Chapter 5

The effects of defoliation interval on the productivity of grasses

5.1 Introduction

The response of plants to defoliation is controlled by a complex of interactions between physiological processes and abiotic effects (McNaughton 1979). Defoliation initiates immediate reactions within the plant which vary depending on the type and amount of material removed in combination with environmental conditions (Richards 1993). Repeated defoliation has long lasting effects on the vigour of grasses and these effects are cumulative (Voison 1961). Land managers have the ability to exert a degree of control over four main aspects of defoliation: the amount of biomass removed, the length of time plants are exposed to animals (graze period), the frequency of defoliation (rest period) and the timing of defoliation.

Cutting experiments cannot adequately account for all factors associated with grazing, such as animal preference for plant species or plant parts, trampling and the effects of non-uniform nutrient distribution. As such the relationship between grazing and cutting experiments may not be clearly defined (Watkin and Clements 1978; Belesky and Fedders 1994). However, data from this type of experiment should provide a basis for identifying some effects of defoliation interval on the production of individual species and may provide clues for the improvement of their long-term productivity (Spedding 1965).

The experiment described here was designed to complement the field experiments detailed in Chapter 6, wherein the effect of extended rest periods on the persistence and productivity of the dominant perennial grasses was compared to continuous grazing under field conditions on commercial grazing properties.

5.2 Methods

Seed was collected during the summer preceding the experiment from four perennial grass species from two sites. Species selected from the Strathroy site were *Eragrostis leptostachya, Sporobolus creber, Stipa scabra and Aristida ramosa.* Species selected from the Green Hills site were *Phalaris aquatica, Bothriochloa macra, Sporobolus creber and Poa sieberiana.*

Seeds of each species were sown in trays in September 1994 in the glasshouse. In December 1994 the seedlings were transplanted into PVC tubes, 90 mm in diameter and 1 m tall, located outdoors to expose the potted plants to ambient environmental conditions (Plate 5.1). The length of the PVC tubes was chosen to enable the simulation of natural root growth under field conditions. Wallace *et al.* (1984) noted that lateral roots in a sward may contribute a relatively small proportion to water and nutrient uptake due to competition from neighbouring plants. The morphology of plants grown in the PVC tubes was observed to be similar to their growth in the field and the plants were not pot bound at the completion of the experiment, a feature also noted by Wallace *et al.* (1984).

Soil of the same type and chemical composition as occurred at each of the field sites was collected from roadside areas in close proximity to these sites. The soil was sieved to remove excess organic material and rocks. Seedlings were planted into PVC tubes containing the soil type of their site of origin. Three months were allowed for acclimatisation and establishment. On 5 April 1994, after most species had flowered, the defoliation treatments were initiated and continued over a period of 13 months.

The experiment was a randomised block design with five replicates of each treatment. The four defoliation treatments imposed were cutting frequencies at 2, 4 and 8 week intervals and an uncut treatment. Plants were cut to a height of 3 cm (Plate 5.2). The 3 cm cutting height was chosen since it reflected the level of defoliation of the more palatable species observed in the field.

While in the glasshouse seedlings were fertilised each week with Aquasol® (N:P:K 23:4:18) at a rate of 4g/5l to promote growth. The rate was increased to 8g/5l applied fortnightly after transplantation to aid establishment in the tubes. When defoliation treatments were initiated 4g/5l was applied every four weeks to simulate lower levels of natural nutrient cycling. Water was non-limiting.

After each cutting the material from each plant was dried at 60°C for 48 hours. The leaf and inflorescence sections were weighed separately and the number of inflorescences was recorded. Following the final harvest on 1 May 1996, roots were washed and the total dry weight of root biomass was determined. The distribution of roots within the PVC tubes was determined by division into two 50 cm sections. The weight of the plant crowns was recorded and the basal diameter of plants was measured. The calculation of root:shoot ratios in section 5.3.4 includes all material from the final harvest i.e. clipped biomass above 3 cm and the crown weight.

The concentration of nitrogen in the leaf material of defoliated plants was determined by the combustion method (Sweeney 1989) using a LECO FP-428 nitrogen determinator. Protein content was calculated by multiplication of nitrogen content by 6.25. Bulked replicate samples from each treatment were used for analyses due to the often low weights of harvested material. For comparison with seasonal production data the mean protein concentration values for each 8 week period were used to present the data.

Temperatures were recorded daily from a weather station located approximately 1 km from the experimental site.

5.2.1 Statistical analyses

Analysis of variance was used to determine significant treatment effects for cumulative dry weight, root dry weight, root distribution, crown dry weight, basal diameter and reproductive tiller production. Dry weight data (ln+1) and root distribution data (arcsine) were transformed to achieve normality and homogeneity of variance. Scheffe's test was used to estimate least significant differences between treatment means. Regression analysis was used to identify correlations between root dry weight, basal diameter and crown weight with yield. Repeated measures analysis of variance was used to determine significant treatment effects in seasonal production. To compare treatments the dry matter produced from defoliation treatments during each 8 week period was calculated and used for this analysis. Insufficient material was available for adequate replication of chemical composition data.

Plate 5.1 Arrangement of plants in PVC pipes set up outdoors at Clarks Farm UNE.

Plate 5.2 Defoliated plant cut to 3 cm.

5.3 Results

5.3.1 *Climatic data*

The mean weekly maximum and minimum temperatures recorded during the experimental period are shown in Figure 5.1.

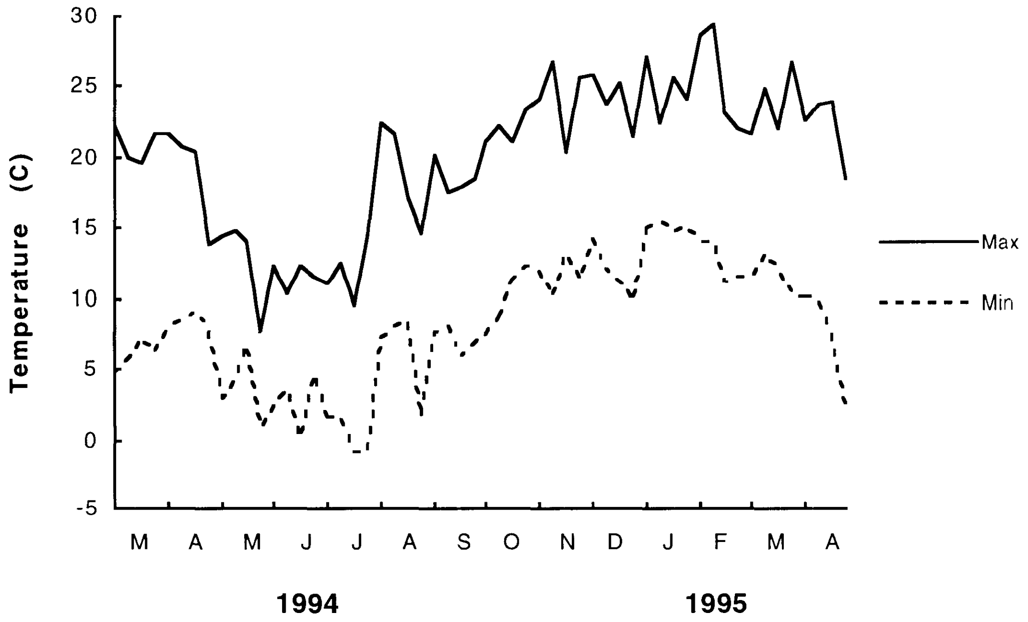

Fig. 5.1 Mean weekly maximum and minimum temperatures experienced at the Clarks Farm experimental site.

5.3.2 *Cumulative clipped biomass*

The cumulative yields of the native grasses *Stipa scabra* and *Eragrostis leptostachya* were significantly greater than those of *Poa sieberiana*, *Bothriochloa macra* and the two *Sporobolus creber* accessions. The cumulative clipped biomass yields of *Phalaris aquatica* and *Aristida ramosa* were significantly less than other species.

Defoliation interval had no significant effect on the clipped biomass production of the introduced species *P. aquatica* (Fig. 5.2). Conversely, the frequent 2 week defoliation interval had a deleterious effect on all the native species.

Extending the defoliation interval from 2 to 8 weeks increased the clipped biomass production of the native perennial grasses in the experiment. When cut at 8 week intervals *S. scabra, E. leptostachya* and *B. macra* produced significantly more cumulative clipped biomass than when cut more frequently (Fig. 5.2). *Aristida ramosa* did not tolerate any of the cutting treatments and most cut plants of this species died within the first two months of the treatments being imposed.

With defoliation at 8 week intervals, the clipped biomass attained from most of the native grasses exceeded that of *P. aquatica* (Fig. 5.2). In two species, *E. leptostachya* and *S. scabra*, production was more than double that of *P. aquatica*. The highly palatable warm season native grass *E. leptostachya* was the only species to produce significantly more above ground biomass when defoliated at 8 week intervals in comparison to remaining uncut.

On average, extending the defoliation interval from 2 to 4 weeks effectively doubled the cumulative clipped biomass produced across all species. The mean clipped biomass from plants cut at 2 week intervals was 8.6g while plants cut at 4 week intervals produced significantly more clipped biomass averaging 14.5g among all species. Extending the defoliation interval from 4 to 8 weeks resulted in a further significant increase, 19.4g of cumulative clipped biomass production, similar to that of unclipped plants which averaged 20.7g.

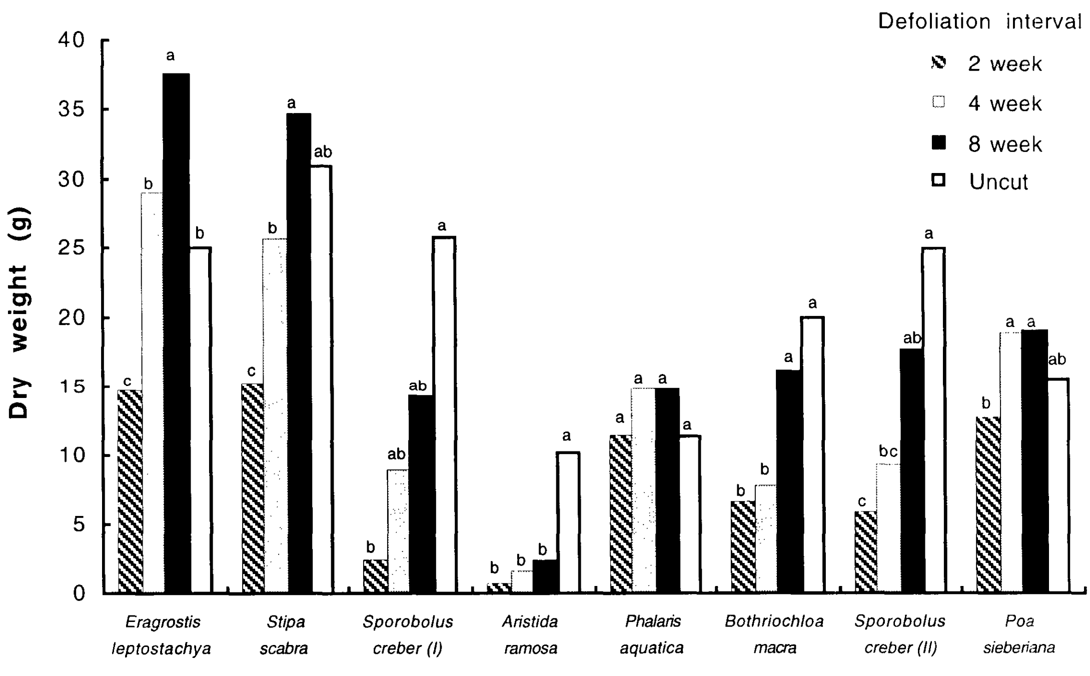

Fig. 5.2 Mean cumulative clipped biomas production (g/plant) of species cut at 2, 4 or 8 week defoliation intervals or uncut. Within species, bars sharing the same letter are not significantly different (P<0.05).

5.3.3 Root biomass

In comparison with other species, *P. aquatica* produced a significantly greater root biomass across all treatments. Of the native grasses, the cool-season species *P. sieberiana* produced the highest root dry weight and the warm-season perennial *A. ramosa* recorded significantly less root biomass than all other species.

While there was no statistically significant difference between the mean root dry weights of plants which remained uncut and plants cut at 8 week intervals for both *E. leptostachya* and *S. scabra* (Fig. 5.3a and 5.3b), within all other species root biomass of uncut plants was significantly higher than the defoliated treatments, indicating that even a defoliation interval of 8 weeks was insufficient to replenish root reserves. Averaged across all species, uncut plants produced significantly greater root biomass (24.1g) than plants cut every 8 weeks (12.1g) and as the defoliation interval was reduced the mean root weight for each treatment was significantly reduced. The mean root biomass of all species within the 4 week defoliation treatment was 6.7g and those plants cut at 2 week intervals averaged 2.9g root biomass.

The mean root weight of plants of *P. aquatica* cut every 8 weeks was significantly higher than those cut more frequently, although there was no significant difference between root weights of plants cut at 2 and 4 week intervals (Fig. 5.4a). Similarly, the mean root weights of *B. macra* and *P. sieberiana* plants cut every 2 and 4 weeks and 4 and 8 weeks showed no significant difference (Fig. 5.4b and 5.4d). While there was no difference between *E. leptostachya* plants cut at 4 and 8 weekly intervals, the mean root weights of plants cut every 2 weeks was significantly lower than the 8 week treatment but not the 4 week clipping (Fig. 5.3a). No significant differences were recorded in the root weights of *S. scabra*, *A. ramosa* and both *S. creber* ecotypes whether defoliated at 2, 4 or 8 week intervals (Fig. 5.3b, 5.3c, 5.3d and 5.4c).

The differences in root biomass of all species following 13 months of defoliation treatments are illustrated in Plates 5.3 and 5.4. Differences in root morphology among species are also apparent in these photographs.

The greatest percentage of root biomass of all species was measured from within the top 50 cm of the PVC tubes. There was no significant difference between defoliation treatments in the proportion of root material which occurred in this section, either within or between species (Fig. 5.5). *Phalaris aquatica* and *B. macra* had a greater proportion of root biomass, 32 and 35% respectively, present in the lower 50 cm section of the soil than did the other species.

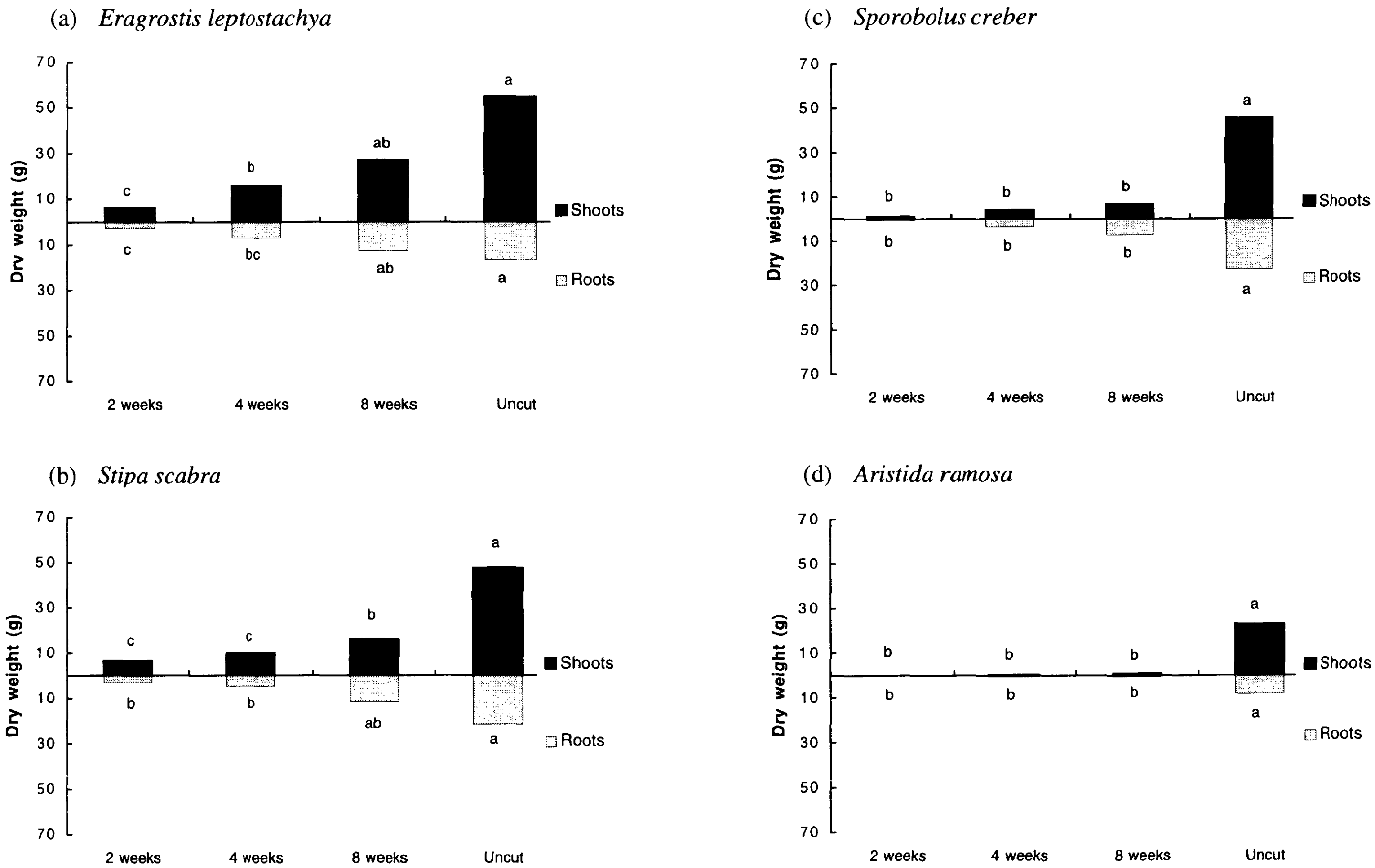

Fig. 5.3 Dry weight of shoot (including crown weight) and root material at final harvest from (a) *Eragrostis leptostachya*, (b) *Stipa scabra*, (c) *Sporobolus creber* and (d) *Aristida ramosa* defoliated at intervals of 2, 4 or 8 weeks or uncut. Accessions originated from the Strathroy site. Bars within species with the same letter are not significantly different ($P<0.05$).

