CHAPTER FIVE

Short-term impacts of burning grassland at Kirramingly Nature Reserve

5.1 Introduction

Grasslands that are not grazed are thought to require some form of disturbance to reduce the density of grass tussocks and allow regeneration of forbs, sub-shrubs and less dominant grasses (Collins & Barber 1985; Lunt 1990a, 1994; Belsky 1992; Noy-Meir 1995; Bekker *et al.* 1997; Morgan 1998; Wright 2001). The use of fire as a disturbance mechanism is the obvious option for nature reserves, such as Kirramingly Nature Reserve, where livestock grazing is not permitted. However, there are no reports detailing the impacts of burning native grassland on plant species composition and diversity on the Moree Plains. The effects of fire on plant community composition and richness are varied and are dependent on a number of factors, such as the intensity, frequency, season and area of fire, as well as soil fertility and the sensitivity of individual plants to fire (Daubenmire 1968; Vogl 1974; Wright 1974; Lunt 1990a, 1991; Gill & Bradstock 1995; Morgan 1996; Peláez *et al.* 2003; Uys *et al.* 2004). Given this variation it is inadvisable to apply findings from studies across regions, highlighting the need for research into the effects of fire on native grassland composition and diversity on the Moree Plains.

Many studies report positive effects of fire on the abundance, richness, evenness or reproductive performance of native plants (e.g. Vogl 1965; Duabenmire 1968; Lloyd 1972; Vogl 1974; Stuwe & Parsons 1977; Gill 1981; Hester & Hobbs 1992; Morgan & Lunt 1999; Wright 2001). However, the impact of fire on Mitchell grasslands from a conservation perspective is largely unknown. A previous study in *Astrebla* grasslands of Queensland suggested that fire may result in an increase in diversity and evenness (Wright 2001); hence it was hypothesised that burning would have a similar influence at Kirramingly Nature Reserve. However, it is difficult to predict the consequences of re-establishing a fire regime in areas that have not been burnt for a long time, after a history of grazing. Replacing grazing with intermittent burning in temperate grasslands of south-eastern Australia did not encourage native species and instead promoted ruderal colonising species (Lunt & Morgan 1999). Fires create pioneer conditions and, hence, sometimes allow invasion of undesirable opportunistic species (Lunt 1990a; Butler & Fairfax 2003). The invasion of remnant native vegetation by introduced plants is a serious problem (Groves & Burdon 1986; Hester & Hobbs 1992) and the interaction between fire and recruitment of weeds requires further investigation at Kirramingly Nature Reserve (Clarke *et al.* 1998). Given the occurrence of winter-growing introduced species on the Moree Plains and the fact that most native perennial grasses at Kirramingly Nature Reserve are summer-active, we might expect autumn burning to favour the winter-growing introduced species. On the other hand, spring burning might favour native species over introduced species.

Repeated burning in native grasslands generally does not reduce the number of species present and may even increase diversity by promoting growth of additional grasses and forbs, including annual plants (Vogl 1974). The time taken for grass density and litter on a burnt site to return to pre-burn conditions varies between different grassland communities (Hadley & Kieckhefer 1963; Vogl 1965; Morgan 1998). I am unaware of any studies on the influence of fire frequency in Mitchell grasslands, or of any recommendations of an appropriate fire frequency for these grasslands. Hazard reduction burning on a regular basis has been proposed by the National Parks and Wildlife Service (NPWS) as a method to reduce fuel loads adjacent to neighbouring properties of Kirramingly Nature Reserve. However, if fire is to be used as a management option for this Reserve, or other Mitchell grassland reserves, information on the influence of repeated burning is required.

The effects of fire on plants may depend on phenological stage, climatic conditions (particularly rainfall), fire intensity and season, grazing intensity post-fire, plant growth form, and the persistence strategies of individual species in response to fire (i.e. vegetative reproduction or establishment from seeds) (Wright & Klemmedson 1965; Scanlan 1980; Mulham 1985; Pfeiffer & Steuter 1994; Henderson & Keith 2002). Species show varied responses to fires in different seasons given this range of variables. Information on the biological response and ability to survive fire is lacking for many grassland species. While burning often stimulates flowering and seeding of herbaceous vegetation (Old 1969; Lloyd 1972; Vogl 1974; Gill 1981; Lunt 1994; Morgan 1996), little is known about grassland species on the Moree Plains. However, it is known that many native species are able to survive fire through vegetative reproduction (Vogl 1974; Christensen & Kimber 1975; Gill 1981; Lunt 1990a; Morgan 1996, 1999; Wright 2001). Resprouting of perennial species after fire appears to be common in Mitchell grasslands of Queensland (Scanlan 1980; Wright 2001) and other Australian grasslands (Lunt 1990a; Morgan 1996, 1999). Hence we might expect a recovery of native perennial species by resprouting after fire on the Moree Plains.

Many species in fire-prone environments have soil seed banks whose dormancy is broken by fire-stimulated cues (Keith 1996). Smoke from fire may play an important role in breaking seed dormancy of certain species (Brown 1993; Dixon *et al.* 1995; Read & Bellairs 1999) and therefore could have some influence on species composition and diversity. Dixon *et al.* (1995) reported positive germination responses to smoke in 45 of 94 south-western Australian species, and Read and Bellairs (1999) reported that smoke had a significant influence on native grass germination in NSW. Hence the influence of smoke in an experiment investigating fire should not be ignored.

Grazing following fire can have a strong influence on community composition (Leigh & Holgate 1979; Irvin *et al.* 2000). Increased grazing intensity in recently burnt areas has been widely reported (Leigh & Holgate 1979; Robertson 1985; Biondini *et al.* 1989; Meers & Adams 2003; Fuhlendorf & Engle 2004; Letnic 2004) because burning removes dead material from perennial grasses and increases the relative palatability of the forage (Scanlan 1980; Robertson 1985). The interaction between fire and grazing has not been studied on the Moree Plains. Past prescribed burns at Kirramingly Nature Reserve have been relatively small (<20 ha) and hence may have resulted in higher post-fire grazing intensities by kangaroos (Mulham 1985; Meers & Adams 2003). Eastern Grey Kangaroos (*Macropus giganteus*) are known to be highly selective grazers, with a preference for grasses over dicots (Robertson 1985; Landsberg & Stol 1996). Grazing may have a particularly negative effect on grasses that resprout vegetatively after fire because stored resources that are used to recover after the fire would be severely taxed (Daubenmire 1968). Hence we might expect a decrease in the abundance of certain grass species due to kangaroo grazing post-fire. If fire is to be used for conservation management in Kirramingly Nature Reserve, the effects of post-fire grazing (by kangaroos in this case) should be determined and monitored.

Managers are concerned about the potential negative impact on conservation value that burning may cause and there is a need to determine the influence of fire on plant diversity before it is used in long-term management of nature reserves like Kirramingly (Clarke *et al.* 1998). The major objectives of this chapter are to determine:

1. The influence of burning in two seasons (autumn and spring) on species composition, richness and evenness.
2. The influence of repeated burning (two burns approximately 3 years apart *vs* one burn) on species composition, richness and evenness.
3. The effect of native herbivore grazing, immediately after fire in autumn and spring, on species composition, richness and evenness.
4. Whether smoke from fires influences species composition, richness and evenness.
5. How some individual plant species respond to fire in autumn and spring, in terms of survival and seed production.

5.2 Methods

5.2.1 Experimental design and site establishment

Fire experiment

To determine the influence of controlled burns carried out in autumn and spring of 2002 on plant species richness, evenness and composition, 18 plots (200 x 200 m) in a lattice framework were established (Fig. 5.1). The 18 plots were randomly divided into one of three treatments (control, spring burn and autumn burn), with six plots in each treatment. The experiment was established in the north-west corner of Kirramingly Nature Reserve. This part of the Reserve was chosen because: (1) It included an area that had previously been burnt in May of 1999 by NPWS, for hazard reduction. This allowed six of the 18 plots (two control, two spring and two autumn plots) to be established in this previously burnt area (Fig. 5.1) to provide information on fire frequency. (2) The vegetation within the area is relatively homogeneous and is dominated by *Astrebla elymoides* and *Dichanthium sericeum*. (3) The experimental area runs along part of the northern border of the Reserve, thereby providing a fire-break. NPWS is required to maintain a fire-break on the northern boundary of the Reserve to protect the neighbouring property.

Plots were delineated in March 2002, using a compass, flagging tape and tape measures. The corner of each plot was marked with a steel post and the border of plots to be burnt was defined by grading and then disc ploughing a 3 m wide strip of the vegetation. The

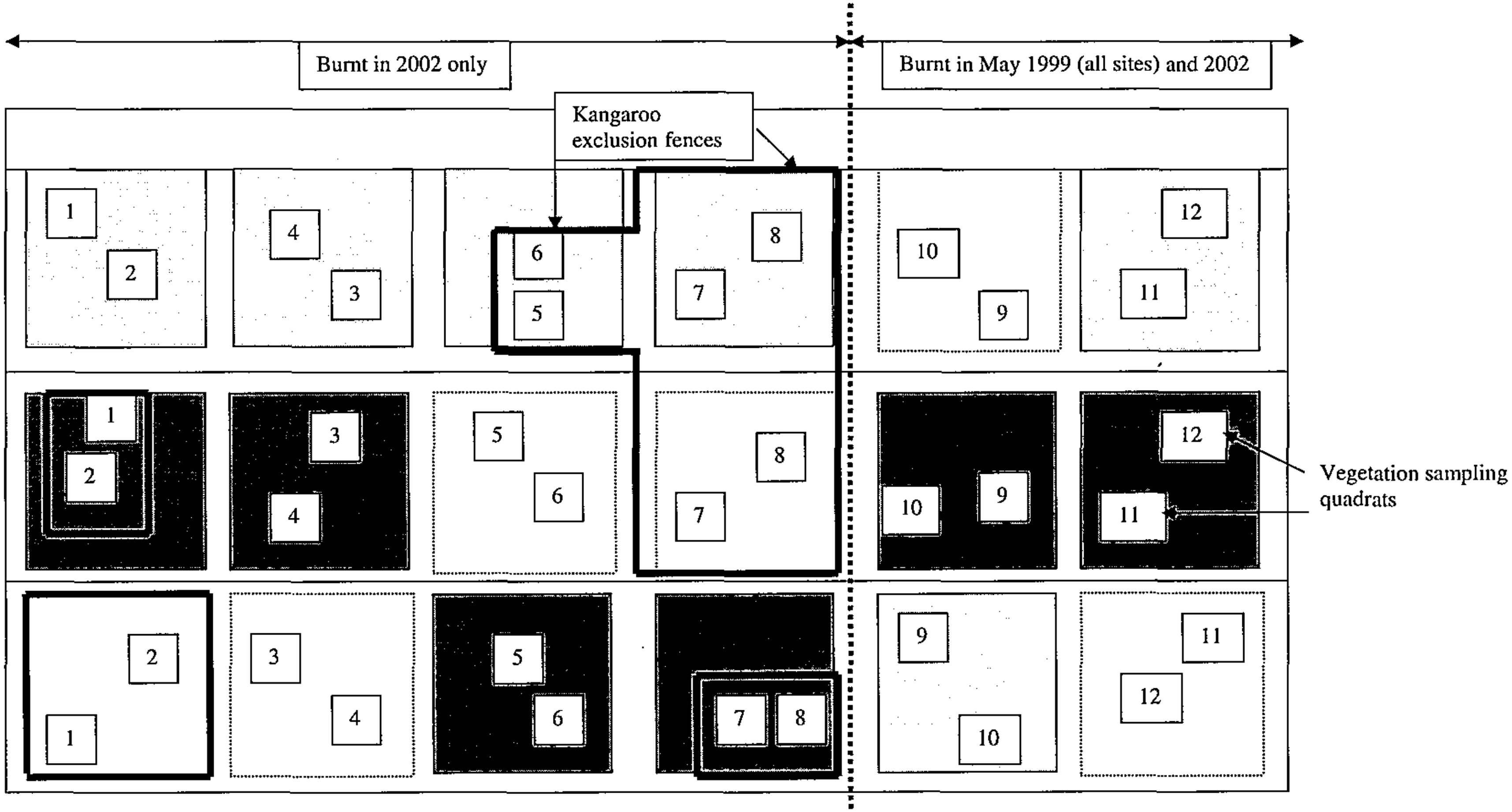


Fig. 5.1. Experimental design for the fire and kangaroo grazing experiment, showing positioning of plots (200 x 200 m) within areas burnt and unburnt in autumn 1999, and kangaroo exclusion fences. Light grey, spring 2002-burnt plots; dark grey, autumn 2002-burnt plots; white, plots unburnt in 2002 (controls). Numbered squares represent vegetation-sampling quadrats. Eight distant control quadrats are positioned outside of the experimental area.

grading and ploughing was carried out by a private contractor in April-May 2002. Within each plot two permanent points (quadrats) were marked for measurements on vegetation response. This was done randomly, by dividing each plot into a 10 by 10 grid, and obtaining two random grid references for each plot. The centre of each quadrat was marked using a steel post and the location of each was recorded using a Garmin® GPS. A steel label with the quadrat number punched into it was attached to each post. A further eight sampling quadrats were established outside the experimental area, but within the same vegetation type, as additional controls to determine whether smoke from the fires influences species composition, richness and evenness. These quadrats were positioned south of the experimental area in the same management unit (paddock), at least 500 m from the experimental plots.

Kangaroo grazing post-fire

In addition to the influence of fire season and repeated burning, the effect of kangaroo grazing post-fire was investigated. This involved fencing areas to exclude native herbivores. Two kangaroo exclusion areas were constructed in each seasonal treatment (six in total). Figure 5.1 illustrates how the exclusion areas were positioned within the area. Exclusion areas were only constructed in the plots that had not previously been burnt in May 1999, due to the cost of fencing materials.

The same sampling quadrats established for the fire experiment were used to determine the influence of kangaroo grazing post-fire on vegetation composition and richness. Kangaroo exclusion areas varied in size but were constructed to include both quadrats within each plot (Fig. 5.1). Two control plots (i.e. unburnt) were entirely fenced (200 x 200 m) to allow establishment of another experiment to investigate mowing impacts (Chapter 6). Exclusion areas were made as large as possible given the funding constraints, to allow future studies. In one case, where three of the exclusion areas were bordering each other, they were joined together to save money on fencing materials (Fig. 5.1).

All fences were constructed by a private contractor (G.M. Bourke) in September 2002, immediately after the spring burn and approximately 5 months after the autumn burn. Kangaroo grazing on plots burnt in autumn was almost non-existent prior to fence construction, due to the lack of grass germination after this burn. Fences were 1.8 m high, and were made out of hinge joint wire. Each exclusion area had a vehicle access gate.

5.2.2 Vegetation sampling

The frequency score method of vegetation sampling was used, with five nested concentric quadrats (sub-quadrats), each doubling in sample area (i.e. 2, 4, 8, 16 and 32 m^2). The incidence of all vascular plant species was recorded in each of the concentric sub-quadrats, and a score assigned to each species based on the number of sub-quadrats in which they were recorded (i.e. out of five). Data collected from previous surveys at the Reserve (Clarke *et al.* 1998; and myself) were used to determine the total quadrat size. Species-area curves for data with ten concentric sub-quadrats (0.1024 ha) suggested that five concentric sub-quadrats was adequate to record most species present, and this was far less time consuming than sampling 0.1024-ha areas. A cover score based on projected cover was recorded for all species within each quadrat (Table 3.1). Vegetation at all quadrats was sampled immediately before each burn, starting in April of 2002 and at approximately 5-6 month intervals after each burn. Actual months of sampling were April 2002, September 2002, April 2003, October 2003 and February-March 2004. A total of 44 quadrats were sampled at each time (36 within the experimental area and eight distant controls).

5.2.3 Assessing kangaroo grazing habitat preference post-fire

Dung counts are correlated with herbivore activity (Landsberg & Stol 1996; Letnic 2004), and, hence, were used to assess the habitat preference of kangaroos. To determine whether kangaroos preferentially grazed in areas regenerating after the burns, dung pellet counts were made in burnt and unburnt plots. Dung counts were also made in the unfenced and fenced plots, to ensure that there was no herbivore activity within fenced plots. Counts were made within circles with an area of 20 m^2 in October 2003. Two counts were made within each 200 x 200-m plot (Fig. 5.1), by randomly positioning the two circles in the plot. To search the 20-m^2 areas accurately, a length of string of appropriate radius (2.52 m) was anchored to the centre of the circle to delineate its boundary. The centre of each counting circle was marked with a wooden post to allow each location to be revisited in March 2004. Sites were revisited in 2004 to count accumulated dung over the 5-month period.

Counts were made by thoroughly searching the area, recording all individual pellets and removing them from the area. Pellets were recorded as either brown (relatively recent) or grey (i.e. at least 1 month old). Counts were made in the autumn-burnt, spring-burnt and unburnt treatments (4 fenced and 8 unfenced). Dung counts in 2003 were made approximately 12 months after the spring burn and 18 months after the autumn burn. The 2004 counts were made 18 and 24 months after burns, respectively. Means were calculated for each fire treatment at both times. No recent dung and very little grey-coloured dung was recorded in the unburnt fenced plots, which suggests that most dung had decomposed within 12 months. However, the fact that some grey dung may last for >12 months meant that only recent (brown coloured) dung could be analysed, as control sites may have had old dung there prior to burning.

5.2.4 Tagged individuals

The responses of certain plant species to the experimental burns in each season were measured by tagging individual plants. Species were chosen to represent a range of plant functional groups (grasses, forbs, sub-shrubs and shrubs) growing in the area, and were considered important in aiding management decisions for the Reserve (T. Waters, pers. comm., 2002). A total of 18 *Astrebla elymoides*, *Dichanthium sericeum*, mature *Acacia farnesiana,* juvenile *Acacia farnesiana* and *Desmodium campylocaulon* plants were tagged in each seasonal fire treatment (spring burn, autumn burn and unburnt). Juvenile *A. farnesiana* plants varied from 20-80 cm in height and had narrow basal diameters (generally <1 cm). Eight *Acacia stenophylla, Maireana aphylla* and *Astrebla lappacea* plants were tagged in each treatment due to their lesser abundance. Plants were tagged in the vicinity of quadrats to ensure that they could easily be found. They were tagged using steel pins (approximately 75 cm tall) with a label attached, which were pushed into the ground 5-10 cm west from the base of the plant. Labels were attached directly to the base of mature *A. farnesiana* and *A. stenophylla* plants. The location of each tagged plant was also mapped relative to the steel post marking the centre of sampling quadrats. In general, there were two or three tagged plants of each species in the vicinity of one quadrat in each plot. Unfortunately, over the course of the study several steel pins and labels were removed by kangaroos and these plants were excluded from the experiment.

To determine the survival of individuals after fire, tagged plants were revisited in April 2003 and March 2004 to record their presence or absence. The number of seed heads produced was recorded for each tagged grass plant. Initial measurements were made before each fire in April and September 2002, with subsequent measurements in April

2003 and March 2004. The counts of seed heads in September 2002 were omitted from the analysis because flowering of these species occurs mostly over summer.

5.2.5 Controlled burning, pre-fire conditions and fire intensity

Prior to each fire, fuel loads were estimated by harvesting a number of herbaceous biomass samples to ground level, and estimating the biomass of *Acacia farnesiana*. Four herbaceous biomass samples were collected the day before each fire, at each vegetation sampling quadrat within plots to be burnt. A 28 by 28-cm square was randomly thrown 3-10 m from the centre of each quadrat in four directions (i.e. north, south, east and west). All vegetative material within each square was collected using secateurs and placed into a labelled paper bag. Large shrubs (i.e. *Acacia farnesiana*) were avoided, as biomass of shrubs was calculated separately. Herbaceous biomass samples were weighed in the laboratory, oven dried for approximately 70 hours at 80°C, then reweighed. This was done to provide an estimate of fuel moisture content and average dry weight of herbaceous material (Table 5.1).

The biomass of shrubs (*Acacia farnesiana*) was calculated by firstly estimating the density of shrubs in each 200 x 200-m plot. The number of plants was counted within a 2500-m^2 area, randomly chosen within the plot. The average weight of an *Acacia farnesiana* plant was estimated by randomly choosing 10 plants (five in the plots that had no previous fire history and five in the plots that had been burnt in May 1999). The individual plants were cut into pieces using secateurs and a handsaw, and then oven dried at 80°C until a constant weight was reached. The average weight per plant was then calculated for the plots that had been previously burnt and those that had not, as plants in the previously burnt area appeared smaller. Average biomass of *Acacia farnesiana* was estimated for each plot using the average weight per plant and density. This value was added to the average dry weight of herbaceous material to estimate total biomass (Table 5.1).

