Effect of seasonal soil moisture, nitrogen fertiliser and stocking rate on unsown species in a sown subtropical pasture

C.K. McDONALD, R.M. JONES AND M.W. SILVEY[1]
CSIRO Division of Tropical Crops and Pastures, St Lucia, Queensland, Australia
[1]Present address: Department of Primary Industries, Brisbane, Queensland, Australia

Summary

Green panic (*Panicum maximum* var. *trichoglume)* and rhodes grass (*Chloris gayana*) were sown on a fertile soil in subcoastal south-east Queensland, Australia, and grazed at 5 stocking rates (1.0 to 2.2 steers/ha), with and without nitrogen fertiliser (100kg N/ha/yr). The occurrence of unsown species within $1m^2$ quadrats on a 25m x 20m grid was monitored annually in summer from 1973–1980. Spatial data were analysed by cluster analysis and the number of species per paddock and per quadrat were analysed by regression and analysis of variance.

The number of species per paddock and per quadrat was reduced by the application of nitrogen fertiliser. Increasing stocking rate increased the number of species per quadrat but not per paddock, except at the highest stocking rate.

Factors affecting the composition of unsown species were, in order of importance, soil moisture >> fertiliser > stocking rate.

Soil moisture affected the composition of unsown species in 2 ways. Changes in the availability of winter-spring soil moisture from above average to below average caused a shift in the unsown species present. Drought followed by good winter soil moisture triggered extraordinary pulses of *Cirsium vulgare*. There was no apparent effect of either the species shift or pulses of unsown species on animal liveweight gain.

The results are examined in terms of biodiversity and selection of species as indicators of overgrazing.

Correspondence: Mr C.K.McDonald, CSIRO, Cunningham Laboratory, 306 Carmody Road, St Lucia, Qld 4067, Australia

Introduction

The changing contribution of unsown species in grazed, improved pastures in response to climate and management is well recognised. Tothill *et al.* (1982) indicated that fertility status can affect which species will invade a pasture. Jones (1992) reported the invasion of unsown species under sustained heavy grazing, which, for a limited period of time, could be reversed by removing the grazing pressure. In terms of the state and transition model (Westoby *et al.* 1989), invasion by unsown species can be an indicator of the onset of a transition to a less productive state (Filet 1994). The unsown species also represent the inherent biodiversity of the area. It is now recognised that the biodiversity in many communities will be maintained in grazed pastures rather than in national parks (McIntyre 1994).

However, most of the literature on unsown species in grazed tropical pastures refers to native grassland (e.g. Tothill 1974; Orr 1981; Olff and Bakker 1991; Ter Heerdt *et al.* 1991). There has been little study of the number of unsown species in improved tropical pastures, their variation with treatment, or their effect on animal production (Tothill *et al.* 1982). Any mention of unsown species is usually in a collective sense (e.g. Walker *et al.* 1987; Silvey and Jones 1990) or concentrates on a single species (Tothill and Berry 1981).

An experiment in subtropical Queensland examined the effect of a range of stocking rates, with and without nitrogen (N) fertiliser, on pasture composition of and animal production from sown pastures of green panic (*Panicum maximum* var. *trichoglume*) and rhodes grass (*Chloris gayana*).

In a previous paper describing the results of this experiment, Jones *et al.* (1995) presented the key findings of the effects of fertiliser and stocking rate on pasture composition and liveweight gain. McDonald *et al.* (1995) gave detailed climate, soil, animal and pasture data from the experiment. The sown pastures were largely replaced by unsown species at stocking rates above 1.0 steer/ha without N fertiliser, and at rates above 2.0 steers/ha with N fertiliser (Jones *et al.* 1995). Again, these data refer mainly to the sown species and deal with the unsown species in a collective sense.

In view of the importance of unsown species for biodiversity and as indicators of transition, detailed analyses were performed on the effects of soil moisture, stocking rate and N fertiliser on the occurrence of the unsown species.

Materials and methods

Experimental design

The experiment was located on Narayen Research Station (25°41′ S, 150°52′ E) near Mundubbera in south-east Queensland, Australia. The 80 ha experimental area was on a fertile, dark brown, cracking clay, formerly under *Acacia harpophylla* (brigalow) softwood forest. The soils (mostly Dr 4.1, Gn 3.1 and Ug 5.1; Northcote 1979) were vertisols and alfisols in the U.S. Soil Taxonomy (C.H.Thompson, personal communication). The mean annual rainfall is 709mm, occurring largely in summer. The forest was cleared in 1937–38, the area sown to rhodes grass, and intermittently grazed.

In 1968, the experimental area was cultivated and sown with green panic. From 1968–1973, the area was used for an experiment grazed by cows and calves. From 1973, the experimental design was 2 replicates x 2 levels of P fertiliser (0 and 18 kg/ha P per year) x 2 levels of N fertiliser (0 and 100 kg/ha N per year) x 5 stocking rates (1.0, 1.4, 1.8, 2.0 and 2.2 yearling steers/ha). Yearling heifers were used after May 1981. A full description of the experimental treatments, the re-design from the previous experiment which ran from 1968–1973, and soil and climate information are presented by Jones *et al.* (1995) and McDonald *et al.* (1995).

Measurements

The presence (occurrence) of all unsown species was recorded in November–December 1973, 1974, 1975, 1976, 1977, 1979 and 1980 in 1295 fixed quadrat sites of 1m^2, sited on a 25m x 20m grid over the whole experimental area. The number of quadrats per paddock ranged from 24 in the high stocking rate to 48 in the low stocking rate. Species frequency percent per paddock was determined as the percentage of quadrats within a paddock in which a particular species occurred.

