rainfall occurs in summer (October–March) (Clewett *et al*. 2002). Mean daily maximum temperatures in summer average 30.5°C and mean daily minimum temperatures in winter average 12°C. Frosts occur between June and August.

The 2 predominant soil types were a duplex (Dy3) and a grey clay (Ug5) (Barton 1991); both soils were of low fertility. The original over-storey vegetation had been cleared before this study but was predominantly *Eucalyptus crebra* (narrow-leaved ironbark) and *E. melanophloia* (silver-leaved ironbark) on the duplex soil and *E. populnea* (poplar box) on the clay soil. Initial pasture measurements indicated that *H. contortus* and *Bothriochloa bladhii* (forest bluegrass) were co-dominant in the ground layer vegetation.

Treatments

The study was designed originally as a randomised complete block with 11 treatments and 2 replicates, 1 replicate on each of the 2 predominant soil types. The 11 treatments consisted of a nested 3 stocking rates × 3 pasture types factorial and 2 additional treatments. The 3 stocking rates were 4, 3, and 2 ha/steer and the 3 pasture types were native pasture, native pasture oversown with introduced legumes, and native pasture where a dry-season protein supplement was offered to the cattle. The 2 additional treatments were native pasture grazed at 8 and 5 ha/steer (Table 1).

Five *Bos indicus* crossbred steers (initial liveweight 250–300 kg) grazed each paddock. Paddock sizes varied from 10 to 40 ha to achieve these stocking rates and steers were replaced annually. In order to accelerate stocking rate effects, steer numbers were increased from 5 to 6 per paddock in the third

Table 1. Experimental design for stocking rate and pasture type treatments at Galloway Plains between 1988 and 2001

Stocking rate (ha/steer)	Native pasture	Native pasture with legume	Native pasture with dry season supplement/ burning
8	+[A]		
5	+		+[B]
4	+	+	+
3	+	+	+
2	+	+	+

[A]Treatment conducted between 1988 and 1996.
[B]Treatment conducted between 1996 and 2001.

(July 1990–June 1991), fifth (July 1992–June 1993), eighth (August 1995–August 1996), twelfth (July 1999–August 2000), and thirteenth (July 2000–June 2001) years of grazing.

The legumes *Stylosanthes scabra* cv. Seca, *S. hamata* cv. Verano, and *Chamaecrista rotoundifolia* cv. Wynn were surface sown at seeding rates of 4.0, 0.5, and 0.5 kg/ha, respectively, on 13–15 October 1987. *C. rotoundifolia* cv. Wynn failed to establish over the 1987–88 summer and was sown again into cultivated strips in August 1988 using a seeding rate of 0.5 kg/ha seed. Animals grazing the legume oversown treatments had access to a phosphorous (P) supplement while the pasture was actively growing in summer. The dry-season supplement was supplied as cottonseed meal once per week and was provided in late winter/spring; the duration of feeding was determined by seasonal rainfall conditions. (Further details are provided in Burrows *et al*. 2010.)

Changes to experimental design

Two changes were made to the original experimental design. In 1992, the dry-season supplement treatments were replaced by spring burning treatments because the effect of the dry-season supplement treatment on pasture condition and animal liveweight was similar to the native pasture treatments at equivalent stocking rates. Furthermore, other research (e.g. Orr *et al*. 1997) indicated that fire is important in the management of these pastures so that the 3 dry-season supplement treatments were replaced by spring burning of the pasture with stocking rates unchanged.

By 1996, the combination of burning and heavy stocking rate resulted in inadequate fuel loads further compounded by below-average rainfall. At stocking rates of 2 and 3 ha/steer, burning was possible only in spring 1992 and 1999, whereas at 4 ha/steer, burning occurred in spring 1992, 1998, and 1999 with a ‘patchy’ burn in 1996. The second change occurred in 1996: the 8 ha/steer native pasture treatment was discontinued because pasture and animal production data were similar to the 5 ha/steer treatment. This former 8 ha/steer treatment was reassigned to evaluate the effect of burning at the lighter stocking rate of 5 ha/steer where sufficient fuel load was available for annual burning between 1996 and 1999. However, in 1997, it was decided not to burn because the Southern Oscillation Index in spring was low and there was a consequent reduced probability of adequate pasture growth over the 1997–98 summer (McKeon *et al*. 1990).

Measurements

Pasture yield and composition

Pasture yield, composition (% contribution to yield), and frequency (% occurrence) were recorded every 6 months, in autumn (end of summer growing season) and again in spring (end of the dry season), using Botanal (Tothill *et al.* 1992). In total, 150 quadrats, each 0.5 by 0.5 m, were recorded in each paddock at each sampling with 6 trained operators each assessing 25 quadrats along 6 transects across each paddock, with quadrats spaced 40–50 m apart. The density of sown legumes was counted in each quadrat in the legume treatments during each Botanal assessment. Due to the large number of species with diverse occurrences, for clarity of presentation, the species were classified into groups on the basis of maximum recorded yields: major (>1000 kg/ha), intermediate (<1000 kg/ha), and minor (<100 kg/ha). In this paper, changes in these species groups are described in terms of yield and frequency for major species, composition for intermediate species, and frequency for the minor species.

Pasture utilisation

The annual level of pasture utilisation achieved at each stocking rate was retrospectively calculated as the proportion of pasture intake to pasture grown expressed as a percentage for the period of time that each draft of steers grazed the pasture. Forage intake was calculated for each annual draft of steers based on the intake of a 200-kg steer equivalent (details of the initial and end date of each of these annual draft of steers are presented in Burrows *et al.* 2010). Pasture grown was determined for the grazing period for each draft using the pasture growth model GRASP (Littleboy and McKeon 1997). The GRASP model was parameterised using pasture production data measured using the SWIFTSYND methodology (Day and Philp 1997).

Statistical analyses

The grazing experiment was a randomised complete block design consisting of 2 replicates of 11 treatments. The treatments were set up in a factorial structure comprising 5 stocking rates and 3 pasture types with 4 treatment combinations missing in 1988–96 and 4 stocking rates and 3 pasture types with 1 treatment combination missing in 1997–2001. Given this lack of balance in the treatment structure, the data were analysed using analysis of variance with an appropriate nested factorial structure in GENSTAT 6.1 Reference Manual (GENSTAT 2002). Yields, compositions, and frequencies in each paddock were analysed separately for each year. Angular transformations were applied to composition and frequency measures. Results presented in this paper are limited to those species where treatment differences were significant ($P < 0.05$). For those species where no results are presented, treatment differences were not significant ($P > 0.05$).

In evaluating the effects of treatments across time, both overall trends and seasonal effects were considered using REML. First splines (Orchard *et al.* 2000) were used to assess seasonal fluctuations while fitting the full fixed (treatment by time) model. The significance of the splines was evaluated by a chi-square test on the change in deviance. Subsequently the fixed effects were assessed for overall trends. As few splines were significant, they will not be discussed further in this paper.