Table 5.1. Total and herbaceous biomass and fuel moisture content (mean ± SE (*n*)) estimated for plots prior to burning in autumn and spring 2002

Season	Fuel moisture content (%)	Herbaceous biomass (t/ha)	Total biomass (t/ha)
Autumn	2.6 ± 0.23 (48)	3.1 ± 0.32 (6)	4.7 ± 0.46 (6)
Spring	3.1 ± 0.35 (48)	3.5 ± 0.55 (6)	4.7 ± 0.56 (6)

Given the importance of seasonal conditions on vegetation response to fire, soil moisture was measured immediately before each burn, by taking gravimetric soil samples in containers, 7.5 cm in diameter and 5 cm deep, with tight seal lids. Two soil samples were collected at each vegetation sampling quadrat in plots to be burnt. Samples were collected approximately 4 m north and west from the centre of each quadrat, by pushing the container into the ground and sealing immediately. All soil samples were weighed 4 days after collection, and were oven dried at 110°C to constant weight (about 24 hours). Samples were allowed to cool before reweighing. The mass of water and percentage water per sample were then calculated. Unfortunately, soil moisture measurements were considered inaccurate (i.e. unusually low values for clay soils) and have not been reported in this thesis.

Controlled burns were carried out by NPWS staff over one day in May and again in September 2002. A number of measurements were made immediately before and during each burn at each plot. These included, average wind speed, maximum wind speed, wind direction, wind behaviour (i.e. erratic, gusty, steady), ambient air temperature, relative humidity, flame height and rate of spread. Weather information was measured using a Kestrel® 3000. Measurements were recorded 2-6 times for each plot and, where appropriate, averages were calculated (Table 5.2). Flame height generally varied from 1-3 m for fires in both seasons (e.g. Fig. 5.2). Numerous photos were taken during each burn to confirm visual estimates (e.g. flame heights). Winds were gusty during burns in both seasons, but were generally from the south-west during the autumn burns and east to south-east during the spring burns. Given these wind directions it is very unlikely that control sites distant from the experiment were affected by smoke. Most herbaceous vegetation was consumed by the fires (Fig. 5.3). Foliage of *Acacia farnesiana* was burnt, but there were patches of *A. farnesiana* in some plots where the canopy was not completely removed. Fire temperatures just below the ground were estimated using Thermax, Level B, surface temperature indicating strips. Six strips were buried 1 cm below the ground at randomly selected quadrats.

Fire intensity (I) in each plot was estimated using the equation from Cheney and Sullivan (1997):

$$I = H \times W \times R$$

where H = heat yield (kJ/kg), W = fuel consumed (kg/m^2) and R = rate of spread (m/s).

An estimate of heat yield was obtained from Cheney and Sullivan (1997). For *Themeda australis* grassland, heat yield varies from 14 500-17 800 kJ/kg depending on moisture content (Cheney & Sullivan 1997). Based on these values, and values for other grasslands (Cheney & Sullivan 1997), I used a heat yield of 15 000 kJ/kg for calculating fire intensity. Fuel consumed was calculated from the total biomass of each plot and rate of spread was estimated visually during the fires. A mean rate of spread and fire intensity was calculated for burns in each season (Table 5.3). The burns in autumn 2002 covered an area of approximately 24 ha (six 4-ha plots), while spring burns covered approximately 50 ha (six 4-ha plots, plus an additional fire-break along some of the northern boundary of the Reserve).

Table 5.2. Climatic variables (mean ± SE) recorded on the day of burning plots in autumn and spring 2002 (n = 6 for all)

Season	Air temperature (°C)	Relative humidity (%)	Wind speed (km/hr)
Autumn	18.5 ± 0.35	36.0 ± 0.37	7.7 ± 0.31
Spring	21.8 ± 1.33	21.4 ± 3.09	5.1 ± 0.54

Fig. 5.2. Controlled burning (back-burning) in September 2002 along the edge of a ploughed containment line. Flame heights for fires in both seasons generally varied from 1-3 m.

Fig. 5.3. Vegetation monitoring site (marked by the steel post) immediately after controlled burning in May 2002.

Table 5.3. Rate of spread of fires and an estimation of fire intensity (mean ± SE) for plots burnt in autumn and spring 2002 ($n = 6$ for all)

Season	Rate of spread (km/hr)	Intensity (kW/m)
Autumn	1.5 ± 0.13	2880 ± 440
Spring	1.1 ± 0.14	2260 ± 385

5.2.6 Statistical analysis

Multivariate redundancy analysis (RDA) was used to investigate the influence of different fire and grazing treatments on composition using CANOCO, version 4.5 (ter Braak & Šmilauer 2002). The reasons for choosing this multivariate analysis technique have previously been discussed in Sections 3.2.7 and 4.2.5. Indirect gradient analysis using detrended correspondence analysis (DCA) of species cover data produced a gradient length of 1.83. This is a short gradient length (i.e. species were responding roughly linearly to the explanatory variable gradients) indicating that RDA was a more appropriate technique than correspondence analysis (CCA). However, data were analysed using both techniques and similar results were obtained for both methods. Data were also analysed for both species frequency and species cover scores. Similar results were obtained so only results from the species cover data are reported (to be consistent with earlier chapters). The final data set consisted of three environmental variables (with 14 categories), 44 sites, five sample times (220 surveys in all) and 98 species. The environmental variables and their categories are outlined in Table 5.4. All environmental variables were nominal and, hence, dummy variables were defined prior to analysis (Section 3.2.7). Automatic forward selection was used to determine the rank of each explanatory variable and its relative importance in determining species composition (ter Braak & Šmilauer 2002). Unconstrained ordination using principal components analysis (PCA) was used to create plots to show changes in species composition before and after fire treatments. PCA is considered the unconstrained linear method equivalent to RDA (Lepš & Šmilauer 2003). Environmental variables were kept in the analysis and were passively projected *post hoc* into the ordination space. Further information regarding the options used in analysis and interpretation of ordination output can be found in Sections 3.2.7 and 4.2.5.

Table 5.4. Environmental variables used in multivariate analysis, and their codes used in tables and figures

Environmental variable	Variable categories	Code
Sampling period	1) Autumn 2002 2) Spring 2002 3) Autumn 2003 4) Spring 2003 5) Autumn 2004	1) Autumn 02 sampling 2) Spring 02 sampling 3) Autumn 03 sampling 4) Spring 03 sampling 5) Autumn 04 sampling
Fire history	1) Burnt autumn 2002 2) Burnt spring 2002 3) Burnt autumn 1999 4) Burnt autumn 1999 & 2002 5) Burnt autumn 1999 & spring 02 6) Unburnt (within experiment) 7) Unburnt (distant)	1) Autumn 02 burn 2) Spring 02 burn 3) Autumn 99 burn 4) Autumn 99 & autumn 02 burns 5) Autumn 99 & spring 02 burns 6) Not burnt 7) Distant controls
Kangaroo grazing	3) Yes 4) No	1) Kangaroo grazed 2) Not grazed

Univariate analyses of total, native, introduced, grass and forb species richness, species evenness (Smith and Wilson's Index) and heterogeneity (Simpson's Index) were carried out using GenStat (6th edition) and the program R (Version 1.7.1). Shrub and graminoid richness was low within the experimental area and these variables were not analysed. Smith and Wilson's Index for evenness and Simpson's Index for heterogeneity (or diversity) were calculated using the software 'Programs for Ecological Methodology' (Krebs 2002). In these calculations frequency scores (1-5) were used as a measure of abundance. Frequency scores were used in preference to cover abundance scores because cover abundance was insensitive to variation for the majority of less common species. That is, the majority of species in each quadrat were given a cover abundance score of one or two because they had a projected cover of <5% (Table 3.1). Methods for calculating these indices are provided in Krebs (1999).

Evenness measures attempt to quantify the unequal representation of species within a community against a hypothetical community in which all species are equally common

(Krebs 1999). A review by Krebs (1999) suggested the use of Smith and Wilson's Index to measure evenness. This index is considered superior to other evenness measures because it is independent of species richness and is sensitive to both rare and common species in the community (Krebs 1999). Simpson's Index was chosen as a measure of heterogeneity (or diversity) because it is a simple and commonly used index that takes into account species richness and evenness (Begon *et al.* 1996). For many ecologists the term heterogeneity is synonymous with diversity (Krebs 1999). There are many ways of measuring species diversity, and there is much controversy about which indices are best (Krebs 1999). Simpson's Index was chosen to allow comparisons with a similar study by Wright (2001), who used this index for measuring diversity in *Astrebla* grasslands after fire in Queensland.

Generalised linear models were used to identify differences in the mean frequency score of species per quadrat between different fire treatments. Comparisons were made between: (1) sites burnt in autumn 2002, spring 2002 and unburnt sites; (2) sites burnt once in autumn 2002 and twice in autumn (1999 and 2002); and (3) sites burnt once in spring 2002 and sites burnt twice (autumn 1999 and spring 2002). Pre-existing differences in frequency (i.e. in autumn 2002) are also reported when comparing sites burnt in autumn 1999 with sites that had not yet been burnt. To account for pre-existing differences in frequency, differences between the initial sampling time (autumn 2002) and other sampling times (autumn 2003 and 2004) were analysed. Comparisons were made only for the autumn sampling periods due to the lack of spring data obtained prior to certain treatments. Species with less than five occurrences for each test were ignored, because results could easily have been due to chance. Bonferroni adjustment was used to incorporate the number of statistical tests and reduce the possibility of inappropriately assigning a significant conclusion (type 1 error; Zar 1999). In addition to recording species responding significantly after Bonferroni adjustment, some responses considered biologically significant are also reported.

To determine the effect of burning and kangaroo grazing on total, native, introduced, grass and forb species richness, species evenness and heterogeneity, analysis of variance (ANOVA) was carried out. Given that I returned to the same sampling quadrats for successive data collections (i.e. sampling was not re-randomised for each sampling time), repeated measures ANOVA was used. Repeated measures ANOVA treats time as a fixed factor nested within treatment plots (Green 1993). Pre-treatment (autumn 2002) data were used as a covariate to increase the sensitivity of the important main effects (i.e. between subjects stratum) by reducing the magnitude of the between subjects error term. A three-factor repeated measures ANOVA compared once-off burns in autumn and spring 2002 and unburnt areas, with treatments either exposed to, or excluded from, kangaroo grazing. All interactions between sampling time, fire treatment and grazing occurrence were investigated. In this analysis, there were four quadrats within each of the fire and grazing treatment combinations (Table 5.5). These quadrats were sampled five times (autumn 2002, spring 2002, autumn 2003, spring 2003 and autumn 2004). Given that the four quadrats in each treatment were situated over two replicated plots (Fig. 5.1), the potential differences between plots were taken into account in the analysis by nesting quadrats (subplots) within plots. While establishing two quadrats in each plot gives a better indication of the composition and richness of that plot, multiple quadrats do no increase the number of degrees of freedom available for testing for treatment effects Hurlbert (1984).

Table 5.5. The number of quadrats sampled at each time for the experiment investigating the influence of burning season and the occurrence of kangaroo grazing. There were two quadrats in each replicated plot

	2002 Fire treatment		
Grazing	Unburnt	Spring-burnt	Autumn-burnt
Grazed	4	4	4
Ungrazed	4	4	4

A second analysis was carried out to investigate repeated burning without exclusion of kangaroo grazing. A two-factor repeated measures ANOVA compared areas burnt once in spring or autumn 2002 with areas burnt twice (spring or autumn 2002 and May 1999), and unburnt areas. Interactions between repeated burning and season of burn could not be investigated because of the unbalanced experimental design (Table 5.6). It is recognised that allocation of treatments is not strictly random when an experiment is placed over existing differences (i.e. the 1999 fire), however, given the short time available for this research, this was unavoidable.

Repeated measures ANOVA was also used to compare controls distant from the experiment with unburnt controls in the experimental area. Interactions with sampling time were again investigated. Unfortunately this comparison is pseudoreplicated (Hurlbert 1984), because the eight distant control quadtrats only represent a single replicate. Given this lack of replication care should be taken when making inferences from this data.

For all of the above analyses unplanned, one degree of freedom contrasts were used to identify differences between treatments at certain times, after looking at graphs to determine where contrasts were necessary.

Table 5.6. Unbalanced design for the experiment investigating the influence of repeated burning and fire season. There were two quadrats in each replicated plot. NA, treatment combinations not sampled

	2002 Fire treatment		
Frequency	Unburnt	Spring-burnt	Autumn-burnt
Unburnt	4	NA	NA
Burnt once (in 1999 or 2002)	4	4	4
Burnt twice (1999 and 2002)	NA	4	4

Asymmetrical variance/covariance matrices over time were accounted for in the repeated measures analyses by multiplying the degrees of freedom by correction factors before calculating F probabilities (Payne 2002). For each of the above analyses the assumptions of ANOVA were checked using a normal probability plot of the residuals (to check the assumption of normally distributed data) and a residual plot (to check the assumption of equal variances). Square root transforms were applied to the variables' total, native, introduced, grass and forb richness, while an arcsine transform was applied to species evenness and heterogeneity, before the final analysis. In comparing seed head production of grass species, the nonparametric Kruskal-Wallis (H) test was used because the data could not be transformed to meet the assumptions of ANOVA. To compare herbaceous biomass in the different seasons prior to burning, t-tests were used. The Pearson chi-square test was used to identify differences in the percentage survival of tagged individuals associated with fire treatments in 2002.

5.3 Results

5.3.1 General survey findings

A total of 103 plant taxa were recorded in the 220 surveys at 44 sites, of which 86% (89) were native and 13% (13) were introduced (Appendix 5.1). The taxa belonged to 32 plant families (Appendix 5.1). The ten most frequently occurring taxa (and their mean ± SE frequency per quadrat) across all 220 surveys were: *Astrebla elymoides* (4.6 ± 0.08), *Eriochloa pseudoacrotricha* (4.1 ± 0.10), *Cullen tenax* (3.9 ± 0.10), *Aristida leptopoda* (3.8 ± 0.09), *Dichanthium sericeum* (3.7 ± 0.11), *Neptunia gracilis* (3.7 ± 0.13), *Convolvulus erubescens* (3.5 ± 0.10), *Chloris truncata* (3.5 ± 0.11), *Sida trichopoda* (3.4 ± 0.13) and *Panicum queenslandicum* (3.2 ± 0.14).

Prior to treatments in autumn 2002, total species richness varied from 30 to 45 species per quadrat, with an average of 36.6 ± 0.46, while native and introduced species richness was 35.1 ± 0.47 and 1.5 ± 0.11 per quadrat, respectively. Sites were comprised mostly of forbs (18.1 ± 0.34 species per quadrat) and grasses (14.2 ± 0.21 species per quadrat).

5.3.2 Influence of burning season and kangaroo grazing post-fire

Pre-fire conditions and variables recorded during the fires were similar during burns in both seasons (Section 5.2.5); hence it is not surprising that fire intensity was also similar for spring and autumn burns (Table 5.3). There were no significant differences in herbaceous biomass between areas burnt in May 1999 and unburnt areas prior to burning in autumn 2002 ($t = -0.28$, d.f. = 94, $P = 0.783$) and spring 2002 ($t = 1.07$, d.f. = 94, $P = 0.287$). Soil temperatures at approximately 1 cm below the surface did not reach 77°C during the fires, which was the lowest temperature to induce a colour change on the indicator strips.

ANOVA of seven species richness and evenness variables in relation to season of burn, kangaroo grazing and time are reported in Table 5.7. There was no significant three-way interaction (Time*Grazing*Fire) for any of the variables (Table 5.7). There were significant interactions between sampling time and season of burn for total, native, forb and grass species richness and heterogeneity (Table 5.7). These interactions were the result of significant reductions in richness in spring 2002 across all treatments (and controls), and a more pronounced treatment-related reduction at this time for autumn-burnt sites (Fig. 5.4a,b,e,g). All variables, except species evenness, were influenced by sampling time (Table 5.7; Fig. 5.4a,b,c,d,e,g).

There were no significant interactions between fire treatment and kangaroo grazing (Table 5.7). Burning had a significant effect on total, native and grass species richness and heterogeneity (Table 5.7). This was mostly due to a reduction in grass species richness at autumn-burnt sites in spring 2002 (Fig. 5.4e), which also reduced total and native richness and species heterogeneity at this time.

Significant treatment effects were identified in spring 2002 and spring 2003 only. In spring 2002 total, native and grass species richness and species heterogeneity were significantly higher at unburnt sites than sites burnt in autumn (Fig. 5.4a,b,e,g; total, $F_{1,6} = 157.21$, $P < 0.001$; native, $F_{1,6} = 160.25$, $P < 0.001$; grass, $F_{1,6} = 96.14$, $P < 0.001$; heterogeneity, $F_{1,6} = 222.90$, $P < 0.001$). Species evenness was higher at the autumn-burnt sites than the unburnt sites (Fig. 5.4f; $F_{1,6} = 9.22$, $P = 0.023$).

In spring 2002 very few grass species were recorded at sites burnt in autumn 2002 (Fig. 5.4e, 5.5). These burnt sites consisted mostly of forbs such as *Boerhavia dominii, Chamaesyce drummondii, Convolvulus erubescens, Cullen tenax, Sida trichopoda, Neptunia gracilis, Swainsona queenslandica, Ptilotus semilanatus, Solanum esuriale, Eryngium plantagineum, Wahlenbergia communis* and *Oxalis perennans*. Most of these species appeared to be resprouting from rootstock. The shrub, *Acacia farnesiana,* and sub-shrubs, *Maireana decalvans* and *Sclerolaena muricata* var. *villosa,* were also resprouting in spring 2002 at some autumn-burnt sites.

In spring 2003 only minor differences in richness existed (Fig. 5.4a,b,c,d,e). Introduced and grass species richness was significantly higher at spring-burnt sites than control sites (Fig. 5.4c,e; $F_{1,6} = 9.75$, $P = 0.021$ and $F_{1,6} = 9.92$, $P = 0.020$, respectively). Differences in richness between autumn-burnt sites and controls were not significant.

Table 5.7. Repeated measures ANOVA table showing effects of fire treatments, kangaroo grazing and sampling time on species richness (total, native, introduced, forb and grass) and evenness measures (evenness and heterogeneity). The quadrat within plot stratum has not been included in this table, for ease of interpretation

Variable		Total		Native		Introduced	
	d.f.	*F*	*P*	*F*	*P*	*F*	*P*
Between-subjects							
Fire	2	22.81	0.003	17.77	0.005	0.55	0.611
Grazing	1	0.58	0.481	0.35	0.581	0.19	0.683
Fire*Grazing	2	1.74	0.267	1.36	0.337	0.07	0.935
Covariate (Autumn 2002 sampling)	1	2.16	0.201	2.02	0.215	0.23	0.655
Residual	5	0.96		1.07		9.28	
Within-subjects							
Time	3	402.70	<0.001	292.24	<0.001	331.86	<0.001
Time*Fire	6	24.92	<0.001	23.93	<0.001	0.93	0.467
Time*Grazing	3	0.71	0.516	0.61	0.563	0.51	0.640
Time*Fire*Grazing	6	0.39	0.832	0.32	0.878	0.99	0.434
Residual	54						

Table 5.7. (continued)

Variable	d.f.	Forb *F*	*P*	Grass *F*	*P*	Evenness *F*	*P*	Heterogeneity *F*	*P*
Between-subjects									
Fire	2	0.48	0.646	93.93	<0.001	2.13	0.214	147.77	<0.001
Grazing	1	0.09	0.782	0.55	0.490	1.18	0.327	0.33	0.591
Fire*Grazing	2	2.88	0.147	5.55	0.054	0.70	0.541	4.99	0.064
Covariate (Autumn 2002 sampling)	1	3.43	0.123	9.80	0.026	1.30	0.306	6.92	0.047
Residual	5	4.10		2.87		0.62		1.06	
Within-subjects									
Time	3	330.09	<0.001	133.80	<0.001	1.01	0.382	712.24	<0.001
Time*Fire	6	3.39	0.031	132.29	<0.001	1.39	0.247	94.62	<0.001
Time*Grazing	3	0.57	0.528	2.49	0.082	0.43	0.686	0.26	0.715
Time*Fire*Grazing	6	1.41	0.261	1.81	0.129	0.86	0.513	0.31	0.821
Residual	54								

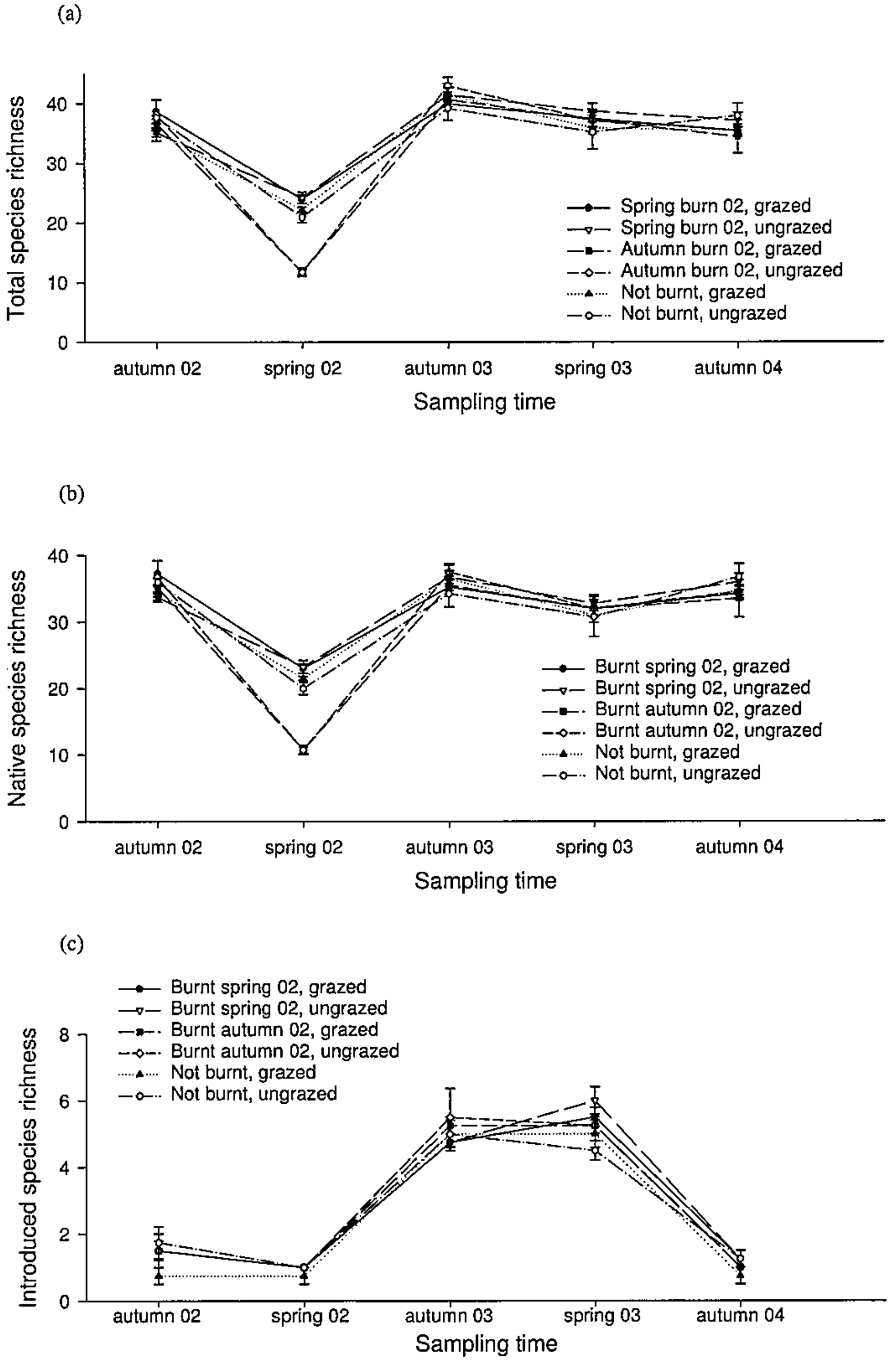


Fig. 5.4. Changes in mean (± SE) species richness, evenness and heterogeneity through time at quadrats either burnt in autumn or spring, or unburnt, and either kangaroo grazed or ungrazed (*n* = 4 quadrats for all treatments). Variables: (a) total; (b) native; (c) introduced; (d) forb; and (e) grass species richness; (f) species evenness; and (g) species heterogeneity.