Stanley and Ross (1986) have provided the basis for species authorities as well as their classification as exotic or native. Exotic species are noted with an asterisk in the text.

Analysis

The numbers of species per quadrat and per paddock, in relation to treatment, were analysed by analysis of variance and regression analysis. To remove any bias associated with increasing numbers of quadrats with decreasing stocking rate, only 24 quadrats were used in each paddock to determine the number of species per paddock. In paddocks with more than 24 quadrats, the 24 quadrats to be used were selected at random. Repeated measurements were treated as a split-plot when years were included as a factor in the ANOVA model.

Species association with treatment, soil boundaries, contour levels and season were analysed using cluster analysis procedures contained in the pattern analysis package, PATN (Belbin 1991).

Species with a frequency of occurrence of less than 0.2% averaged over the 7 samplings and not more than 0.5% at any one sampling were excluded from cluster analysis. Dale and Williams (1978) indicate this method of species reduction to be reasonably suitable for small-scale surveys. Based on the findings of Faith *et al.* (1987) and Belbin (1991), the Bray-Curtis measure was chosen as the most suitable dissimilarity measure for occurrence data and the Gower metric measure for frequency data. Data were classified using the non-hierarchical allocation clustering method (Belbin 1987) and sorted using Unweighted Pair Group Arithmetic Averaging (Belbin 1991).

Three strategies were used for cluster analysis:

- classification of species occurrence data on a quadrat basis for each sampling separately;
- occurrence data on a quadrat basis were pooled over the 7 samplings (7 x 1295 sites giving 9065 data records) and then classified; and
- species frequency percent of occurrence in each paddock was calculated for each sampling, and the 7 samplings pooled (7 samplings by 40 paddocks giving 280 records), then classified.

Soil moisture indices were derived from on-site rainfall and evaporation records using the growth index model of McDonald (1994).

Results

Applying superphosphate had very few significant effects on pasture yield, species composition or animal production (Jones *et al.* 1995), so data tabled here, other than data for cluster analysis, have been averaged over phosphate treatments. Hereafter in this paper, the terms, 'fertiliser' and 'fertilisation', refer to N fertiliser only.

Number of species

Ninety-seven species were recorded over the 7 samplings from 1973–1980. Eliminating species which occurred in less than 0.2% of quadrats, averaged over all 7 samplings, and not more than 0.5% of quadrats in any one sampling, reduced the number of species to 62.

Averaged over the 7 samplings, only 3 species (*Rhagodia nutans, Urochloa panicoides* and *Chloris divaricata*) had a frequency of occurrence greater than 30% over the whole site, and only 35 species averaged more than 1% frequency (Figure 1). The highest frequency recorded in any year was 64% for *R. nutans* in 1979. The lowest maximum frequency in any year was 31% (*C. divaricata*) in 1975. Each individual year had a similar curve to that shown in Figure 1, but mostly with a higher maximum frequency.

Number of species per paddock differed ($P<0.001$) between years, with fewer ($P<0.001$) in fertilised areas. There was a significant ($P<0.01$) interaction between year and applied N (Table 1). In 1975, 1976, 1977 and 1979, the number of species per paddock at the lowest stocking rate was significantly lower ($P<0.05$) than at the highest stocking rate, but not significantly different from the other 3 stocking rates. Stocking rate had no significant effect on the number of species per paddock in the other 3 years.

The number of species per quadrat was also significantly different ($P<0.001$) between years,

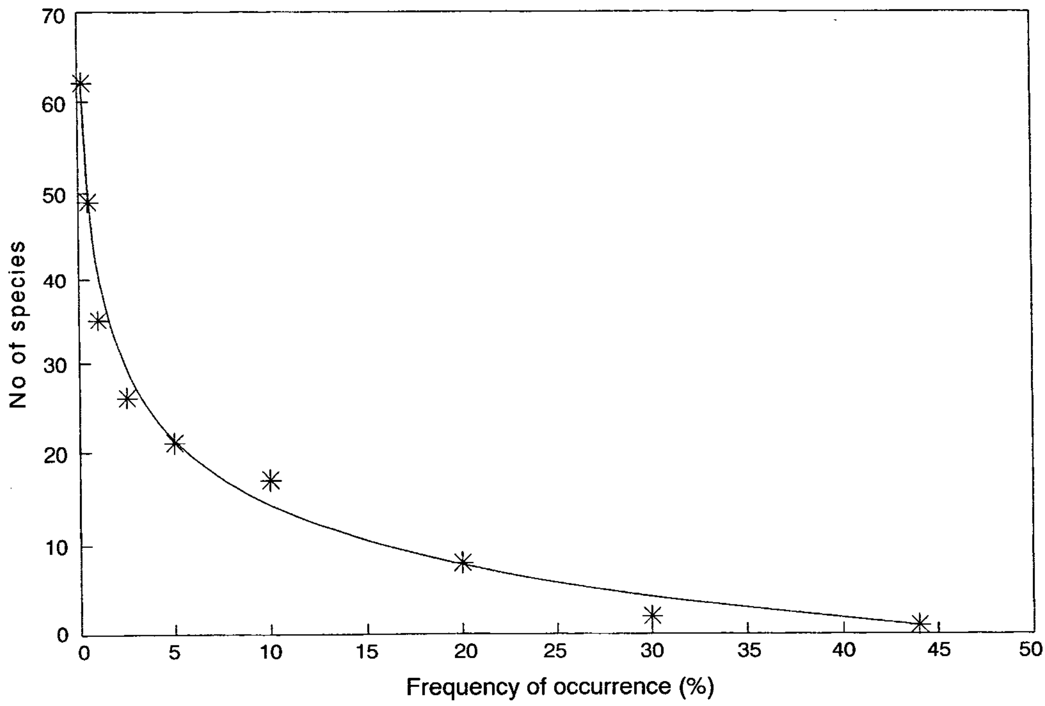

Figure 1. Distribution of frequency % of occurrence of unsown species averaged over 7 samplings from 1973–1980, over all sites.