Results

Rainfall

Trends in the 5-year moving average summer (October–March) rainfall for Calliope Station indicated that our experiment was conducted during the driest period of the past 100 years (Fig. 1*a*). At Galloway Plains, summer rainfall in some years, e.g. 1990–91 and 1996–97, approached the long-term mean, while in other years, e.g. 1992–93 and 1994–95, it was very much below the long-term mean (Fig. 1*b*).

Pasture utilisation

Mean annual pasture utilisation averaged over all years in the 5 native pasture treatments was 13, 24, 30, 47, and 61% for the 8, 5, 4, 3, and 2 ha/steer treatments, respectively. Utilisation varied widely between 10% at 8 ha/steer in 1988–89 and 96% at 2 ha/steer in 1997–98 (Fig. 2). Furthermore, utilisation varied

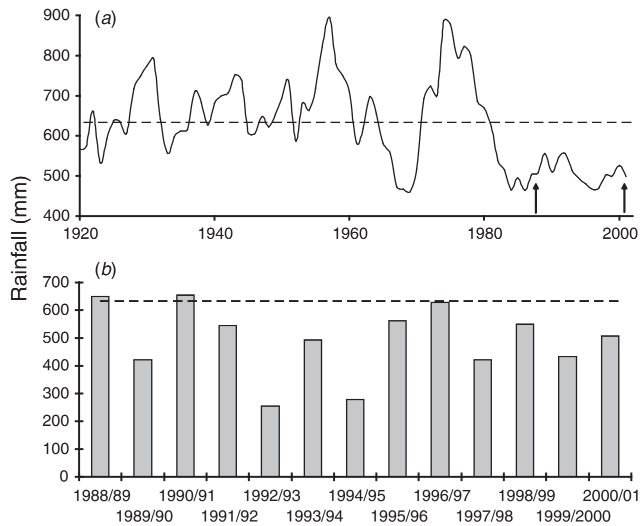

Fig. 1. Rainfall (mm) trends for (*a*) the 5-year moving average summer rainfall (solid line) for Calliope Station in relation to the long-term mean (dashed line) (arrows indicate the start and end of this experiment) and (*b*) summer rainfall recorded between 1988–89 and 2000–01 at Galloway Plains in relation to the long-term mean for Calliope station.

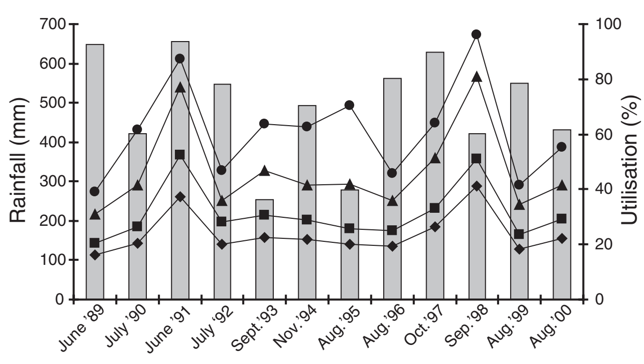

Fig. 2. Changes in annual pasture utilisation (%) for annual drafts of steers grazing native pasture at 4 stocking rates (◆ 5, ■ 4, ▲ 3, ● 2 ha/steer), in relation to rainfall (mm) for each draft between 1988 and 2000 at Galloway Plains.

widely between years within each stocking rate due to the effect of rainfall on pasture growth. There was a clear trend for this annual variation to increase with increasing stocking rate. Utilisation was consistently higher on the duplex soil than on the clay, reflecting lower pasture yields on the duplex soil.

Total pasture yield

Total pasture yields in autumn varied among years from a minimum of 640 kg/ha in the supplement/burning treatments at 2 ha/steer in 1993 to a maximum of 6350 kg/ha in native pasture at 5 ha/steer in 1999, with total yields being closely related to summer rainfall. For native pasture, increasing stocking rate from 8 to 2 ha/steer reduced ($P < 0.05$) total yields and this effect was apparent as early as 1990 (Fig. 3*a*). There was no interaction between stocking rate and pasture type but stocking rate influenced total yields more than pasture type (Fig. 3*b*). Pasture type influenced ($P < 0.05$) total yields only in autumn 1993 and 2000 following spring burning in 1992 and 1999.

Stocking rate effects in native pasture

Of the major species, increasing stocking rates reduced the yields of both *H. contortus* and *B. bladhii* (Fig. 4). For *H. contortus*, yield varied widely throughout the study from 30 kg/ha at 2 ha/steer in 1997 to 1500 kg/ha at 8 ha/steer in 1994. Increasing stocking reduced *H. contortus* yield, although this reduction was significant ($P < 0.05$) in 1989 and 1993 only, but there was a trend ($P < 0.1$) for reduced yield with increasing stocking rate apparent in 1998, 2000, and 2001. For *B. bladhii*, yield varied widely throughout the study from 150 kg/ha at 2 ha/steer in 1989 to 3400 kg/ha at 5 ha/steer in 1999. Increasing stocking rates reduced ($P < 0.05$) *B. bladhii* yield in 1991, 1993, 1995–98, and 2001 (Fig. 4*b*). Despite these reductions in yield of both species, there was no ($P > 0.05$) reduction in their frequency (data not presented).

The initial yield of *Aristida* spp. was 60 kg/ha and increased slightly at 4, 3, and 2 ha/steer to be 80 kg/ha in 2001 (Fig. 5*a*). At 5 ha/steer, *Aristida* spp. yield generally increased faster than at the heavier stocking rates to 500 kg/ha in 2000 and these differences were higher ($P < 0.05$) in 1996, 1997, and 1998 relative to the heavier stocking rates (Fig. 5*a*). *Aristida* spp. frequency increased slightly from 8% in 1988 to 12% in 2001 (Fig. 5*b*) and, although it was generally higher at 5 ha/steer, this increase was significant ($P < 0.05$) in 1995 only.

Increasing stocking rate increased the composition of the intermediate species *Bothriochloa decipiens*, *Chloris divaricata*, and *Eragrostis* spp. *Bothriochloa decipiens* composition generally declined from 5% in 1988 to 2% in 2001, although after 1992, it was higher at 2 ha/steer with this treatment effect significant ($P < 0.05$) in 1995, 1996, and 1998 (Fig. 6*a*). Nevertheless, in 1991, *B. decipiens* composition was highest ($P < 0.05$) at 4 ha/steer. A trend ($P < 0.1$) for higher *B. decipiens* composition at 2 ha/steer was also evident in 1999 and 2000. *Chloris divaricata* composition increased from 3% in 1988 to be highest in 1991 and subsequently declined to 1% in 2001 (Fig. 6*b*). In 1991, *C. divaricata* composition was highest ($P < 0.05$) at 2 ha/steer and this treatment effect was also significant ($P < 0.05$) in 1992, 1994, 1996, and 1998–2001. *Eragrostis* spp. composition generally increased from 2% in 1988 to be highest in 1991, after which time it declined to 1% in 2001 but with higher ($P < 0.05$) composition at higher stocking rates by 1995 (Fig. 6c). A trend ($P < 0.1$) for higher