Fig. 5.4. (continued)

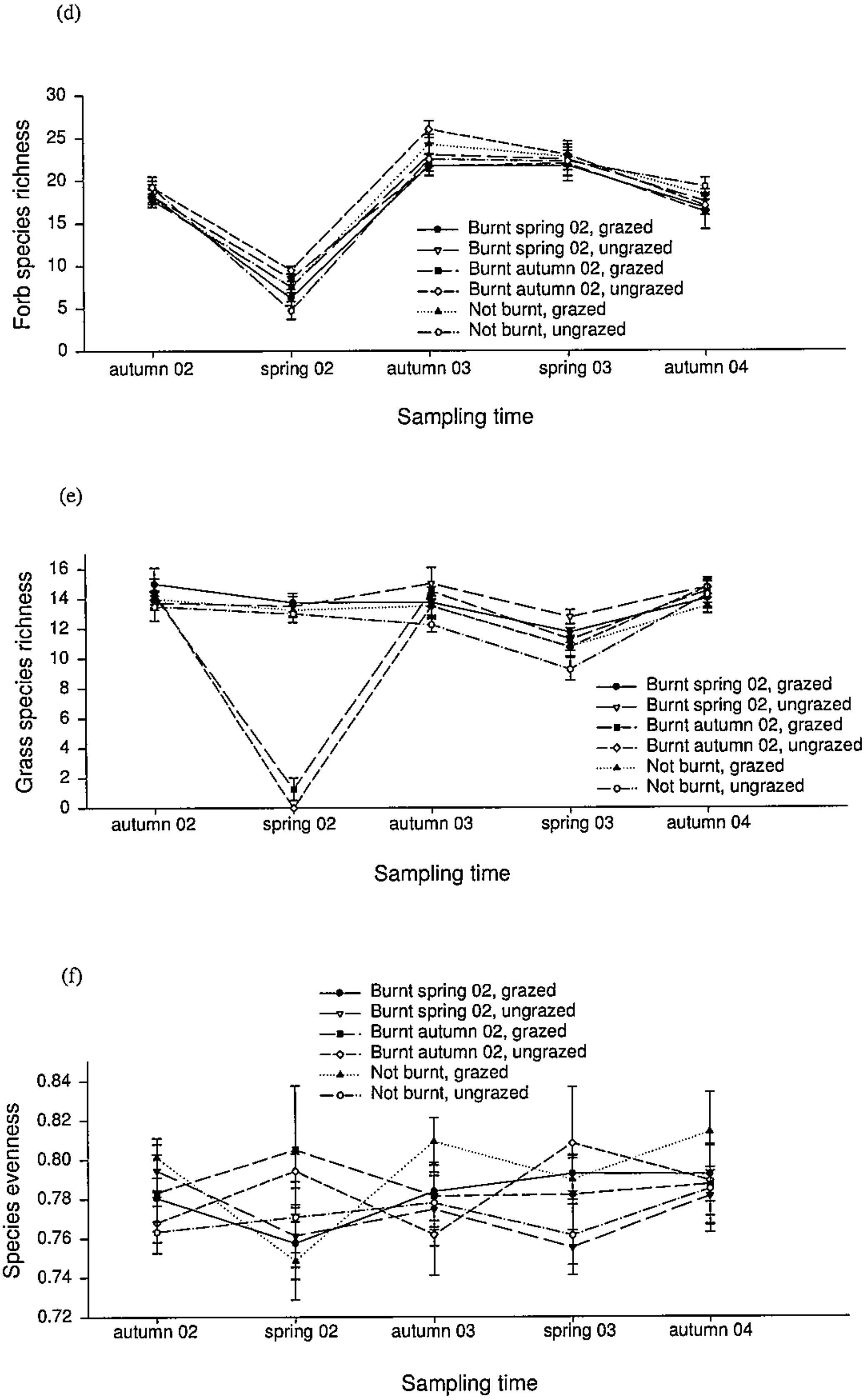
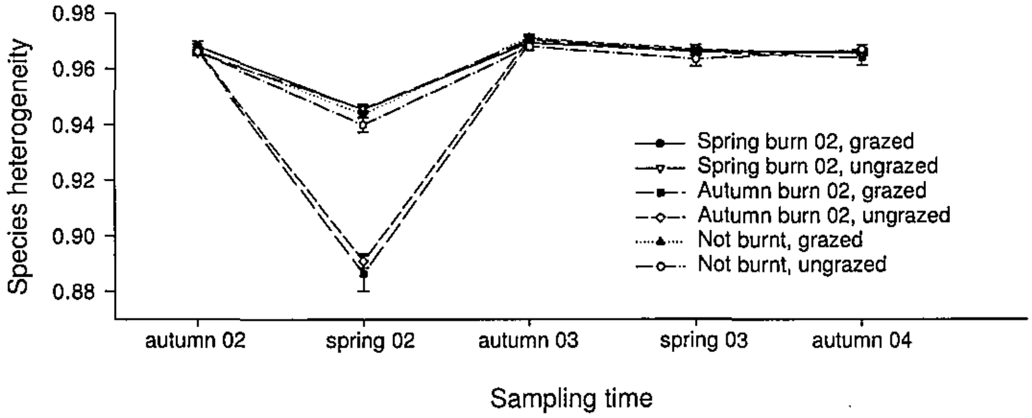


Fig. 5.4. (continued)

(g)



Species evenness was not influenced by sampling time nor fire treatment (Table 5.7). No variables were significantly affected by kangaroo grazing (Table 5.7).

In 2003 there was marginally more recent kangaroo dung within the autumn-burnt areas than in spring-burnt or control areas ($F_{2,12} = 3.15$, $P = 0.080$; Table 5.8). However, in 2004 there was no difference in dung counts between areas ($F_{2,12} = 0.64$, $P = 0.543$; Table 5.8). The effect of fencing on kangaroo grazing was obvious, as no recent dung was recorded within fenced areas in 2003 or 2004.

Mean frequency score per quadrat for all species in each fire and grazing treatment averaged over all times, is provided in Appendix 5.2. Six species responded positively to burning (either or both treatments). Four of these were annuals (*Eragrostis parviflora, Sporobolus caroli, Portulaca oleracea* and **Medicago truncatula*) and two were perennials (*Panicum buncei* and *Boerhavia dominii*). In autumn 2003, *Eragrostis parviflora* and *Panicum buncei* were favoured by burning in both seasons (Table 5.9). At this time *Portulaca oleracea* and **Medicago truncatula* were favoured more by spring burning than by autumn burning (Table 5.9). In autumn 2004, *Sporobolus caroli* and *Boerhavia dominii* were favoured by autumn burning (Table 5.9).

Five species responded negatively to burning or were more frequent at control sites than at burnt sites (Table 5.9). In autumn 2003, *Goodenia fascicularis*, **Hedypnois* *rhagadioloides* and **Sonchus oleraceus* were more frequent at unburnt sites (Table 5.9). *Goodenia fascicularis* remained more frequent at unburnt sites in autumn 2004. *Oxalis perennans* decreased in frequency in response to burning in both seasons and remained less frequent at burnt sites in autumn 2004 (Table 5.9). In autumn 2003, *Vittadinia cuneata* responded negatively to autumn burning but not spring burning.

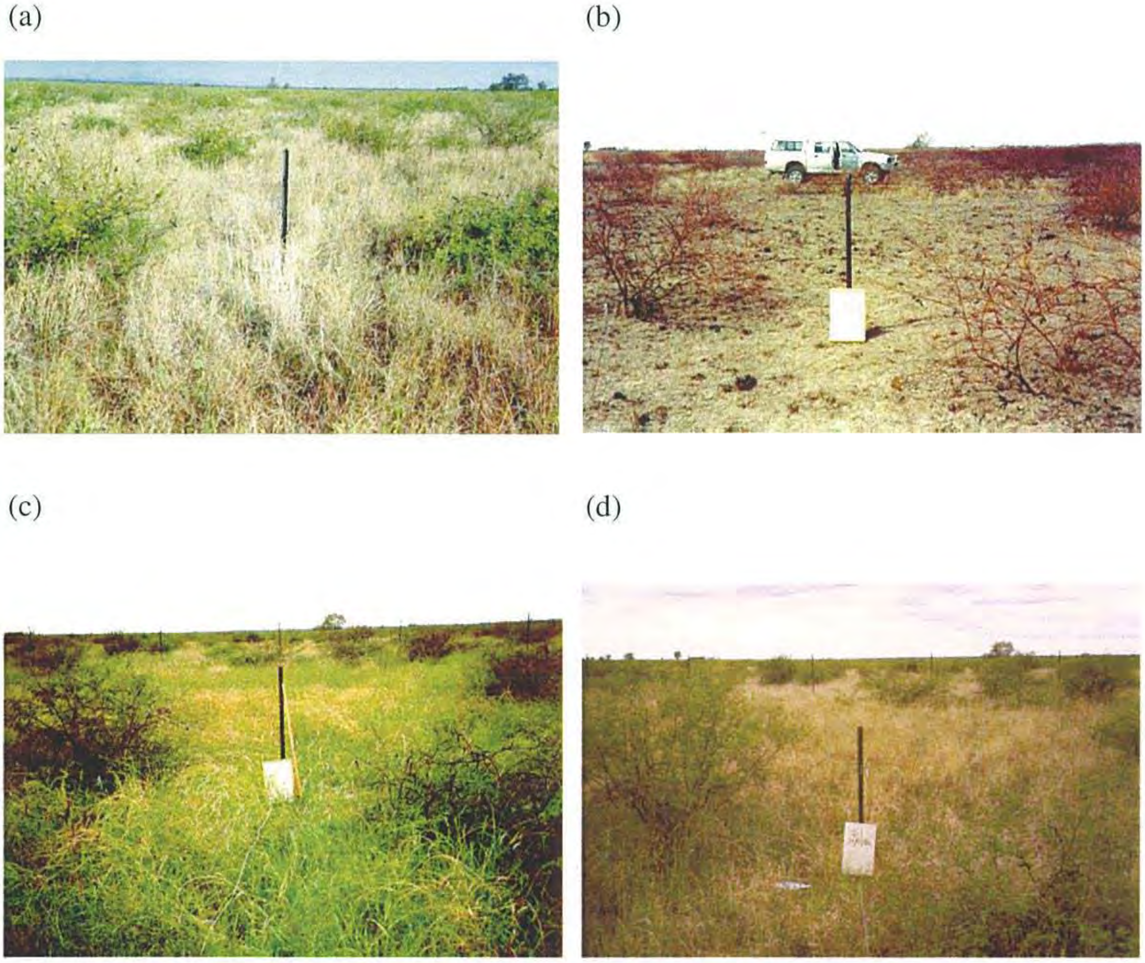


Fig. 5.5. An autumn 2002-burnt sampling quadrat excluded from kangaroo grazing, showing changes over time: (a) autumn 2002 (pre-fire), 43 native species; (b) spring 2002, 11 native species; (c) autumn 2003, 40 native species; (d) autumn 2004, 37 native species.

Table 5.8. Number of recent kangaroo dung pellets (mean ± SE) in spring 2003 and autumn 2004 in unfenced plots burnt in autumn and spring 2002 and in unburnt controls ($n = 8$ for all)

Fire treatment	2003	2004
Spring 2002 burn	9.0 ± 1.99	11.0 ± 2.18
Autumn 2002 burn	18.1 ± 3.31	13.9 ± 3.25
Control	11.6 ± 2.54	8.4 ± 2.60

5.3.3 Influence of repeated burning

There were significant interactions between burning treatment (burnt once in autumn 1999, autumn 2002 or spring 2002; burnt in autumn 1999 and autumn 2002 or in autumn 1999 and spring 2002; and unburnt) and sampling time for total, native and grass richness and heterogeneity (Table 5.10). These interactions were again due to the decrease in species richness in spring 2002 across all sites, with a more pronounced decrease in richness at sites burnt in autumn 2002 (see below). Introduced and forb species richness varied significantly through time, but were not significantly influenced by burning treatment (Table 5.10). Forb species richness was particularly low in spring 2002 (Fig. 5.6d). Introduced species richness increased in autumn and spring 2003 before falling again in autumn 2004 (Fig. 5.6c). Species evenness was not influenced by burning and did not vary through time (Table 5.10).

There were no differences between sites previously burnt in autumn 1999 and unburnt sites prior to treatments in autumn 2002 (Appendix 5.3). In spring 2002 contrasts showed that total, native and grass richness and species heterogeneity were lower at autumn 2002-burnt sites than at all other sites (Fig. 5.6a,b,e,g; total, $F_{1,23} = 88.68$, $P < 0.001$; native, $F_{1,23} = 87.87$, $P < 0.001$; grass, $F_{1,23} = 61.47$, $P < 0.001$; heterogeneity, $F_{1,23} = 46.30$, $P < 0.001$). In autumn 2003, total, introduced and forb species richness and heterogeneity were higher at sites burnt only in autumn 1999 than at all other burnt and unburnt sites (Fig. 5.6a,c,d,g; total, $F_{1,23} = 7.37$, $P = 0.035$; introduced, $F_{1,23} = 12.50$, $P = 0.012$; forb, $F_{1,23} = 19.25$, $P = 0.005$; heterogeneity, $F_{1,23} = 8.31$, $P = 0.028$). The higher forb richness at these sites was due to a higher incidence of **Hedypnois rhagadioloides, *Physalis lanceifolia* and *Daucus glochidiatus* (Appendix 5.2).

Table 5.9. Mean (± SE) frequency score per quadrat (i.e. out of five) for individual species with significantly different ($P < 0.002$ after Bonferroni adjustment) scores between sites burnt in spring 2002 or autumn 2002, or unburnt, 1 and 2 years after the fires. Differences in frequency between the initial sampling (pre-treatment) and other sampling times (autumn 2003 and 2004) were analysed with generalised linear models (binomial error structure). $n = 4$ quadrats for all

	Sampling time	Autumn 2002 burn	Spring 2002 burn	Control	Deviance (χ^2)	P
Responded positively to both burns *Eragrostis parviflora*	Pre-treatment	1.3 ± 0.75	1.0 ± 0.41	0.3 ± 0.25		
	Aut 03	3.8 ± 0.48	2.8 ± 0.63	0.0 ± 0.00	8.95	<0.001
Panicum buncei	Pre-treatment	1.5 ± 0.87	2.8 ± 0.85	4.0 ± 0.71		
	Aut 03	2.3 ± 0.48	3.3 ± 0.63	2.3 ± 0.75	6.64	0.001
Responded more positively to autumn burns *Boerhavia dominii*	Pre-treatment	2.0 ± 0.91	4.3 ± 0.48	3.8 ± 0.63		
	Aut 04	4.0 ± 0.41	4.5 ± 0.50	3.5 ± 0.65	7.93	<0.001
Sporobolus caroli	Pre-treatment	3.3 ± 0.85	4.0 ± 0.41	4.5 ± 0.29		
	Aut 04	5.0 ± 0.00	4.0 ± 0.71	4.3 ± 0.48	4.47	$0.011^{\dagger}$
Responded more positively to spring burns **Medicago truncatula*	Pre-treatment	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00		
	Aut 03	3.0 ± 0.41	5.0 ± 0.00	4.3 ± 0.48	6.67	0.001

Table 5.9. (continued)

	Sampling time	Autumn 2002 burn	Spring 2002 burn	Control	Deviance (χ^2)	*P*
Portulaca oleracea	Pre-treatment	0.0 ± 0.00	0.5 ± 0.50	1.0 ± 0.71		
	Aut 03	0.5 ± 0.29	2.8 ± 0.85	1.0 ± 1.00	5.79	0.003†
Responded more positively in controls	Pre-treatment	0.0 ± 0.00	2.3 ± 1.11	0.8 ± 0.48		
Goodenia fascicularis	Aut 03	2.3 ± 1.11	3.3 ± 0.75	4.5 ± 0.29	5.30	0.005†
	Aut 04	2.5 ± 1.44	2.8 ± 0.75	4.5 ± 0.50	7.89	<0.001
**Hedypnois rhagadioloides*	Pre-treatment	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00		
	Aut 03	0.5 ± 0.50	0.0 ± 0.00	2.5 ± 1.44	9.66	<0.001
**Sonchus oleraceus*	Pre-treatment	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00		
	Aut 03	1.0 ± 0.41	0.8 ± 0.48	3.3 ± 0.63	6.78	0.001
Responded negatively to both burns *Oxalis perennans*	Pre-treatment	4.8 ± 0.25	4.0 ± 1.00	3.0 ± 0.91		
	Aut 03	1.5 ± 0.50	0.8 ± 0.25	2.5 ± 0.87	9.06	<0.001
	Aut 04	1.8 ± 0.25	0.5 ± 0.50	2.8 ± 0.85	9.28	<0.001
Responded negatively to autumn burns *Vittadinia cuneata*	Pre-treatment	2.3 ± 0.75	1.5 ± 0.87	3.0 ± 0.41		
	Aut 04	0.0 ± 0.00	1.3 ± 0.95	3.0 ± 0.41	6.88	0.001

† = Not significant after Bonferroni adjustment.