Table 1. The number of species per paddock and per 1 m^2 quadrat for unfertilised (N0) and fertilised (N100) treatments, and the number of species per 1 m^2 quadrat for each stocking rate, for the period 1973–1980.

T'ment	1973	1974	1975	1976	1977	1979	1980	LSD[1]
No. of species/paddock								
N0	23.4	23.6	27.0	23.3	24.7	21.1	18.6	2.9
N100	20.6	19.8	22.2	15.3	19.1	13.0	14.6	2.9
Signif[2]	ns	**	***	***	***	***	**	
No. of species/quadrat								
N0	5.2	6.0	7.8	5.2	6.9	6.0	4.2	0.8
N100	4.2	4.1	5.6	2.2	3.7	2.8	2.4	0.8
Signif[2]	ns	**	***	***	***	***	**	
No. of species/quadrat								
Animals/ha								
1.0	2.4	3.5	4.2	2.5	3.2	1.9	1.9	1.4
1.4	4.9	4.6	5.6	2.7	4.1	3.8	3.7	1.4
1.8	3.9	5.0	7.0	3.9	5.6	4.9	3.4	1.4
2.0	6.6	6.1	7.3	3.5	5.6	4.9	3.4	1.4
2.2	5.5	6.2	9.4	5.8	7.9	6.5	4.2	1.4
LSD[3]	2.1	2.0	1.5	1.5	1.7	1.2	2.2	

[1] LSD (P<0.05) for N x Year interaction and Stocking Rate x Year interaction.
[2] Significance between N levels within year.
[3] LSD (P<0.05) within each Year.

with fewer species in fertilised paddocks (P<0.01) (Table 1) and a significant interaction (P<0.01) between year and applied N. There was also a significant (P<0.001) increase with increasing stocking rate (Table 1), with an interaction (P<0.01) between stocking rate and years, the highest number of species occurring at the highest stocking rate in most years but at the second highest rate in 1973.

With time, stocking rate reduced presentation yield, especially in the unfertilised paddocks (Jones *et al.* 1995), and these were the treatments with the greatest number of species. However, regression analysis showed that presentation yield at the time of sampling, although ranging from less than 500 to over 7000 kg/ha, accounted for only 33% and 13% of the variance in species numbers for the unfertilised and fertilised treatments, respectively. Minimum yield in the previous 12 months accounted for 37% and 29%, respectively; grazing pressure, determined as the metabolic liveweight per unit of pasture [(kg of animal)$^{0.75}$/(kg of pasture)], accounted for 40% and 19%, respectively. The strongest correlation was with stocking rate (steers/ha), which accounted for 52% and 30%, respectively.

Data for the mean number of species per quadrat for each treatment were then standardised to remove year-to-year fluctuations. All treatment means for a particular year were divided by the maximum mean value for any treatment for that year. These standardised data represented the 'proportional' species per quadrat and ranged in value from 0 to 1. Regressing the standardised species number against stocking rate increased the variance accounted for to 65% and 37%, respectively, for the unfertilised and fertilised treatments. As stocking rate increased, the rate of increase in the proportional number of species per quadrat in the unfertilised treatment was almost double that in the fertilised treatment (Figure 2).

Quadrats with a high number of species were usually in the unfertilised paddocks. By 1977, the majority of quadrats with more than 12 species were in unfertilised paddocks stocked at 1.8–2.2 steers/ha, whereas nearly all quadrats in fertilised paddocks had fewer than 8 species, with most fewer than 4.

Cluster analysis

Groupings from cluster analyses of occurrence data, on an annual basis and pooled over the 7 samplings, showed little if any correlation with soil boundaries or contour levels, although a small area in one paddock showed up each year