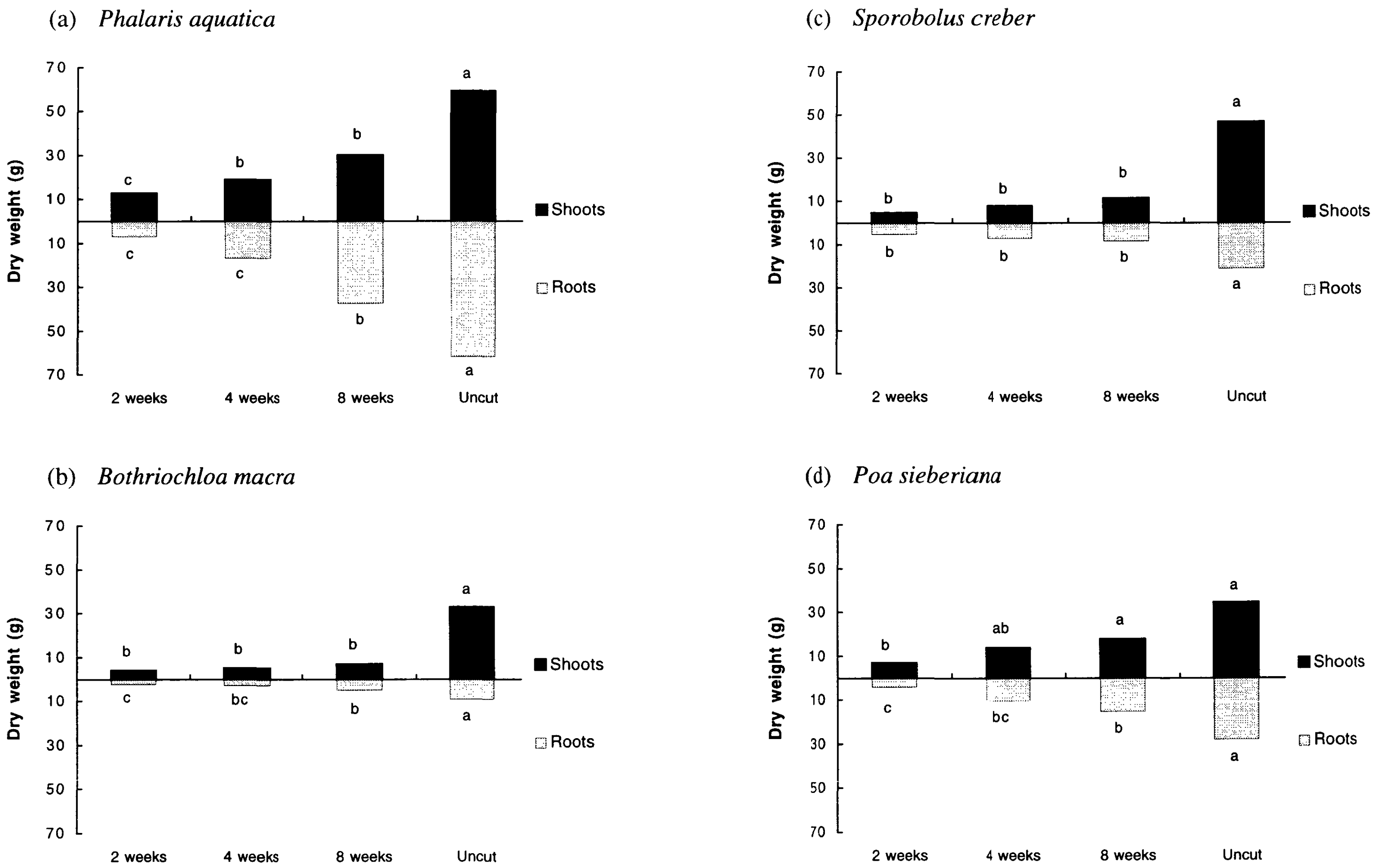

Fig. 5.4 Dry weight of shoot (including crown weight) and root material at final harvest from (a) *Phalaris aquatica,* (b) *Bothriochloa macra,* (c) *Sporobolus creber* and (d) *Poa sieberiana* defoliated at intervals of 2, 4 or 8 weeks or uncut. Accessions originated from the Green Hills site. Bars within species with the same letter are not significantly different (P<0.05).

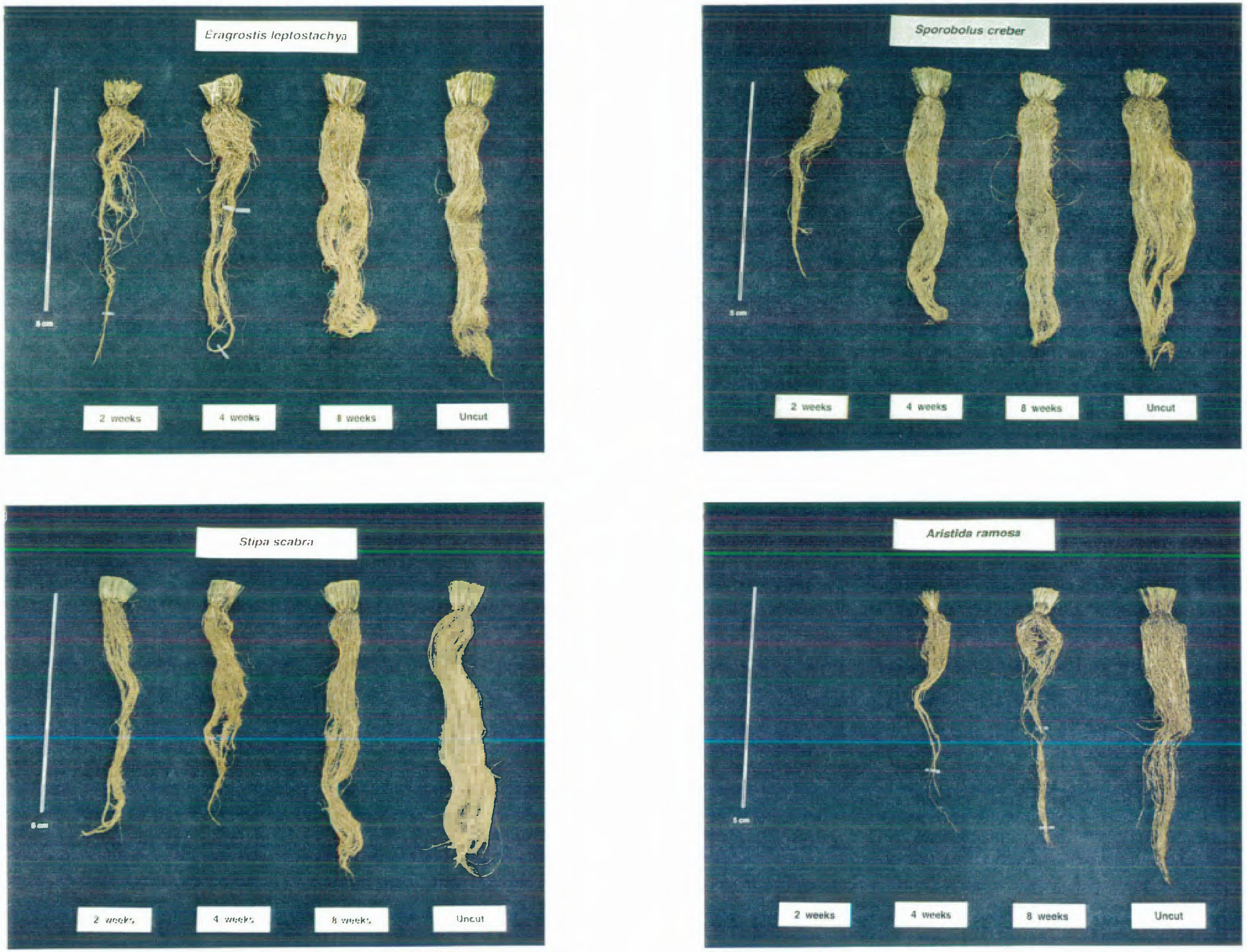

Plate 5.3 Root systems to 50 cm depth of *Eragrostis leptostachya, Sporobolus creber*, *Stipa scabra* and *Aristida ramosa* cut at 2, 4 and 8 week intervals or uncut, from the Strathroy site.

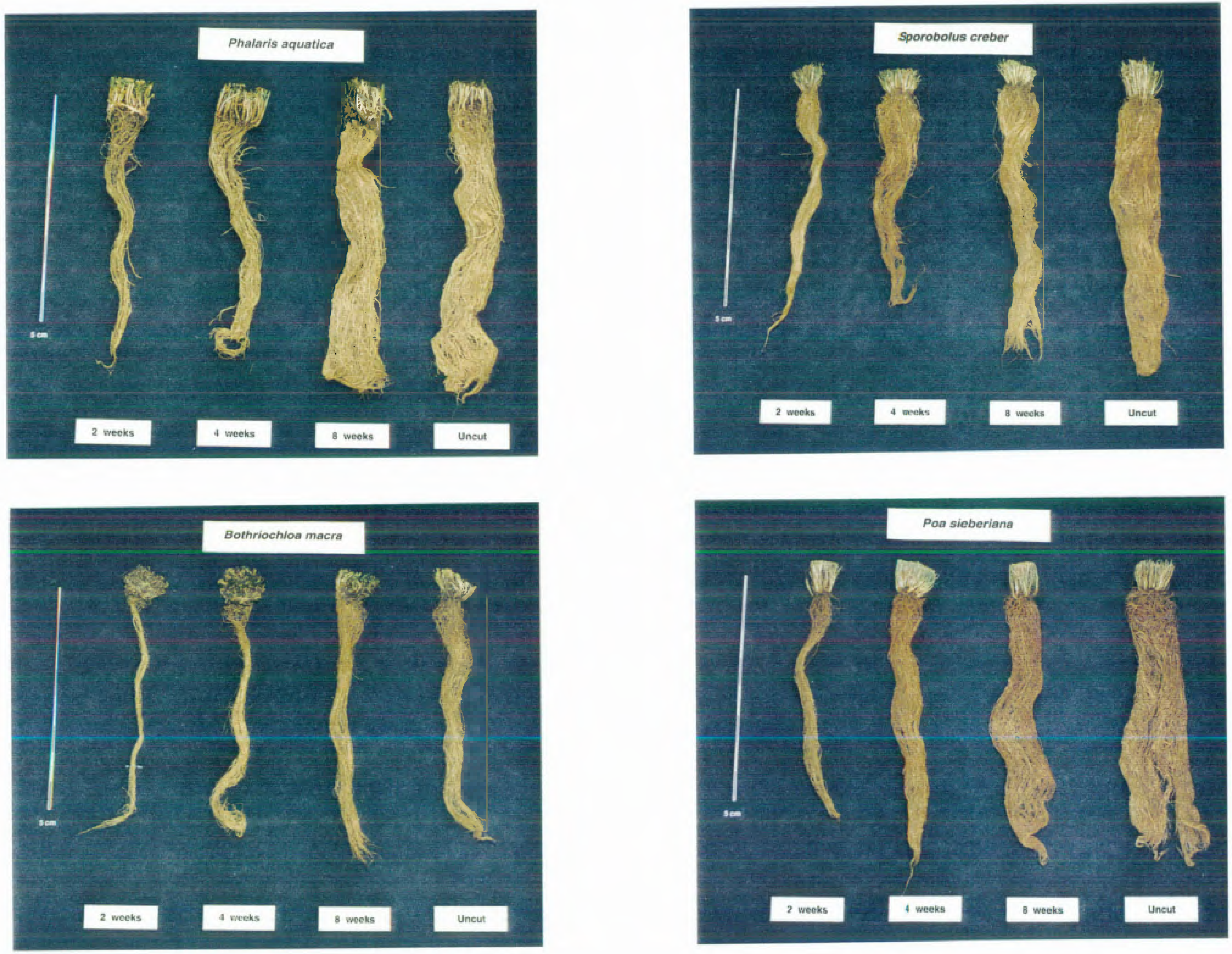

Plate 5.4 Root systems to 50 cm depth of *Phalaris aquatica*, *Bothriochloa macra*, *Sporobolus creber* and *Poa sieberiana* cut at 2, 4 and 8 week intervals or uncut, from the Green Hills site.

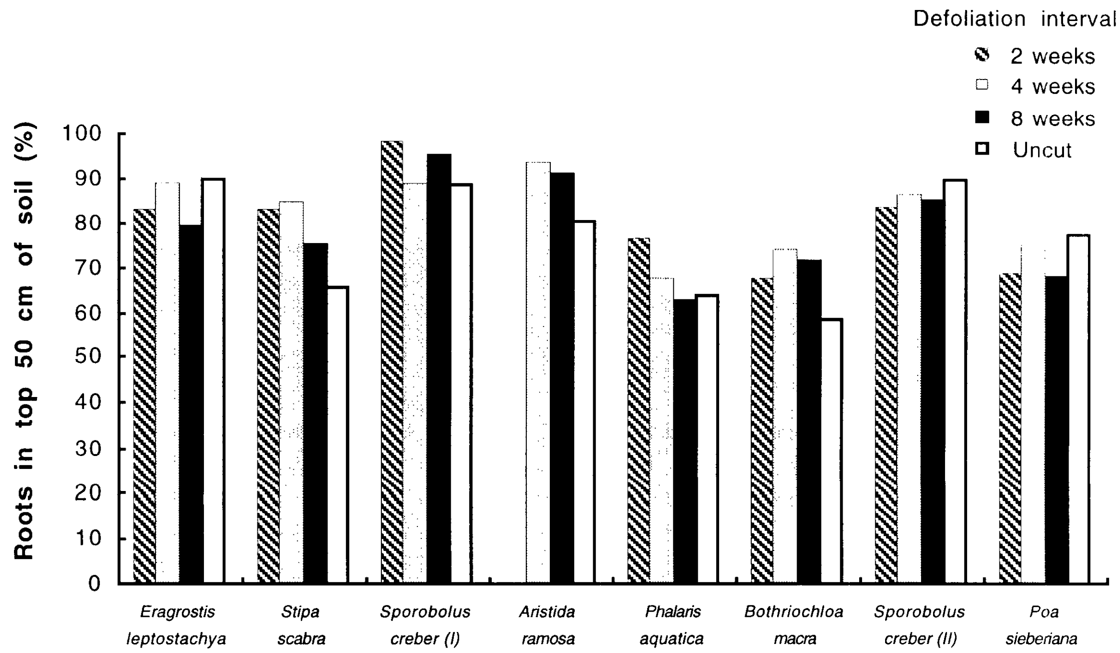

Fig. 5.5 Percentage of total root biomass present in the top 50 cm of soil. Plants were cut at 2, 4 or 8 week intervals or uncut. There were no significant differences between treatments within species.

5.3.4 *Root:shoot ratio*

Although the partitioning of biomass into root and shoot material varied widely among species (Table 5.1), generally the native grasses invested relatively less in root biomass than the introduced species, *P. aquatica*. With the exception of *P. sieberiana* the root:shoot ratio of the native grasses was lowest when plants remained uncut.

Defoliation frequency had little effect on the root:shoot ratio of *E. leptostachya*. The root production of *S. scabra* and *B. macra* was higher than the above-ground production when defoliated at 8 week intervals in comparison to more frequent defoliation. The root:shoot ratio of *S. creber* (Strathroy accession), *P. aquatica* and *P. sieberiana* increased as the interval between defoliation increased. Conversely, the ratio between roots and shoots of *A. ramosa* and *S. creber* (Green Hills ecotype) decreased when defoliation was more frequent (Table 5.1).

Table 5.1 Root:shoot ratios of plants cut at 2, 4 and 8 week intervals and uncut.

	Defoliation Interval			
	2 weeks	4 weeks	8 weeks	Uncut
Strathroy accessions				
Eragrostis leptostachya	0.47	0.45	0.47	0.31
Stipa scabra	0.49	0.47	0.72	0.46
Sporobolus creber	0.56	0.87	1.10	0.50
Aristida ramosa	0†	1.53	0.82	0.36
Green Hills accessions				
Phalaris aquatica	0.55	0.89	1.24	1.04
Bothriochloa macra	0.61	0.59	0.75	0.29
Sporobolus creber	1.22	0.95	0.76	0.45
Poa sieberiana	0.62	0.79	0.86	0.81

† All plants of Aristida ramosa died in the 2 week defoliation treatment.

5.3.5 *Basal diameter*

When averaged across species, defoliation at 8, 4 and 2 week intervals reduced the basal diameter of cut plants by 18, 25 and 43% respectively compared to the uncut plants. In two species, *E leptostachya* and *S. scabra,* the basal diameter of plants cut every 8 weeks slightly exceeded the size of uncut plants, although the difference was not significant (Fig. 5.6).