Table 5.10. Repeated measures ANOVA table showing effects of burning treatments (burnt once in autumn 1999, autumn 2002 or spring 2002; burnt in autumn 1999 and autumn 2002 or in autumn 1999 and spring 2002; and unburnt) and sampling time, on species richness and evenness measures. The quadrat within plot stratum has not been included in this table, for ease of interpretation

Variable		Total		Native		Introduced	
	d.f.	*F*	*P*	*F*	*P*	*F*	*P*
Between-subjects							
Fire history	5	20.71	0.002	14.80	0.005	1.14	0.445
Covariate (Autumn 2002 sampling)	1	1.31	0.304	1.69	0.250	6.11	0.056
Residual	5	0.89		1.02		5.08	
Within-subjects							
Time	3	402.44	<0.001	283.19	<0.001	340.13	<0.001
Time*Fire history	15	7.63	<0.001	7.79	<0.001	1.45	0.215
Residual	54						

Variable		Forb		Grass		Evenness		Heterogeneity	
	d.f.	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Between-subjects									
Fire history	5	1.06	0.477	19.89	0.003	1.70	0.288	17.40	0.004
Covariate (Autumn 2002 sampling)	1	2.61	0.167	2.35	0.186	0.71	0.439	0.03	0.865
Residual	5	2.57		1.46		1.21		3.33	
Within-subjects									
Time	3	653.34	<0.001	35.94	<0.001	1.09	0.353	211.65	<0.001
Time*Fire history	15	2.54	0.014	14.61	<0.001	1.01	0.458	13.06	<0.001
Residual	54								

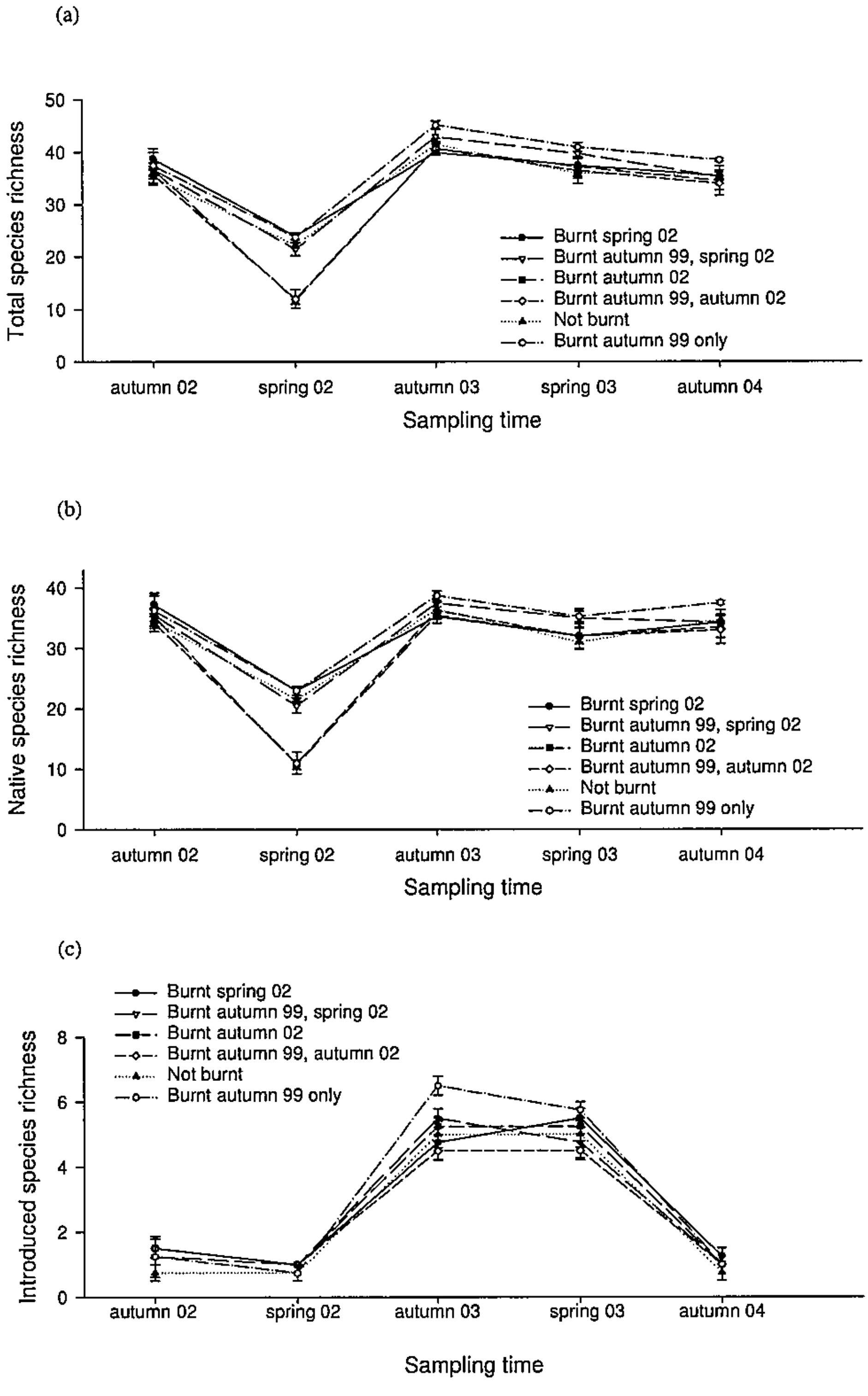


Fig. 5.6. Changes in mean (± SE) species richness, evenness and heterogeneity through time at quadrats either burnt once in autumn 1999, autumn 2002 or spring 2002; burnt in autumn 1999 and autumn 2002 or in autumn 1999 and spring 2002; and unburnt ($n = 4$ quadrats for all treatments). Variables: (a) total; (b) native; (c) introduced; (d) forb; and (e) grass species richness; (f) species evenness; and (g) species heterogeneity.

Fig. 5.6. (continued)

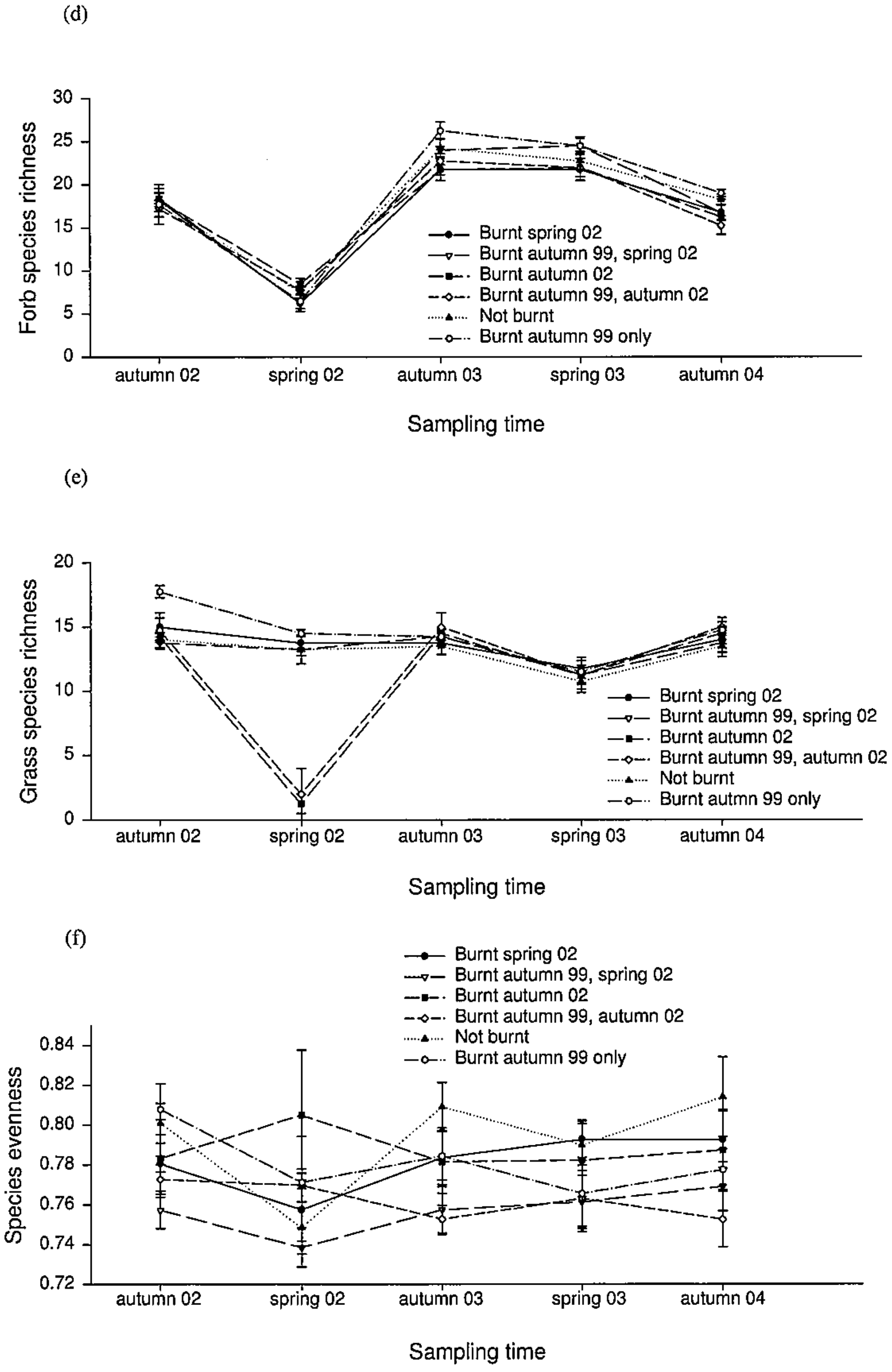


Fig. 5.6. (continued)

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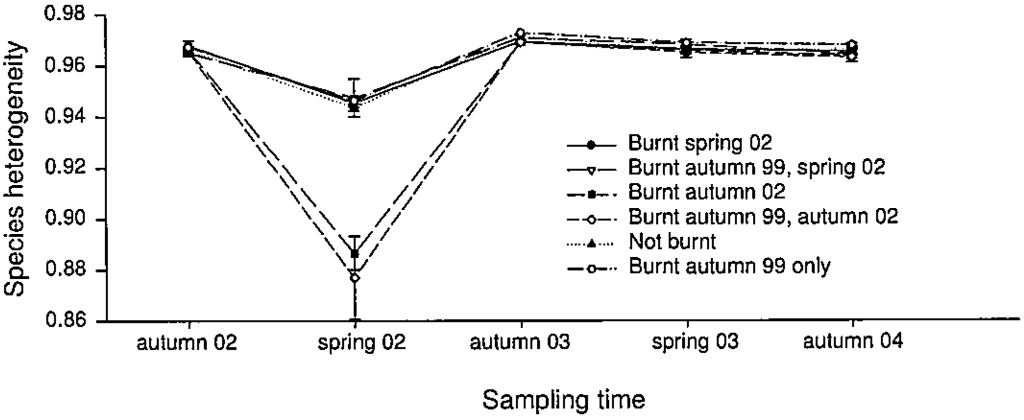


In autumn 2004, evenness was higher at unburnt sites than at sites that had been burnt at some time (Fig. 5.6f; $F_{1,6} = 7.25$, $P = 0.036$).

Eight taxa had differing frequencies prior to the autumn burn in 2002, for sites that were burnt in autumn 1999 and unburnt (Table 5.11). Species that were more frequent at autumn 1999 sites initially (i.e. may have responded positively to the autumn 1999 burn) included *Eragrostis parviflora, Maireana aphylla, Goodenia fascicularis, Pycnosorus globosus* and *Brachycome ciliaris* var. *subintegrifolia* (Table 5.11). Species that were initially less frequent at autumn 1999 burnt sites included *Rhynchosia minima, Haloragis aspera* and *Einadia nutans* subsp. *linifolia* (Table 5.11). Due to the lack of data prior to the autumn 1999 burn it is possible that some of these differences in frequency were due to chance. *Goodenia fascicularis* increased in frequency after the 2002 burn, although this species increased between 2002 and 2003 irrespective of fire (Table 5.9). *Pycnosorus globosus* and *Brachycome ciliaris* decreased in frequency after the 2002 burns, with greater decreases at the autumn 1999 burnt sites because of their higher initial frequencies at these sites. Three winter annuals increased in frequency in autumn 2003 after burning. **Rapistrum rugosum* occurred at higher frequencies at sites burnt once in autumn than at sites burnt twice (Table 5.11). *Erodium crinitum* and **Physalis lanceifolia* occurred at higher frequencies at sites burnt twice than those burnt once in autumn (Table 5.11).

In autumn 2003, two species (*Einadia nutans* and *Cyperus bifax*) responded negatively to 2002 burns. However, these species only decreased in frequency at sites that had not been previously burnt (Table 5.11).

Two species had differing frequencies prior to the spring burn in 2002, for sites that were burnt in autumn 1999 and unburnt (Table 5.12). *Digitaria divaricatissima* was more frequent at the previously burnt sites, while *Enteropogon acicularis* was less frequent at such sites. In autumn 2003, **Hedypnois rhagadioloides* increased in frequency at sites burnt twice, but not at sites burnt once in spring 2002, while **Medicago truncatula* was more frequent at sites burnt once in spring (Table 5.12).

5.3.4 Controls distant from the experiment

There was a significant interaction between sampling time and location of controls for grass species richness (Table 5.13). This was brought about by a decrease in grass species richness in spring 2003 across both sets of controls, but a more pronounced decrease at distant control sites (Fig. 5.7e). No other interaction terms were significant (Table 5.13). Sampling time had a significant influence on all richness measures, heterogeneity and evenness (Table 5.13; Fig. 5.7). Total, native and forb richness, species evenness and heterogeneity were higher at control sites within the experiment than at distant controls sites (Fig. 5.7a,b,d,f,g).

Distant control sites varied in species composition from sites within the experimental area (Fig. 5.8). However, these differences were relatively minor and were not obviously recognisable when the sites were established in autumn 2002. The differences in composition also appeared to vary over time. Some of the differences in composition can be attributed to higher perennial grass cover at the distant sites in autumn 2003. *Astrebla elymoides* cover increased in autumn 2003 at all sites (Appendix 5.4) but more so in the distant control sites (hence has a vector in the upper half of Fig. 5.8). At this time, five of the eight distant sites had cover abundance scores of 51-75% for *Astrebla elymoides*. No cover scores in this category were recorded at any other time, or at any sites in the experimental area.

Table 5.11. Mean (± SE) frequency score per quadrat (i.e. out of five) for individual species with significantly different ($P < 0.002$ after Bonferroni adjustment) scores between sites burnt in autumn 2002 only and in both autumn 1999 and 2002, 1 and 2 years after the fires. Differences in frequency between the initial sampling (pre-treatment) and other sampling times (autumn 2003 and 2004) were analysed with generalised linear models (binomial error structure). Pre-2002 treatment frequency scores (i.e. autumn 2002) for each species are also shown. Pre-2002 treatment frequencies were analysed to determine possible effects of the autumn 1999 burn. $n = 4$ quadrats for all

	Sampling time	Burnt autumn 2002 only	Burnt 1999 and autumn 2002	Deviance (χ^2)	P
Responded positively to 1999 burn only					
Eragrostis parviflora	Pre-2002 burn	1.3 ± 0.75	3.5 ± 0.29	8.42	0.004[†]
Maireana aphylla	Pre-2002 burn	0.0 ± 0.00	1.5 ± 0.87	9.38	0.002
Responded positively to 1999 and 2002 burns					
Goodenia fascicularis	Pre-2002 burn	0.0 ± 0.00	1.2 ± 1.22	13.11	<0.001
	Aut 03	2.3 ± 1.11	2.0 ± 1.15	9.52	0.002
Responded positively to 1999 but negatively to 2002 burns					
Pycnosorus globosus	Pre-2002 burn	0.3 ± 0.25	2.5 ± 0.29	11.39	<0.001
	Aut 03	0.0 ± 0.00	0.0 ± 0.00	11.39	<0.001
Brachycome ciliaris var. *subintegrifolia*	Pre-2002 burn	2.0 ± 0.71	5.0 ± 0.00	21.95	<0.001
	Aut 04	0.3 ± 0.25	0.3 ± 0.25	17.96	<0.001

Table 5.11. (continued)

	Sampling time	Burnt autumn 2002 only	Burnt 1999 and autumn 2002	Deviance (χ^2)	*P*
Responded positively to 2002 burns at previously unburnt sites					
**Rapistrum rugosum*	Pre-2002 burn	0.0 ± 0.00	0.0 ± 0.00		
	Aut 03	2.8 ± 0.48	0.5 ± 0.50	9.92	0.002
Responded positively to 2002 burns at sites burnt in 1999					
**Physalis lanceifolia*	Pre-2002 burn	0.0 ± 0.00	0.0 ± 0.00		
	Aut 03	0.0 ± 0.00	1.5 ± 0.65	9.38	0.002
Erodium crinitum	Pre-2002 burn	0.0 ± 0.00	0.0 ± 0.00		
	Aut 03	0.0 ± 0.00	1.8 ± 1.18	11.20	<0.001
Responded negatively to 1999 burn only					
Rhynchosia minima	Pre-2002 burn	1.5 ± 0.96	0.0 ± 0.00	9.38	0.002
Haloragis aspera	Pre-2002 burn	2.3 ± 1.31	0.0 ± 0.00	15.13	<0.001

Table 5.11. (continued)

	Sampling time	Burnt autumn 2002 only	Burnt 1999 and autumn 2002	Deviance (χ^2)	*P*
Responded negatively to 2002 burns at previously unburnt sites					
Einadia nutans subsp. *linifolia*	Pre-2002 burn	3.3 ± 0.85	0.8 ± 0.48	11.03	<0.001
	Aut 03	0.8 ± 0.48	0.5 ± 0.29	11.03	<0.001
Cyperus bifax	Pre-2002 burn	4.3 ± 0.25	4.8 ± 0.25		
	Aut 03	2.8 ± 0.48	5.0 ± 0.00	9.38	0.002

† = Not significant after Bonferroni adjustment.

Table 5.12. Mean (± SE) frequency score per quadrat (i.e. out of five) for individual species with significantly different ($P < 0.002$ after Bonferroni adjustment) scores between sites burnt in spring 2002 only and sites burnt in both autumn 1999 and spring 2002, 1 and 2 years after the fires. Differences in frequency between the initial sampling (pre-treatment) and other sampling times (autumn 2003 and 2004) were analysed with generalised linear models (binomial error structure). Pre-2002 treatment frequency scores (i.e. autumn 2002) for each species are also shown. Pre-2002 treatment frequencies were analysed to determine possible effects of the autumn 1999 burn. $n = 4$ quadrats for all

		Burnt spring 2002 only	Burnt 1999 and spring 2002	Deviance (χ^2)	P
Responded positively to 1999 burn only					
Digitaria divaricatissima	Pre-2002 burn	1.0 ± 0.41	5.0 ± 0.00	33.82	<0.001
Responded positively to 2002 burns at sites burnt in 1999					
**Hedypnois rhagadioloides*	Pre-2002 burn	0.0 ± 0.00	0.0 ± 0.00		
	Aut 03	0.0 ± 0.00	2.3 ± 1.31	15.13	<0.001
Responded more positively to 2002 burns at previously unburnt sites					
**Medicago truncatula*	Pre-2002 burn	0.0 ± 0.00	0.0 ± 0.00		
	Aut 03	5.0 ± 0.00	3.5 ± 0.87	9.38	0.002
Responded negatively to 1999 burn only					
Enteropogon acicularis	Pre-2002 burn	2.3 ± 0.25	0.3 ± 0.25	9.52	0.002

Table 5.13. Repeated measures ANOVA table showing differences in species richness and evenness measures between controls distant from the experiment and those within the experiment, and the effect of sampling time

Variable		Total		Native		Introduced	
	d.f.	*F*	*P*	*F*	*P*	*F*	*P*
Between-subjects							
Control effects	1	13.29	0.005	5.86	0.039	4.59	0.061
Covariate (Autumn 2002 sampling)	1	10.06	0.011	5.16	0.049	8.42	0.018
Residual	3	0.83		1.12		1.70	
Within-subjects							
Time	3	93.49	<0.001	65.12	<0.001	96.36	<0.001
Time*Control effects	3	0.76	0.478	0.71	0.500	0.23	0.737
Residual	30						

Variable		Forb		Grass		Evenness		Heterogeneity	
	d.f.	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Between-subjects									
Control effects	1	8.46	0.017	3.95	0.078	7.93	0.020	13.74	0.005
Covariate (Autumn 2002 sampling)	1	4.01	0.076	3.15	0.110	0.44	0.524	10.09	0.011
Residual	3	1.65		1.37		0.70		0.65	
Within-subjects									
Time	3	220.00	<0.001	43.24	<0.001	4.44	0.021	165.07	<0.001
Time*Control effects	3	0.70	0.520	4.97	0.015	1.79	0.189	1.55	0.235
Residual	30								

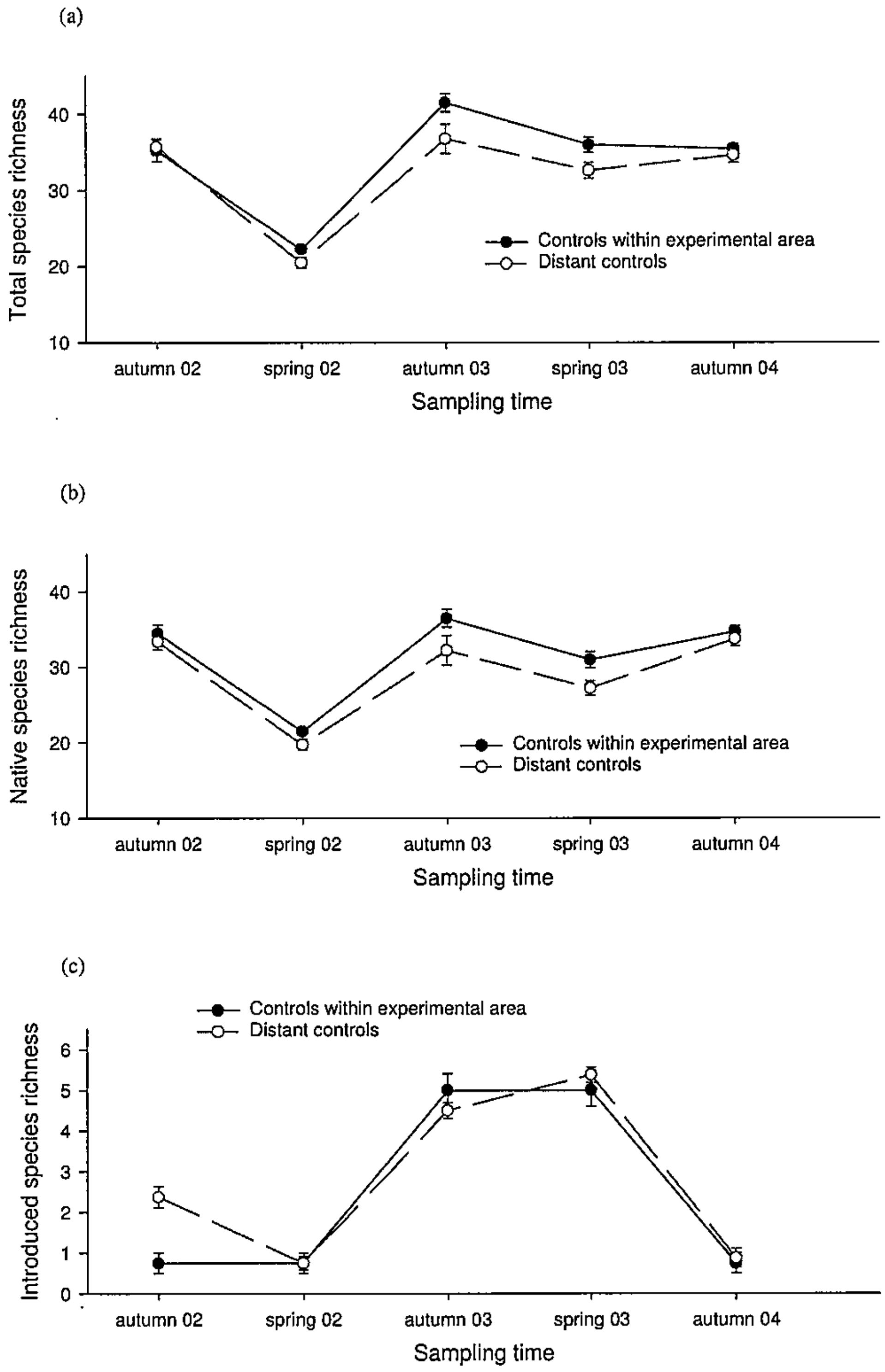


Fig. 5.7. Changes in mean (± SE) species richness, evenness and heterogeneity through time at quadrats distant from and within the experimental area (n = 8 quadrats for distant controls and n = 4 quadrats for controls within the experimental area). Variables: (a) total; (b) native; (c) introduced; (d) forb; and (e) grass species richness; (f) species evenness; and (g) species heterogeneity.