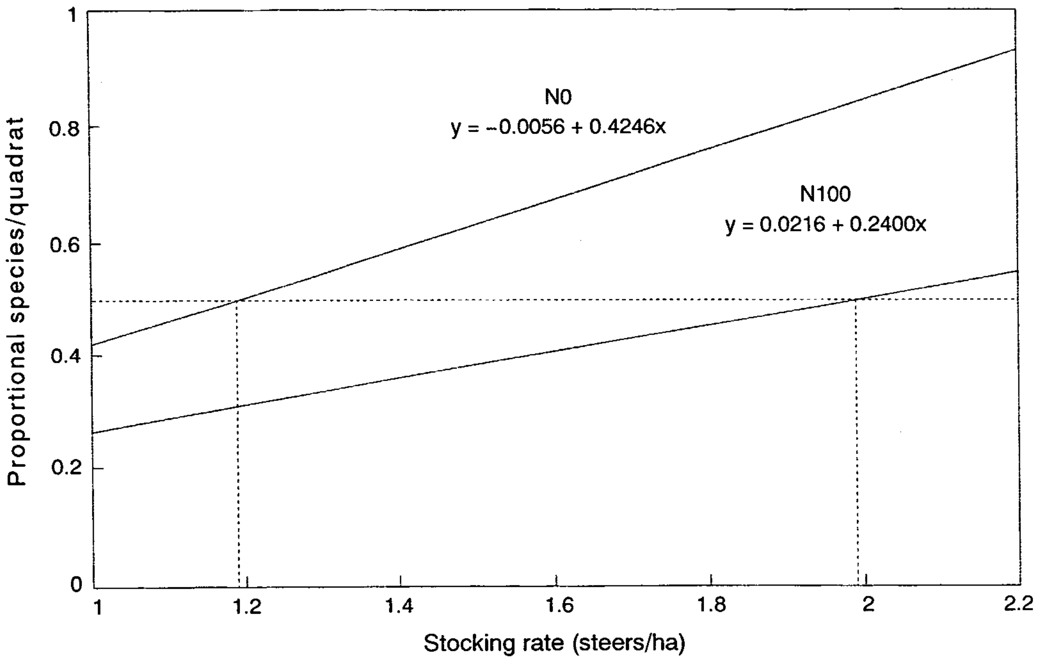

Figure 2. Regression lines showing the trend in the proportional number of species per quadrat with increasing stocking rate for the unfertilised (N0) and fertilised (N100) treatments. The dotted lines indicate the stocking rates at which the number of species is half the maximum.

due to a high occurrence of Queensland blue grass (*Dichanthium sericeum*) and slender chloris (*Chloris divaricata*). Analysis of species frequency percent per paddock, pooled over the 7 samplings, produced similar results.

Each year had 2 or 3 major classification groups, which were similar across years up to 1977. In 1979 and 1980, the groups were similar to each other but different from those for the period 1973–1977. For brevity, results from the analysis of the frequency percent per paddock data only are reported here.

Over all years there were only 6 major groups. The species in the major groups are given below; those with an asterisk are classed as exotic. Since a non-hierarchical rather than a divisive analysis was used, it is not just the presence of a species that is important, but which other species occur with it. Hence, a species can occur in several groups (e.g. *U. panicoides**). The species have been divided into those with greater than 35% occurrence in the group, and those with 18–35% occurrence. This separation is chosen as it best indicates the species shift from 1973 to 1980.

GROUP 1	>35%	*Rhagodia nutans; R. linifolia; Urochloa panicoides*; Chloris divaricata; Conyza bonariense*; Gnaphalium involucratum; Lepidium bonariense*; L.hyssopifolium; Plantago varians; Oxalis corniculata; Verbena officinalis*.*
	18–35%	*Cirsium vulgare*; Sonchus oleraceus*; Malvastrum americanum*; Eriochloa pseudoacrotricha.*
GROUP 2	>35%	*R. nutans; R. linifolia.*
	18–35%	*U. panicoides*; C. bonariense*; L. bonariense*; L. hyssopifolium.*
GROUP 3	>35%	*C. divaricata; Dichanthium sericeum.*
	18–35%	*U. panicoides*; Euphorbia drummondii; Calotis cuneata.*

GROUP 4 >35% *U. panicoides**.

GROUP 5 >35% *R. nutans; R. linifolia.*
18–35% *U. panicoides**.

GROUP 6 >35% *R. nutans; R. linifolia; U. panicoides**; *C. divaricata; Tribulus terrestris.*
18–35% *O. corniculata; M. americanum***; E. pseudoacrotricha; E. drummondii; Alternanthera pungens***; Portulaca oleracea.*

Although individual paddocks changed groups, there was no consistent effect of fertiliser or stocking rate until 1976, and despite being a drought year, 1977 was little different from 1976. During this time, Group 2 was mainly in the fertilised and the low-stocking-rate unfertilised paddocks, while Group 1 was mainly in the 3 higher stocking rates of the unfertilised paddocks. Group 3, a smaller group, showed no apparent correlation with treatment, but contained the paddock with higher levels of blue grass (Figure 3).

However, by 1979 there had been considerable change. There was a shift from cool season species (*C. bonariense**, *C. vulgare**, *Lepidium*