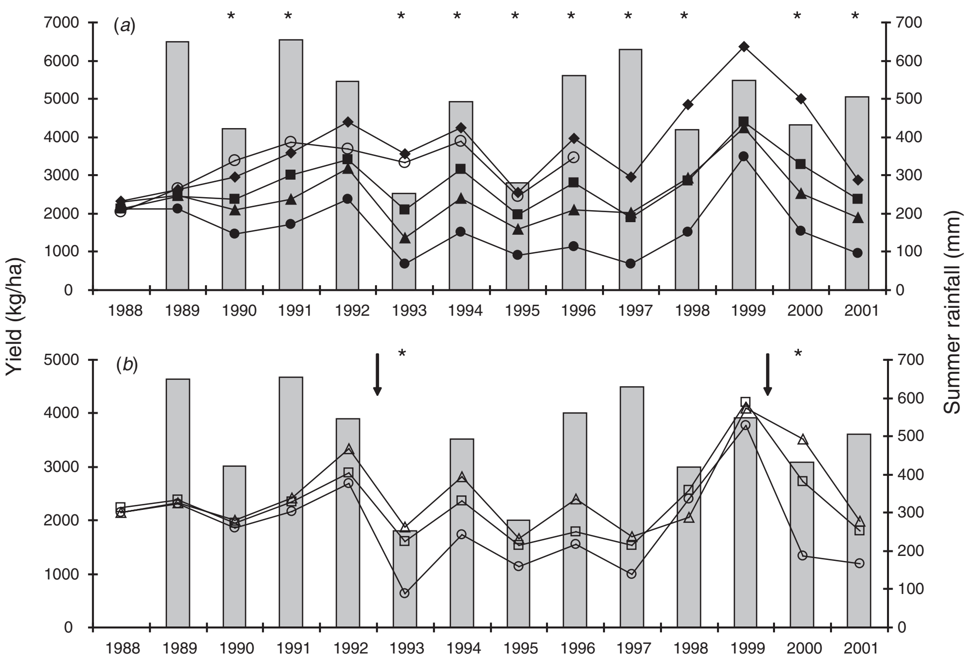

Fig. 3. Changes in total yield (kg/ha) at (*a*) 5 stocking rates (○ 8, ◆ 5, ■ 4, ▲ 3, ● 2 ha/steer) in native pasture, and (*b*) 3 pasture types (averaged over stocking rates) (□ native pasture, △ oversown pasture, ○ supplement/burnt pasture) in autumn in relation to summer rainfall between 1988 and 2001. Within years, asterisks indicate differences ($P < 0.05$) between treatments. Arrows indicate time of spring burning for the supplement/burnt treatment.

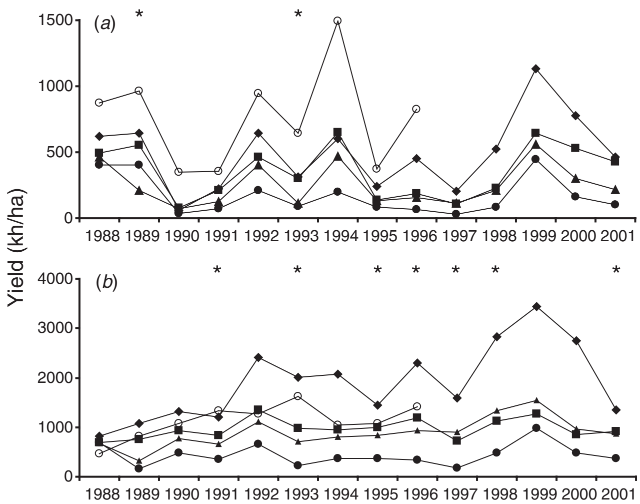

Fig. 4. Changes in yield (kg/ha) of (*a*) *H. contortus* and (*b*) *B. bladhii* in relation to 5 stocking rates (○ 8, ◆ 5, ■ 4, ▲ 3, ● 2 ha/steer) in native pasture in autumn between 1988 and 2001. Within years, asterisks indicate differences ($P < 0.05$) between treatments.

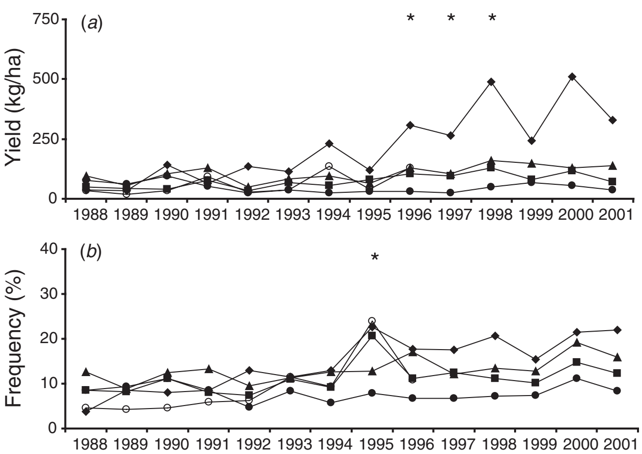

Fig. 5. Changes in (*a*) yield (kg/ha) and (*b*) frequency (%) of *Aristida* spp. in relation to 5 stocking rates (○ 8, ◆ 5, ■ 4, ▲ 3, ● 2 ha/steer) in native pasture in autumn between 1988 and 2001. Within years, asterisks indicate differences ($P < 0.05$) between treatments. Analyses of frequency performed on logarithmic transformed data.

Eragrostis spp. composition at 2 ha/steer was apparent in 1993 and 1998. These changes in composition were also reflected in changes in the frequencies of these three species (data not presented).

Stocking rate also altered the frequency of *Panicum* spp., *Sporobolus* spp., *Tragus australianus*, and Malvaceae. *Panicum* spp. frequency in 1988 was 10% and, although there was some seasonal variation, remained at 10% in 2001 (Fig. 7*a*). *Panicum* spp. frequency was reduced ($P < 0.05$) with increasing stocking rate in 1992 and 1998 while a trend ($P < 0.1$) for lower *Panicum* spp. frequency with increasing stocking rate was apparent in 1990, 1997, and 2000. *Sporobolus* spp. frequency declined from 10% in 1988 to <1% in 1997 and was unaffected by stocking rate (Fig. 7*b*). After 1997, *Sporobolus* spp. frequency increased with