Fig. 5.7. (continued)

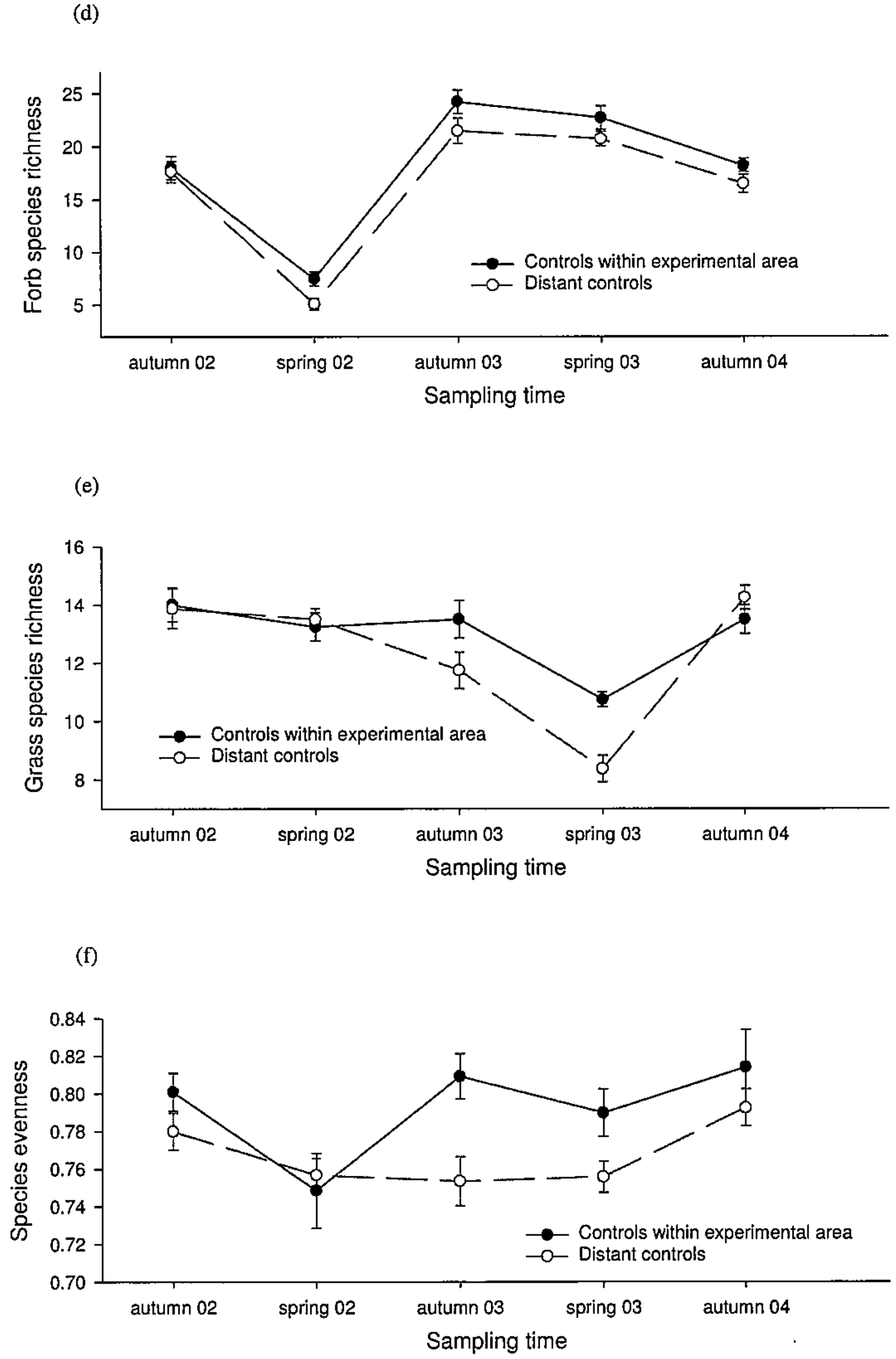
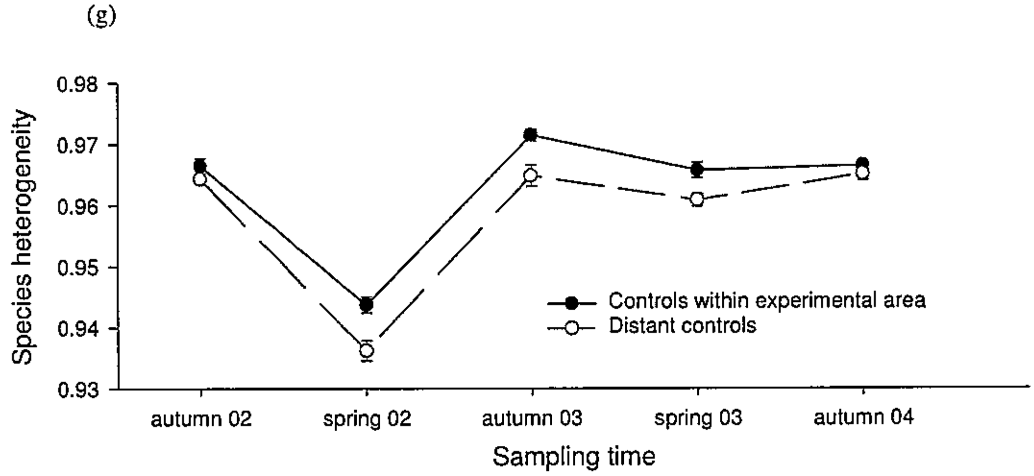


Fig. 5.7. (continued)



5.3.5 *Ordination output*

Redundancy analysis of the species cover data produced eigenvalues for the first four ordination axes of 0.138, 0.092, 0.037 and 0.029. Sampling time was the dominant gradient (i.e. had the strongest influence on species composition), with sites grouped into separate sampling times in ordination (Table 5.14; Fig. 5.8). Species composition differed between the two spring sampling periods and between spring and autumn sampling periods (Fig. 5.8). Species composition in autumn 2003 differed from the other two autumn sampling times, which were similar (Fig. 5.8). Distant control sites differed slightly in composition to the experimental sites (Table 5.14) but some of these differences were pre-existing (Fig. 5.8).

Forward selection suggested burning in autumn and spring 2002 resulted in differences in species composition (Table 5.14). Autumn and spring 2002-burnt sites were separated by ordination (Fig. 5.9); however, there was some pre-existing separation between these variables (Fig. 5.10). Burning in 2002 had an influence on native grass composition (Figs 5.9, 5.10). Spring 2002-burnt sites were associated with higher abundances of common grass species, such as *Astrebla elymoides, Eriochloa pseudoacrotricha, Aristida leptopoda, Dichanthium sericeum, Chloris truncata, Sporobolus caroli, Panicum queenslandicum* and *Panicum buncei* (Fig. 5.9). However, this association may be related to the short-term removal of these grass species at autumn 2002-burnt sites in spring 2002. Forbs, such as *Oxalis perennans, Solanum esuriale, Asperula cunninghamii, Wahlenbergia* *communis* and *Neptunia gracilis* were associated with autumn 2002-burnt sites (Fig. 5.9), although their higher abundance at these sites did not persist over time.

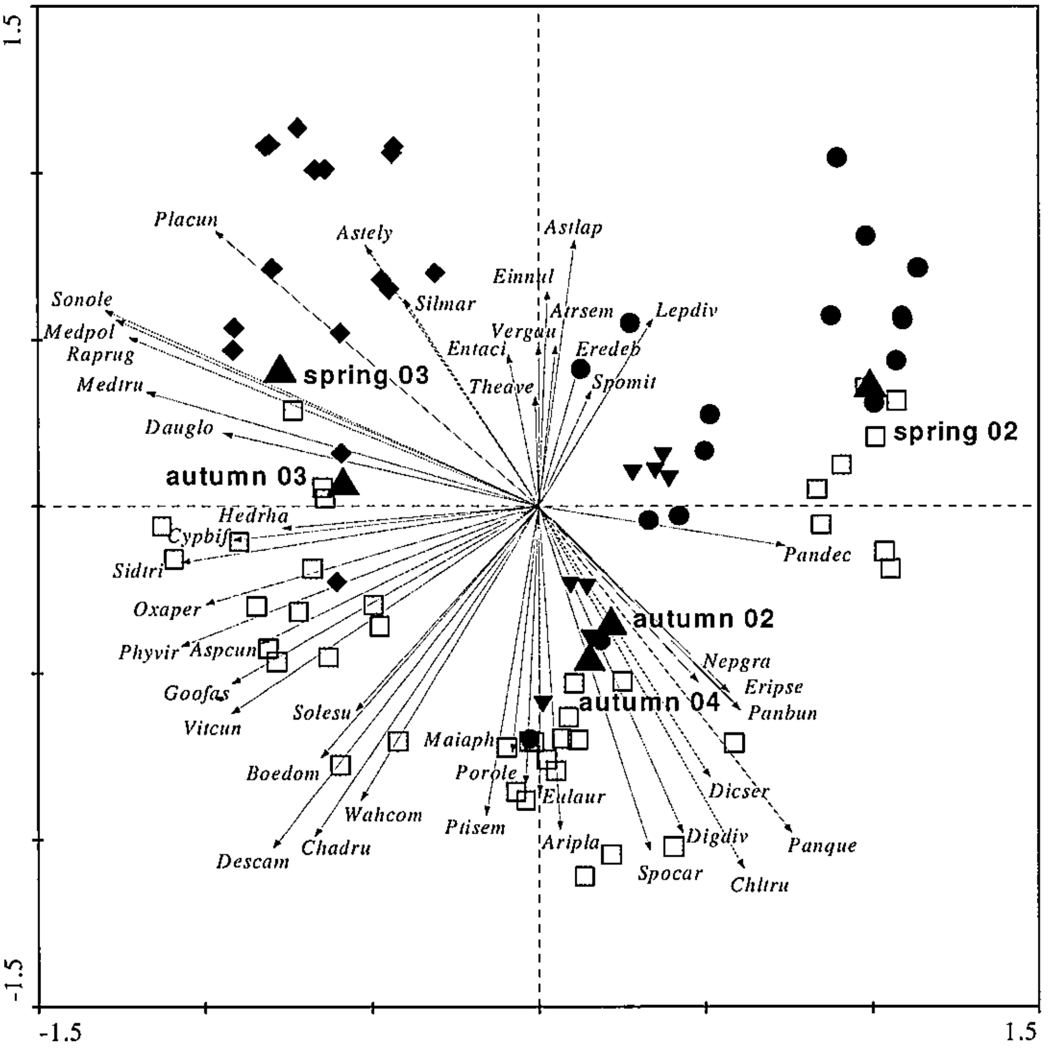


Fig. 5.8. Ordination (RDA triplot) showing differences in composition between distant controls (smaller filled symbols) and sites within the experiment (empty squares), and species (vectors for cover scores) associated with the different sites and sampling times (larger up-triangles). Distant control sites were classified by sampling time (autumn 2002, down-triangles; spring 2002, black circles; autumn 2003, grey diamonds; spring 2003, black diamonds; autumn 2004, grey circles. Species codes (italics) in Appendix 5.1.

Table 5.14. Forward selection results, showing conditional effects (CE) and marginal effects (ME) for significant ($P < 0.05$) variable categories in the RDA for species cover scores. λ = eigenvalues. The reported significance level estimates (0.002) are the lowest achievable given the number of permutations (i.e. 499)

Variable category	ME λ	CE λ	*F*	*P*
Spring 02 sampling	0.12	0.12	30.59	0.002
Spring 03 sampling	0.08	0.08	19.42	0.002
Autumn 03 sampling	0.05	0.05	15.82	0.002
Distant controls	0.04	0.04	10.99	0.002
Spring 02 burn	0.02	0.01	5.43	0.002
Autumn 02 burn	0.02	0.02	5.48	0.002
Not burnt	0.02	0.02	5.86	0.002
Autumn 02 sampling	0.04	0.01	4.44	0.002

The differences in composition prior to treatments in 2002 were largely random, with small differences in the abundances of species in control sites and sites to be burnt in autumn and spring. Sites burnt in autumn 1999 had a similar composition to previously unburnt sites, prior to fires in 2002 (Fig. 5.10). While there was a slight grouping of autumn 1999 burnt sites in Figure 5.10, there were no obvious trends in species abundances towards these sites. Sites burnt twice did not differ greatly in composition to sites burnt once only or unburnt sites (Fig. 5.9).

Kangaroo grazing did not have a significant influence on composition (Table 5.14). No species had abundances that were significantly correlated with kangaroo exclusion areas.

5.3.6 Seasonal changes in composition and richness

As previously mentioned there were significant changes in all richness measures due to different sampling times (e.g. Table 5.13), and sampling time had a strong influence on species composition (Table 5.14). Variation in frequency scores per quadrat for each species, at each sampling time, is shown in Appendix 5.5. The reduction in total and native species richness in spring 2002 was largely due to a reduction in forb richness at this time (Fig. 5.7a,b,d). Common forbs that were less frequent, or absent from sites in spring 2002 included *Boerhavia dominii, Desmodium campylocaulon, Neptunia gracilis, Phyllanthus virgatus, Sida trichopoda, Solanum esuriale, Goodenia fascicularis* and

Wahlenbergia communis. Introduced species richness was significantly higher in autumn 2003 and spring 2003 than at other sampling times (Fig. 5.7c). This increase in richness was due to the germination of winter-growing introduced species prior to sampling in autumn 2003. These winter-growing forbs (e.g. **Plantago cunninghamii, *Hedypnois rhagadioloides, *Sonchus oleraceus, *Medicago polymorpha, *M. truncatula* and **Rapistrum rugosum*) were most abundant in spring 2003 (Fig. 5.11).

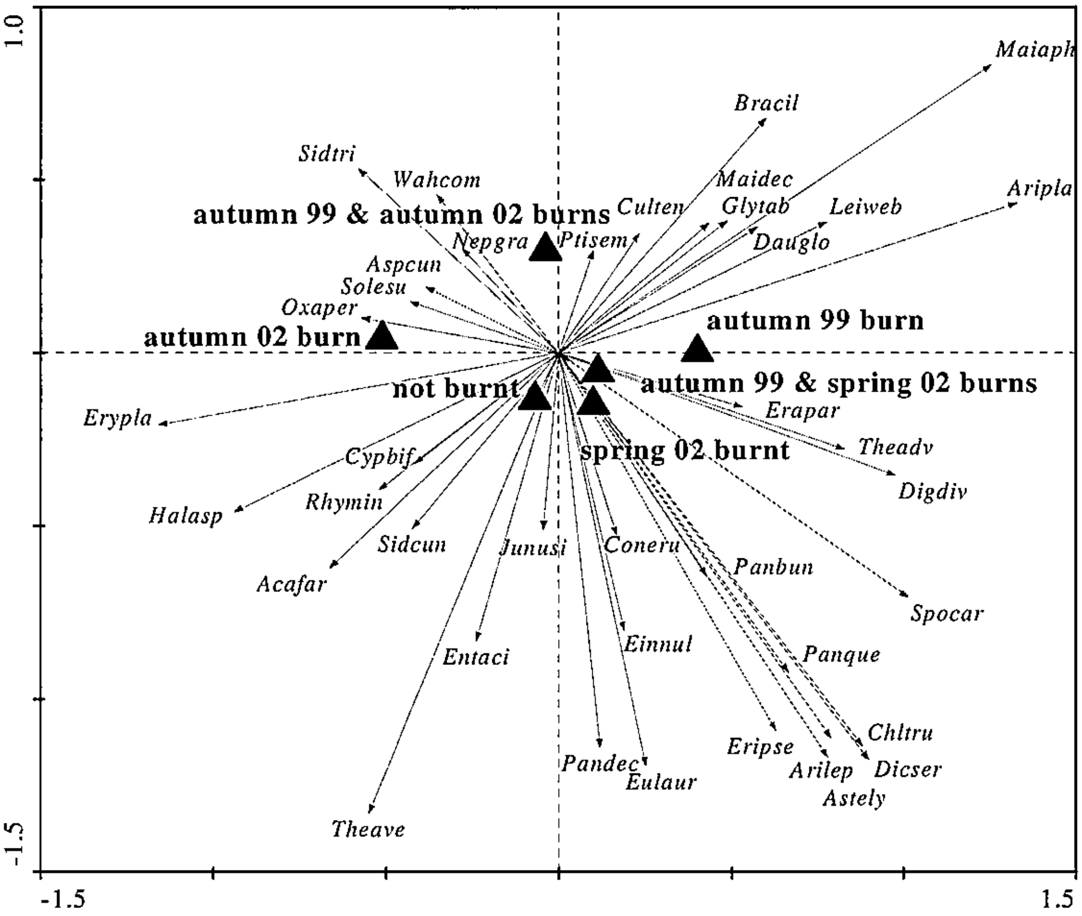


Fig. 5.9. Ordination (partial PCA) biplot, with sampling time as a covariable, showing species (vectors for cover scores) associated with the different fire treatments (post-fire sampling times only). Filled triangles, nominal environmental variable categories. Species codes (italics) in Appendix 5.1. Refer to Fig. 5.10 for an ordination of the pre-treatment data.