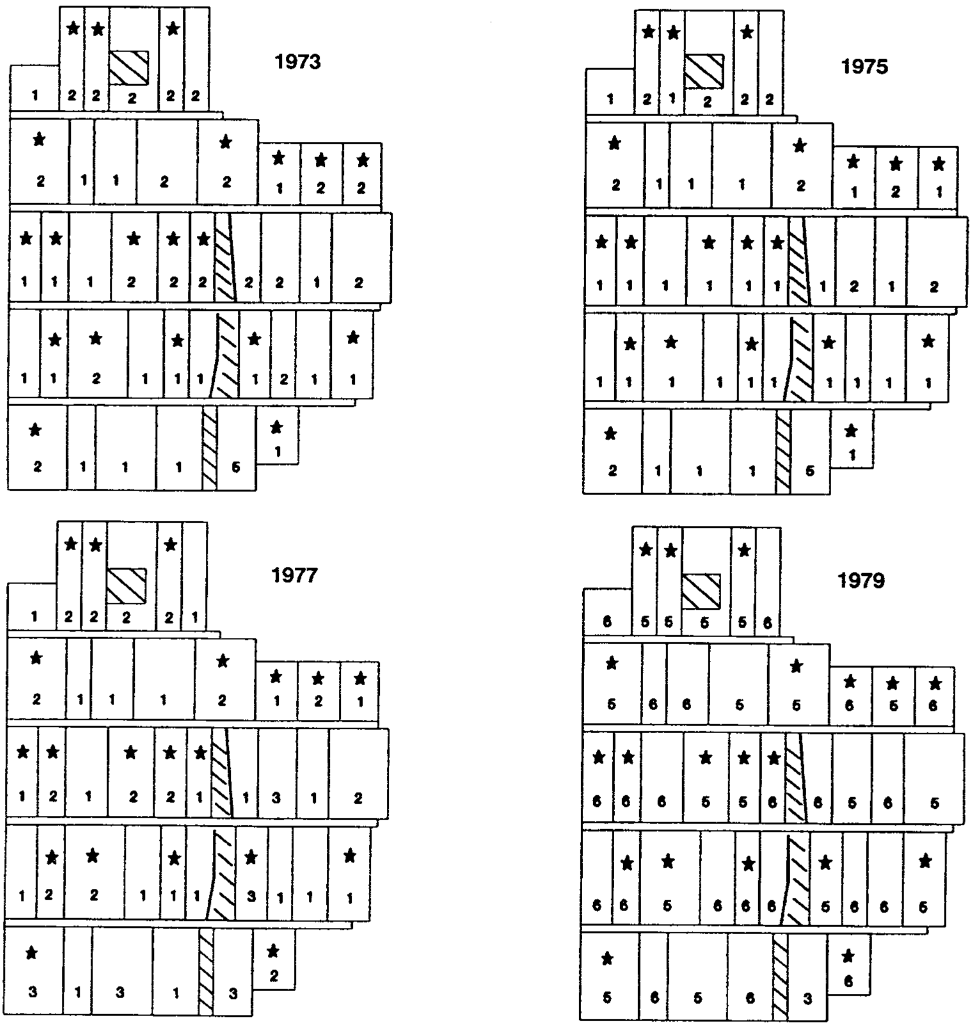

Figure 3. Distribution of the 6 major species groups over the experimental site in 1973, 1975, 1977 and 1979. Fertilised paddocks are denoted with a ★. The larger the paddock the lower the stocking rate. Hatched areas indicate depressions and stony areas excluded from the experimental area.

spp., *P. varians, V. officinalis**, and *G. involucratum* — Groups 1 and 2) to spring-summer species (*T. terrestris, P. oleracea, A. pungens*, C. divaricata,* and *U. panicoides** — Groups 5 and 6). *Rhagodia* spp. increased in 1979 and then decreased in 1980. As a result of these changes, Group 6 comprised most of the unfertilised paddocks and the high-stocking-rate fertilised paddocks (formerly mainly Group 1); Group 5 contained most of the fertilised paddocks and low-stocking-rate unfertilised paddocks (formerly Group 2); Group 3 contained similar paddocks in most years up to 1977, with only a few paddocks with higher levels of slender chloris adding to the group in 1976 and 1977, but by 1979 only the blue grass paddock remained in the group.

In 1980, there was a further increase in *U. panicoides** coincidental with a decrease in *Rhagodia* spp. Group 5 all but disappeared to form Group 4, with some fertilised paddocks from Group 6 also moving to Group 4.

Many exotic and native species not listed above were present in all groups.

Species interaction with climate/soil moisture

The climatic processes had 2 distinct effects on the unsown species. The first was a change in species across years, and the second was an episodic pulse of a single species (McDonald *et al.* 1995).

The species change related to the summer and winter rainfall patterns can be understood better by examining the changes in the seasonal soil moisture index (SMI) (Figure 4). This shows the quarterly average of the soil moisture index. A moisture index of 0.5 indicates the available soil moisture is 50% of that available at field capacity. Pastures in this region will maintain good growth at moisture indices above 0.5, but will generally cease active growth at indices below 0.2–0.3 (McDonald 1994).

From 1974–1977, there were seasons each year with average SMI>0.4 and considerable periods with SMI>0.3, but in 1979 and 1980, there was no seasonal period with an average SMI>0.3. The species shift was emphasised by the timing of sampling (late spring-early summer) and the decreasing yield of sown grass in later years exerting less competition against unsown species.

The episodic pulses were almost entirely the nitrophilous weed *C. vulgare** (W.Messer, personal communication). The 2 major pulses were in 1978 and 1983, yielding 770 and 1150 kg/ha,

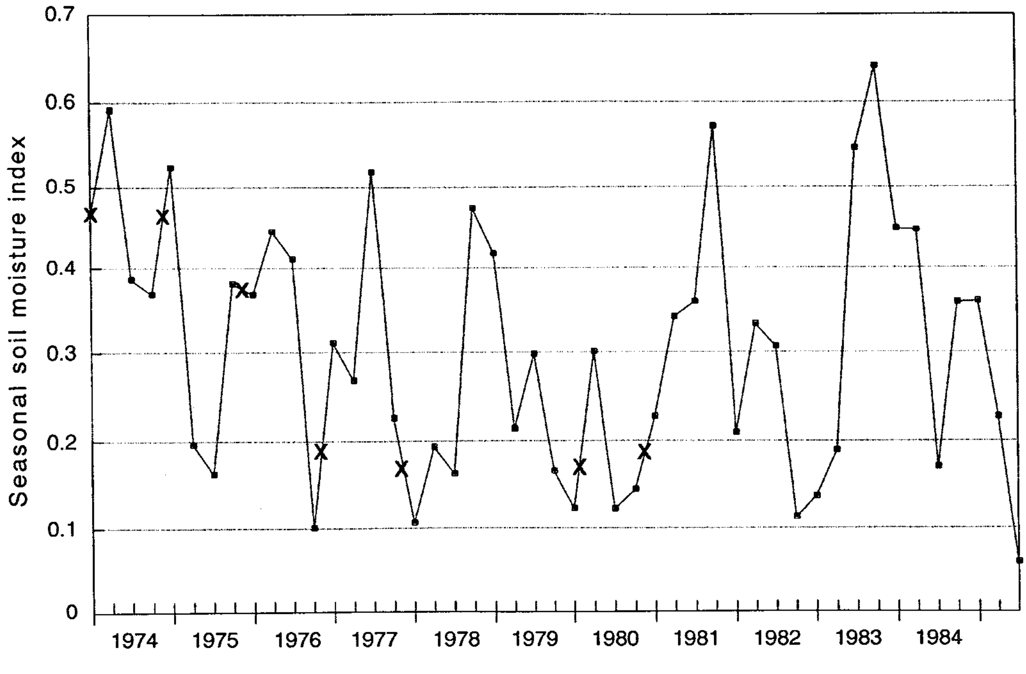

Figure 4. Seasonal soil moisture index from spring 1973 to autumn 1985. Each point is a quarterly average. X - denotes sampling times.