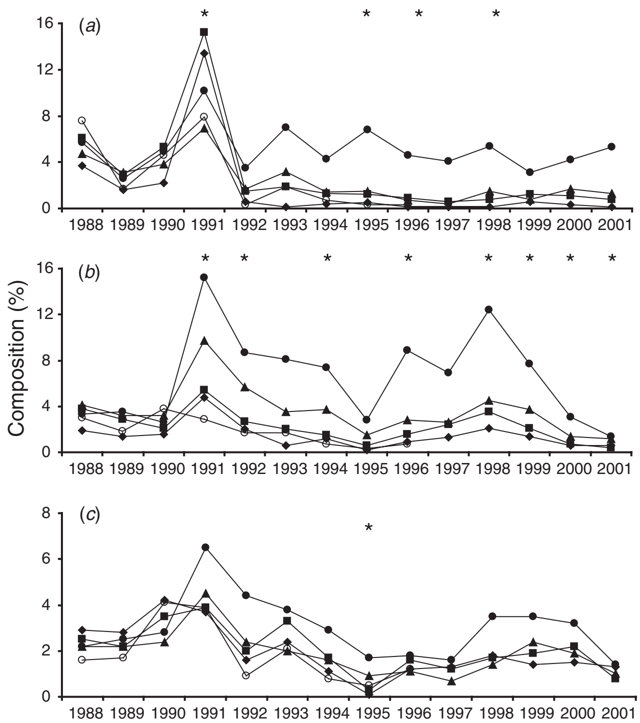

Fig. 6. Changes in the composition (%) of (*a*) *B. decipiens*, (*b*) *C. divaricata* and (*c*) *Eragrostis* spp. in relation to 5 stocking rates (○ 8, ◆ 5, ■ 4, ▲ 3, ● 2 ha/steer) in native pasture in autumn between 1988 and 2001. Within years, asterisks indicate differences ($P < 0.05$) between treatments. Analyses performed on angular transformed data.

increasing stocking rate to be 17% at 2 ha/steer in 2001 with differences being significant ($P < 0.05$) in 2000. *Tragus australianus* frequency remained at 1% and unaffected by stocking rate between 1988 and 1993 (Fig. 7*c*). By 1994, *T. australianus* frequency increased with increasing stocking rate, reaching 17% at 2 ha/steer in 1995, and these differences were significant ($P < 0.05$) in 1994, 1995, and 2000. A trend ($P < 0.1$) to higher *T. australianus* frequency with increased stocking rate was also apparent in 1996 and 1998. The frequency of Malvaceae was 14% in 1988 and generally increased, with some seasonal variation, to 27% in 2001, although it increased more with increasing stocking rate, with differences significant ($P < 0.05$) in 1995 and 2000 (Fig. 7*d*). A trend ($P < 0.1$) to higher Malvaceae frequency with increasing stocking rate was also apparent in 1997.

Legume effects

Stylosanthes scabra cv. Seca stylo was the dominant oversown legume. Some *S. hamata* cv. Verano persisted while *Chamaecrista rotoundifolia* cv. Wynn failed to persist beyond 1990. In 1988, Seca contributed <1% to composition but increased progressively to 50% in 2000 (Fig. 8), with little effect of stocking rate. The lower ($P < 0.05$) Seca composition in 1995 and 1997 at 3 ha/steer resulted from a paddock effect whereby the Seca growth was limited on the *Eucalyptus tereticornis* (blue gum) flat that traversed the grey clay soil of the western replicate paddock. The marked decline in Seca composition between 2000 and 2001 occurred as a result of a large decline in Seca yield rather than a decline in Seca plant density. Initial Seca density was 1–2 plants/m^2 and increased gradually to 15 plants/m^2 in 1996. Thereafter, the rate of increase accelerated so that, by 2001, Seca density was 60 and 90 plants/m^2 at 2 and 3 ha/steer respectively (data not presented).

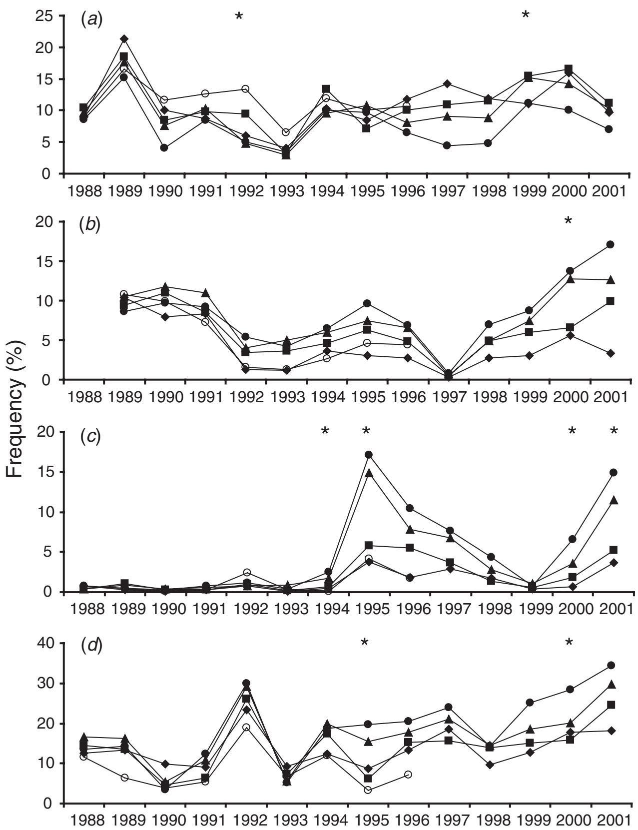

Fig. 7. Changes in the frequency (%) of (*a*) *Panicum* spp., (*b*) *Sporobolus* spp., (*c*) *Tragus australianus*, and (*d*) Malvaceae in relation to 5 stocking rates (○ 8, ◆ 5, ■ 4, 3, ● 2 ha/steer) in native pasture autumn between 1988 and 2001. Within years, asterisks indicate differences ($P < 0.05$) between treatments. Analyses performed on angular transformed data. Note differences in scale.

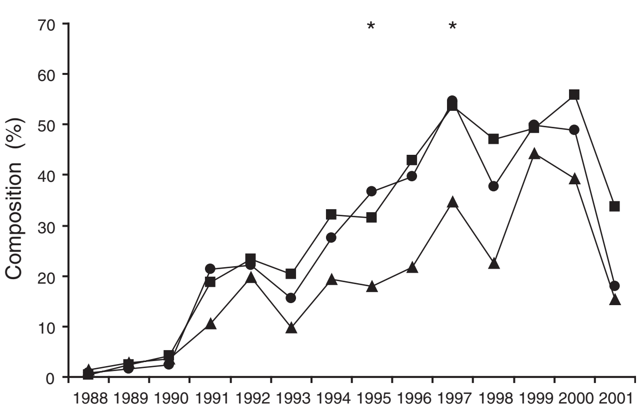

Fig. 8. Changes in the composition (%) of Seca stylo at 3 stocking rates (■ 4, ▲ 3, ● 2 ha/steer) in legume oversown native pasture between 1988 and 2001. Within years, asterisks indicate differences ($P < 0.05$) between treatments. Analyses performed on angular transformed data.