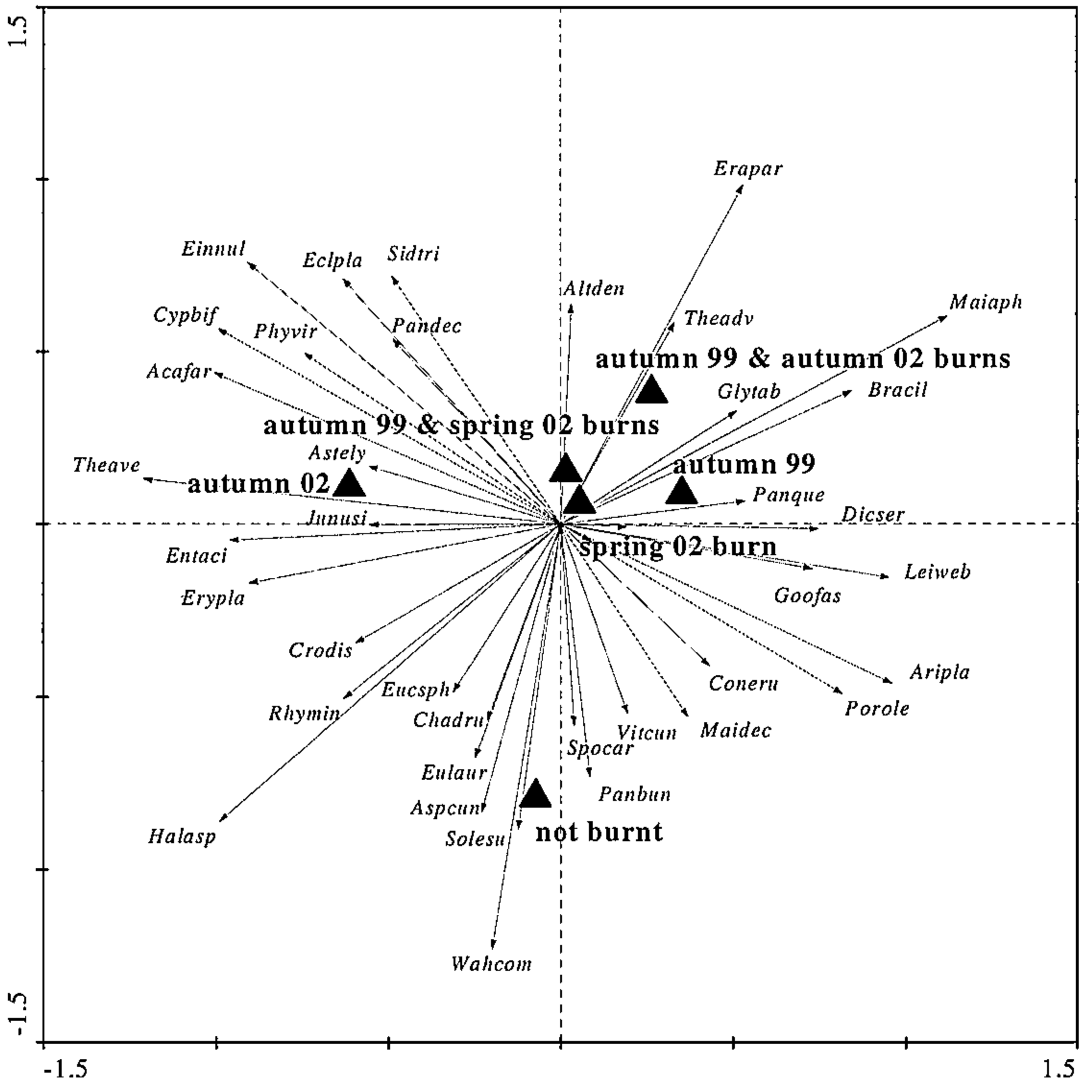


Fig. 5.10. Ordination (partial PCA) for initial sampling time only (with time as a covariable), showing pre-existing differences (pre-fire in 2002) in composition between sites allocated to the different fire treatments. Filled triangles, nominal environmental variable categories. Species codes (italics) in Appendix 5.1.

While grass species richness did not decline greatly in spring 2002 or spring 2003, certain grass species were more abundant during autumn sampling periods (e.g. *Sporobolus caroli, Panicum queenslandicum, P. buncei, Chloris truncata, Eragrostis parviflora* and *Eriochloa pseudoacrotricha*). Three uncommon grass species were only recorded in autumn 2003 (*Dactyloctenium radulans, Tripogon loliiformis* and *Iseilema* *membranaceum*). No winter-growing annual grasses were recorded within the experimental area. Abundance of grass species also varied between autumn sampling periods. *Dichanthium sericeum* decreased in abundance between 2002 and 2004, while *Eriochloa pseudoacrotricha* increased in abundance over time (Appendix 5.4). *Astrebla elymoides* had highest abundance scores in autumn of 2003 (Appendix 5.4).

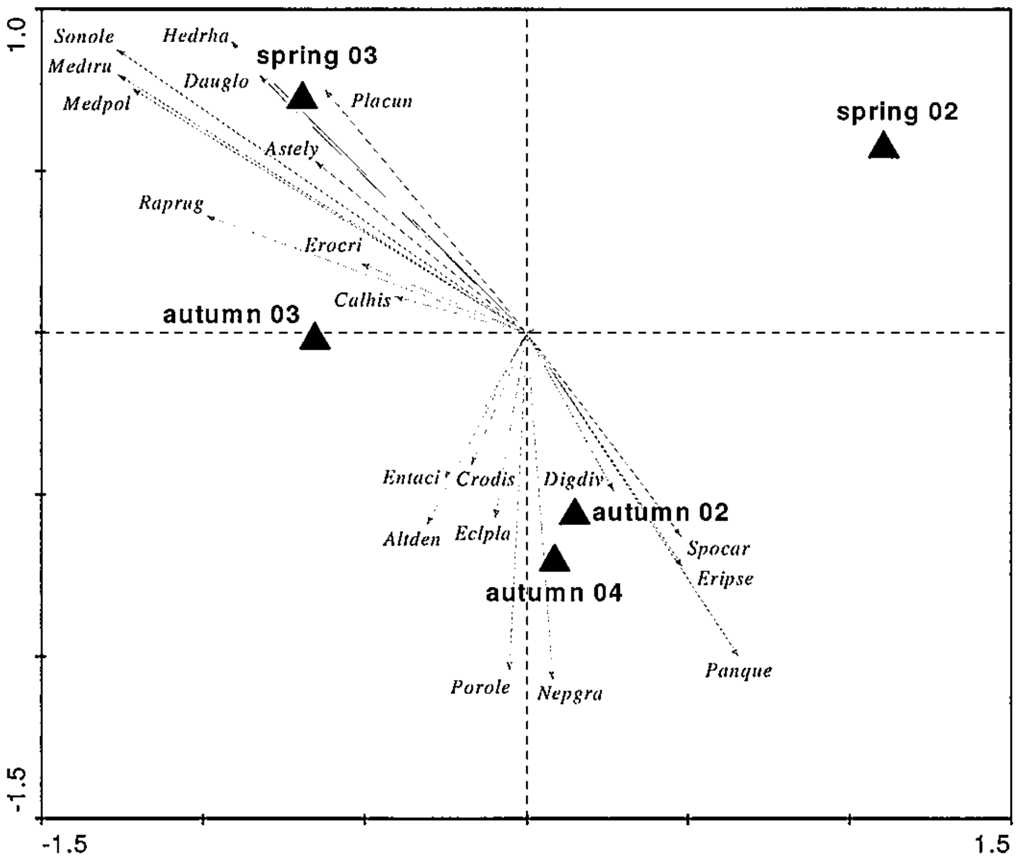


Fig. 5.11. RDA ordination biplot showing species (vectors for cover scores) associated with the different sampling times (filled triangles). No species were associated with the spring 2002 sampling time; species had lower abundances or were absent at this time.

5.3.7 Responses of tagged plants to fire

Survival of mature and juvenile *Acacia farnesiana* plants was not greatly influenced by controlled burns in autumn or spring 2002 (Table 5.15). *Astrebla elymoides, A. lappacea, Maireana aphylla* and *Acacia stenophylla* individuals also survived the fires in most cases.

Only three out of 18 *Desmodium campylocaulon* individuals in the spring 2002 burn treatment were not present in autumn 2003 and 100% survival was observed for this species 12 months after the autumn 2002 burn (Table 5.15).

The percentage survival of *Dichanthium sericeum* differed between spring-burnt, autumn-burnt and control areas ($\chi^2 = 9.05$, d.f. = 2, $P = 0.01$) in 2003, with lowest survival at the control sites (Table 5.15). There was no difference in percentage survival between spring-burnt, autumn-burnt and control areas in 2004 ($\chi^2 = 0.81$, d.f. = 2, $P = 0.668$). Survival of *Dichanthium sericeum* decreased significantly over time at all sites (spring-burnt sites, $\chi^2 = 24.68$, d.f. = 2, $P < 0.001$; autumn-burnt sites, $\chi^2 = 23.58$, d.f. = 2, $P < 0.001$; control sites, $\chi^2 = 32.33$, d.f. = 2, $P < 0.001$).

All seven species followed over time were able to resprout after fire, although *Dichanthium sericeum* did not always resprout successfully. *Dichanthium sericeum* resprouts were often much smaller than the original plant and appeared fragile. Tussocks of both *Astrebla* spp. were divided as a result of burning in both seasons. The large tussocks for these species were divided into a ring of smaller tussocks around the perimeter of the existing tussock. Both *Acacia* spp. and the sub-shrub, *Maireana aphylla*, were able to resprout from the base. Only one *Acacia stenophylla* and one *A. farnesiana* were killed by fire and both of these plants were juveniles.

Table 5.15. Survival (%) of tagged individuals at sites burnt in spring or autumn 2002, or unburnt ($n = 18$ for all, except *Astrebla lappacea, Maireana aphylla* and *Acacia stenophylla*, where $n = 8$)

	Spring burn		Autumn burn		Control	
Species	2003	2004	2003	2004	2003	2004
Acacia farnesiana	100	100	100	100	100	100
Acacia farnesiana juveniles	100	100	94	94	100	100
Astrebla elymoides	100	100	94	100	100	100
Dichanthium sericeum	78	24	50	19	28	11
Desmodium campylocaulon	82	75	100	89	100	94
Astrebla lappacea	100	100	100	100	100	100
Maireana aphylla	100	100	100	100	100	100
Acacia stenophylla	88	88	100	100	100	100

There was no significant difference in seed head production of *Astrebla elymoides* between burnt sites (autumn 2002) and unburnt controls ($H = 0.0004$, $P = 0.985$), but there were differences due to time ($H = 68.86$, $P < 0.001$). Seed head production was highest in 2003 for *A. elymoides* plants at all sites (Table 5.16). Seed head production was also significantly higher in 2003 for *A. lappacea* plants ($H = 27.20$, $P < 0.001$). There was no difference in seed head production between autumn 2002-burnt sites and controls for this species ($H = 0.2152$, $P = 0.641$). *Dichanthium sericeum* seed head production was initially reduced in autumn-burnt sites compared to controls ($H = 7.318$, $P = 0.007$), but there were no differences between controls and sites burnt in either season in 2003 ($H = 0.3185$, $P = 0.813$). Seed head production declined significantly between 2002 and 2003 in this species ($H = 29.30$, $P < 0.001$).

Table 5.16. Mean number ± SE (*n*) of seed heads for individuals measured in 2002 (pre-fire), 2003 and 2004, for three common grass species. NA, data inaccurate due to timing of initial measurements (i.e. spring 2002)

	2002	2003	2004
Spring burn			
Astrebla elymoides	NA	37.9 ± 2.92 (15)	10.0 ± 2.15 (13)
Dichanthium sericeum	NA	1.9 ± 0.48 (14)	0.5 ± 0.50 (4)
Astrebla lappacea	NA	11.8 ± 3.17 (8)	3.9 ± 1.99 (7)
Autumn burn			
Astrebla elymoides	8.3 ± 1.15 (18)	36.1 ± 2.51 (17)	16.8 ± 2.89 (17)
Dichanthium sericeum	14.3 ± 1.73 (18)	2.0 ± 0.65 (9)	0.0 ± 0.00 (3)
Astrebla lappacea	3.4 ± 0.82 (8)	15.4 ± 1.93 (8)	7.6 ± 2.56 (8)
Control			
Astrebla elymoides	5.7 ± 1.02 (18)	45.6 ± 2.35 (18)	14.4 ± 2.23 (18)
Dichanthium sericeum	21.5 ± 1.78 (18)	1.6 ± 0.60 (5)	1.0 ± 0.00 (2)
Astrebla lappacea	2.9 ± 0.77 (8)	20.4 ± 2.63 (8)	7.9 ± 1.67 (8)

5.4 Discussion

5.4.1 Variation due to sampling time

Species composition varied greatly between sampling times (Fig. 5.11), indeed more so between sampling times than in response to fire and grazing treatments (Table 5.14). Composition of grasses varied between spring and autumn. Grass species such as *Sporobolus caroli, Panicum queenslandicum, P. buncei, Chloris truncata, Eragrostis parviflora* and *Eriochloa pseudoacrotricha* were more abundant in autumn. Grass species richness was slightly lower during spring 2003 (Fig. 5.7e) due to the absence of some summer-growing annual grasses (e.g. *E. parviflora, S. caroli* and *C. truncata*). There were also fluctuations in the abundance of grasses between years. *Astrebla elymoides* increased in abundance in 2003 while, *Dichanthium sericeum* was more abundant in autumn 2002 (Fig. 5.8; Appendix 5.4). Similar variations in the abundance of these species were reported at a regional scale (Section 3.3.2, Table 3.15). Fluctuations in the abundance of *A. elymoides* and *D. sericeum* over time were discussed in earlier chapters (Chapters 3 and 4). The seasonal conditions that may favour one of these species over the other are still uncertain, although *D. sericeum* appears to respond well in years of higher rainfall (Roberts 1978; Hunter & Earl 1999).

The reduction in species richness at all sites in spring 2002 was due to very low winter rainfall. Only 44 mm was recorded for Moree in the 4 months prior to sampling in September 2002. The reduction in total and native species richness in spring 2002 was largely attributed to a reduction in forb richness at this time (Fig. 5.7a,b,d). Several common forbs that were less frequent, or absent from sites in spring 2002 (Section 5.3.6). Frequency scores for these forbs were similar during all autumn sampling periods, suggesting that most were able to resprout vegetatively from existing rootstock. There were also a number of annual forbs that were present in spring 2003 but not spring 2002 (Fig. 5.11), supporting findings from the regional vegetation survey (Chapter 3). Winter-growing forbs, including several introduced species (e.g. **Plantago cunninghamii, *Hedypnois rhagadioloides, *Sonchus oleraceus, *Medicago polymorpha, *M. truncatula* and **Rapistrum rugosum*), have previously been reported in grasslands on the Moree Plains (Clarke *et al.* 1998; Hunter & Earl 1999; Chapter 3) but were absent in spring 2002 presumably because of the low winter rainfall (Fig. 4.2).

5.4.2 The influence of burning in autumn and spring

The lack of differences in species richness, evenness and heterogeneity 1 year after the different fire treatments in the grasslands of the Moree Plains (Figs 5.4, 5.6) was unexpected, given that Wright (2001) reported short-term increases in species diversity and evenness after fire in Mitchell grasslands in Queensland. The short-term increase in richness reported by Wright (2001) was related to increases in annual grasses and forbs, due to removal of accumulated leaf litter and cover of perennial grasses. Annual forbs also increased in burnt areas in the spring following a burn in far north-western NSW (Mulham 1985). However, most of the annual forb and grass species that increased after burning in these studies were absent from Kirramingly Nature Reserve (Mulham 1985; Wright 2001). Despite the difference to these other studies, the lack of fire-mediated enhancement of richness is consistent with the lack of livestock grazing enhancement of richness reported in Chapter 4 (i.e. at TSRs surrounding the Reserve). Further studies are required to determine whether increases in richness in response to fire occur in certain years (perhaps when grass density is high immediately prior to fire) or in other similar grasslands on the Moree Plains.

Significant treatment effects on species richness and evenness measures were recognised in spring 2002 and spring 2003 only. In spring 2002, total, native and grass species richness and heterogeneity were significantly higher at control sites than sites burnt in autumn 2002 (Fig. 5.4a,b,e,g). In autumn 2003, species richness (total and native) was not significantly lower at spring 2002-burnt sites than at unburnt sites, only 6 months after the burn. Hence, recovery of species richness was faster following the spring burn than following the autumn burn. This may have been partly due to the dry conditions following the autumn burn. Only 62 mm was recorded for Moree in the 5 months following the autumn 2002 burn, while 196 mm was recorded in the 5 months following the spring 2002 burn. The amount and timing of rainfall is known to have a major effect on post-fire recovery of vegetation (Gibson & Hulbert 1987; Biondini *et al.* 1989). Seasonal conditions, especially rainfall before and after fire, also influence the response of Mitchell grasslands. Low soil moisture at the time of, and after burning, is known to decrease pasture yield in these grasslands (Scanlan 1980; Mulham 1985).

Recovery after the autumn 2002 burn was probably also slower because most of the grass species in the experimental area grow during warmer conditions (spring, summer and autumn). In spring 2002, very few grass species were recorded at autumn 2002-burnt sites, while approximately 6 months after the spring 2003 burn grass richness was similar to control sites (Fig. 5.4e). Morgan and Rollason (1995) similarly reported a slower recovery of canopy cover for autumn-burnt grasslands than spring-burnt grasslands. It is likely that most of the perennial grasses were dormant when the spring 2003 burn took place. Little labile carbohydrate would have been lost, allowing a vigorous response after burning once temperature and soil moisture permitted (Morgan 1999).

Burning in autumn 2002 did not encourage winter annuals and introduced species as hypothesised. This may have been due to the dry conditions through winter in 2002. However, sites burnt in May 1999, in a year of above average rainfall (717 mm) did not differ in composition and richness to unburnt areas, 3 years after this burn. In autumn 2003, introduced species richness was higher at sites burnt in autumn 1999 than at unburnt sites. However, this relatively minor increase in richness (i.e. 1-2 species) was short-lived, as it was not apparent in 2004, and should not be of concern to managers. Repeated burning in spring could have a negative effect on winter annuals if fire kills seed produced by these species (Auld & O'Connell 1991). However, one spring burn in 2002 had no obvious effect on winter-growing species. The fact that winter 2002 was dry and that plant species composition and richness were not typical of spring conditions in 2002, begs the question whether the vegetation response to fire in autumn and spring would be the same in a year with average or above average winter rainfall. It is unfortunate that because of time and funding constraints, fire treatments could not be replicated over time. However, the establishment of permanent sites will allow monitoring to determine the effect of future autumn and spring burns at the Reserve.

Analysis of species frequency scores identified several species that responded significantly to 2002 fire treatments. *Eragrostis parviflora* and *Panicum buncei* responded positively in quadrats burnt in both seasons; **Medicago truncatula* and *Portulaca oleracea* preferred spring burning; *Boerhavia dominii* and *Sporobolus caroli* preferred autumn burning; and *Oxalis perennans*, **Hedypnois rhagadioloides*, **Sonchus oleraceus*, *Goodenia fascicularis* and *Vittadinia cuneata* were negatively influenced by burning in one or both seasons. It is interesting that two introduced forbs were negatively influenced by fire, as introduced or 'weedy' species sometimes increase in response to fire (Lunt 1990a; Milberg & Lamont 1995; Lunt & Morgan 1999). The lack of increase in introduced species on the Moree

Plains may be due to differences in composition. There are probably fewer competitive annual and introduced grasses in the seed banks at Kirramingly Nature Reserve, and on the Moree Plains in general, than in the grasslands of south-eastern Australia. For example, Lunt (1990a) reported increases in the densities of grasses like *Agrostis avenacea, *Vulpia bromoides, *Briza minor* and **Aira cupaniana* in response to fire, but such species are uncommon, or do not occur in Kirramingly Nature Reserve.

Some annual or short-lived species (e.g. *Eragrostis parviflora, *Medicago truncatula, Portulaca oleracea* and *Sporobolus caroli*) did increase in frequency in response to burning, supporting the findings of Lunt (1990a) and Wright (2001). Suijdendorp (1981) also reported an increase in annuals after fire in hummock grasslands. Of the seven annual species that increased in frequency after burning in the study by Wright (2001) in Queensland, only *Portulaca oleracea* occurred at Kirramingly Nature Reserve, and this species responded positively to spring burning in the current study.

Wright (2001) reported significantly higher cover of the perennials, *Desmodium campylocaulon* and *Panicum decompositum*, in a recently burnt area, than in unburnt areas. These two species are common at Kirramingly Nature Reserve, but their frequency was not significantly influenced by fires in the current study. It is likely that species respond differently to fire in differing environments just as species respond inconsistently to grazing in different environments (Vesk & Westoby 2001). Several factors may influence a species' response to fire, such as rainfall prior to and after fire, post-fire grazing intensity, soil fertility, fire intensity and phenological stage at the time of burning (Wright & Klemmedson 1965; Scanlan 1980; Mulham 1985; Pfeiffer & Steuter 1994; Henderson & Keith 2002).

The abundance of dominant grasses like *Astrebla* spp., *Dichanthium sericeum* and *Eulalia aurea* at Kirramingly Nature Reserve was not significantly influenced by fire. The cover of such species was also unaffected by fire in Queensland (Wright 2001). In central-western Queensland fire had little effect on the frequency of *Astrebla* spp. (Purcell & Lee 1970) and Everist (personal observations) observed no effect on botanical composition and vigour of pasture some years after a fire (Orr 1975). Similarly, in north-west Queensland Radford *et al.* (2001) reported little change in species composition and frequency of pasture species after fire, but there was a reduction in biomass of

Astrebla. However, the effect of fire on *Astrebla* spp. varies. Four years after a burn in arid far north-western NSW, foliage cover of *Astrebla* spp. remained less than in the unburnt areas (Mulham 1985). An even poorer recovery of *Astrebla* spp. occurred after a wildfire, and this was ascribed to low summer rainfall (Mulham 1985). Perhaps *Astrebla* spp. are less able to recover after fire in arid environments, as fire can result in reductions in diversity and productivity in such environments (Daubenmire 1968; Vogl 1974; Scanlan 1980).