Significant reductions in the size of plant bases were recorded in *E. leptostachya*, *S. scabra* and *P. aquatica* plants cut at 2 week intervals in comparison to those cut every 8 weeks. All defoliation treatments of *A. ramosa,* and the 2 week defoliation interval for *E. leptostachya*, *S. scabra*, *P. aquatica* and *B. macra*, resulted in a significant reduction in the basal diameter of these plants relative to those which remained uncut. No treatment effects could be detected for either accession of *S. creber* or *P. sieberiana.*

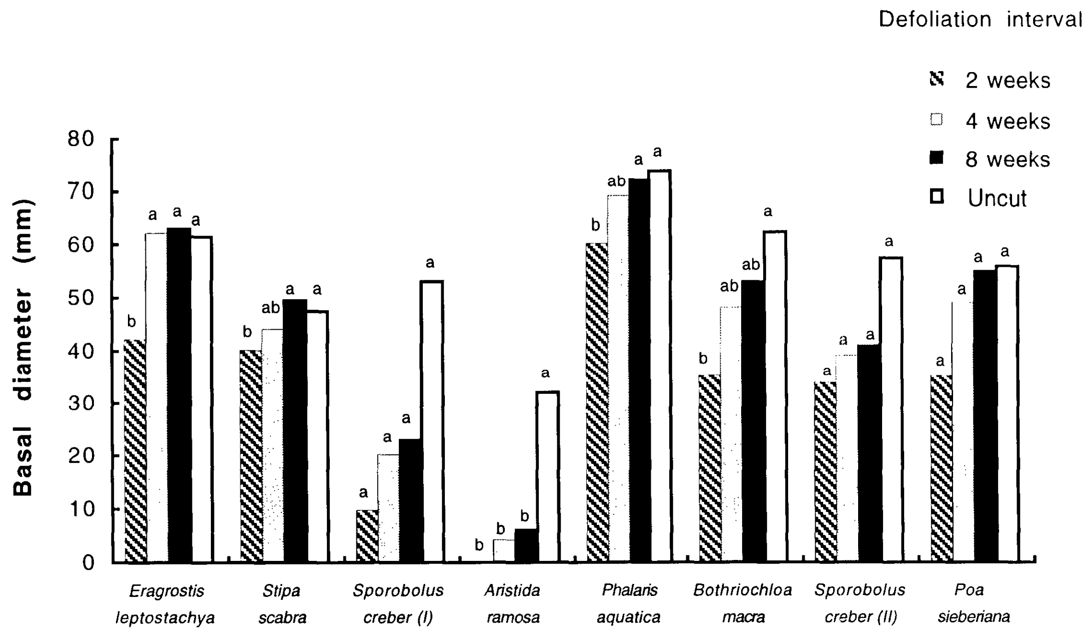

Fig. 5.6 Mean basal diameter of plants cut at 2, 4 or 8 week intervals or uncut. Bars within species with the same letter are not significantly different (P<0.05).

5.3.6 *Crown weight*

Across all species the weight of the crowns (to 3 cm above the soil surface) showed a similar trend to that recorded for plant basal diameter, although the differences among treatments were more marked (Fig. 5.7). For all species the uncut plants had greater crown weights than defoliated plants. Within species, no significant differences were recorded between plants which were uncut and cut at 8 week intervals or plants cut at 8 and 4 week intervals. Significantly lower crown weights were recorded for *E. leptostachya*, *S. scabra* and *P. sieberiana* which were cut at 2 week intervals.

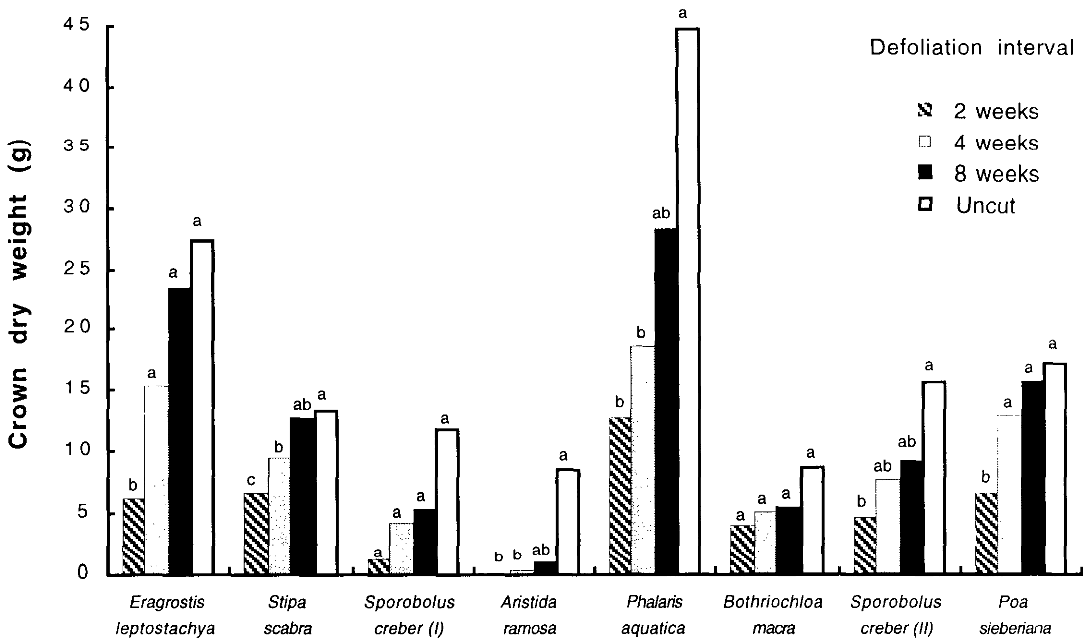

Fig. 5.7 Mean crown weight of plants cut at 2, 4 or 8 week intervals or uncut. Bars within species with the same letter are not significantly different ($P<0.05$).

5.3.7 *Correlations with total yield*

Regression analyses showed that among species, all factors measured, crown weight (R^2=0.70), root weight (R^2=0.58) and basal diameter (R^2=0.44), were significantly correlated to total dry matter yield, although the relative importance of each factor varied within species.

Basal diameter had the strongest correlation with total yield in *E. leptostachya*, *S. scabra*, *A. ramosa*, *P. aquatica* and *B. macra*. For *P. sieberiana* and both accessions of *S. creber* crown weight was the factor most highly correlated with total yield (Table 5.2).

Table 5.2 Regression parameters for the influence of crown weight, basal diameter and root biomass on final yield of plants.

	Parameter					
	α	Crown weight	Basal diameter	Root biomass	R^2	P
Strathroy accessions						
Eragrostis leptostachya	-15.70	-0.28	0.84	-0.07	0.38	NS
Stipa scabra	-18.02	1.23	0.81	-0.29	0.74	<0.05
Sporobolus creber	8.63	2.11	0.04	-0.32	0.87	<0.05
Aristida ramosa	4.75	0.98	-0.01	0.37	0.81	<0.05
Green Hills accessions						
Phalaris aquatica	-7.73	-0.11	0.41	-0.06	0.43	<0.05
Bothriochloa macra	3.99	-0.26	0.24	-0.06	0.28	NS
Sporobolus creber	5.59	1.77	0.03	-0.46	0.74	<0.05
Poa sieberiana	9.99	1.28	-0.06	-0.42	0.53	<0.05

5.3.8 *Reproductive tiller production*

Defoliation at 2 week intervals significantly reduced the number of reproductive tillers of all species except *P. sieberiana*, relative to uncut plants (Fig. 5.8). The effects of defoliation at 4 and 8 weeks were inconsistent. *Stipa scabra* and *B. macra* produced a significantly greater number of reproductive tillers when cut at 4 week intervals in comparison to the 8 week defoliation interval treatment. Only *P. sieberiana* produced a greater number of reproductive tillers per plant when cut at 8 week intervals although, the difference was not statistically significant.

The mean weight of reproductive tillers consistently increased as defoliation interval increased (Fig. 5.9). Within species, the mean weight of reproductive tillers of plants cut at 2 week intervals was significantly less than that for plants which remained uncut.

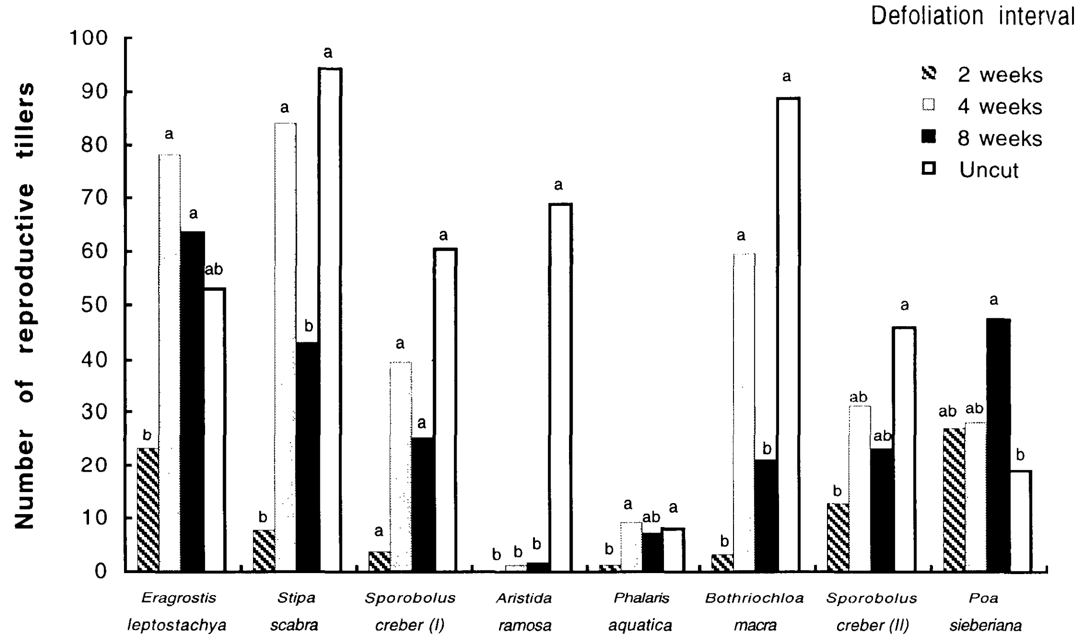

Fig. 5.8 Mean number of reproductive tillers per plant produced by plants cut at 2, 4 or 8 week intervals or uncut plants. Bars within species with the same letter are not significantly different (P<0.05).

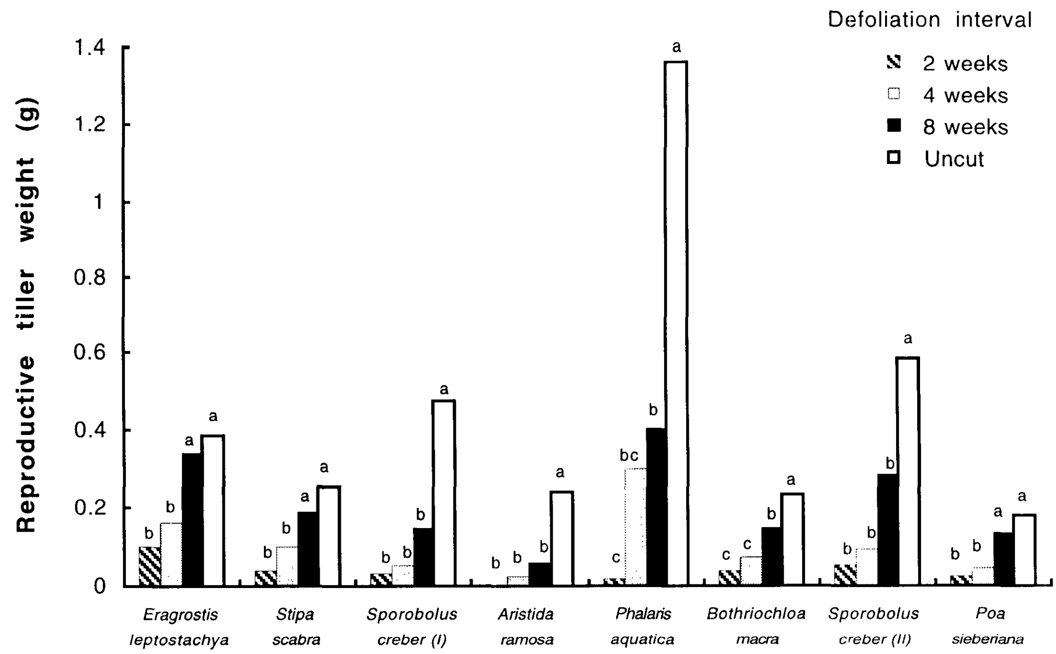

Fig. 5.9 Mean weight of reproductive tillers per plant produced by plants cut at 2, 4 or 8 week intervals or uncut plants. Bars within species with the same letter are not significantly different (P<0.05).

5.3.9 *Seasonal variation*

For the first three 8 week periods up to 20 September 1995 there were no differences in clipped biomass in response to defoliation interval (Figs. 5.10 and 5.11). In the subsequent 8 week period to 11 November 1995 the cumulative clipped biomass of plants cut at 2 weekly intervals was significantly less than the longer 4 and 8 week cutting treatments. Over the summer period 10 January to 6 March 1996, which corresponded to the growing season of most species in the experiment, there were significant differences among all treatments. In the 8 weeks preceding the final cut on 1 May 1996, those plants cut at 8 weekly intervals produced significantly more dry matter than plants cut every 2 or 4 weeks (Figs. 5.10 and 5.11).

The cool season grasses *S. scabra* (Fig. 5.10), *P. aquatica* and *P. sieberiana* (Fig. 5.11) produced significantly more dry matter than other species during the period from April 1995 to 20 September 1995. From the period 15 November 1995 to 6 March 1996, which incorporated the summer months, the most productive of the accessions from the Strathroy site were *E. leptostachya* and *S. scabra* under all cutting treatments. Of the Green Hills accessions measured over the same time period, *S. creber* and *B. macra* cut at 8 week intervals were the most productive (Fig. 5.11c).

Defoliation interval had relatively little effect on the growth curves of the grasses. With the exception of the cool-season species *S. scabra* and *P. sieberiana* cut at 2 week intervals, all species produced their highest dry weights in the 8 week period 5 November 1995 to 10 January 1996. This period corresponded to the time when temperatures (Fig. 5.1) and daylight hours at the site were approaching maximum levels. Production of *S. scabra* and *P. sieberiana* plants cut at 2 week intervals peaked 8 weeks earlier than when cut at longer intervals. The shape of the production curves for all other species and defoliation intervals were almost identical (Fig. 5.10 and Fig. 5.11).

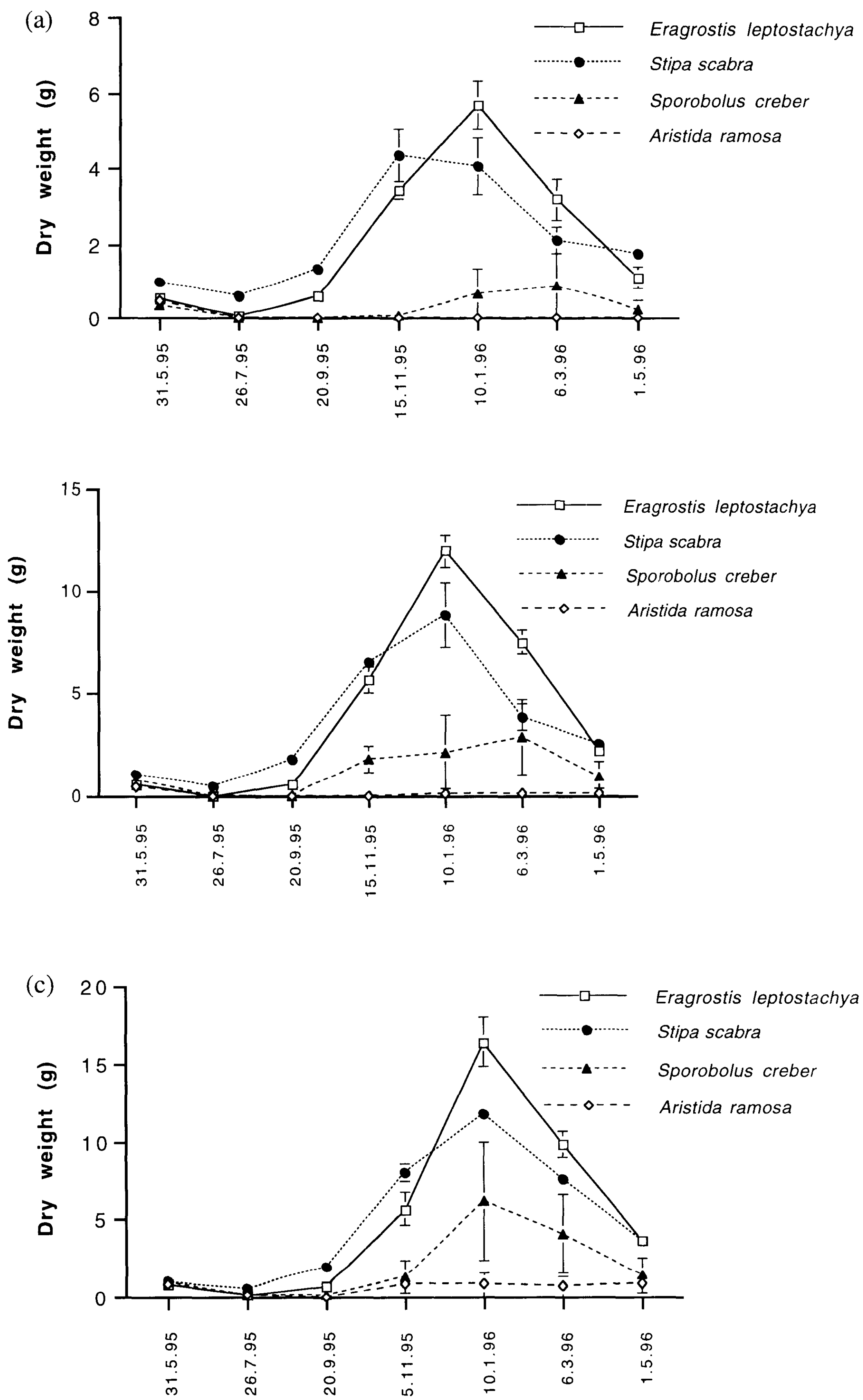

Fig. 5.10 Clipped biomass production for each 8 week period of species from Strathroy cut at (a) 2 week, (b) 4 week and (c) 8 week intervals. Error bars represent one SE. Note: scale of y axis is different for each graph.