Across the 3 pasture types, yields of *H. contortus* and *B. bladhii* fluctuated among years (Fig. 9). Minimum yields were 100 kg/ha for *H. contortus* in 1990 and 400 kg/ha for *B. bladhii* in 1989 while maximum yields were 800 kg/ha for *H. contortus* in 1999 and 1500 kg/ha for *B. bladhii* also in 1999. The yield of *H. contortus* was reduced ($P < 0.05$) by legume oversowing in 1999 while a trend ($P < 0.1$) for reduced *H. contortus* with legume oversowing was apparent also in 1998. The yield of *B. bladhii* was reduced ($P < 0.05$) in the supplement/burning treatment in 1993 following spring burning in 1992.

Legume oversowing changed the frequency of 3 minor species. The frequency of native legume fluctuated between 20 and 40% throughout the study and was reduced ($P < 0.05$) by legume oversowing in 1994, with this reduction also significant ($P < 0.05$) in 1999–2001 (Fig. 10*a*). The frequency of 'Other forbs' fluctuated markedly with seasonal conditions between 20% in 1990 and 60% in 1994 and was reduced ($P < 0.05$) by legume oversowing in 1991, 1994–95, 1998–99, and 2001 (Fig. 10*b*). The frequency of *Chloris inflata* remained below 3% until 1994 after which time it increased to be higher ($P < 0.05$) in the legume oversowing treatments in 1995, 1998, 2000, and 2001 (Fig. 10*c*). By 2001, *C. inflata* frequency had increased to 15% in the legume oversown compared with only 3% in the other 2 pasture types.

Supplement/burning effects

Burning in spring 1992 failed to increase the yield of *H. contortus* in autumn 1993 relative to unburnt native pasture (Fig. 9*a*) but did reduce ($P < 0.05$) the yield of *B. bladhii* (Fig. 9*b*). However, spring burning at the lighter stocking rate of 5 ha/steer in 1996, 1998, 1999, and 2000 altered both yield and composition compared with unburnt native pasture. Total pasture yield

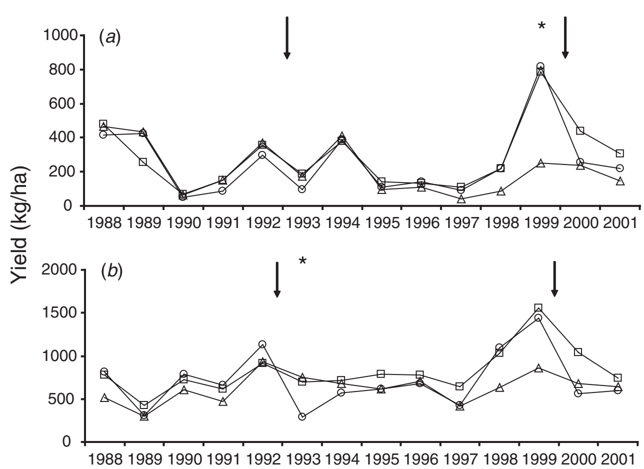

Fig. 9. Changes in the yield (kg/ha) of (*a*) *H. contortus* and (*b*) *B. bladhii* at 3 pasture types (averaged over stocking rates) (□ native pasture, △ oversown pasture, ○ supplement/burnt pasture) between 1988 and 2001. Within years, asterisks indicate differences ($P < 0.05$) between treatments. Arrows indicate time of burning for the supplement/burnt treatment.

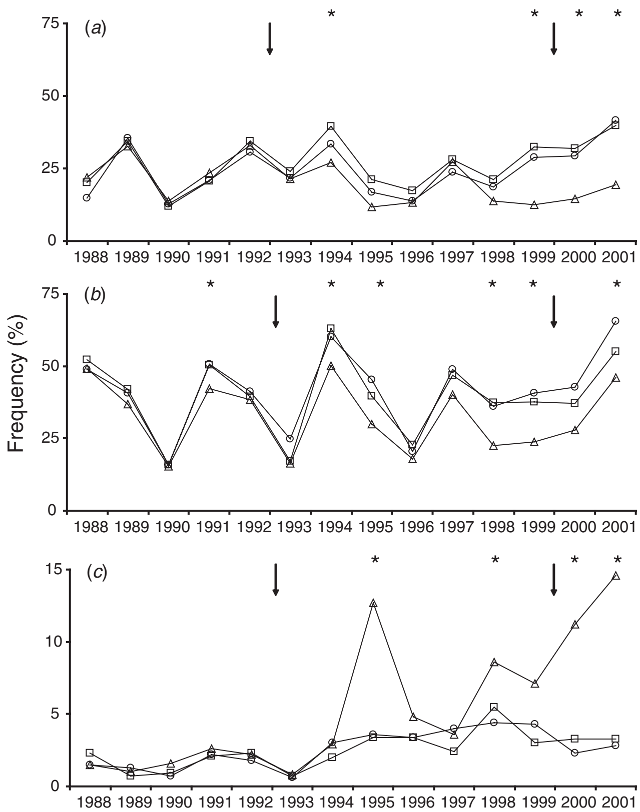

Fig. 10. Changes in the frequency (%) of (*a*) native legumes, (*b*) ‘other forbs’, and (*c*) *Chloris inflata* at 3 pasture types (averaged over stocking rates) (□ native pasture, △ oversown pasture, ○ supplement/burnt pasture) between 1988 and 2001. Within years, asterisks indicate differences ($P<0.05$) between treatments. Analyses performed on angular transformed data. Arrows indicate time of burning for the supplement/burnt treatment.

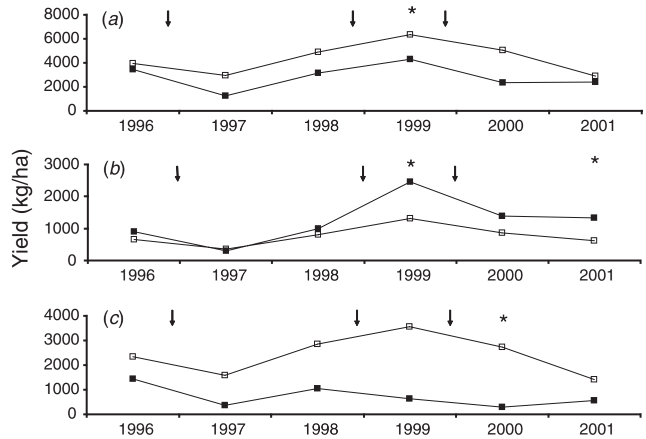

Fig. 11. Changes in the yield (kg/ha) of (*a*) total pasture, (*b*) *H. contortus*, and (*c*) *B. bladhii* with (■) and without (□) burning at a stocking rate of 5 ha/steer between 1996 and 2001. Within years, asterisks indicate differences ($P<0.05$) between treatments. Arrows indicate time of burning for the supplement/burnt treatment.