The recovery of perennial grasses following fire appeared to be due to their ability to resprout vegetatively from protected buds and rhizomes at or below the surface (i.e. they are hemicryptophytes or geophytes). A similar response for perennial grasses was recorded by Wright (2001) for Mitchell grasslands in Queensland. This suggests that growing points at or below the soil surface were not killed by fire in either season. Soil temperatures at 1 cm did not exceed 77°C during either burn, supporting the idea that buds at or just below the surface may have survived the fires. It is possible, however, that a more intense, slow-moving burn could have a negative effect on perennial grasses.

Resprouting of perennial species after fire appears to be common in Australian grasslands. For example, Lunt (1990a) found that all perennial species regenerated vegetatively following burning and only 19% of native species recruited by seedlings, in temperate grasslands of Victoria. Similarly, Morgan (1996, 1999) reported that resprouting was the dominant fire response of perennial species. It is not known whether any native perennial species at Kirramingly Nature Reserve have limited capacity to resprout vegetatively after fire, but I suspect such species are rare (Morgan 1996, 1999). Perennials with rhizomatous storage organs are able to use stored carbohydrate reserves after a fire, enabling rapid regrowth (Mallik & Grimingham 1983; Morgan 1996, 1999). Hence vegetative reproduction may be favoured over reproduction from seed, as vegetatively reproducing species may respond faster, allowing them to take advantage of the post-fire conditions which enable rapid growth because of high light and water availability (Lunt 1994; Morgan 1996). Seeds of annual species on the soil surface are probably also killed by fire (Auld & O'Connell 1991) and this may influence their persistence in fire-prone areas.

There were no species that disappeared entirely from burnt areas. Uys *et al.* (2004) suggested that there are two suites of plants in southern African grasslands, one tolerant of fire and the other preferring no burning. While this was not obvious for the limited number of species in the current study, it is possible that some native species at the regional scale cannot survive fire. In terms of management of Kirramingly Nature Reserve, it appears that fire will not have a negative influence on native species richness (at least for plants), but some areas within the main vegetation types defined by Clarke *et al.* (1998) should be left unburnt given that the effect of fire on animal diversity in the region is unknown.

5.4.3 The influence of repeated burning

Species richness did not differ between sites burnt once, twice and control sites in autumn 2004, approximately 18 months after the last burn. In autumn 2003, 12 and 6 months after the 2002 burns, there were no obvious differences in richness between sites burnt once in 2002 and sites burnt twice (Fig. 5.6). Hence species richness appears to recover relatively quickly in these grasslands and the ability of most (if not all) perennial species within the experimental area to resprout vegetatively (personal observations) suggests these grasslands may not be negatively affected by repeated fires. Such a response may be common as repeated burning in other native grasslands, even annually, generally does not reduce the number of species present (Vogl 1974; Morgan 1999). A similar fast recovery has been reported for *Themeda*-dominated grasslands of Victoria, where species are able to complete their phenological cycles within 1 year of burning (Morgan 1996, 1999). An exception to this, however, is reported for North American grasslands where frequent fires increased the dominance of perennial grasses and reduced plant species diversity (Collins *et al.* 1998). While the effect of long-term fire regimes could not be investigated in this study, it is possible that some native species would be adversely affected if fires were repeated over many years.

The ability of grasslands on the Moree Plains to recover after livestock grazing (Chapters 3 and 4) may be related to their adaptations to survive in fire-prone environments (i.e. if the flora has evolved with burning regimes and is consequently fire-tolerant). Unfortunately, the fire frequency prior to European settlement is not known for the region. However, there are records of Aboriginal use of fire. Fires regularly burnt right across the Gallathera Plain, including the area that is now Kirramingly Nature Reserve (L. Swan, pers. comm., 2001). Fensham (1997) reported that fires were recorded in explorer journals in Queensland for *Dichanthium* and *Astrebla* communities, across a range of seasons. Further research is required to determine the pre-European fire regime for the Moree Plains. Climatic conditions are likely to influence when and how often fires can occur in the region because the rate of biomass accumulation is driven by moisture availability. My findings suggest that herbaceous biomass can accumulate quickly, with no differences in biomass between unburnt areas and those burnt 3 years previously. However, this rate of biomass accumulation may not be typical, since rainfall was above average in the 3 years after the May 1999 burn (717, 564 and 805 mm for Moree in the years 1999-2001).

It is interesting that species evenness was lower at burnt sites (all frequency treatments) than unburnt sites in autumn 2004 and suggests that there may be some less obvious, longer-lasting effects of burning that were not present in 2003. This finding is perhaps converse to what we might expect, as a reduction in grass canopy by fire should allow greater numbers of the less common species (i.e. forbs and smaller grasses) to grow. Indeed, in spring 2002 evenness was higher at the autumn 2002-burnt sites than at the unburnt sites (Fig. 5.4f) and Wright (2001) reported an increase in species evenness at a recently burnt site in Mitchell grasslands of central Queensland. It is possible that burning actually increased canopy cover of certain dominant grasses in burnt quadrats at Kirramingly Nature Reserve in 2004 as vegetative reproduction of perennial species on post-burn sites often occurs more rapidly and vigorously than growth on unburnt sites (Vogl 1965, 1974; Scanlan 1980). Unfortunately cover was not measured accurately enough to detect differences (i.e. a cover score was assigned to each species). It is also possible that this finding was the result of Type 1 error given the small sample sizes (and, hence, low statistical power).

Two introduced forbs (**Hedypnois rhagadioloides* and **Physalis lanceifolia*) were more frequent at sites burnt twice than sites burnt once, while another two introduced forbs were more common at sites burnt once only in either autumn (**Rapistrum rugosum*) or spring (**Medicago truncatula*). Despite these increases in frequency, repeated fires did not greatly promote introduced species over natives. Native species also showed mixed responses to fire frequency with some species occurring at higher frequencies in sites burnt once in 1999 only (e.g. *Digitaria divaricatissima*) and some species preferring two burns (e.g. *Erodium crinitum*) (Tables 5.11, 5.12). There were no consistent negative responses to repeated fires, although some species (e.g. *Oxalis perennans, Vittadinia cuneata, Cyperus bifax* and *Einadia nutans*) decreased in frequency at sites burnt once only (Tables

5.9, 5.11). Further studies are required to monitor changes in species composition with repeated fires over time, because continued high fire frequency can potentially eliminate certain plant species if their life cycle processes are interrupted (Noble & Slatyer 1980; Henderson & Keith 2002). For short-lived species that reproduce by seed only, a short interval between fires may prevent completion of the phenological cycle and establishment of seedlings.

5.4.4 The influence of kangaroo grazing post-fire

Species composition, richness and evenness were not significantly influenced by kangaroo grazing in burnt and unburnt quadrats, and there was no obvious decrease in the abundance of grass species. The lack of significant grazing effects is surprising given that post-burn plants are generally preferred by herbivores, which seek out burned sites to select more palatable and nutritious forage (Leigh & Holgate 1979; Robertson 1985; Biondini *et al.* 1989; Meers & Adams 2003; Fuhlendorf & Engle 2004; Letnic 2004).

The lack of vegetation response to kangaroo grazing was probably related to low grazing intensities. The relatively large areas burnt (24 ha in autumn and 50 ha in spring) probably resulted in dispersed grazing pressure over the burnt areas. Marginally more dung was recorded in the autumn-burnt areas than in spring or control areas ($P = 0.080$), perhaps due to the smaller area burnt in autumn. However, dung counts suggested that kangaroos did not show an obvious preference to the burnt areas. Grazing intensities within the Reserve probably fluctuate over time depending on the availability of cereal crops in the vicinity of the Reserve, recent culling of kangaroos and water availability. The timing of dung counts after the fires (i.e. approximately 12 months after the autumn burn and 6 months after the spring burn) may have also contributed to the lack of difference in dung counts between burnt and unburnt areas. The preference to graze in burnt areas may only be short-lived (perhaps in the first 3 months of grass growth).

5.4.5 Controls distant from the experiment

Distant control sites were established to determine the influence of smoke on unburnt sites in the experiment. Unfortunately, the initial differences in composition between the two sets of control sites, and differences through time, made it difficult to determine any smoke effects. Seedling regeneration was not obvious for most species in the fire experiment (personal observations), suggesting smoke-induced germination was not common. There was also no obvious recruitment of seedlings of hard-seeded native forbs (e.g. *Cullen tenax*) following fire, suggesting that fire may not be necessary for breaking seed dormancy in these grasslands (Auld & O'Connell 1991). It is possible that the lack of obvious fire responses is partly due to the loss of fire dependent species from the assemblage, given the long period of non-burning since European settlement.

Smoke can have a significant influence on native grass germination (Read & Bellairs 1999). *Dichanthium sericeum* and *Panicum decompositum* had increased germination due to smoke in the experiment by Read & Bellairs (1999). However, seedlings of these two species did not appear to be more frequent at control sites, or recently burnt sites, within the experiment at Kirramingly Nature Reserve. Perhaps other environmental conditions (i.e. moisture and temperature) were not suitable for germination of these species after the fires in 2002 and seed banks for these species may have been low (Lunt 1990b). It is also possible that penetration of smoke derivatives into the soil profile was not sufficient to stimulate germination. To better determine the effects of smoke, controls without smoke would need to be established near burnt sites to prevent confounding spatial influences. This may involve establishing more control sites in all directions around burnt sites and measuring whether each site receives smoke treatment or not. Future studies could also investigate the influence of smoke on seeds in these grasslands under controlled conditions.

Despite the problems in determining smoke effects, spatial differences between the two sets of control sites were interesting. Total, native and forb species richness, evenness and heterogeneity were lower at distant control sites than at control sites within the experiment (Table 5.13; Fig. 5.7a,b,d,f,g). There were also some differences in composition between control sites (Fig. 5.8). Some distant control sites had dense grass cover (with high abundances of *Astrebla* spp. and *Aristida leptopoda*), and it is possible that the cover and grass litter at these sites inhibited recruitment of forbs. After the dry conditions in spring 2002, grass cover was high in the following autumn. In fact, cover scores for *Astrebla elymoides* increased in autumn 2003 at the distant control sites (five cover abundance scores of 51-75% were recorded for the eight distant control sites, and no cover scores in this category were recorded at any other time, or at any sites within the experimental area). Hence it seems likely that the increase in grass cover resulted in the lower total, native and forb species richness, evenness and heterogeneity, especially in autumn 2003. Differences in grass species richness between control sites varied over time (significant interaction term in Table 5.13), but the greater reduction in grass richness at distant control sites in spring 2003 (Fig. 5.7e) may have also been a response to higher perennial grass cover in autumn 2002.

The reason for the differences in perennial grass cover and species composition between distant controls and those within the experiment is not known. The differences may be related to the history of grazing prior to removal of livestock, or perhaps kangaroo-grazing intensity is higher in the northern section of the Reserve where the experiment was carried out. Unfortunately no kangaroo dung counts were made at distant control sites to test this idea. The findings for distant control sites suggest that some sections of the Reserve may indeed benefit from removal of perennial grass cover (i.e. controlled burning) at certain times (as hypothesised in Chapter 4). However, it appears that natural fluctuations in perennial grass density over time may allow recruitment of forbs and smaller grasses at times of reduced perennial grass dominance.

5.4.6 Individual species survival and seed production after fire

All of the individual species followed over time were perennial (although *Dichanthium sericeum* and *Desmodium campylocaulon* may be short-lived) and were able to resprout vegetatively after fire. The lower survival of *D. sericeum* and the decrease in survival over-time (Table 5.15) was probably related to seasonal conditions (see Chapter 3 and 4) as this species decreased in abundance at all sites after autumn 2002. Fire may be beneficial in the vegetative resprouting of *D. sericeum*; however, higher frequency of *D. sericeum* was not recorded at burnt sites.

Fire resulted in the division of large *Astrebla* tussocks into a ring of smaller tussocks around the perimeter of the existing tussock. Similar findings are reported by Scanlan (1983), who reported an increase in tussock numbers after a burn, as a result of large tussocks being divided into smaller ones. Both *Astrebla* spp. and *Dichanthium sericeum* individuals that resprouted after fire appeared fragile and it is likely that such individuals may be more susceptible to grazing following fire. Further studies are required to determine whether livestock grazing after fire has a negative effect on these species.

Acacia stenophylla and the dominant shrub, *A. farnesiana*, were in most cases not killed by fire treatments at Kirramingly Nature Reserve (Table 5.15). Similarly, burning did not kill *A. farnesiana* in south Texas, but did reduce canopy cover and increased stem number (Scifres *et al.* 1982 cited in Burrows *et al.* 1991). Repeated fire often favours herbaceous species over woody vegetation and has been used in the management of woody weeds (Daubenmire 1968; Kayll 1974; Vogl 1974; Partridge 1996; McPherson 1997; Uys *et al.* 2004). Hence the response of *A. farnesiana* and *A. stenophylla* to further repeated fires within the experimental area should be monitored. Both *A. farnesiana* and *A. stenophylla* resprouted vegetatively following fire (Table 5.17) without obvious seedling recruitment, suggesting that there was no fire-related seed dormancy. However, observations in the field suggest that fire greatly increased the amount of *A. farnesiana* seed on the soil surface, as fires either burnt or stimulated opening of seed pods. It will be interesting to see whether this influx of seed results in greater seedling recruitment in burnt areas over time. Further monitoring at the established quadrats will enable an assessment of this.

Seed head production of both *Astrebla* spp. and *Dichanthium sericeum* was not significantly increased as a result of burning. This is interesting as increased numbers of grass and forb flowers and seed are usually stimulated by burning (Daubenmire 1968; Old 1969; Lloyd 1972; Vogl 1974; Scanlan 1980; Lunt 1994). In grassland in Illinois, Old (1969) reported a ten-fold increase in flowering rates after an early spring burn when compared to unburnt areas. Further, Lunt (1994) reported that seven out of nine species flowered more abundantly in burnt areas than in areas not recently burnt in temperate grasslands of Victoria. Lunt (1994) believed that these differences were due to competition with the dominant grasses, with plants less likely to flower where competition was high. Increased reproductive performances have also been recorded in *Astrebla* grasslands in north-west Queensland, where Scanlan (1980) reported increased production of seed heads of *Astrebla lappacea* and *A. pectinata* at burnt sites.

Despite the lack of fire-stimulated seed head production, there was strong year-to-year variation in seed head production for all three species (Table 5.16). *Dichanthium sericeum* produced more seed in 2002 while both *Astrebla* spp. produced more seed in 2003. Increased seed production in different years by *D. sericeum* and *Astrebla* spp. is to be expected given the fluctuations in the dominance of these species (Chapter 3), which probably result in reduced competition for resources. Growth and reproduction of

D. sericeum and *Astrebla* spp. in response to differing seasonal conditions probably assists the coexistence of these species in the same area. The high seed production by *Astrebla* spp. in 2003 did not result in obvious recruitment of seedlings in 2004 (personal observations). This is perhaps not surprising given that recruitment of *Astrebla* spp. from seedlings is irregular, and persistence of *Astrebla* tussocks is due to their longevity, which may be up to 26 years (Williams & Roe 1975; Orr & Holmes 1984). Recruitment of *D. sericeum* is probably more frequent given that this species is relatively short-lived (Williams & Roe 1975).

5.4.7 Conclusions

By 2004, neither fire treatment nor kangaroo grazing had a major lasting effect on species composition or richness. The major changes in composition were brought about by seasonal variations (i.e. differences between spring and autumn and differences due to rainfall). Species richness (total and native) and species evenness had reached levels similar to control sites within 6 months of the spring 2002 burns and 12 months of the autumn 2002 burns. Recovery of composition and richness in these grasslands appears to be relatively rapid because of the high proportion of perennial species that are able to resprout vegetatively after fire. Frequencies of certain species, including a number of annual or short-lived species, increased after fire, which is not surprising given that the bare ground would encourage recruitment from seed.

There were no differences in richness or evenness between spring-burnt and autumn-burnt sites within 12 months of burning. However, spring burning rather than autumn burning is recommended for future controlled burns in the Reserve, and within the region, as it is better aligned with the growth period of most native species, and autumn burning could potentially favour winter-growing introduced species. Fire frequency should be determined by herbaceous biomass accumulation. It appears that a high fire frequency may not be necessary in these grasslands due to seasonal fluctuations in perennial grass density, which may allow sporadic recruitment of inter-tussock species. Monitoring of the vegetation at quadrats established for these experiments is recommended as 3 years might be an inadequate response time in perennial herbaceous communities (Belsky 1992). It will be interesting to see whether exclusion of kangaroos over a long period of time (e.g. 10 years) has any influence on species composition and richness.

CHAPTER SIX

Short-term impacts of mowing (artificial grazing) and disc ploughing grassland at Kirramingly Nature Reserve

6.1 Introduction

Mowing or slashing often has a positive influence on grassland species richness through decreasing competition with perennial grasses (e.g. Collins *et al.* 1998; Peet *et al.* 1999; Kirkpatrick *et al.* 2005; Verrier & Kirkpatrick 2005). Hence mowing and slashing are sometimes used as a method of defoliation in small areas (e.g. cemeteries) where grazing is not permitted or desirable (Eddy 2002; Verrier & Kirkpatrick 2005). In Tasmania, Verrier and Kirkpatrick (2005) reported that frequent mowing resulted in greater cover of rare or threatened species and native species. At Kirramingly Nature Reserve, mowing or slashing could potentially be an alternative disturbance mechanism (to livestock grazing or fire) to reduce perennial grass density at certain times and enhance species richness. However, increases in richness do not always occur after mowing (Kirkpatrick 1986), and richness may be influenced by mowing frequency (Zechmeister *et al.* 2003) and litter removal (Verrier & Kirkpatrick 2005). Few Australian studies have investigated the influence of mowing on species composition and diversity, but there is a need to determine the effects of mowing if it is to be used in the management of native grasslands on the Moree Plains.

Defoliation by mowing or cutting is sometimes used as a surrogate for the effects of grazing (e.g. Neiland & Curtis 1956; Davis 1960; Smith 1960; Tomlinson 1986; Hodgkinson *et al.* 1989; Orr & Evenson 1991b), assuming treatments simulate the effects of defoliation by livestock. The important differences between mowing and livestock grazing are: (1) mowing is non-selective; (2) mowing does not simulate the hoof action of ungulates; and (3) mowing does not simulate the effects of dung and urine distribution (Jameson 1963; Snaydon 1981; Brown & Stuth 1993; Sun & Liddle 1993; Hoffman 2003). As a result, differences in species richness and composition have been reported between mown and grazed areas (Kirkpatrick *et al.* 2005; Verrier & Kirkpatrick 2005). Despite the limitations of using mowing to simulate the effects of grazing, an experiment to determine the impacts of mowing was established to provide information for the management of Kirramingly Nature Reserve and the *Astrebla* and *Dichanthium sericeum* dominated grasslands of the Moree Plains. If mowing has a significant impact on species richness or composition, it can be assumed that grazing that removes a similar amount of herbaceous biomass also has an effect (Jameson 1963). However, if mowing has no effect it does not necessarily suggest that grazing will also have no effect, given the additional influences of grazing.

Grazing intensity often has some influence on species richness and composition (McIntyre & Lavorel 2001). Heavily grazed grasslands can have increased proportions of forbs and grasses that are annual and small-statured, while lightly grazed grasslands often have a more diverse range of growth forms (Trémont & McIntyre 1994; McIntyre *et al.* 1995; McIntyre & Lavorel 2001). Percentage utilisation of native grasslands on the Moree Plains varies greatly, but local landholders suggested that a 50% utilisation was appropriate for Mitchell grasslands in the region (R. Whalley, pers. comm., 2002). To determine whether differing mowing intensities influence species richness and abundance, mowing treatments involving cutting at two heights (low cut *vs* high cut) and two frequencies (once *vs* twice per year) were administered. It was hypothesised that mowing (and removal of litter) would result in increased total and native richness and evenness, and it was considered likely that mowing close to the ground would have a more positive effect on richness and evenness than once-off mowing some distance above the ground, or not mowing. Further, mowing treatments might encourage short species (i.e. forbs and low-growing grasses) and annual species.

The effect of ploughing on species richness is variable, but often negative (Belsky 1986b; Montalvo *et al.* 1993; Austrheim & Olsson 1999; Nadolny & Eldridge 1999; Fulbright 2004; Römermann *et al.* 2005). Disc ploughing in conjunction with grading has been used to maintain fire-breaks at Kirramingly Nature Reserve and was used to delineate plots in the fire experiment (Chapter 5). However, the impacts of ploughing native grasslands at Kirramingly Nature Reserve and on the Moree Plains are largely unknown. Given that ploughing could potentially influence vegetation community composition in the Reserve (i.e. perhaps by encouraging introduced species or eliminating tuber-and bulb-forming herbs), an experiment to investigate the effect of ploughing was established. Based on previous surveys within the Reserve (Chapter 4) it was expected that ploughing would result in a reduction in native species richness, but possibly an increase in introduced species richness. Even more so than mowing, ploughing is likely to encourage annual species that can grow quickly when there is more bare ground and hence less competition. The results from this experiment may also be useful for comparing the impacts of ploughing in cropping systems in the regional survey (Chapter 3) and could be applied in a broader context. While there are differences between once-off disc ploughing and continued cultivation in cropping systems, the disturbance mechanism is essentially the same.