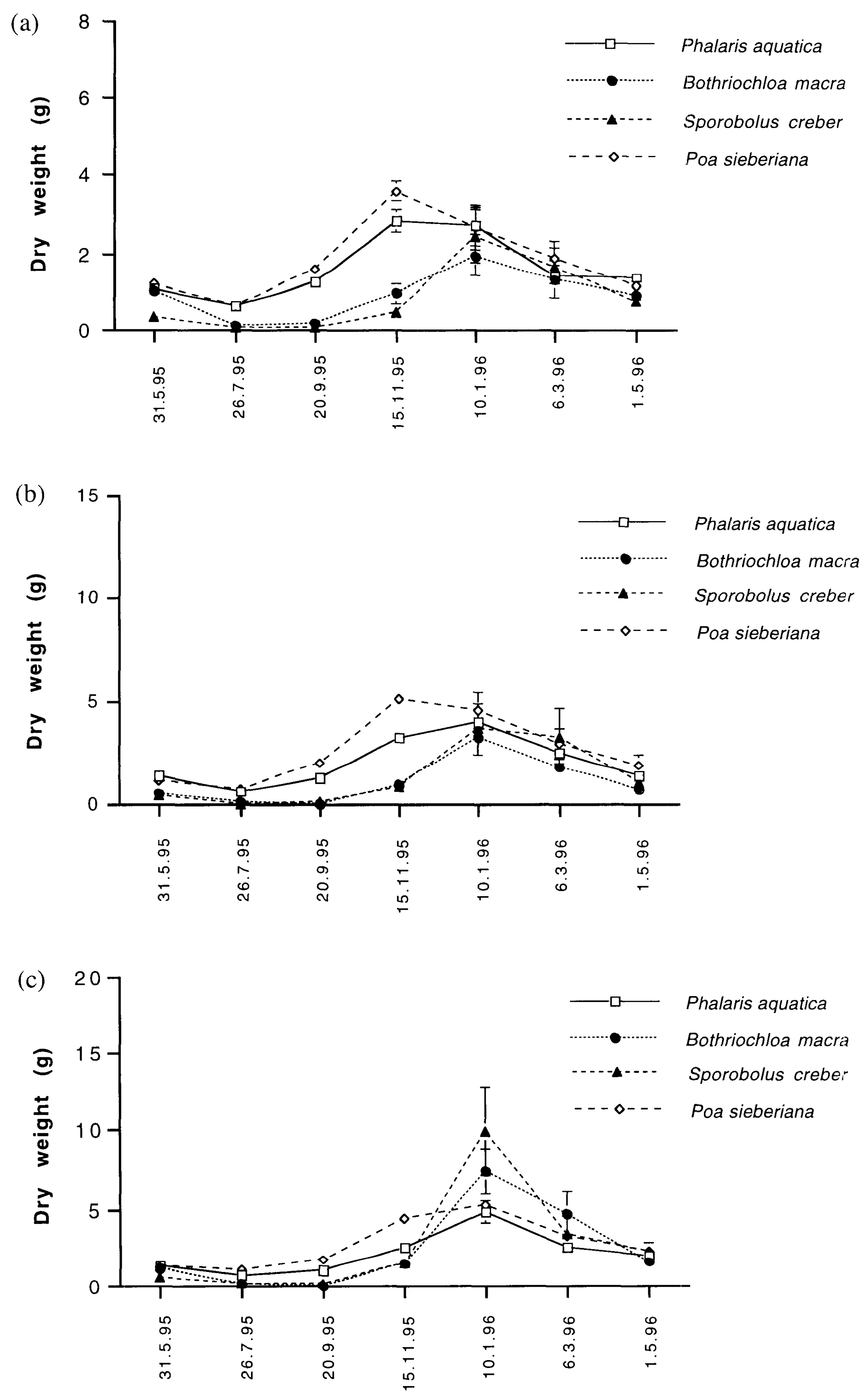

Fig. 5.11 Clipped biomass production for each 8 week period of species from Green Hills cut at (a) 2 week, (b) 4 week and (c) 8 week intervals. Error bars represent one SE. Note: scale of y axis is different for each graph.

The protein content of leaf material decreased with increasing defoliation interval. The continual regeneration of new leaf material throughout the growing season resulted in the generally higher crude protein content of plants which were cut at 2 week intervals. However, towards the end of the experimental period and most notably during the final 8 week period, the protein content of *E. leptostachya*, *S. scabra* (Fig. 5.12a) and *P. aquatica* (Fig. 5.13a) cut at 2 week intervals were lower than plants cut at less frequent intervals. Material collected from plants of *A. ramosa* within all treatments was of insufficient quantity for analysis.

The protein content of all species cut at 4 week intervals tended to show less variation than in other treatments. With the exception of the early season (20 September 1995) protein concentration of *E. leptostachya* (26%) and the final measure (1 May 1996) of *P. aquatica* (26%), the protein content of all species in this treatment ranged from 14% to 21% over the experimental period.

There was a decline in leaf protein content associated with the initiation of flowering. Exceptions to this trend were *B. macra* and the Strathroy accession of *S. creber* when cut at 2 and 4 week intervals, and the Green Hills accession of *S. creber* cut at 4 week intervals. Plants cut at 8 week intervals exhibited the greatest decline in leaf protein levels during their period of flowering (Fig. 5.12c, 5.13c). Within this treatment all species produced reproductive tillers of a greater individual weight than those of plants cut more frequently (Fig. 5.9). This would suggest a greater level of translocation of leaf nitrogen to the reproductive structures. The protein content of all species in the 8 week defoliation interval treatment, with the exception of *B. macra,* increased from 6 March 1996 following the cessation of flowering.

While the protein content of plants was generally higher when cut at 2 week intervals, the actual yield of protein (harvested dry weight x protein content) in leaf material during each 8 week period varied. For most species the total protein yield was generally greater for plants cut at 8 week intervals. To illustrate the variation in protein yield with defoliation interval, Table 5.3 and Table 5.4 show the values for each species recorded for two 8 week periods. During the 8 week period 15 November 1995 to 10 January 1996, dry matter production was highest and protein content was generally lower than for other periods of the experiment. Conversely, during the 8 week period 6 March to 1 May 1996, growth of most species was slowing and protein content was relatively high. Despite this, the total protein yield was lower at this time (Table 5.4).

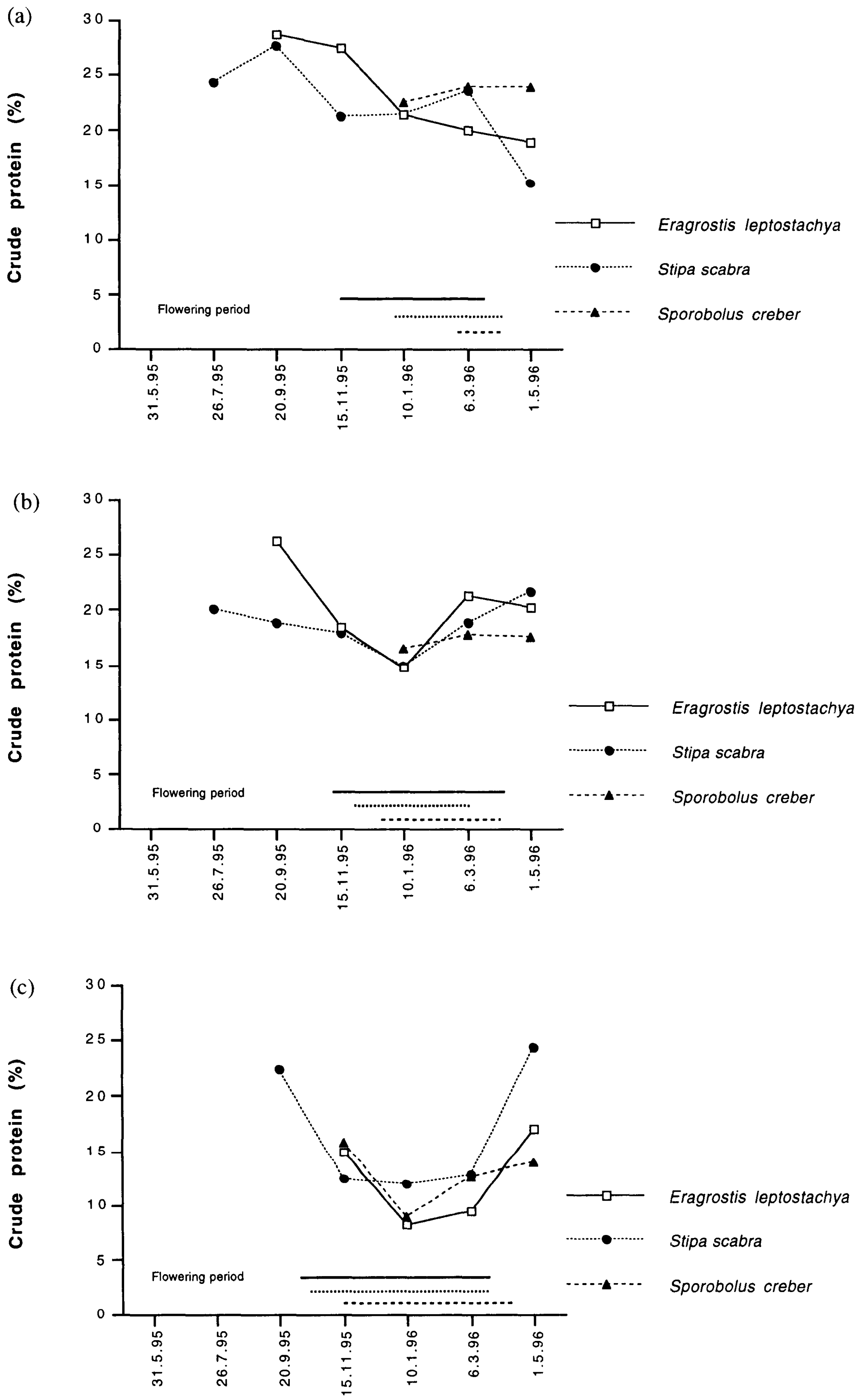

Fig. 5.12 Crude protein content for each 8 week period of species from Strathroy cut at (a) 2 week, (b) 4 week and (c) 8 week intervals.

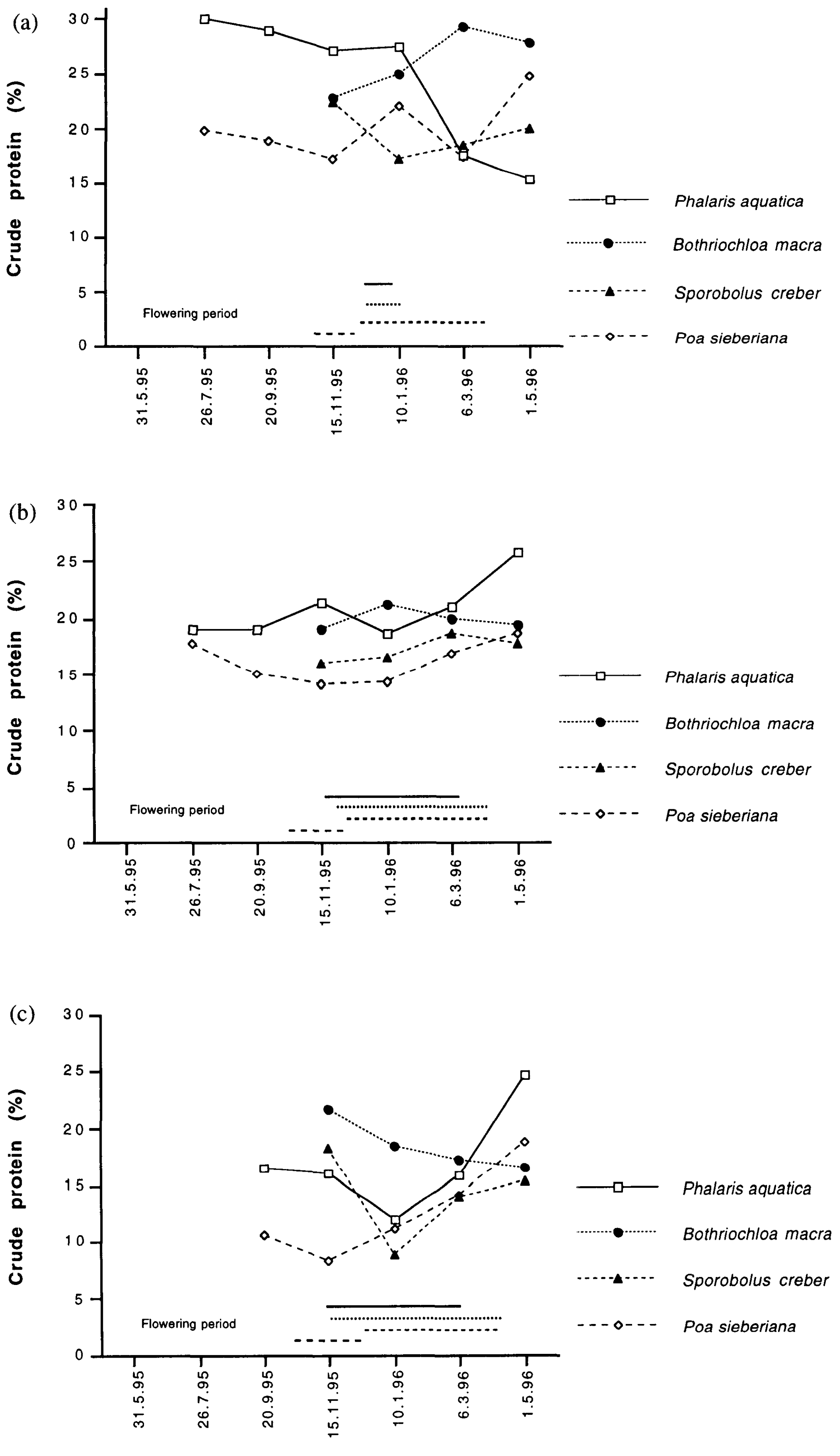

Fig. 5.13 Crude protein content for each 8 week period of species from Green Hills cut at (a) 2 week, (b) 4 week and (c) 8 week intervals.

Table 5.3 Total protein yield (g) of plants cut at 2, 4 and 8 week intervals for the 8 week period 15 November 1995 to 10 January 1996.

	Defoliation interval		
Species	2 weeks	4 weeks	8 weeks
Strathroy accessions			
Eragrostis leptostachya	1.23	1.78	1.37
Stipa scabra	0.87	1.32	1.41
Sporobolus creber	0.15	0.35	0.56
Green Hills accessions			
Phalaris aquatica	0.75	0.77	0.88
Bothriochloa macra	0.49	0.70	0.87
Sporobolus creber	0.42	0.61	0.87
Poa sieberiana	0.57	0.66	0.59

Table 5.4 Total protein yield (g) of plants cut at 2, 4 and 8 week intervals for the 8 week period 6 March to 1 May 1996.

	Defoliation interval		
Species	2 weeks	4 weeks	8 weeks
Strathroy accessions			
Eragrostis leptostachya	0.21	0.46	0.63
Stipa scabra	0.27	0.56	0.87
Sporobolus creber	0.05	0.18	0.06
Green Hills accessions			
Phalaris aquatica	0.21	0.35	0.32
Bothriochloa macra	0.26	0.15	0.39
Sporobolus creber	0.15	0.18	0.35
Poa sieberiana	0.28	0.36	0.42

5.4 Discussion

Cumulative yield

Lengthening the interval between defoliation events has been shown to have positive effects on the dry matter production of a wide range of grass species (Steinke and Booysen 1968; Garden *et al.* 1978; Harris 1978; Belsky 1986; Simpson and Culvenor 1987; Bell and Ritchie 1989; Hill 1989; Binnie and Chestnutt 1991). The native species, *E. leptostachya*, *S. scabra*, *B. macra* and *P. sieberiana* produced a greater amount of clipped biomass under the 8 week cutting treatment than when cut more frequently. When cut at 8 week intervals four species exhibited a trend towards compensatory growth, a response described by McNaughton (1979; 1983) where defoliated plants produce a greater amount of dry matter than the uncut "controls". Of these, only the highly palatable warm season native *E. leptostachya* produced a statistically significant greater amount of dry matter (Fig. 5.2). Other species to show this response were the cool season species, *S. scabra*, *P. sieberiana* and *P. aquatica*.

Selection of introduced species such as *P. aquatica* for animal production has been based on their ability to tolerate frequent defoliation via rapid regeneration of leaf material. *Phalaris aquatica* was the only grass tested in which no significant effect of defoliation interval was recorded. At the other end of the palatability spectrum, species such as *A. ramosa* persist in pastures because they are largely avoided by livestock due to fibrous stems, sharp callus on seeds and relatively low leaf production. The constant suppression of more palatable species under continuous grazing gives *A. ramosa* a competitive advantage in mixed species swards. *Aristida ramosa* did not tolerate any of the defoliation treatments imposed and the majority of defoliated plants died within the first two months of the experiment. A small amount of defoliation maybe more detrimental to unpalatable plants than severe defoliation is to plants which are tolerant of grazing.