respectively, in the unfertilised paddocks, and 1740 and 1850 kg/ha in the fertilised paddocks. Both pulses followed a prolonged dry period in summer, followed by a reasonably wet winter, a time when growth of the sown grasses was restricted by temperature. Stocking rate had no consistent effect on the biomass or the temporal or spatial extent of these pulses (McDonald *et al.* 1995). These 2 dry periods, the 1977–78 and 1982–83 droughts, show up in Figure 4 as the 2 periods with SMI<0.2 for 3 consecutive quarters.

Discussion

The number of species

The relationship between stocking rate and the proportional species per quadrat (Figure 2) gives interesting insight into the stability of the system. The sown grasses were largely eliminated at 1.4 and 2.0 steers/ha in the unfertilised and fertilised pastures, respectively. By October 1980, the proportion of green panic in the unfertilised pastures fell from 63% to 33% as stocking rate increased from 1.0 to 1.4 steers/ha. Correspondingly, in the fertilised pastures, the proportion dropped from 82% to 30% as stocking rate increased from 1.8 to 2.0 steers/ha (McDonald *et al.* 1995). From Figure 2 it can be seen that these large changes occur at roughly the same level (0.5) of ingress by unsown species. The 0.5 level may give a broad indication of the stocking rate at which this sown pasture system will collapse. The steeper the regression line, and in this case the lower the fertility, the lower the stocking rate at which it will happen.

The better correlation between the number of species per quadrat and stocking rate than between other measures such as grazing pressure and yield was somewhat surprising. We consider this may be a function of stocking rate effects integrating a number of attributes, including presentation yield and grazing pressure, as well as integrating the timespan of their respective influences, and that of climatic factors.

This linearity contradicts the intermediate disturbance hypothesis (Grime 1979), which suggests there is an increase in the number of species up to a certain level of disturbance but a decrease in numbers beyond that disturbance level. However, it is possible that the highest stocking rate was not maintained for sufficient duration for the number of species to fall.

In contrast with the findings of du Toit and Aucamp (1985), grazing did not affect the number of species within a paddock, except at the highest stocking rate in some years. The same species were present in all treatments, and only overall abundance increased at the higher stocking rates, especially in the absence of fertiliser. Orr (1981) reported similar responses, and Austin *et al.* (1981) found no effect of grazing intensity on species presence in southern Australia.

The lack of any treatment differences in the species present or the number of species within whole paddocks in the first year indicates that the species diversity of the area was reasonably homogeneous. Furthermore, this gives confidence that any subsequent differences found were real treatment effects.

Increasing numbers of species within individual quadrats coincided with declining yields and decreasing vigour of sown grass in the higher stocking rates of the unfertilised paddocks. This indicates that opportunistic species (Tothill and Berry 1981) took advantage of the ecological niches created. Even though the paddocks were small (up to 3 ha) by commercial standards, there was little effect of stocking rate on biodiversity. At the paddock scale, the major impact was on species abundance rather than on species extinction. N fertiliser reduced the number of species per paddock by 20–40%; however, it could be expected that this difference would be less in larger paddocks.

Although the frequency distribution of unsown species was much lower in this study than in native grasslands on a neighbouring low-fertility, sandy soil (J.C. Tothill, personal communication), the introduction of sown grasses diminished the number of species further. Of 128 herbaceous species known to exist in the local cleared brigalow area, only 97 were found during the 7 samplings.

The results of this study highlight the importance of the spatial and temporal scale at which measurements are taken. The difference between species occurrence when measured at paddock and quadrat levels shows the importance of spatial scale. Had measurements been analysed at the paddock scale only, little effect of stocking rate would have been found. Cullinan and Thomas (1992) suggest using several techniques (e.g. spatial variance analysis, patch size analysis) to derive estimates of the scale of pattern before sampling strategies are determined. The results of this study may have been clearer had such an approach been used. *Cirsium vulgare** was absent as an indicator species in the classification after 1977, but was a major component of the pasture in 1978, when no sampling was done. This highlights the importance of regular sampling, at least annual. The move from cool-season species to summer species with drier seasonal patterns of soil moisture was similar to that found by Orr (1981) in the Mitchell grass (*Astrebla* spp.) communities of western Queensland, and suggests that sampling twice a year (spring and autumn) may have enhanced the understanding of the dynamics of individual species. Although the December sampling time was selected to overlap both winter and summer species, drier conditions in later years reduced this overlap.

The decrease in the number of species after application of fertiliser is consistent with other studies (Gibson *et al.* 1993; Marrs 1993). Gibson *et al.* (1993) also found an increase in the number of species as yields fell below about 4000 kg/ha. Olff and Bakker (1991) and Oomes (1990) report similar values, whereas Ter Heerdt *et al.* (1991) found no correlation between the number of species and yield within a community, although there was a negative correlation across communities. Jones *et al.* (1995) indicate a sustained presentation yield of around 1000 kg/ha as a critical level for the long-term survival of green panic. It was at or below this level that the ingress of unsown species was most rapid, particularly when pastures were kept at this level for 2 or more growing seasons.