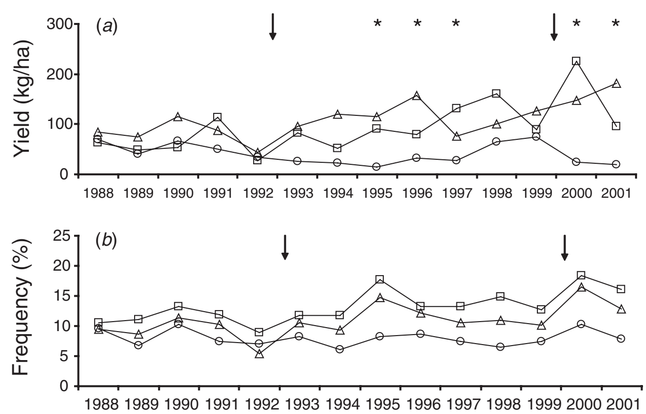

Fig. 12. Changes in (*a*) yield (kg/ha) and (*b*) frequency (%) of *Aristida* spp. at 3 pasture types (averaged over stocking rates) (□ native pasture, △ oversown pasture, ○ supplement/burnt pasture) between 1988 and 2001. Within years, asterisks indicate differences ($P<0.05$) between treatments. Analyses of frequency performed on angular transformed data. Arrows indicate time of burning for the supplement/burnt treatment.

varied between 3000 and 6400 kg/ha in unburnt pasture and was consistently higher than that under burning with this difference being significant ($P<0.05$) in 1999 (Fig. 11*a*). In contrast, burning consistently increased *H. contortus* yield to a highest of 2500 kg/ha and this difference was significant ($P<0.05$) in both 1999 and 2001 (Fig. 11*b*). *B. bladhii* yield was consistently higher in unburnt pasture, with highest yield of 2700 kg/ha in 2000, and while the highest *B. bladhii* yield was 1400 kg/ha in 1996, this difference was significant ($P<0.05$) in 2000 (Fig. 11*c*).

The yield of *Aristida* spp. increased from 75 kg/ha in 1988 to 225 kg/ha in native pasture in 2000 and 180 kg/ha in the legume oversown treatments in 2001 (Fig. 12*a*). In contrast, *Aristida* spp. yield in the supplement/burning treatments declined consistently to be 20 kg/ha in 2001, with reductions ($P<0.05$) in 1995–97 following the first burn in spring 1992 and again in 2000–01 following the second burn in spring 1999. The frequency of *Aristida* spp. increased from 10% in 1988 to 16 and 18% in the native pasture and legume oversown treatments in 2000 (Fig. 12*b*). In contrast, there was a consistent decline in *Aristida* spp. frequency throughout this study in the supplement/burning treatment to be 7% in 2001, although this decline was not significant ($P>0.05$) in any individual year.

The supplement/burning treatment affected the composition of 2 intermediate species. In native pasture and legume oversown treatments, the composition of *Eragrostis* spp. increased from 2% in 1988 to 4% in 1991 and then steadily declined to <1% in 2001 (Fig. 13*a*). In the supplement/burning treatments, *Eragrostis* spp. composition increased to 6% in 1991 and then remained consistently higher than that in the other 2 pasture types, with differences significant ($P<0.05$) in 1993, 1997, and 1999–2000. *Chrysopogon fallax* composition in native pasture and legume oversown treatments generally declined from 5% in 1988 to be 1.5% in 2001 (Fig. 13*b*). In the supplement/burning treatments, *C. fallax* spp. composition was consistently higher between 1999 and 2001 and these differences were significant ($P<0.05$) in 1999 and 2000.

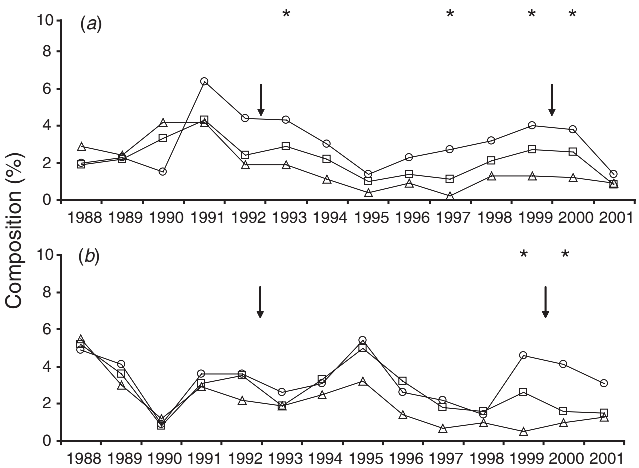

Fig. 13. Changes in the composition (%) of (*a*) *Eragrostis* spp. and (*b*) *Chrysopogon fallax* at 3 pasture types (averaged over stocking rates) (□ native pasture, △ oversown pasture, ○ supplement/burnt pasture) between 1988 and 2001. Within years, asterisks indicate differences ($P < 0.05$) between treatments. Analyses performed on angular transformed data. Arrows indicate time of burning for the supplement/burnt treatment.

The frequency of 2 minor species was also affected by supplement/burning treatments. The frequency of sedges declined from 40% in 1988 to 10% in 1990 in all treatments and then increased again to be 42% in 1992, although it was reduced ($P < 0.05$) in 1991 by legume oversowing (Fig. 14*a*). Between 1992 and 1999, sedges frequency fluctuated little, but increased again between 1999 and 2001 to be higher ($P < 0.05$) in 1999 and 2000 in the supplement/burning compared with native and legume oversowing treatments. Throughout this study, the frequency of 'Other grasses' fluctuated between a minimum of 9% in 1989 and a maximum of 28% in 1995 with the highest value of 40% in the legume oversown treatments in 2001 (Fig. 14*b*). 'Other grasses' frequency was reduced ($P < 0.05$) in native pasture in 1993, in the supplement/burning treatment in 1997

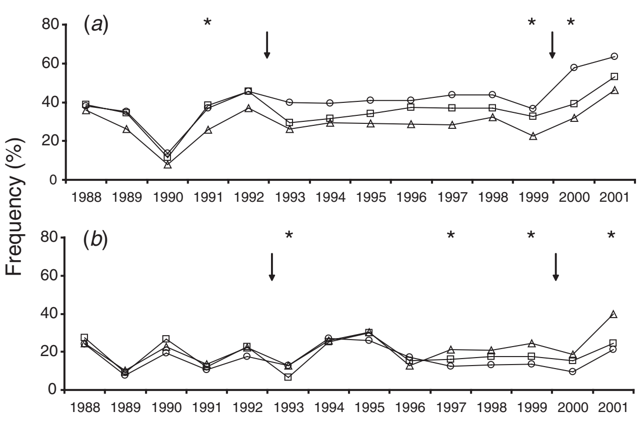

Fig. 14. Changes in the frequency (%) of (*a*) sedges and (*b*) 'other grasses' at 3 pasture types (averaged over stocking rates) (□ native pasture, △ oversown pasture, ○ supplement/burnt pasture) between 1988 and 2001. Within years, asterisks indicate differences ($P < 0.05$) between treatments. Analyses performed on angular transformed data. Arrows indicate time of burning for the supplement/burnt treatment.

and 1999, and in both the native pasture and the supplement/burning treatments 2001.