The intensity (height) of defoliation will depend on the acceptability of the respective species to animals and the relative proportions of the different components present in the vegetation. In a review of the effects of cutting height on production of cool season species Tainton *et al.* (1970) found that cutting at 7.5 cm was optimal for most species. This level of defoliation would have little or no cost in terms of root reserves since remaining photosynthetic material would be sufficient to meet the current plant demands for assimilate (Steinke 1975). However, in mixed swards under extended periods of grazing it is not possible to control the grazing process to such an extent.

Under field conditions the defoliation of plants is rarely uniform. The response to defoliation is dependent on the phenology of the plants, the amount of material removed relative to the residual material, the age and type of the structures removed and soil moisture and temperature conditions (McNaughton 1979). The combination of these factors influences the number and type of active meristematic regions which remain on the plant and thus directly influences the subsequent level of seed and herbage production potential (Richards 1993; Briske 1991; Becker *et al.* 1997c).

Defoliation at 2 week intervals reduced the production of reproductive tillers relative to other treatments in all species except *P. sieberiana*. With the exception of *P. sieberiana* and *A. ramosa* plants of other species produced the greatest number of reproductive tillers when cut at 4 week intervals (Fig. 5.8). This may have been a type of compensatory response to the continual removal of immature reproductive tillers. The weight of tillers cut at 4 week intervals was significantly lower than that of those cut every 8 weeks in four species, *E. leptostachya*, *S. scabra, B. macra* and *P.sieberiana* (Fig. 5.9).

Frequent defoliation is of greater detriment to species which produce a relatively higher proportion of reproductive tillers (Hyder 1972; Briske 1991). Those species which possess indeterminant flowering mechanisms rely on a relatively larger proportion of leaf material to regenerate from axillary buds rather than from intercalary meristematic regions. It takes longer to restore comparable levels of leaf area through regeneration from buds than through regrowth directly from laminae (Briske 1991; Becker *et al.* 1997c). In the experiment reported here, *E. leptostachya* and *S. scabra* produced the greatest amount of dry weight when cut at 8 week intervals relative to more frequent defoliation intervals. Across all species and treatments these two also produced the greatest number of inflorescences (Fig. 5.8). In contrast, while cutting at 2 week intervals reduced the dry matter production of all species, only in *E. leptostachya* and *S. scabra* was the clipped biomass production significantly reduced in comparison with the other defoliation treatments.

Root biomass

The frequency of defoliation was found to have more pronounced effects on the root production than on the above-ground production of the grasses tested. This result has significance for the long-term persistence and production of perennial grasses. Larcher (1995) considered the root system to be the most vulnerable organ of many higher plants. Only *S. scabra* and *E. leptostachya*, cut at 8 week intervals, were able to regenerate root biomass to a level not significantly different from plants which were uncut. It is also significant to note that the root biomass of these species was 30% that of *P. aquatica* while the dry matter production of above-ground material of the two native species was more than double the biomass produced by *P. aquatica*.

The lower root biomass of the native species relative to the introduced *P. aquatica* is in apparent conflict with the findings of a number of previous studies. Native grasses are well adapted for growth and persistence in low fertility environments (Kemp and Michalk 1994). Species originating from low fertility sites are frequently reported to allocate a relatively greater proportion of resources to the root system (Thornton *et al.* 1993; Larigaurdie and Richards 1994; Gedroc *et al.* 1996). However, the morphology of root systems may be influenced by the nutrient status of the soil (Boot and Messink 1990) and the plants in this experiment were fertilised frequently. The plasticity of root systems is an important attribute in competitive environments. The ability to produce fine roots and root hairs reduces the energy cost associated with the exploitation of limited nutrient resources and therefore acts as an effective buffer against habitat variability (Larigaurdie and Richards 1994).

Most grasses have the capacity for a high degree of flexibility in the pattern of resource allocation between above- and below-ground structures (Olff *et al.* 1990). This flexibility may confer grazing tolerance by influencing the rate of re-establishment of leaf area (Briske 1991; Richards 1993). The root:shoot ratio represents a functional balance within species in response to their environment (Harris 1978; Rodriguez *et al.* 1995). The findings reported for all species tested here support this concept. Within species no significant difference in the root:shoot ratio was recorded due to defoliation interval.

A reduction in root biomass effectively reduces a plant's ability to acquire nutrients and limits the potential uptake of soil moisture (Steinke 1969). The ability of plants to compete for limited resources may also be reduced if fewer and/or shallower roots occupy a given volume of soil. These factors may combine to significantly affect the productivity of grasses (Cornish 1987). Root growth following defoliation will be further impaired if it occurs under situations of moisture stress (Becker *et al.* 1997c). A vigorous root system plays an important role in drought resistance and survival (Volaire 1994).

Root morphology also has an important role in plant nutrient uptake and is influenced by nutrient availability, longer thinner roots having a relatively greater surface area. It has been suggested that root length and the presence of root hairs may be a more important factor than root biomass in influencing the ability of individual plants to increase the uptake of nutrients, particularly phosphorus and potassium (Boot and Messink 1990; Larigaurdie and Richards 1994). While significant differences in root biomass were recorded within species when the interval between defoliation was varied, there was no significant effect on the proportional distribution of roots through the tubes. The grasses tested in this experiment exhibited wide variation in the architecture of the root systems. No clear relationship between growth pattern (i.e. warm season or cool season species) or site of origin was apparent in the structural features of the roots of the species which were evaluated. Although evaluation of root diameter/density was beyond the scope of this study it is likely to play a critical role in the ability of grasses to access nutrients when they are limited.

Plant reserve status

The greatest source of carbon and nitrogen reserves for remobilisation within the plant following defoliation is within the crown region of plants (Briske 1991). Defoliation at 2 weekly intervals resulted in a reduction in both the basal diameters and crown weights of all species. Both parameters were positively correlated with total yield and could therefore be used as indicators of relative plant vigour. Basal diameter was found to be more highly correlated with the dry matter yield of the more productive grasses *E. leptostachya* and *S. scabra*. Other species exhibiting a correlation between basal diameter and yield were *P. aquatica* and *B. macra*. Crown weight was the more important factor influencing the yield of *P. sieberiana* and both accessions of *S. creber*.

A reduction in the basal diameter of pasture plants as a result of frequent defoliation increases the susceptibility of those plants to extreme environmental conditions such as drought (Scott *et al.* 1997) and overgrazing. When the basal diameter of pasture plants is reduced, subsequent changes in competitive relationships within the plant community are likely to result in changes in botanical composition (Briske 1991). A reduction in the basal diameters of perennial grasses also results in more bare ground, facilitating the invasion of annual grasses and broadleaved weeds and rendering soils prone to erosion.

Seasonal variation in herbage quantity and quality

The seasonal pattern of dry matter production within species was not greatly influenced by defoliation at 2, 4 or 8 week intervals. The peak period of production of *P. sieberiana* when cut at 2 and 4 week intervals and *S. scabra* cut at 2 week intervals occurred earlier than when cut at longer intervals. No other differences in the pattern of production were recorded for other species.

In contrast, defoliation interval had marked effects on the protein content of most of the species tested. The quality of herbage of *P. aquatica*, *E. leptostachya* and *S. scabra* declined during the latter periods of the experiment when cut at 2 week intervals while under the 4 and 8 week defoliation treatments the leaf protein content of these species increased dramatically. No one species consistently had higher protein concentrations than other species over the duration of the growing season. Differences in quality between grasses is likely to be of less consequence than the differential persistence of species (Wilson and Simpson 1994).

While increased dry matter production was generally associated with lower leaf protein content, the overall protein yield of each species was reduced by defoliation at 2 week intervals. Under continuous grazing younger leaves which contain a higher percentage of nitrogen tend to be preferentially selected, increasing plant demand for nitrogen uptake from the soil (Field and Ball 1982). Such high levels of utilisation result in a decline in the efficiency of use of available nitrogen. In older plants the translocation from senescing leaves reduces the loss of nitrogen from the ecosystem (Field and Ball 1982; Parsons *et al.* 1991). Since the availability and competition for nitrogen is one of the main limiting factors to plant growth (Tilman 1990a) efficiency of utilisation of such a resource is critical. Potentially 70 - 80% of nitrogen may be recycled within the plant and 20 - 25% is incorporated into the organic matter pool of the soil (Lemaire and Culleton 1989). The return of nitrogen to the soil in the form of organic matter it is not a "loss", but a contribution to vital soil processes.

A number of studies have reported the seasonal decline in the quality of grasses as they progress from the vegetative stage to flowering (Archer and Robinson 1988; Mayland *et al.* 1992) however, few have studied the seasonal variation in nutritive quality in response to defoliation interval.

Defoliation at 2 week intervals both delayed the onset and reduced the time of production of reproductive tillers of all species (Fig. 5.12 and Fig. 5.13). Frequent defoliation would reduce the opportunity of these plants to produce viable flowering tillers. In the period immediately following defoliation nitrogen is preferentially allocated to growing shoots (Ourry *et al.* 1988) resulting in the higher protein content recorded in plants cut at two week intervals. The reason for the late season reduction in protein of *P. aquatica*, *E. leptostachya* and *S. scabra* when cut at two week intervals is unclear, but may indicate a decline in the ability of frequently defoliated plants to continually access this nutrient.

Increasing the defoliation interval significantly increased production of clipped biomass of the more desirable native grasses. Root biomass and plant basal diameter of all species increased as the interval between successive defoliations increased. The combination of these factors indicate that the production and persistence of desirable pasture species should be enhanced when allowed more time to recover from a defoliation event.

The production potential of many native grasses has been vastly underestimated in the past (e.g. Donald 1970). It has been suggested that the findings of many early studies were biased against native species (Wilson and Simpson 1994; Jones 1995). Recent studies have shown that when plants of similar age are compared after being grown under the same environmental conditions many native species are at least as productive as introduced species and are often more persistent under grazing (Robinson and Whalley 1986; Archer and Robinson 1988; Myers and Robbins 1991; Thompson 1992; Jones 1996). The results reported here provide further support for these later studies.

In the Northern Tableland region periods of moisture stress are experienced frequently. Pasture communities which are maintained in a healthy, more vigorous state through moisture-limited periods will be able to regenerate more quickly when favourable conditions return. This is of particular importance with respect to the most palatable species of the sward. Allowing plants extended periods of rest will encourage the formation of larger plant bases and the growth of more extensive root systems, enhancing plant vigour and increasing the ability of plants to extract nutrients and water, particularly during periods when these resources are limited.

Chapter 6

Vegetation change in response to grazing regime

6.1 Introduction

Changes in the structure and species composition of grasslands in response to grazing have been well documented in the literature (Belsky 1992; Wilson and Simpson 1994; Anderson and Briske 1995). These changes have usually been considered negative and the terms "grazing" and "land degradation" have frequently been linked, particularly by those concerned for the environment. The term grazing is normally applied in an absolute sense, land being classified as either grazed or ungrazed. Grazing animals are however, integral components of grassland ecosystems. Through their feedback effects on ecosystem processes, herbivores have the capacity to modify the landscape in either a positive or negative direction (McNaughton 1986; McNaughton *et al.* 1989; Huntly 1995) depending on the method of grazing.

The direct effects of grazing are dependent on initial species composition and the relative palatability, grazing resistance and competitive ability of the components of the vegetation (Peiper 1994; Briske 1996; Bullock 1996). The process of selective grazing of the most palatable, nutritious and actively growing species under a continuous grazing regime is widely considered to be the most detrimental influence of grazing animals on grasslands (Brown and Stuth 1993; Wilson and Harrington 1994; Anderson and Briske 1995). The grazing pressure on the palatable species increases as their representation in the sward declines (Hormay 1970; Tainton and Walker 1993). Competitive relationships in the sward may be altered in response to different patterns of defoliation experienced by the component plants and plant parts. As the species composition changes, vital ecosystem processes are also altered.

In the short term no single method can be used with confidence to adequately assess the direction of change in vegetation and ecosystem health. The aim of this study was to use a range of measurements to evaluate changes in the components of the extant vegetation under cell grazing and continuous grazing regimes.

6.2 Methods

The criteria used to select sampling plots is described in detail in Chapter 3. The methodology used in the monitoring of the vegetation parameters at each of the sites is described below.

6.2.1 *Basal diameter*

Four dominant perennial grass species were selected at each site as indicators of the response of a range of individual species to grazing method. Indicator species were selected on the basis of the following criteria; they covered a range of desirability/palatability in terms of animal preference, the populations of each species in each of the paired plots were sufficiently high to be representative and the communities in which they occurred were similar in both treatments. The species monitored at the Strathroy and Lana sites in order of conventional ratings of desirability for animal production were *Eragrostis leptostachya*, *Sporobolus creber*, *Stipa scabra* and *Aristida ramosa*. The species at the Green Hills site in order of desirability for animal production were *Phalaris aquatica, Bothriochloa macra*, *Sporobolus creber* and *Poa sieberiana*.

The line intercept method was used to determine the basal diameter of the four indicator perennial grass species selected at each site. This technique was developed by Dr Christine Jones (unpublished) to detect changes in the basal diameters of invasive pasture species under contrasting grazing regimes. A 2 m length of rod marked with 1 cm gradations was passed through the centres of three permanently marked rows of plants of each species in each of the six measurement areas at each site (Plate 6.1). The exact location and diameter of each individual plant lying along the transect was recorded to the nearest centimetre and the sum of the total distance was calculated. At each measurement time, the total diameter of plants along the transects was calculated and expressed as a percentage change relative to the initial measurements. Only the rooted plant material of the respective species that was present beneath the measurement rod was recorded and species other than the species of interest were ignored.

6.2.2 *Percentage plant basal cover*

Plant basal cover is considered to be a more accurate measure of pasture condition than the more commonly used canopy cover (Munnich *et al.* 1991; McCartney and Bittman 1994; Welch and Scott 1995), since the amount of foliar cover present at any time will be affected by time since grazing, stage of growth of individual species and the timing and amount of rainfall.

A 100 point quadrat with pins located 10 cm apart in a square grid formation was used to estimate percentage plant basal cover (Plate 6.2). Within each treatment 1600 fixed points were measured at each site. A "hit" was recorded when the point of the pin contacted a rooted portion of a living plant base. The species of plant occurring under the pin was recorded, or if no plant base was present the presence of litter, bare ground, dung or stone under a point was recorded. Strikes occurring on dead tillers which persisted on a plant were classified as part of the litter fraction.

6.2.3 *Relative species frequency*

The determination of relative species frequency by the presence/absence method enables the importance of different species within a pasture to be evaluated and gives an indication of the total number of species present and their distribution over a site (Walker 1970). Relative species frequency measures are a function of the size of the quadrat (Brummer *et al.* 1993). Baseline measurements were made using 20x20, 40x40 and 100x100 cm square quadrats and the variance estimate was calculated for each quadrat size. The lowest variance on each of the properties was recorded from the 40x40 cm quadrat and this size was used for all subsequent measurements.

The relative frequency of species which occurred in twenty 40x40 cm permanent quadrats placed within each of the three plots in both the cell grazed and continuously grazed treatments was determined at regular intervals over the period of the study. These data were used to determine changes in species richness and rank abundance which occurred over time at each site.

6.2.4 *Species contribution to dry weight*

Each spring and autumn, the contribution of the dominant species to pasture dry weight was estimated at each site using the dry-weight-rank (Botanal) technique (Tothill *et al.* 1992). Thirty 50x50 cm permanent quadrats were measured, 2 m apart along three 25 m transects within each treatment at each site. Initial sampling using sixty 40x40 cm quadrats indicated no significant difference in the two data sets and subsequent measurements were taken from the former sample plots.

Plate 6.1 The line intercept method used to determine plant basal diameter (Photo: C. Jones).

Plate 6.2 The 100 point quadrat used to determine percentage plant basal cover.

6.2.5 *Diversity*

The Shannon diversity index (Shannon and Weaver 1949) was used to estimate changes in the evenness of distribution of species across each of the sites. The population parameters derived from the percentage contribution of species to plant basal cover and biomass were used to calculate the Shannon index. The values obtained from each of the methods were compared.

6.2.6 *Statistical analyses*

The experiment took the form of a BACI design as described in Chapter 3. Analysis of the baseline data for each site showed no significant difference between the Control (continuously grazed) and Impact (cell grazed) treatment paddocks for any parameter measured at the commencement of the experiment. At each property the paired replicate measurement plots were situated sufficiently far from the fences to avoid fenceline effects but close enough to be exposed to the same range of environmental/edaphic/climatic influences. During each sampling period, data for each of the parameters measured was collected from the paired Control and Impact measurement areas on the same day.

The basal diameter of indicator species, percentage plant basal cover, species richness, pasture dry weight and species contribution to dry weight data were analysed using the general linear model procedure (SAS 1990) for repeated measures analysis of variance. The raw data for basal diameter, plant basal cover and species richness measurements satisfied the assumptions for analysis of variance (ANOVA). Pasture biomass and species contribution to biomass were transformed (ln + 1) to achieve normality and homogeneity of variance. Presence/absence data were analysed using the CATMOD procedure in SAS (1990). This program is specifically designed for analysis of repeated measures of categorical data (Crowder and Hand 1990). Linear models were fitted to the data using weighted least squares.

The univariate repeated measures was the most appropriate test for the analysis of the vegetation data since it is valid for any number of times (Green 1993). The test of interest was the time by treatment interaction, since variation over time is expected in biological systems. Degrees of freedom were adjusted using the Huynh and Feldt (1976) estimator. Decomposition into pairwise contrasts of consecutive time periods were performed to identify significant time trends.