Species changes

The occurrence of *U. panicoides** and *Rhagodia* spp. in almost all groups suggests that the mere presence of these species is not a good indicator of impending compositional change. However, *C. bonariense**, *C. vulgare** and *Lepidium* spp., which were prevalent in the unfertilised pastures up to 1976, later declined to be replaced by *T. terrestris* and *M. americanum**. As the former are high fertility invaders (Tothill and Berry 1981), this decline may have been an indication of declining fertility. Although there was a pulse of *C. vulgare** in 1983, this was mostly in the fertilised pastures. The continued occurrence, over the whole period, of *C. divaricata, O. corniculata* and *E. pseudoacrotricha* in the paddocks with declining sown grass suggests they may be indicators of over-utilisation of the sown grass.

There was some indication that, with time, plant structure was associated with the frequency of occurrence of species. Most of the erect species considered to be palatable (e.g. *C. bonariense**, *Sonchus oleraceus**, *Lepidium* spp.) decreased, erect species considered unpalatable (e.g. *M. americanum**, *C. cuneata*) remained reasonably constant, and some of the prostrate species (e.g. *A. pungens**, *T. terrestris, P. oleracea*) also increased. However, the more prostrate species are also the spring-summer species, thus confounding plant structure with the species shift.

In contrast with the results of McIntyre and Lavorel (1994), there was no indication of exotic species responding differently to treatment from native species. However, both pulses of unsown species were the exotic *C. vulgare**.

Climate/soil moisture

The composition of unsown species in native grassland is known to be sensitive to soil moisture, soil type, fertility, grazing and introduction of other species (Tothill 1983). In this study, the changes in species in drier years were greater than differences between fertilised and unfertilised paddocks, while stocking rate affected mainly the abundance rather than the species occurrence. These results, coupled with the pulses of *C. vulgare**, indicate an order of importance of soil moisture >> fertiliser > stocking rate.

The temporal changes in species composition were clearly related to the temporal changes in soil moisture. The year effect reflected the more favourable winter-spring rainfall in the period, 1973–1976, than in 1979 and 1980 (Jones *et al.* 1995). As such, at least in the short term, the changes could reverse if the seasons also reversed. Austin *et al.* (1981) and Barnes and Denny (1991) indicate that care should be taken when interpreting these temporal changes, as changes driven by climate could be misleading if used as indicators of mismanagement.

Silvey and Jones (1990) noted the importance of droughts on species composition in the first stage of this trial (1968–1973), and again, drought had significant effects in this study. Drought, followed by good autumn rain, was the trigger for the pulses of *C. vulgare**.

Liveweight gain

The ingress by unsown species coincided with the decrease in sown grass at the higher stocking rates. As such, no direct statistical comparison of the effect of either the ingress by unsown species or the species shift on liveweight gain can be made. However, examination of the liveweight gain data (McDonald *et al.* 1995) showed that even the major pulses of *C. vulgare** in 1978 and 1983 had no apparent effect on liveweight gain. Similar results were found by Walker *et al.* (1987) in central Queensland, Barnes and Denny (1991) in southern Africa, and Tothill and Berry (1981) on a neighbouring sandy soil. In our experiment, as with Orr *et al.* (1988), the beneficial effects of good rainfall on quantity and quality of edible species seem to be of greater importance than its transitory effects on the yield of undesirable species.

Practical implications

Unsown species will exploit open ground (Tothill and Berry 1981) when there is available soil moisture. As indicated above, the proportion of sown grasses declined rapidly when the yield of all species combined was below 1000 kg/ha for extended periods. At these yields, open spaces would exist in the pasture, allowing the ingress of unsown species. The identification of critical levels or resource thresholds for plant survival is essential for understanding pasture species dynamics.

The particular species which invade a declining sown pasture can provide added information regarding the stability of the system. An ingress by low-fertility species could indicate a low or declining fertility status and the recovery to good sown pasture may be more difficult to achieve than if high-fertility species had invaded.

While managers should avoid any excessive ingress by unsown species, these species appear to have little effect on animal liveweight gain, provided they are not indicating an irreversible decline in the sown grass. Even pulses as large as 70% of the pasture composition had little effect, at least in the short term.

The overriding effect of climate on the presence and composition of unsown species in improved pastures at this site suggests that little can be done to exclude them totally, and little can be done to prevent extraordinary pulses. However, the general replacement of sown species through ingress by unsown species was prevented by avoiding sustained overgrazing and maintaining a reasonable presentation yield (at this site, >1000 kg/ha).

Acknowledgements

We wish to thank Mr W.B. Messer, Mr G.W. McHarg and Mr J.J. Hodgkinson for valuable technical support, and the staff of the Narayen Research Station for field assistance. Financial support from the Australian Meat Research Committee and donation of fertiliser by Incitec Ltd are gratefully acknowledged.

References

Austin, M.P., Williams, O.B. and Belbin, L. (1981) Grassland dynamics under sheep grazing in an Australian Mediterranean type climate. *Vegetatio*, **47**, 201–211.

Barnes, D.L. and Denny, R.P. (1991) A comparison of continuous and rotational grazing on veld at 2 stocking rates. *Journal of the Grassland Society of southern Africa*, **8**, 168–173.

Belbin, L. (1987) The use of non-hierarchical allocation methods for clustering large sets of data. *The Australian Computer Journal*, **19**, 32–41.

Belbin, L. (1991) PATN Technical Reference. *Division of Wildlife and Ecology, CSIRO, Australia.*

Cullinan, V.I. and Thomas, J.M. (1992) A comparison of methods for examining landscape pattern and scale. *Landscape Ecology*, **7**, 211–217.