Discussion

Effects of stocking rate and pasture type

Increasing stocking rate from 8 to 2 ha/steer reduced total pasture yield and was associated with a reduction in *H. contortus* yield and an increase in *B. decipiens*, *C. divaricata*, and *Eragrostis* spp. composition. Compared with stocking rate, pasture type had less effect on yield and composition, although spring burning reduced total yields in the subsequent autumn while legume oversowing progressively increased the composition of Seca stylo, which reduced the yield of native species, particularly of *H. contortus*. Reduced total yield with increased stocking rate was apparent by the second year of treatments, although there was a longer time lag before the effects of treatments were reflected in changes in pasture composition. These findings are consistent with earlier findings from this study (Orr *et al*. 2001), while subsequent data recordings further support the notion of the time lag impact on pasture composition change. In particular, the Orr *et al*. (2001) paper reported no effect of heavy grazing on *H. contortus*, while subsequent data recordings provide evidence of a decline in *H. contortus* yield, particularly since 1998.

This study was conducted through the driest period of the last 100 years in this district and results need to be interpreted accordingly. Nevertheless, our stocking rates of 8, 5, and 4 ha/steer achieved mean annual pasture utilisations of 30% or less while stocking rates of 3 and 2 ha/steer exceeded 30%. McKeon *et al*. (1990) analysed a comprehensive range of stocking rate data from a diverse range of land systems and concluded that 30% represented a long-term 'safe' utilisation rate. Our study supports this figure as a threshold for sustainable grazing because reduced total yields, a trend to reduced *H. contortus* yields and associated deleterious changes in pasture composition, e.g. increases in *B. decipiens*, *C. divaricata*, and *Eragrostis* spp., occurred at 3 and 2 ha/steer only. Our study has not been able to clearly relate specific changes in pasture composition to the co-occurrence of particular utilisation rates, although the increase in intermediate species in 1995 and the reduction in *H. contortus* yields in 1998 were associated with utilisation far in excess of 30%. Given that 30% represents long-term safe utilisation, then higher stocking rates could expected to be sustainable during periods of 'normal' or 'above-normal' rainfall. Orr *et al*. (2006) have demonstrated the ability of *H. contortus* to respond to above-average rainfall.

Further evidence of deleterious pasture change with heavy stocking is provided by two associated studies at Galloway Plains. First, cumulative soil loss (Sallaway and Waters 1996) between 1991 and 2001 was 1670 kg/ha at 2 ha/steer compared with 423 kg/ha at 4 ha/steer and 182 kg/ha in exclosure. Second, landscape function analysis (Tongway and Hindley 2004) conducted in 2001 (Davies 2001) reported that increasing stocking rate from 5 to 2 ha/steer, with or without oversown legume, reduced landscape stability as demonstrated by: the replacement of perennial grass zones, decreased proportion of run-on zones, and decreased landscape infiltration index.

Changes in native pasture composition

Total yields in native pasture recorded in this study were similar to those reported elsewhere in both northern (Jones 2003) and southern (Shaw 1978) *H. contortus* communities. The reduction in total yields with increasing stocking rates at Galloway Plains was similar to that in other studies (e.g. Shaw 1978; McIvor and Gardener 1995; Jones 2003; Orr *et al*. 2006). Despite the generally below-average rainfall throughout our study, total yields were strongly influenced by seasonal rainfall as reported elsewhere for these pastures (Shaw 1978; McLeod and Cook 2004).

Increasing stocking rate reduced the yield of *H. contortus*, particularly after 1998, despite no reduction in this species' frequency. Reductions in yield are consistent with associated diet selection studies (Hendricksen *et al*. 2010), which indicated that steers consistently select *H. contortus* when it is available in the pasture. No reduction in frequency suggests some resilience in *H. contortus* to grazing and is supported by associated basal area studies from this site (R. L. Clem, unpubl. data), which indicate little change in *H. contortus* basal area. Other reports of the reaction of *H. contortus* to increased grazing pressure suggest a variable response. At Rodds Bay, in coastal central Queensland, Shaw and Mannetje (1970) reported that stocking at 1.6 ha/beast over 7 years, when summer rainfall was below average, substantially reduced *H. contortus* frequency. However, at the same site, Shaw and Dale (1978) reported that *H. contortus* maintained its strong dominance at stocking rates up to 1.2 ha/beast over another set of 7 years when summer rainfall was highly variable and when pastures were burnt occasionally in spring.

The apparent resilience of *H. contortus* reported here at the plant community scale and in the basal area studies contrasts strongly with the individual plant scale data indicating that increasing stocking rate reduced *H. contortus* plant density and basal area. Possible reasons for these differences are discussed in Orr *et al*. (2010). Nevertheless, some differences in *H. contortus* yield and frequency result from differences between the 2 replicates that were located on different soil types: both yield and frequency were consistently higher on the duplex soil, which is more suitable for *H. contortus* growth than the clay soil.

Increasing stocking rate reduced the autumn yield of *B. bladhii* and this effect became apparent as early as 1991, consistent with Anderson (1993) who reported that *B. bladhii* is readily grazed by livestock. However, this result became unexpected because the associated diet selection studies (Hendricksen *et al*. 2010) indicated that *B. bladhii* was selected only when the availability of preferred species, especially *H. contortus*, was low. By the end of this study in 2001, the basal area of *B. bladhii* at 2 ha/steer was higher ($P < 0.05$) than at 5 ha/steer (R. L. Clem, unpubl. data). This later finding indicates that this species has increased its crown area with increasing stocking rate and is, in reality, an 'increaser' species rather than a 'decreaser' species as we originally expected. The anomaly is consistent with other data (Orr *et al*. 1999) indicating that *B. bladhii* has replaced *H. contortus* at heavy stocking rate and this finding further supports the Hendricksen *et al*. (2010) data suggesting that *B. bladhii* would be an 'increaser' rather than a 'decreaser' species. An alternative suggestion is that the replacement of *H. contortus* by *B. bladhii* may reflect the absence of burning, which is important in maintaining *H. contortus* (Orr *et al*. 1997, 2010). Nevertheless, our study has shown that *B. bladhii* is an important component of *H. contortus* pastures in central Queensland, while other species of this genus are important elsewhere in northern Australia (Orr and O'Reagain 2005; Silcock *et al*. 2005). Despite this, more needs to be known of the grazing ecology of this genus and further research is warranted.

The highest yields of *Aristida* spp. in unburnt native pasture occurred at light stocking rate consistent with other results from *H. contortus* pastures in both southern (Orr 2004) and central Queensland (Silcock *et al*. 2005). However, this result conflicts directly with the earlier suggestion (Orr *et al*. 1997) that *Aristida* spp. replace *H. contortus* under conditions of heavy grazing. Similarly, Tothill *et al*. (2008) reported that *Aristida* spp. increased with increasing utilisation rates. The highest *Aristida* spp. yields in unburnt pasture at light stocking at Galloway Plains are consistent with associated diet selection studies (Hendricksen *et al*. 2010) indicating that the *Aristida* spp. content of the diet was always less than 2% and there was no effect of stocking rate.