6.3 Results

6.3.1 *Basal diameter*

At all sites the basal diameters of the most desirable/palatable species were significantly higher after two years of cell grazing than under continuous grazing. The basal diameter of *E. leptostachya* at the Strathroy site increased by an average of 17% under both cell grazed treatments compared to a 65% reduction under continuous grazing (Fig. 6.1a, Fig. 6.2a). At the Lana site *E. leptostachya* decreased 7% under cell grazing whereas under continuous grazing the basal diameter was 65% less than that originally recorded (Fig. 6.3a). The most significant change in the basal diameter of *E. leptostachya* at the two sites at which it occurred was recorded during the first 12 months of measurement. During this period the annual rainfall recorded at each property was only 60% of the long-term average (Fig. 3.5).

At the Green Hills site the basal diameter of the introduced species *P. aquatica* was significantly higher after almost two years of cell grazing than under continuous grazing. The basal diameter of *P. aquatica* increased by 47% under cell grazing compared to a 70% decrease under continuous grazing (Fig. 6.4a). Again, the most significant changes occurred within the first twelve months of the treatments being imposed.

Sporobolus creber was the only indicator species of intermediate palatability to occur at all three sites. At the Strathroy and Lana sites grazing treatment had no statistically significant effect on the basal diameter of this species, although there was a trend for it to decline under all grazing regimes. At the Strathroy site the basal diameter of *S. creber* declined 33% under the regular density cell grazing, 11% under the HI cell grazing and 59% under continuous grazing (Fig. 6.1b, Fig. 6.2b). At the Lana site the basal diameter of *S. creber* was reduced 12% under cell grazing compared to 4% under continuous grazing (Fig. 6.3b). Conversely, at the Green Hills site the basal diameter of *S. creber* increased under both grazing regimes (Fig. 6.4c). The 100% increase under continuous grazing was significantly greater than the 28% increase recorded under cell grazing.

The basal diameter of *S. scabra*, another species of intermediate palatability, was reduced to a greater extent under continuous grazing than in the cell grazed treatments during the initial 12 month period of the experiment at the Strathroy site, although final treatment differences were not significant (Fig. 6.1c, Fig 6.2c). At the Lana site however, there was a significant time by treatment interaction, the basal diameter of

S. scabra increasing initially and then decreasing, under continuous grazing. By the final measurement, it had decreased by 56% under cell grazing compared to a 42% reduction under continuous grazing (Fig. 6.3c).

The basal diameter of *B. macra* was initially unaffected by grazing method at the Green Hills site. However, as the experiment proceeded the basal diameter of *B. macra* increased significantly under continuous grazing, 74% compared to the 7% increase under cell grazing (Fig. 6.4b).

The least desirable species in terms of animal preference at the Strathroy and Lana sites was *Aristida ramosa*. During the first 12 months of monitoring at Strathroy the basal diameter of *A. ramosa* decreased significantly under cell grazing, 45% under the regular density cell grazing and 35% under HI cell grazing as compared to a 1% reduction under continuous grazing (Fig. 6.1d, Fig. 6.2d). No significant changes were recorded subsequently under either grazing regime. At the Lana site grazing treatment had no significant effect on the basal diameter of *A. ramosa* (Fig. 6.3d).

Poa sieberiana was the least palatable of the indicator species at the Green Hills site. A 43% reduction in the basal diameter of *P. sieberiana* was recorded under cell grazing and this was significantly different from the 6% decrease recorded under continuous grazing (Fig. 6.4d).

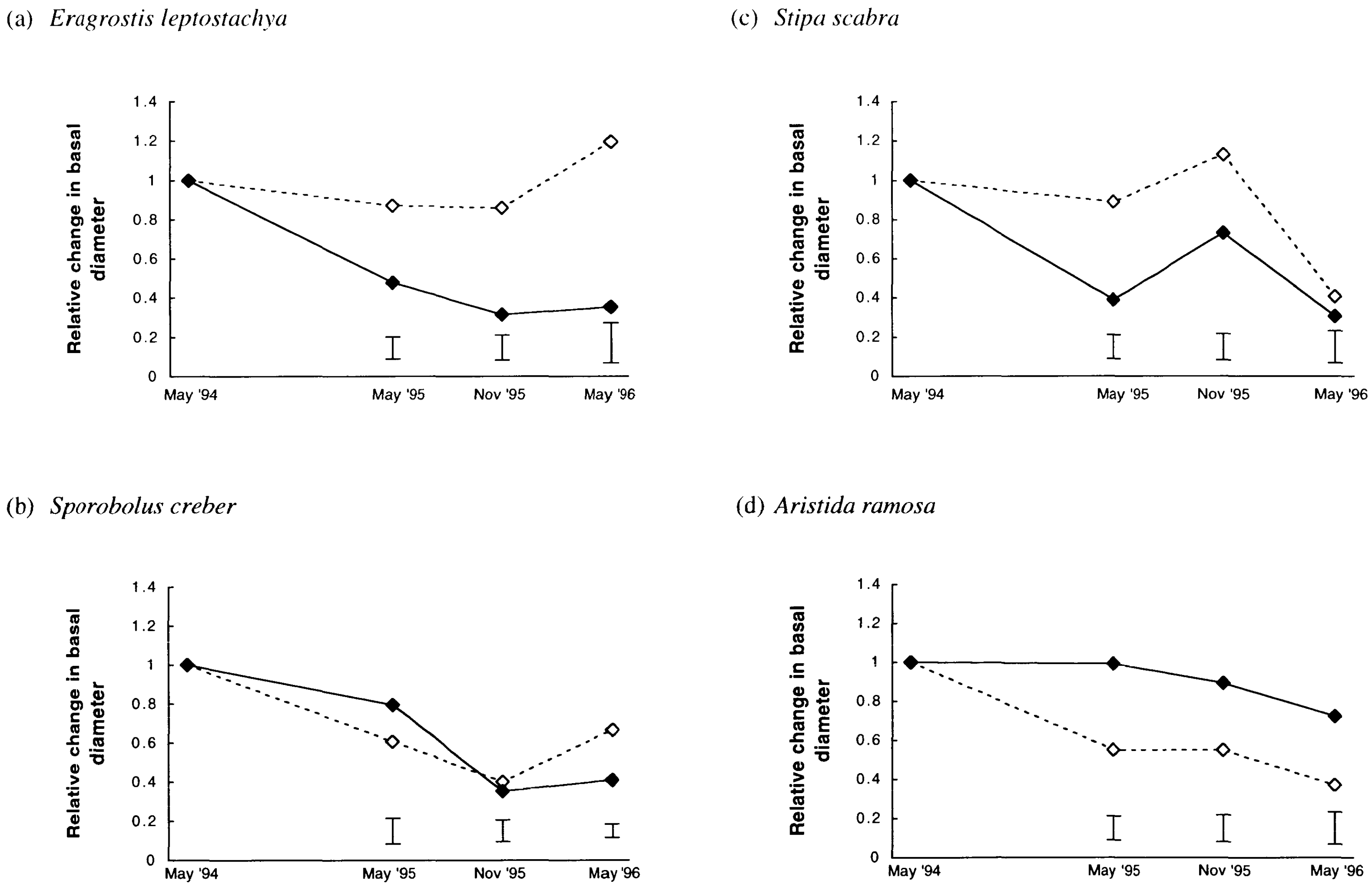

Fig. 6.1 Relative change in basal diameter over time in (a) *Eragrostis leptostachya* , (b) *Sporobolus creber* , (c) *Stipa scabra* and (d) *Aristida ramosa* at the Strathroy site under cell grazing (- - -) and continuous grazing (——). Error bars indicate one standard error.

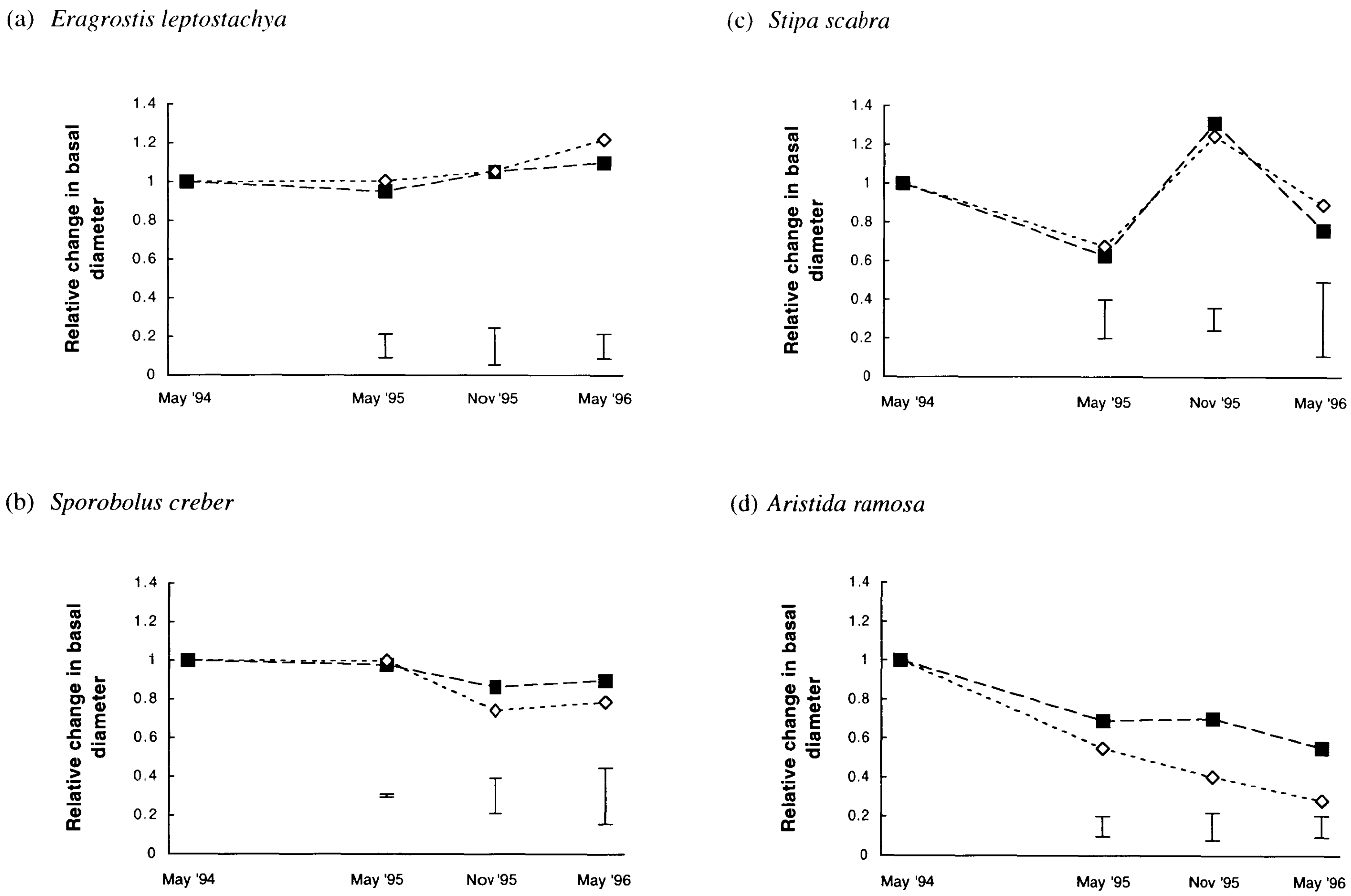

Fig. 6.2 Relative change in basal diameter over time in (a) *Eragrostis leptostachya* (b) *Sporobolus creber* (c) *Stipa scabra* and (d) *Aristida ramosa* at the Strathroy site under regular density cell grazing (- - -) and high density grazing (— — —). Error bars indicate one standard error.

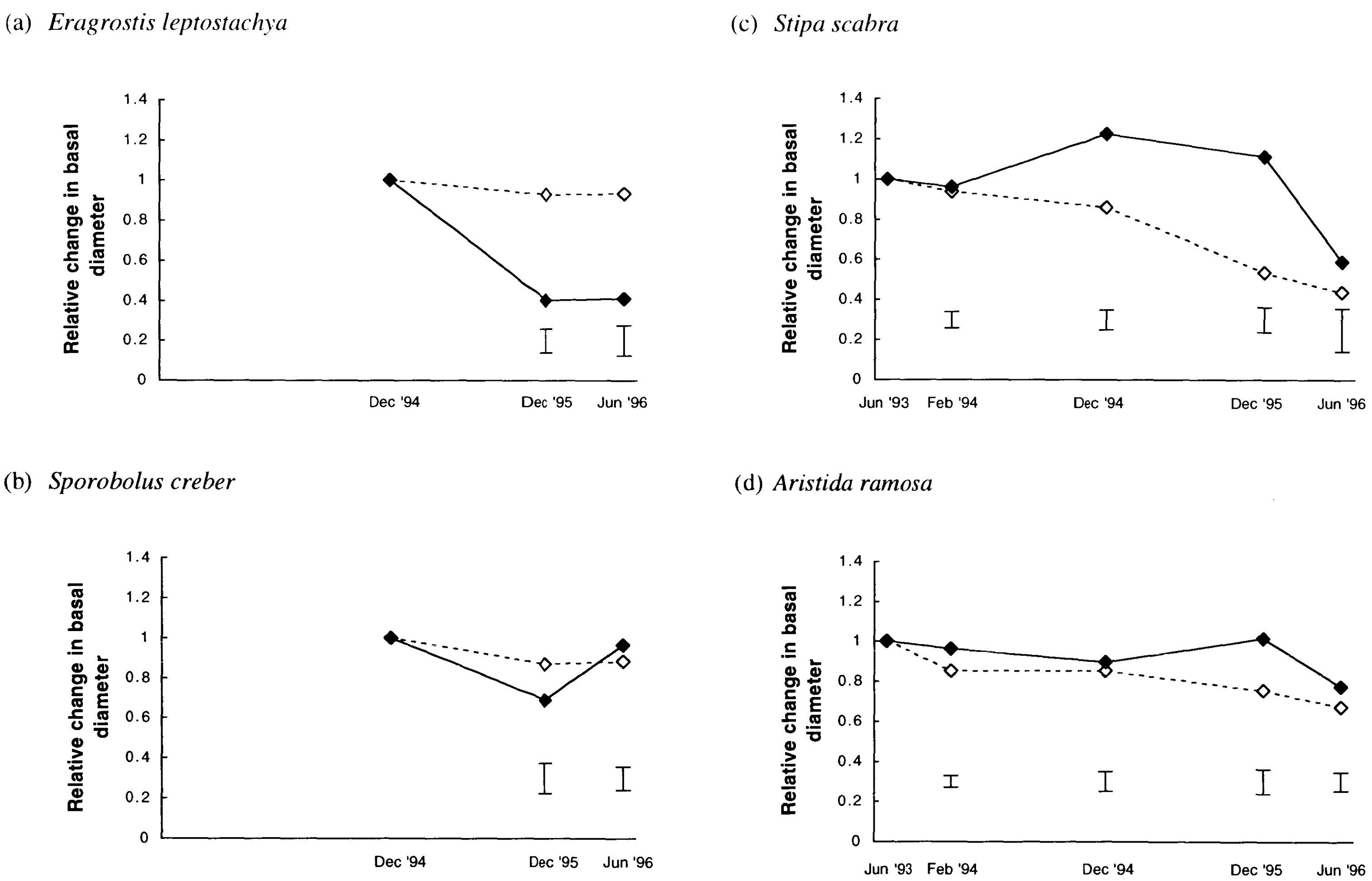

Fig. 6.3 Relative change in basal diameter over time in (a) *Eragrostis leptostachya* (b) *Sporobolus creber* (c) *Stipa scabra* and (d) *Aristida ramosa* at the Lana site under cell grazing (- - -) and continuous grazing (——). Error bars indicate one standard error.