Dale, M.B. and Williams, W.T. (1978) A new method of species reduction for ecological data. *Australian Journal of Ecology*, **3**, 1–5.

du Toit, P.F. and Aucamp, A.J. (1985) Effect of continuous grazing on the Dohne sourveld on species composition and basal cover. *Journal of the Grassland Society of southern Africa*, **2**, 41–45.

Faith, D.P., Minchin, P.R. and Belbin, L. (1987) Compositional dissimilarity as a robust measure of ecological distance. *Vegetatio*, **69**, 57–68.

Filet, P.G. (1994) The impact of the state and transition model on grazing lands research, management and extension: A review. *Tropical Grasslands*, **28**, 214–222.

Gibson, D.J., Seastadt, T.R. and Briggs, J.M. (1993) Management practices in tallgrass prairie: larger and smaller scale experimental effects on species composition. *Journal of Applied Ecology*, **30**, 247–255.

Grime, J.P. (1979) *Plant Strategies and Vegetation Processes.* (Wiley: Chichester).

Jones, R.M. (1992) Resting from grazing to reverse changes in sown pasture composition: application of the 'state-and-transition' model. *Tropical Grasslands*, **26**, 97–99.

Jones, R.M., McDonald, C.K. and Silvey, M.W. (1995) Permanent pastures on a brigalow soil : the effect of nitrogen fertiliser and stocking rate on pastures and liveweight gain. *Tropical Grasslands*, **29**, 193–209.

Marrs, R.H. (1993) Soil fertility and nature conservation in Europe: theoretical considerations and practical implications. *Advances in Ecological Research*, **24**, 241–300.

McDonald, C.K. (1994) Calculating climatic indices affecting plant growth. *Tropical Agronomy Technical Memorandum No.83. Division of Tropical Crops and Pastures, CSIRO, Australia.*

McDonald, C.K., Jones, R.M. and Silvey, M.W. (1995) Detailed pasture and animal data from a long term grazing trial on brigalow soil. *Tropical Agronomy Technical Memorandum No. 86. Division of Tropical Crops and Pastures, CSIRO, Australia.*

McIntyre, S. (1994) Integrating agricultural land-use and management for conservation of a native grassland flora in a variegated landscape. *Pacific Conservation Biology,* **1**, 236–244.

McIntyre, S. and Lavorel, S. (1994) Predicting richness of native, rare and exotic plants in response to habitat and disturbance variables across a variegated landscape. *Conservation Biology*, **8**, 521–531.

Northcote, K.H. (1979) *A Factual Key for the Recognition of Australian Soils.* 4th Edn. (Rellim Technical Publications: Glenside, South Australia).

Olff, H. and Bakker, J.P. (1991) Long-term dynamics of standing crop and species composition after the cessation of fertiliser application to mown grassland. *Journal of Applied Ecology,* **28**, 1040–1052.

Oomes, M.J.M. (1990) Changes in dry matter and nutrient yields during the restoration of species rich grasslands. *Journal of Vegetation Science*, **1**, 333–338.

Orr, D.M. (1981) Changes in the quantitative floristics in some *Astrebla* spp. (Mitchell grass) communities in south-western Queensland in relation to trends in seasonal rainfall. *Australian Journal of Botany*, **29**, 533–545.

Orr, D.M., Evenson, C.J., Jordan, D.J., Bowly, P.S., Lehane, K.J. and Cowan, D.C. (1988) Sheep productivity in an *Astrebla* grassland of south-west Queensland. *Australian Rangelands Journal*, **10**, 39–47.

Silvey, M.W. and Jones R.M. (1990) Permanent pastures on a brigalow soil: changes in pasture yield and composition during the first five years. *Tropical Grasslands,* **24**, 282–290.

Stanley, T.D. and Ross, E.M. (1986) *Flora of South-eastern Queensland.* (Queensland Department of Primary Industries: Brisbane).

Ter Heerdt, G.N.J., Bakker, J.P. and De Leeuw, J. (1991) Seasonal and spatial variation in living and dead plant material in a grazed grassland as related to plant species diversity. *Journal of Applied Ecology,* **28**, 120–127.

Tothill, J.C. (1974) The effects of grazing, burning and fertilising on the botanical composition of a natural pasture in the sub-tropics of south-east Queensland. *Proceedings of the XII International Grassland Congress, Moscow, 1974.* pp. 515–520.

Tothill, J.C. (1983) Floristic analysis in understanding interactions between species in native pasture. In: Liddle, M.J. and Tothill, J.C. (eds) *The Ecological Basis for Interactions between Organisms.* pp. 83–93. (School of Australian Environmental Studies, Griffith University: Brisbane).

Tothill, J.C. and Berry, J. (1981) Cool season invasion of improved subtropical pastures. *Proceedings of the 6th Australian Weeds Conference*, **1**, 29–33.

Tothill, J.C., Mott, J.J. and Gillard, P. (1982) Pasture weeds of the tropics and subtropics with special reference to Australia. In: Holzner, W. and Numata, N. (eds) *Biology and Ecology of Weeds.* pp. 403–427. (Junk Publishers: The Hague).

Walker, B., Hodge, P.B. and O'Rourke, P.K. (1987) Effects of stocking rate and grass species on pasture and cattle productivity of sown pastures on a fertile brigalow soil in central Queensland. *Tropical Grasslands*, **21**, 14–23.

Westoby, M., Walker, B.H. and Noy-Meir, I. (1989) Opportunistic management for rangelands not at equilibrium. *Journal of Range Management,* **42**, 266–273.

(Received for publication December 8, 1994; accepted September 14, 1995)