Increasing stocking rates increased the composition of the intermediate species *B. decipiens*, *C. divaricata*, and *Eragrostis* spp. and such increases agree with reports (Shaw and Dale 1978; Anderson 1993) of their increased occurrence with increasing stocking rates. Increased composition of both *C. divaricata* and *Eragrostis* spp. in the pasture with increasing stocking rate was also reflected in their increased occurrences in the diets selected by steers (Hendricksen *et al*. 2010). Of the minor species, the frequency of *Panicum* spp. was reduced with increasing stocking rate, whereas that of *Sporobolus* spp., *Tragus australianus*, and Malvaceae was all increased with increasing stocking rate. Anderson (1993) described *T. australianus* is an indicator of overgrazing. Similarly, annual grasses and forbs increased in heavily grazed native pastures in northern Queensland (McIvor and Gardener 1995).

Changes in oversown legume pasture composition

Oversowing legumes by surface sowing failed to change total yield relative to the other 2 pasture types at the same stocking rate. In contrast, legumes oversown by band seeding *H. contortus* pastures at Glenwood in southern Queensland reduced total yield compared with unsown native pasture because band seeding involves the removal of 33% of the native pasture in order to improve legume establishment (McLeod and Cook 2004). The major effect of oversowing legumes in our study was the gradual increase in stylo composition from <1% in 1988 to 50% in 2001, and the eventual reduction in the yield of perennial grasses. This stylo increase occurred independently of stocking rate, in contrast to the finding of McIvor and Gardener (1995) that Seca stylo dominated at high stocking rates on infertile soils particularly with native grasses. The gradual increase of stylo at Galloway Plains was associated with increased steer liveweight gain, particularly in autumn (Burrows *et al*. 2010) and was also associated with up to 66% stylo content in the diet of steers in autumn (Hendricksen *et al*. 2010).

Oversowing legumes failed to reduce the occurrence of *H. contortus* or *B. bladhii* in the first 10 years of this study. However, by 1998, legume oversowing had reduced the yield of *H. contortus* and this reduction was associated with reduced plant density relative to the other 2 pasture types (Orr *et al*. 2010). This suggests that *H. contortus* will decline in legume oversown pastures over longer time periods than covered by this study. Thus, longer term management will need to consider the use of, for example, spring burning to maintain a high contribution of *H. contortus*. Noble *et al*. (2000) suggested a role for fire in managing the balance of stylo and native perennial grasses when there was still a relatively high contribution of perennial grasses to carry the fire.

Oversowing legumes resulted in a decline in both the native legumes and 'Other forbs' components of the pasture. Unfortunately, when this study commenced in 1988, little attention was focussed on individual species and their contribution to species diversity and this study made no attempt to identify individual native legume or forb species. Nevertheless, observations indicated that the native legumes *Rhynchosia minima* and *Glycine tabacina* were more common in native pasture (particularly under light grazing) than in the legume oversown treatments. Consistent with the reduced occurrence of 'Other forbs' in the legume oversown treatments, 'Other forbs' contributed a lower proportion to steer diets compared with that in the 2 other pasture types (Hendricksen *et al*. 2010). The annual/short-lived perennial grass *Chloris inflata* was the only species to increase in the legume oversown treatments and is regarded as unpalatable and an indicator of soil disturbance (Anderson 1993).

The gradual increase in the contribution of stylo to overall pasture composition and associated changes in species occurrences during the 13 years of this study indicate the need to understand the long-term consequences of sowing legumes into native pastures. In particular, we need to further understand how legume composition changes and how these changes might be managed in the long-term. McIvor *et al*. (1996) highlighted the problems associated with the long-term maintenance of stylo-based pastures.

Changes in supplement/burning pasture composition

Spring burning reduced total pasture yields in autumn in both 1993 and 2000 following burning in spring 1992 and 1999 (the only two springs when burning was possible at 3 and 2 ha/steer). These differences in total pasture yield represent the carry-over pasture growth from previous summer growth in the unburnt pasture. This is because total yields in autumn following spring burning consist only of that summer's pasture growth, whereas in unburnt pasture, the total yield comprises that summers' pasture growth plus carry-over growth from previous summers (Orr *et al*. 1997).

Spring burning in 1999 substantially increased the composition of *H. contortus* in the pasture, especially where stocking rate was light enough to ensure an effective burn. This result is consistent with outcomes from other burning studies (Orr *et al*. 1997) indicating that burning increases the composition of *H. contortus*. Associated population studies (Orr *et al*. 2010) indicate that light stocking rates are important in promoting *H. contortus* because they enable *H. contortus* to produce a substantial soil seedbank, which leads to substantial seedling recruitment following burning. The poor response to spring burning at 2 and 3 ha/steer resulted from low fuel loads at the time of burning and also low soil seedbanks that limited seedling recruitment following burning. This situation was compounded by the low rainfall throughout the present study.

Spring burning had little effect on *B. bladhii* at 2, 3, and 4 ha/steer, although its yield was reduced at 5 ha/steer when the yield of *H. contortus* increased, suggesting that spring burning may reduce *B. bladhii* yield at light stocking rate. This result is similar to other results (Orr *et al*. 1997) suggesting that *B. bladhii* may be reduced by spring burning under conditions of light grazing pressure. Further research is necessary to understand the role of spring burning in maintaining *B. bladhii.*

Spring burning reduced the occurrence of *Aristida* spp. consistent with similar results at Gayndah (Orr *et al*. 1997), but conflicting with results from Glenwood (Orr 2004) where fire failed to reduce *Aristida* spp. Orr (2004) explained these differences in terms of the different responses of different taxa of *Aristida* spp. to fire. The combination of the highest *Aristida* spp. yields at light stocking rates together with this species' response to spring burning indicates that light stocking rates combined with spring burning should achieve sustainable management of this undesirable species in these pastures. Nevertheless the intermediate species *Eragrostis* spp. and *Chrysopogon fallax* both increased with burning compared with unburnt native pasture. Anderson (1993) reported that increased abundance of both these species indicates that the pasture is being overgrazed. Of the minor species, the occurrences of sedges and 'Other grasses' also increased with burning. Anderson (1993) reported that sedges increase as perennial grasses disappear from the pasture. Thus, increases in these species suggest that burning 'opens up' the pasture and allows space for less desirable grazing species to increase.

Conclusions

This study confirms that increasing stocking rate in native pasture reduces total pasture yields and increases the contribution of less desirable pasture species. Oversowing legumes and supplement/burning treatments produced similar total pasture yields to that of native pasture at similar stocking rates but there are indications that the former pasture 'disturbances' do change pasture composition. In the long-term, these pastures can be managed sustainably by using a stocking rate of 4 ha/steer or lighter, which equates to 30% annual pasture utilisation and through the judicious use of spring burning.

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