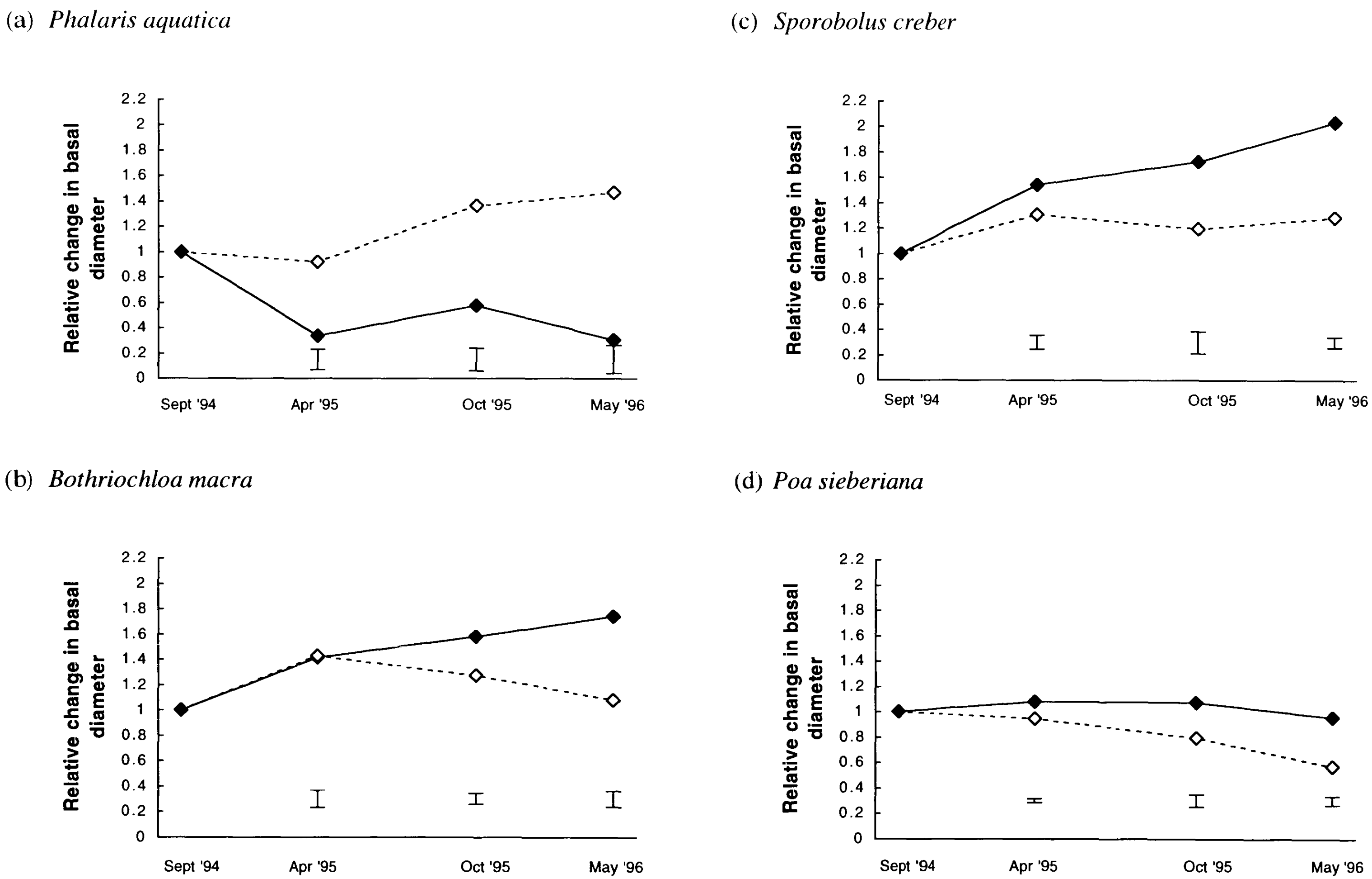

Fig. 6.4 Relative change in basal diameter over time in (a) *Phalaris aquatica* (b) *Bothriochloa macra* (c) *Sporobolus creber* and (d) *Poa sieberiana* at the Green Hills site under cell grazing (- - -) and continuous grazing (——). Error bars indicate one standard error.

6.3.2 *Percentage plant basal cover*

At all three sites the level of plant basal cover was significantly higher after two years of cell grazing than under continuous grazing (Table 6.1). At the Strathroy site cover was significantly reduced from 12% at the initial measurement to around 7% in the two cell grazed and 6% in the continuously grazed treatments, respectively, during the drought period to May 1995. Following substantial rainfall in spring 1995 plant basal cover increased markedly in all treatments due to the germination and establishment of annual species, particularly clovers and grasses. The 16% plant basal cover in the continuously grazed treatment was significantly lower than the 21% recorded under both cell grazing regimes. By the final measurement in June 1996, the perennial component had reasserted dominance and the 16.4% plant basal cover recorded in the regular density cell grazed treatment was significantly higher than the 9% cover in the continuously grazed paddock (Table 6.1). There was no significant difference in the level of plant basal cover in the regular density and HD cell grazed treatments, although the means of basal cover in the HD cell grazed treatment were numerically higher than the means of the regular density cell grazed treatment at all sampling dates.

Table 6.1 Percentage plant basal cover at each site.

Site	**Grazing method**	**Plant basal cover (%)**			
		May 1994	**May 1995**	**Nov 1995**	**June 1996**
Strathroy	Cell	11.6	7.1	21.0*	16.4*
	Continuous	12.1	6.1	16.3	9.0
Strathroy	Cell	12.3	6.8	21.4	18.0
	HI cell	12.3	7.6	21.6	18.3
			Dec 1994	**Dec 1995**	**June 1996**
Lana	Cell		17.8	17.5*	16.7*
	Continuous		16.2	12.2	12.9
		Sept 1994	**Apr 1995**	**Oct 1995**	**May 1996**
Green Hills	Cell	19.0	21.6	23.7*	25.0*
	Continuous	19.8	19.5	18.0	19.7

Note: Asterisks indicate significant differences ($P<0.05$) between the values for cell and continuous grazing at a given measurement time.

Percentage plant basal cover remained relatively stable under cell grazing at the Lana site while decreasing under continuous grazing (Table 6.1). The difference between the treatments was significant over time. At the Green Hills site plant basal cover increased significantly over time under cell grazing while remaining relatively stable under continuous grazing (Table 6.1).

The contribution of the indicator species to percentage basal cover reflected changes similar to those recorded in their basal diameter measurements. A significant time by treatment interaction was recorded for the contribution to basal cover of the desirable species *E. leptostachya* at the Strathroy and Lana sites and *P. aquatica* at the Green Hills site. Basal cover of these grasses was significantly higher under cell grazing than under continuous grazing (Table 6.2). At the Lana site *S. creber* contributed to a significantly greater percentage of plant basal cover under continuous grazing than under cell grazing. No significant differences in the contribution to plant basal cover were detected over time for other indicator species at any of the sites.

6.3.3 *Relative species frequency*

At the Strathroy site the relative frequency of the desirable species *E. leptostachya* increased significantly under cell grazing while decreasing under continuous grazing. Conversely, the frequency of the undesirable species *A. ramosa* declined significantly under cell grazing and increased under continuous grazing (Table 6.2).

Changes in the relative frequency of indicator species could not be detected using the presence/absence technique at either the Lana or the Green Hills sites. At the Lana site there was a trend for the frequency of *A. ramosa* to decline slightly under cell grazing while increasing under continuous grazing (Table 6.2). At the Green Hills site, *P. aquatica* was recorded in 92% of the quadrats in both treatments at the first sampling, and over the experimental period this increased to 98% of quadrats in the cell grazed paddock and decreased to 80% of the quadrats in the continuously grazed paddock (Table 6.2). Similar trends were observed for *T. repens* which increased to a greater extent under cell grazing. However, these differences were not statistically significant. The relative stabililty of the dominant pasture components over time and the small sample size for this type of measurement limited the statistical analysis of these data.

Site	Species	Plant basal cover (%)								Relative species frequency (%)										Dry weight rank (%)									
		cell				continuous				cell					continuous					cell					continuous				
		#	12.94	12.95	6.96		12.94	12.95	6.96	7.93	12.93	12.94	12.95	6.96	7.93	12.93	12.94	12.95	6.96		12.94	6.95	12.95	6.96		12.94	6.95	12.95	6.96
Lana	*Eragrostis leptostachya* ^		7.2	6.9*	8.4*		5.9	3.9*	3.3*	87	90	93	97	98	90	100	97	100	97		76.0	18.9	42.0	32.8		37.7	12.1	22.1	15.7
	Sporobolus creber ^		2.5	1.3	1.5*		3.4	2.5	3.3*	37	80	73	80	85	50	63	67	77	87		7.6	20.8	12.0	31.9		23.6	44.5	27.1	60.8
	Stipa scabra ^		0.6	0.5	0.5		0.8	0.5	0.4	27	17	17	23	20	37	37	33	33	40		3.5	3.7	3.3	1.5		1.0	3.3	0.7	1.8
	Aristida ramosa ^		1.3	0.5	0.5		1.0	0.3	0.6	10	10	10	7	3	17	17	17	20	27		1.2	0.8	0	0.9		1.6	2.0	1.7	1.9
	Microlaena stipoides		2.0	1.6	0.9		0.8	0.8	0.4	26	26	26	23	23	43	43	50	73	60		1.5	5.5	4.7	4.2		14.2	7.4	11.3	4.3
	Elymus scaber		0.4	0.8	0.5		0.3	0.3	0.1	60	60	43	63	73	83	83	43	97	75		0.3	12.9	2.7	11.2*		0.0	4.3	1.1	1.8*
		cell				continuous				cell					continuous					cell					continuous				
		# 9.94	4.95	10.95	5.96	9.94	4.95	10.95	5.96	9.94	12.94	4.95	10.95	5.96	9.94	12.94	4.95	10.95	5.96	9.94	11.94	4.95	11.95	5.96	9.94	11.94	4.95	11.95	5.96
Green Hills	*Phalaris aquatica* ^	3.5	2*	3.8*	5.2*	2.5	0.6*	0.8*	0.6*	92	90	90	97	98	92	88	80	78	80	29.1	26.8*	15.7*	31*	26.7*	25.1	12.4*	0.3*	9.7*	3.2*
	Bothriochloa macra ^	7.3	10.1	7.2	8.9	10.2	10.1	6	7.7	98	100	100	100	100	98	98	100	100	100	45.7	44.6	61.8	32.9	29.9*	53.3	61.2	84.7	51.6	54.4*
	Sporobolus creber ^	2.1	2.4	1.6	2.2	4.1	5.6	4.3	5.4	28	32	33	33	42	60	70	68	65	75	3.6	3.9	3.9	0	1.8	6.2	7.7	6.2	0.7	7.4
	Poa seiberiana ^	2.1	1.2	1.3	1.1	1.0	0.6	0.8	0.7	5	5	5	5	5	15	15	15	15	15	0.7	0.9	0.2	0	0	0	0	0.2	0.1	1.9
	Trifolium repens	0	0.3	0.9	1.3	0	0	0	0.1	28	47	52	72	93	15	38	42	53	72	0	0.9	2.0	3.9	10.6*	0	0	0.5	3.1	3.3*

^ Indicator species at each site.

* Indicates a significant difference between the values for the comparative grazing regimes at a given measurement time.

Date of collection (month.year).

Species richness

The number of species recorded per quadrat increased over time at the Strathroy and Lana sites. After the initial measurement in May 1994 at Strathroy there was a significant decline in the number of species recorded per quadrat in all treatments at the measurement in December 1994 (Fig. 6.5a, Fig. 6.5b). Significantly fewer species were recorded under continuous grazing at this time (Fig. 6.5a). Following relief from drought conditions a significant increase in the number of species was recorded in all treatments at the next measurement in June 1995. Species richness at the Strathroy site peaked at the October 1995 measurement where an average of 16 species per quadrat were recorded in all cell grazed treatments. The mean number of species in the continuously grazed paddock, 15.5, was significantly less than the 17 species recorded in the comparable cell grazed treatment (Fig. 6.5a). By the final winter measurement the number of species recorded had declined slightly in all treatments. A significant time by treatment interaction between means was recorded only for the regular density cell grazed, HI cell grazed comparison at Strathroy, with species richness increasing to a greater degree under the high intensity regime.

At the Lana site, a significant increase in species richness as measured by the number of species per quadrat was recorded between December 1994 and June 1995 (Fig. 6.5c). Grazing treatment had a significant effect only at the December 1995 measurement, where more species were recorded under continuous grazing than in the cell grazed treatment (Fig. 6.5c).

In contrast to the other sites, species richness at the Green Hills site tended to increase in the initial 13 months of the experiment to October 1995 (Fig. 6.5d). At the final measurement in May 1996 there was a significant decline in the number of species recorded per quadrat, although significantly more species were present in the cell grazed treatment than under continuous grazing.

6.3.4 *Diversity indices*

Shannon diversity indices (Shannon and Weaver 1949) calculated on the basis of the percentage of individual species contribution to plant basal cover and species contribution to biomass showed similar trends towards increased species diversity at all sites using both methods (Table 6.3). There were no apparent differences in the diversity indices as a result of grazing management at any of the sites. The values obtained using species contribution to plant basal cover showed a tendency to be slightly higher than those values derived from the species contribution to dry weight.

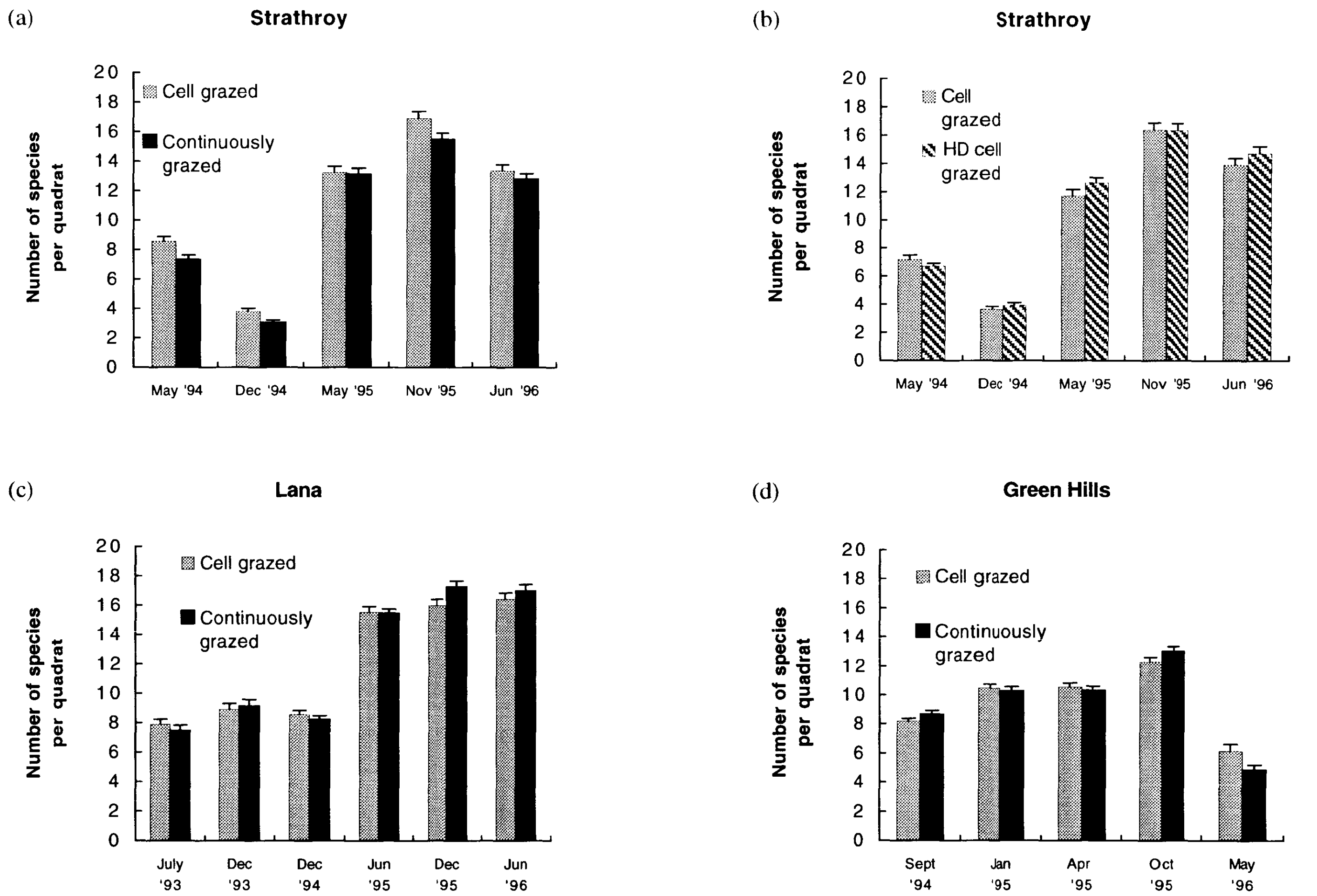

Fig. 6.5 The number of species per quadrat recorded over time at (a) and (b) the Strathroy site (c) the Lana site and (d) the Green Hills site in cell grazed, HD cell grazed and continuously grazed treatments. Error bars indicate one standard error.

Table 6.3 Shannon diversity index values over time calculated using the percentage contribution of species to plant basal cover and pasture dry weight.

		Diversity indices			
Site	**Grazing method**	**Contribution to basal cover (%)**		**Contribution to dry weight (%)**	
		May 1994	**June 1996**	**May 1994**	**June 1996**
Strathroy	Cell	2.32	2.69	2.28	2.51
	Continuous	2.05	2.74	1.92	2.16
Strathroy	Cell	2.34	2.72	2.03	2.82
	HI cell	2.37	2.62	2.00	2.46
		Dec 1994	**Dec 1995**	**Dec 1994**	**Dec 1995**
Lana	Cell	2.06	2.21	1.65	2.28
	Continuous	2.17	2.41	1.11	2.19
		Nov 1994	**Nov 1995**	**Nov 1994**	**Nov 1995**
Green Hills	Cell	2.02	2.36	1.65	1.86
	Continuous	1.62	2.08	1.48	1.79

6.3.5 *Species contribution to dry weight*

The first Botanal measurement made at Strathroy in September 1994 indicated that *A. ramosa* and *S. creber* dominated both the cell grazed and continuously grazed paddocks in terms of dry-weight-rank (Table 6.2). *Eragrostis leptostachya* and *S. scabra* were sub-dominant. Over time, the relative contribution of *E. leptostachya* to dry weight in the cell grazed paddock increased relative to the contribution of other species, and it had become one of the dominant species by the final measurement. Conversely, the relative contribution of *E. leptostachya* to dry weight declined significantly in the continuously grazed paddock, and the pasture remained dominated by *A. ramosa* and *S. creber* (Table 6.2).

The botanical measurements recorded in November 1995 at Strathroy were markedly different from those recorded on other dates. Until June of that year the effects of drought had been particularly severe, and percentage basal cover had been significantly reduced (Table 6.1). Following substantial spring rainfall in 1995 many annual species germinated and dominated the vegetation. Annual species contributed 89.6% to the dry weight of the herbage in the cell grazed paddock and 97.2% in the conventionally grazed paddock in October 1995. This measurement reflected the annual species capacity for rapid growth rather than the absence of perennial grasses from the pasture. By June 1996 the perennial species were again dominant in terms of herbage mass.

The comparison between the regular density cell grazed and the HI cell grazed treatments showed that the changes in species contribution to dry weight were relatively consistent over time, with a few exceptions. Over time the proportion of *S. creber* increased in the HI cell grazed treatment (Table 6.2). *Aristida ramosa* also increased at the April 1995 measurement relative to the average cell grazed treatment, but by the final measurement in June 1996 had decreased below original levels in both treatments. The species which increased over time in all treatments were *S. scabra* and *M. stipoides*. *Stipa scabra* increased to a greater extent under the regular density cell grazing regime and *M. stipoides* increased more under HI cell grazing (Table 6.2).

The only statistically significant change recorded in percentage contribution to dry weight at the Lana site was the increase in the highly palatable winter-active native species *Elymus scaber* under cell grazing (Table 6.2). At the initial measurement *E. leptostachya* (76%) dominated the cell grazed paddock in terms of dry weight. By the final measurement in June 1996 three species, *E. leptostachya* (33%), *S. creber* (32%) and *E. scaber* (11%), contributed to the bulk of the biomass under cell grazing (Table 6.2). In contrast, at the final measurement at the Lana site *S. creber* (61%) dominated the vegetation under continuous grazing in terms of dry weight. The other species which increased its contribution to dry weight over time under continuous grazing relative to the cell grazed treatment was *M. stipoides*.

The baseline measurement of the vegetation biomass at the Green Hills site in spring 1994 revealed that there was on average 27% *P. aquatica* and 50% *B. macra*. After 20 months of contrasting grazing regimes the contribution of *P. aquatica* to total dry weight remained at a similar level of 27% in the cell grazed paddock and had declined significantly to 3% under continuous grazing (Table 6.2). Conversely, the contribution of *B. macra* to dry weight decreased from 46% to 30% under cell grazing, while under continuous grazing it remained the dominant species, contributing 54% to the available biomass.

Trifolium repens was not recorded in either treatment at the initial measurement at Green Hills. At the May 1996 measurement, *T. repens* contributed 11% to the pasture biomass under cell grazing, which was significantly different from the 3% contribution in the continuously grazed paddock (Table 6.2). *Elymus scaber* was another species which increased to a greater extent under cell grazing. The contribution to dry weight of *S. creber* declined significantly under cell grazing while it increased slightly over time under continuous grazing. The contribution to dry weight of *Poa sieberiana* was initially low in the cell grazed paddock but by March 1995 was not detected, whereas its percentage contribution to dry weight tended to increase in the continuously grazed treatment (Table 6.2).

Pasture biomass

Across all sites, grazing treatment generally had relatively little influence on pasture biomass (Fig. 6.6). At the Strathroy site pasture biomass had declined significantly in all treatments at the April 1995 measurement. Only at the final measurement in June 1996 was a significant difference in biomass detected between treatments. At this time, pasture dry weight was significantly greater in the cell grazed paddock than the comparable continuously grazed treatment. At both the Lana and Green Hills sites pasture biomass tended to increase over time in both treatments (Fig. 6.6). There was a significant effect of grazing treatment at Green Hills at the March 1995 measurement where biomass was greater under cell grazing than under the continuous grazing regime. No other significant differences between grazing treatments were identified.

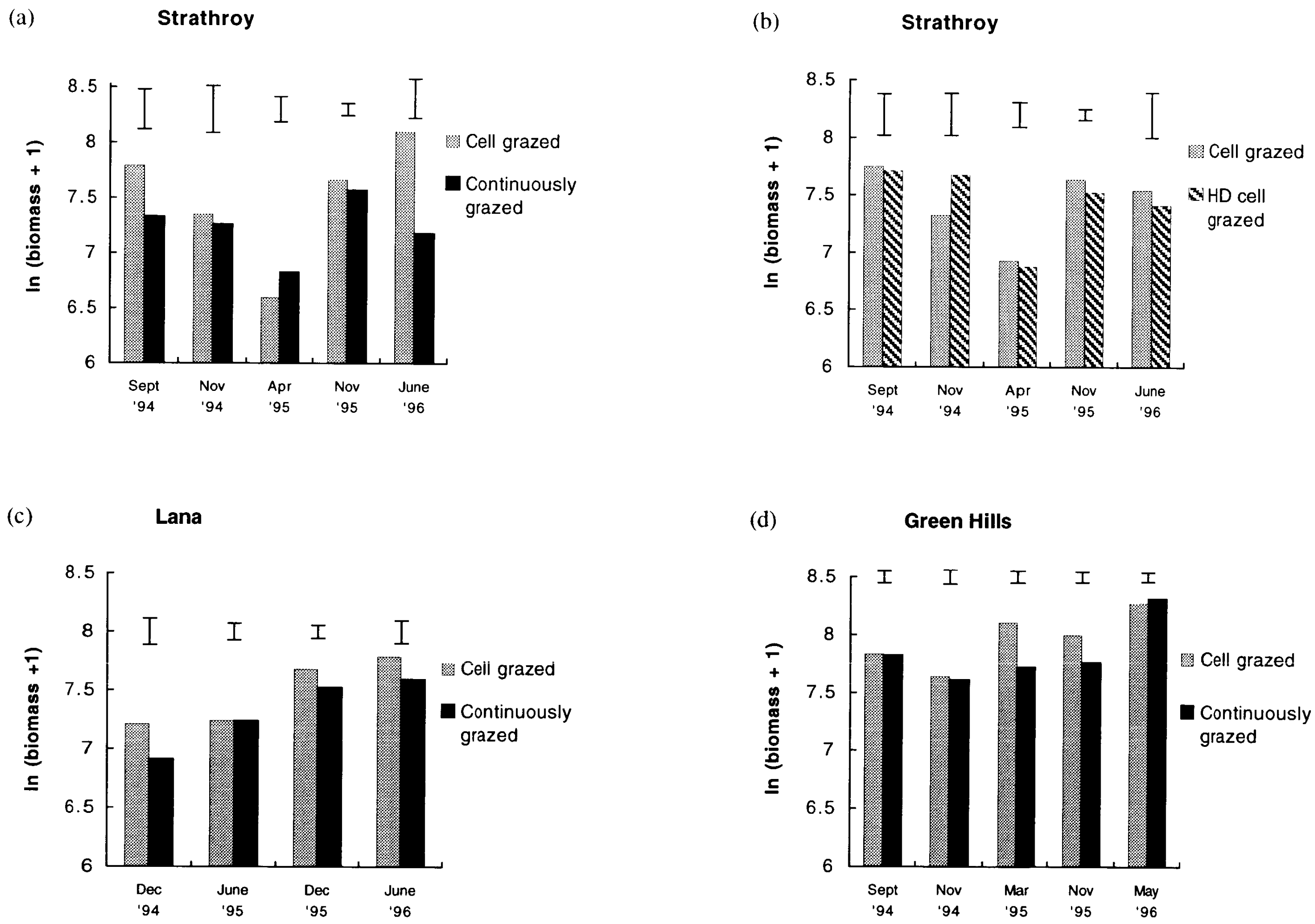

Fig. 6.6 Changes in pasture biomass over time at (a) and (b) the Strathroy site (c) the Lana site and (d) the Green Hills sites under cell grazing, HD cell grazing and continuous grazing. Error bars indicate one standard error.

6.4 Discussion

Change in the botanical composition of grasslands occurs in response to environmental conditions in concert with the impact of grazing livestock. Management can have no direct influence on the prevailing climatic conditions however, control over the grazing process may have a profound influence on the response of the vegetation to stress.

Continuous grazing and cell grazing represent two extremes in the continuum of options for controlling the grazing process. Under continuous grazing animals have the opportunity to maximise their intake of the most palatable components of the sward, effectively minimising the opportunity for plants to recover from each defoliation event. Selective grazing is an inherent characteristic of animal behaviour and cannot be eliminated under a cell grazing regime. However, the opportunity for repeated defoliation of the desirable sward components is minimised with short graze periods. Furthermore, the rest periods associated with cell grazing allow defoliated plants more time to regenerate leaf area and root biomass.

Data obtained from three sites on the Northern Tablelands of NSW, using a range of measurement methods, clearly demonstrated that continuous grazing predisposed vegetation to undesirable change and that cell grazing could prevent or reverse that process. The three cells monitored on Strathroy, Lana and Green Hills comprised 28, 35 and 26 paddocks, respectively, so that each paddock in these cells was rested for more than 95% of the year. The grazing disturbances imposed during the other 5% of the time were intermittent and of short duration.

The effect of grazing method on the indicator species at each site was found to be dependent on both their relative palatability and relative abundance. In general, the protection afforded to the most palatable species under cell grazing resulted in improved vigour and abundance, and this effect was more pronounced if their initial representation in the sward had been relatively low. Conversely, the grazing pressure applied to the least palatable species under cell grazing resulted in a decline in vigour and abundance, and this effect was more pronounced if their initial representation in the sward had been relatively high.

Eragrostis leptostachya is a high quality, leafy summer-active native perennial grass which has been observed to be one of the first species selected by livestock at the Strathroy and Lana sites. Under continuous grazing, the basal diameter of *E. leptostachya* declined by 65% on both of these properties in the low rainfall years of 1994 and 1995 (Fig. 6.1a, Fig. 6.3a). The percentage contribution to biomass of this species was also significantly reduced by continuous grazing at both sites. Similarly, the basal diameter of the palatable introduced species, *P. aquatica*, declined 70% under continuous grazing at the Green Hills site (Fig. 6.4a).

An increase in the basal diameter of *E. leptostachya* under cell grazing was recorded at the Strathroy site under the more favourable rainfall conditions of 1996, whereas little change was recorded under cell grazing at the Lana site. This difference may have been due to the fact that *E. leptostachya* was a sub-dominant of the baseline vegetation at Strathroy, but a highly dominant species at Lana. As previously noted, the grazing pressure on palatable species increases as their representation in the sward declines (Hormay 1970; Tainton and Walker 1993) and releasing the selective grazing pressure may be like "taking the weight off a spring" for some highly palatable species. The basal diameter of *P. aquatica* increased 47% over two years under cell grazing at the Green Hills site (Fig. 6.4a).

At the other end of the palatability spectrum, *A. ramosa* and *P. sieberiana* are generally avoided by livestock and tend to flourish under set-stocking in good rainfall years. Little change was recorded in the basal diameters of these species under continuous grazing in the low rainfall years of 1994 and 1995, whereas under cell grazing the basal diameter of *A. ramosa* declined by 45% at the Strathroy site (Fig. 6.1d) and the basal diameter of *P. sieberiana* declined by 43% at the Green Hills site (Fig. 6.4d).

Harradine and Whalley (1981) found that clipping *A. ramosa* resulted in a concentration of roots in the top 0-10 cm of the soil profile, and suggested that defoliation under field conditions could predispose plants of this normally deep-rooted species to "premature death". The problem is that *A. ramosa* is not defoliated when livestock are set-stocked at low stock densities.

The extent to which grazing pressure can be successfully exerted on unpalatable species will depend on their percentage representation in the sward. Unpalatable species of low relative abundance will be difficult to control, particularly at low stock densities, as they are more easily avoided. This may explain the lesser effect of cell grazing on *A. ramosa* at the Lana site, where it represented only 1% of the sward on a dry weight basis compared with the greater reduction at the Strathroy site, where *A. ramosa* originally represented 21% of the sward on a dry weight basis.

The evidence presented here on the decline in *A. ramosa* under cell grazing suggests that the propensity of this species to dominate the vegetation on light-textured soils on the Northern Tablelands (Norton 1971) may be due to "grazing avoidance" rather than "grazing tolerance". The grazing avoidance strategy can be counteracted to some extent by imposing high stock densities during the graze period and under these conditions *A. ramosa* was found to be relatively intolerant of grazing.

Bothriochloa macra, S. scabra and *S. creber* are generally regarded as being of intermediate palatability to livestock. They are neither highly desirable, nor highly undesirable, pasture components. As with previous examples, the grazing pressure exerted on these species was dependent on the relative palatability and abundance of the other pasture constituents. *Sporobolus creber* occurred at all three sites in this study, and the basal diameter data indicated that at the Strathroy and Lana sites it was a neutral species in terms of palatability and grazing tolerance, responding to seasonal conditions but not to differences in grazing method. At the Green Hills site, *S. creber* appeared to be of lower acceptability to livestock in comparison with other pasture components such as *P. aquatica* and *T. repens*, and increased in basal diameter, relative frequency and percentage contribution to biomass under continuous grazing.

The influence of rest period in maintaining desirable species composition is apparent when all grazing treatments at the Strathroy site are considered. Although stocking rate varied over time it remained constant among all treatments. The statistically significant differences recorded in the vegetation between the cell grazed and the continuously grazed treatments indicates the extent of the influence of animal presence (or absence) on the vegetation. No significant differences were recorded in any of the parameters measured between the regular density cell grazed and HI cell grazed treatment comparison. These results indicate that in terms of changing botanical composition no apparent benefit was gained by increasing the level of stock density above that which was originally implemented under the cell grazing regime at Strathroy during the course of this study.

Stocking rate is frequently reported to be the dominant influence with respect to changes in the botanical composition of pastures. The results from the three sites in the study reported here would suggest that when grazed at an appropriate stocking rate the effect of adequate periods of rest for pastures was a more important factor. At the Lana site the stocking rate in the cell grazed paddock was almost double that in the continuously grazed treatment over the duration of the experiment. Changes in vegetation recorded under cell grazing were more favourable than those which occurred under continuous grazing.

The effect of grazing method on percentage ground-cover

The measurements of percentage plant basal cover recorded in this study are in reasonable agreement with point analysis results obtained by other workers in environments which receive equivalent or lower rainfall (eg. Edwards 1968; Tainton *et al.* 1978; Lodge and Whalley 1983; Naeth *et al.* 1991). Plant basal cover was similar in both of the grazing treatments at each site when baseline measurements were made (Table 6.1). By the final measurement, it was significantly higher in the cell grazed paddocks than in the continuously grazed paddocks at all three sites.

The percentage plant basal cover has well-documented effects on levels of soil biological activity, energy flow, rates of water infiltration, and the losses of dissolved and particulate matter including nutrients and organic matter (Williams and Chartres 1991; Tainton and Walker 1993; Prosser and Hairsine 1995). As Harrington *et al.* (1984) succinctly stated: "Vegetation may change but soils degrade - and once gone, are gone forever for all intents and purposes."

It has been suggested that soil stability and watershed function should have greater weight than any other criteria in the assessment of long-term viability and that any management regime which predisposes a pasture system to soil loss is not sustainable (Williams and Chartres 1991; NRC 1994). The significant differences in ground-cover which developed over time between the cell grazed and continuously grazed treatments are therefore of paramount importance with respect to sustaining the resource base. A higher level of basal cover of perennial grasses will also foster biological recycling and restrict the nutrient losses attributable to leaching and erosion, facilitating closure of the nutrient cycle on grazed pastures (Williams and Chartres 1991; Lefroy *et al.* 1992).

Interactions between grazing method and seasonal conditions

The study detailed here commenced during a period of drought, the severity of which intensified until autumn 1995. It is possible that the effects of lack of control over the grazing process are more readily observed in times of below average rainfall. In good years, the importance of sustaining the soil and pasture resource may be more easily overlooked.

It has frequently been stated that the opportunities for manipulating botanical composition are greatest when seasonal conditions favour the desirable species (eg. Kemp 1993; Garden and Dowling 1995). However, botanical change can be influenced by plant death as well as recruitment, and pasture species weakened by grazing pressure have a reduced chance of survival if climatic conditions are unfavourable. Voisin (1961) suggested that the advantages of a rest/rotational grazing system based on plant requirements were more likely to be observed in dry than in humid regions, or during periods of dry weather in humid and semi-humid regions.

The significant changes in basal diameter of both desirable and undesirable species recorded in the first 12 months of this study may have reflected a heightened response to adverse environmental conditions. That is, the protection from on-going selective grazing afforded by cell grazing may have been more advantageous than usual to the palatable species, and the defoliation of the grazing-intolerant, relatively unpalatable species under cell grazing may have been more disadvantageous than the same degree of defoliation in a high rainfall year. These results suggest that the opportunities for manipulating botanical composition are possibly greatest in dry years, provided that the grazing method used is acting on one or more of the causal mechanisms for vegetation change.

Multiple criteria of vegetation assessment

Of the range of methodologies used to assess changes in components of the vegetation, the basal diameters of key indicator species provided the most definitive results. Since grazing takes place at the level of the individual plant it is important to identify the effects of defoliation on the relative vigour of each species. Critical changes in the vegetation would not have been detected if community based assessment methods had been the sole measurement criteria.

However, the use of multiple criteria for vegetation monitoring was found to be advantageous. The percentage basal cover is central to the maintenance of ecosystem function and is a key indicator of the health of the pastures, as are the components of plant cover and their life history attributes. The trends in these parameters reflected the changes recorded in the basal diameters of the indicator species.

The presence/absence method provides a direct measure of the relative abundance of species and the species richness of pasture communities. However, it gives no indication of their relative contribution to pasture biomass. In contrast, species contribution to pasture dry weight (Botanal) is a relatively fast and accurate method for the determination of the quality and quantity of the pasture available for livestock consumption.

Most of the significant changes recorded in the vegetation at each of the three sites were related to the most palatable species. The basal diameters of these species were significantly reduced when they were subjected to a continuous grazing regime. Although each remained present in the vegetation in relatively high frequency, the fact that they made little contribution to the pasture biomass would suggest that they were approaching their tolerance threshold. Continued grazing pressure may have eventually resulted in their elimination from the sward, particularly if further periods of moisture stress were experienced.