The major objectives of this chapter are to determine:

1. The influence of mowing height (low cut *vs* high cut) on species richness, evenness and composition.
2. The influence of repeated mowing (two mows per year) and once-off mowing on species richness, evenness and composition.
3. The influence of once-off disc ploughing on species richness, evenness and composition.

6.2 Methods

6.2.1 Experimental design and site establishment

Mowing experiment

Two unburnt 4-ha plots were fenced to exclude kangaroo grazing in September 2002 (Fig. 5.1) as part of the fire experiment (Section 5.2.1). The plots appeared to have very similar vegetative composition prior to applying treatments and were separated by approximately 400 m. Within both of the plots, 10 randomly placed sampling quadrats were established by dividing each plot into a 10 x 10 grid, and obtaining 10 random grid references. The centre of each quadrat was marked using a labelled steel post and the location of each was recorded using a Garmin® GPS. One of five treatments was randomly assigned to each quadrat (Fig. 6.1). The treatments were: (1) mowed once, close to the ground (low cut); (2) mowed twice, close to the ground; (3) mowed once, some distance above the ground (high cut); (4) mowed twice, some distance above the ground; and (5) not mowed (control). Hence, in each plot, there were two quadrats for each treatment (Fig. 6.1) and assuming no difference between the plots, there were four quadrats for each treatment.

Mowing was carried out in September 2002 and April 2003 (for sites mowed twice). The low-cut treatment was carried out using an industrial strength lawn mower. Every plant within an area of approximately 5 x 5 m was mowed to a height of approximately 10 cm (i.e. 80-90% utilisation), except the mature *Acacia farnesiana* shrubs (Fig. 6.2). This treatment was chosen to simulate heavy grazing (i.e. crash grazing). The high-cut treatment was implemented using a Stihl® (F4-75) brushcutter. In this case all plants (except large shrubs) were cut to a height of approximately 30 cm above the ground (Fig. 6.2). This was chosen to simulate a less intense grazing event (i.e. 40-60% utilisation). All mowed quadrats were raked after the treatments to remove most but not all of the litter.

Disc ploughing experiment

During the establishment of plots for the fire experiment (Section 5.2.1) a number of containment lines were ploughed to separate plots and prevent the controlled burns from spreading into neighbouring treatments. Containment lines were approximately 3 m wide and were established by firstly grading and then disc ploughing. The grading and ploughing was carried out once only in April-May of 2002, and removed all living plant material above the surface. To determine the effect of grading and disc ploughing, six quadrats were established on the containment lines prior to treatment. The vegetation of the ploughed sites was compared to that in four unfenced, unburnt control sites within the fire experiment to allow a 'BACI' (Before, After, Control, Impact) design (Green 1993).

The six quadrats were randomly distributed over containment lines in the area of the fire experiment (Fig. 5.1), and were marked using labelled steel posts. The location of each was recorded using a GPS. At each quadrat, the containment lines were made wider (approximately 6 m wide) to ensure that the entire area of each quadrat was ploughed. The steel posts were removed from the ground immediately prior to ploughing, and were replaced as accurately as possible after the plough had passed over the quadrat.

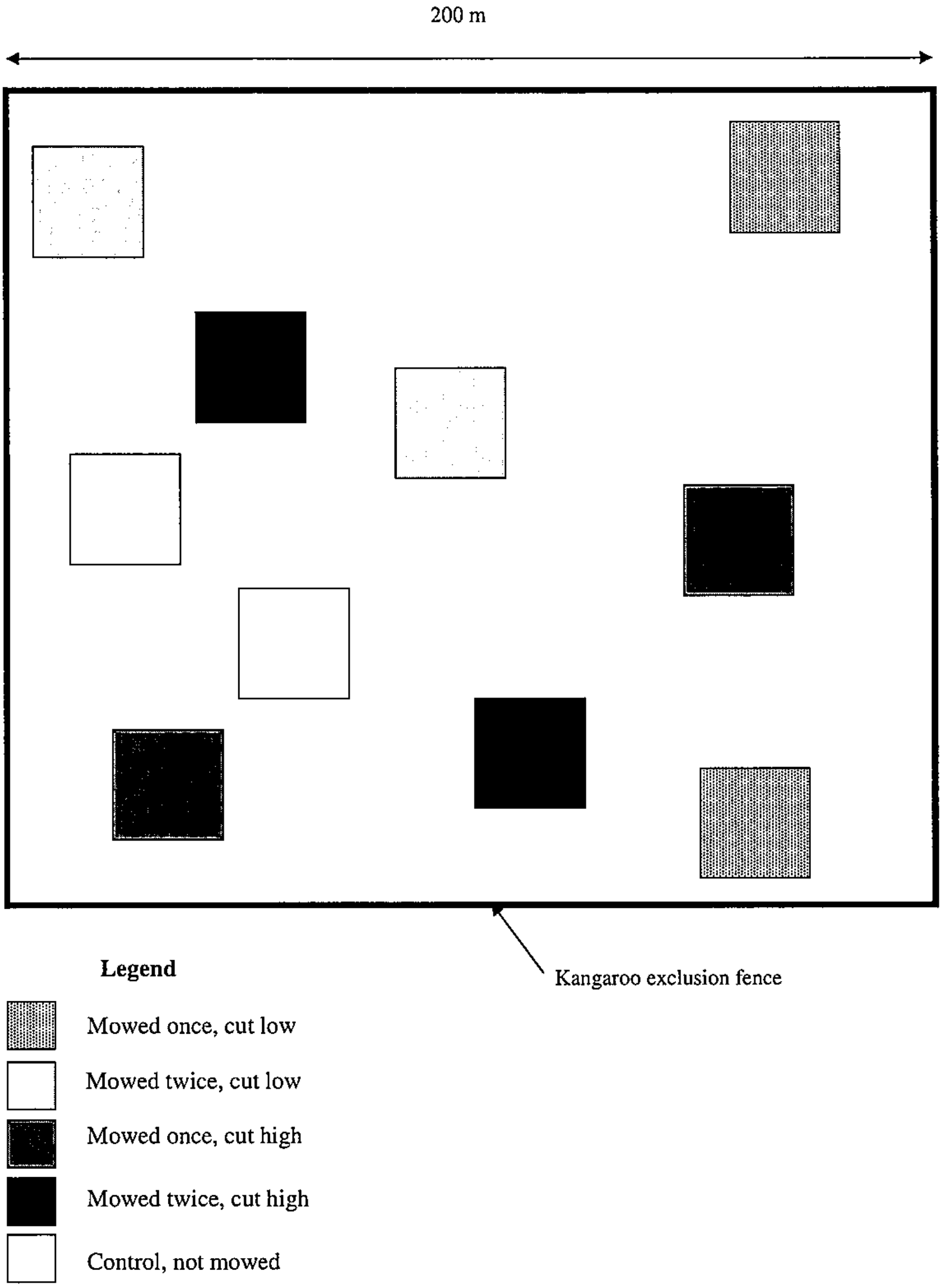
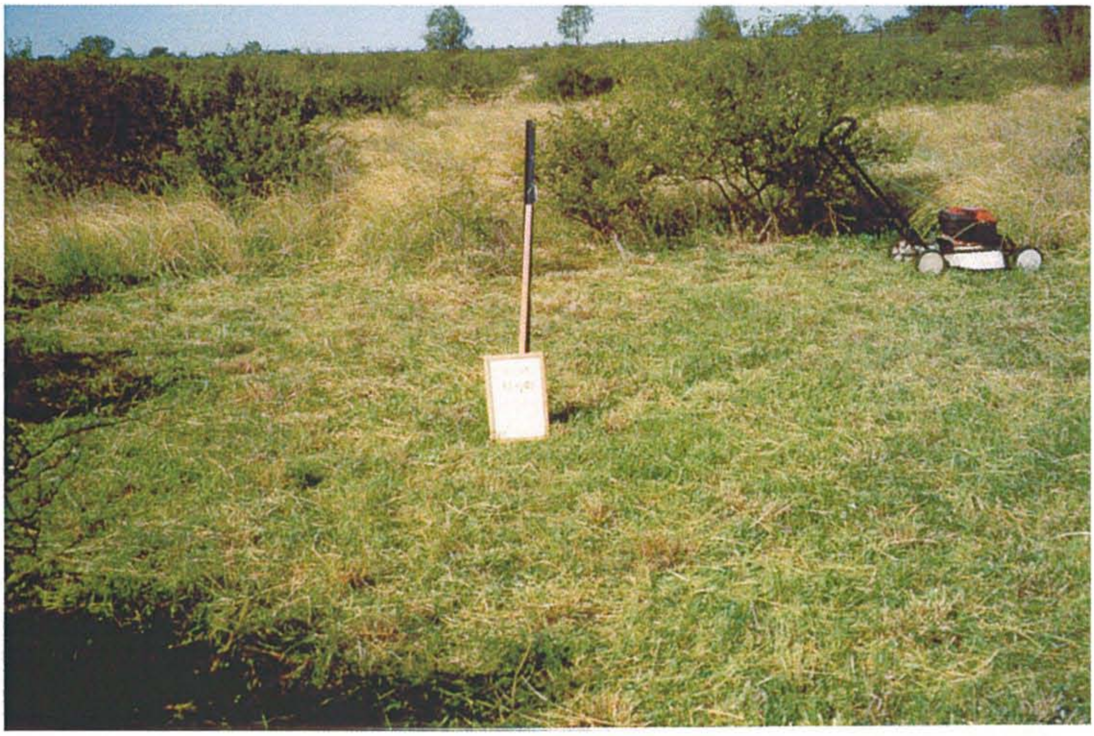


Fig. 6.1. One of two plots fenced to exclude kangaroo grazing in which mowing treatments were applied. Ten sampling quadrats (32 m²) were randomly placed within each plot and assigned to the above treatments.

(a)



(b)

Fig. 6.2. Mowing treatments were applied to simulate (a) heavy grazing (low cut in autumn 2003) and (b) moderate grazing (high-cut in autumn 2003).

6.2.2 Vegetation sampling

In both of the above experiments, the frequency score method of vegetation sampling was used, with five nested concentric sub-quadrats, each doubling in sample area (i.e. 2, 4, 8, 16 and 32 m²). More detail on this sampling method is provided in Sections 4.2.1 and 5.2.2. For the mowing experiment, the vegetation was sampled at each quadrat in September 2002 (prior to initial mowing treatment), April 2003 (prior to the second mowing treatment), October 2003 and late February 2004. For the disc ploughing experiment, vegetation was sampled at each quadrat in April 2002 prior to the ploughing treatment, then re-sampled approximately 1 and 2 years after the initial ploughing event (in April 2003 and March 2004).

6.2.3 Statistical analysis

All analyses were carried out using GenStat (6th edition) and R (Version 1.7.1). Response variables analysed included total, native, introduced, grass and forb species richness, species evenness (Smith and Wilson's Index) and heterogeneity (Simpon's Index). Smith and Wilson's Index for evenness and Simpson's Index for heterogeneity were calculated using the software Programs for Ecological Methodology (2nd edition) (Krebs 2002).

To determine the effect of mowing treatments repeated measures analysis of variance (ANOVA) was used because the same quadrats were sampled on successive occasions. Pre-treatment (spring 2002) data were analysed as a covariate to increase the sensitivity of the important main effects (i.e. between subjects stratum). The mowing experiment was a randomised block design with two replicated blocks (referred to as plots for consistency with chapter 5). By taking out the variation due to plots, the experimental error was reduced, increasing the power to detect treatment differences (Zar 1999). Interactions between mowing and sampling time were investigated. One degree of freedom contrasts were carried out at each sampling time to compare mowed sites with controls, sites mowed twice with sites mowed once, and low-cut sites with high-cut sites.

Repeated measures ANOVA was also used to compare disc-ploughed sites with unploughed control sites. The interaction between ploughing treatment and sampling time was investigated and ANOVA contrasts were also carried out at each sampling time.

Asymmetrical variance/covariance matrices over time were accounted for in the repeated measures analyses by multiplying the degrees of freedom by correction factors before calculating *F* probabilities (Payne 2002). For each analysis, the assumptions of ANOVA were checked using a normal probability plot of the residuals (to check the assumption of normally distributed data) and a residual plot (to check the assumption of equal variances). Square root transformations had to be applied to total, native, introduced, grass and forb richness, while an arcsine transform was applied to species evenness and heterogeneity, to meet the assumptions of ANOVA.

Generalised linear models were used to identify differences in the mean frequency score of species per quadrat between different mowing and ploughing treatments. Comparisons were made between each of the five mowing treatments (Fig. 6.1) and between ploughed and unploughed sites. To account for pre-existing differences in frequency, differences between the initial sampling time (i.e. spring 2002 for the mowing experiment and autumn 2002 for the ploughing experiment) and other sampling times (autumn 2003 and 2004) were analysed. Species with less than five occurrences were ignored, because the occurrence of infrequent species may be due to chance. Bonferroni adjustment was used to incorporate the number of statistical tests and reduce the possibility of inappropriately assigning a significant conclusion (type 1 error; Zar 1999). In addition to recording species responding significantly after Bonferroni adjustment, some responses considered biologically significant are also reported.

6.3 Results

6.3.1 The influence of mowing and sampling time

There were no significant interactions between sampling time and mowing treatments (Table 6.1). Sampling time had a significant effect on all species richness measures, but not species evenness (Table 6.1; Fig. 6.3). Species richness was low initially (prior to the first mowing treatment in spring 2002) due to the low winter rainfall in 2002, but had increased by autumn 2003 and remained higher than the initial richness for all sampling times (Fig. 6.3a,b). There was a decline in introduced species richness between spring 2003 and autumn 2004 due to the lack of winter-growing annual forbs in 2004 (Fig. 6.3c). These introduced forbs were present in autumn 2003 (although often only as germinants), resulting in higher total species richness at this time. Thus, differences were apparent between autumn and spring sampling times and between autumn sampling times

(Fig. 6.3a). Similar seasonal variations in composition and richness at Kirramingly were reported and discussed in Chapter 5 (Sections 5.3.4 and 5.4.1).

Mowing had a significant effect on grass species richness (Table 6.1). In autumn 2003 (after one mowing event only) grass species richness was higher at mown sites than at control sites (Fig. 6.3e; $F_{1,13} = 14.81$, $P = 0.002$). This difference was still apparent in spring 2003 (approximately 6 months after the second mowing event) (Fig. 6.3e; $F_{1,13} = 6.15$, $P = 0.028$), but not in autumn 2004 (Fig. 6.3e). In spring 2003, forb species richness was higher at sites mown twice than at sites mown once (Fig. 6.3d; $F_{1,13} = 5.08$, $P = 0.042$). In autumn 2004, no contrasts were significant (Appendix 6.1). Hence there were no sustained differences in richness and evenness between mown and control sites over time. There were no differences in richness, evenness or heterogeneity between high and low-cut treatments, even 6 months after treatments (Appendix 6.1).

The increase in grass species richness in autumn 2003 at mown sites was due to the greater incidence of species such as *Eragrostis parviflora, Panicum queenslandicum, Digitaria divaricatissima* and *Thellungia advena*. Mean frequency score per quadrat for all species encountered in quadrats in this experiment is provided in Appendix 6.2. Frequencies of some species were significantly influenced by mowing (Table 6.2). Species that benefited from one or more mowing treatments (i.e. were more frequent at mown sites) included *Chloris truncata, Panicum queenslandicum, Vittadinia cuneata, Eclipta platyglossa* and *Portulaca oleracea* (Table 6.2). Species that were disadvantaged by one or more of the mowing treatments (i.e. were more frequent at control sites than at mown sites) included *Panicum buncei, Haloragis aspera, Oxalis perennans, Asperula cunninghamii* and *Boerhavia dominii* (Table 6.2).

Table 6.1. Repeated measures ANOVA table showing differences in species richness and evenness measures in response to mowing treatments, sampling time and the interaction between the two effects

Variable		Total		Native		Introduced	
	d.f.	*F*	*P*	*F*	*P*	*F*	*P*
Between-subjects							
Mowing treatment	4	0.67	0.621	0.87	0.510	0.43	0.786
Covariate (Spring 2002 sampling)	1	0.46	0.510	0.50	0.493	40.74	<0.001
Residual	13	5.35		4.61		0.52	
Within-subjects							
Time	2	38.02	<0.001	30.10	<0.001	427.64	<0.001
Time*Mowing treatment	8	1.42	0.246	1.18	0.350	1.28	0.304
Residual	30						

Variable		Forb		Grass		Evenness		Heterogeneity	
	d.f.	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Between-subjects									
Mowing treatment	4	0.75	0.574	5.96	0.006	0.39	0.810	0.55	0.700
Covariate (Spring 2002 sampling)	1	1.26	0.283	5.34	0.038	0.41	0.531	0.00	0.987
Residual	13	5.26		0.84		2.87		3.63	
Within-subjects									
Time	2	49.19	<0.001	81.30	<0.001	0.51	0.581	35.10	<0.001
Time*Mowing treatment	8	1.14	0.368	2.54	0.051	0.77	0.614	0.84	0.565
Residual	30								

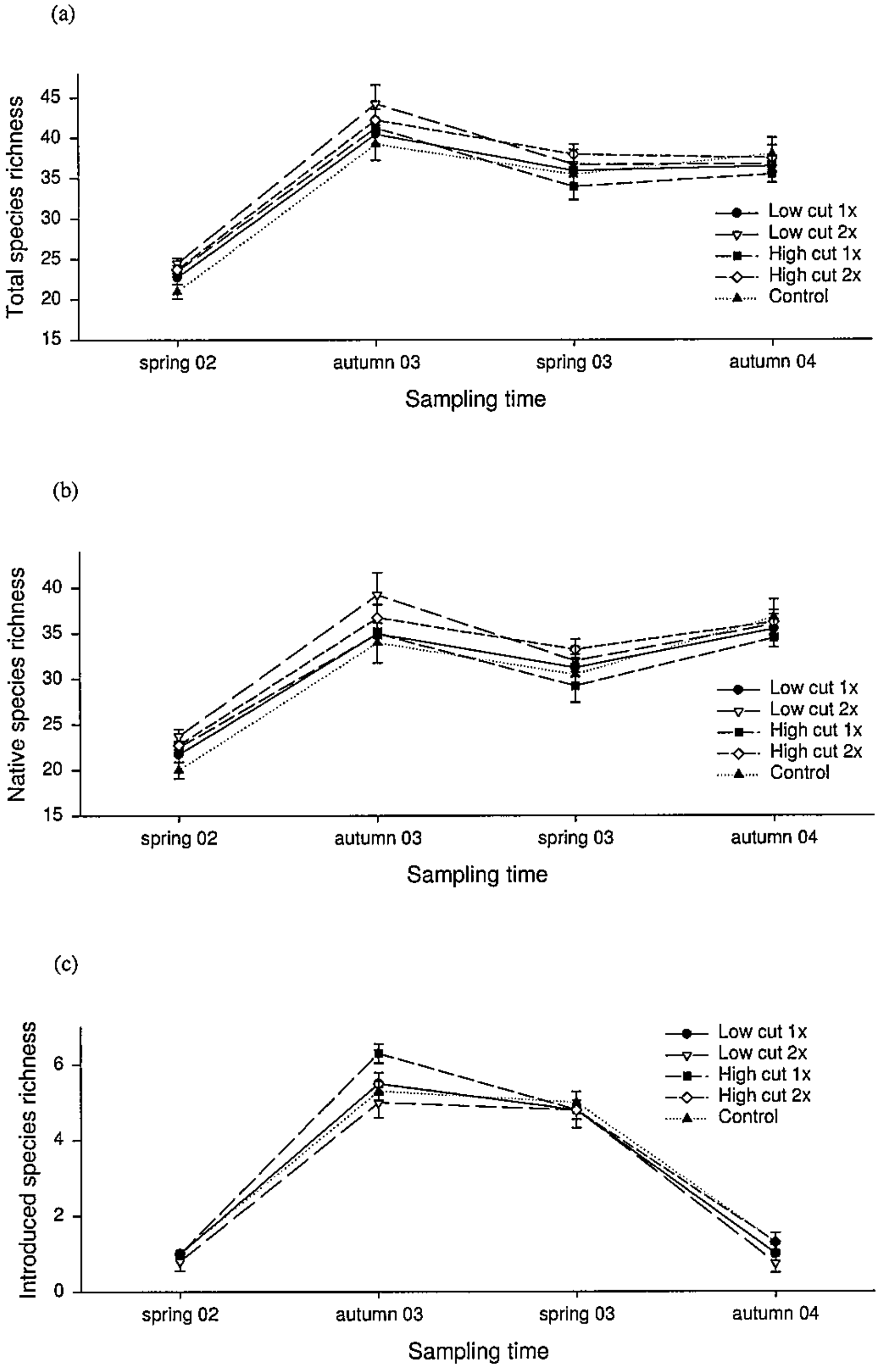


Fig. 6.3. Changes in mean (± SE) species richness, evenness and heterogeneity through time at quadrats in each of the mowing treatments (n = 4 quadrats for all treatments). Variables: (a) total; (b) native; (c) introduced; (d) forb; and (e) grass species richness; (f) species evenness; and (g) species heterogeneity.

Fig. 6.3. (continued)

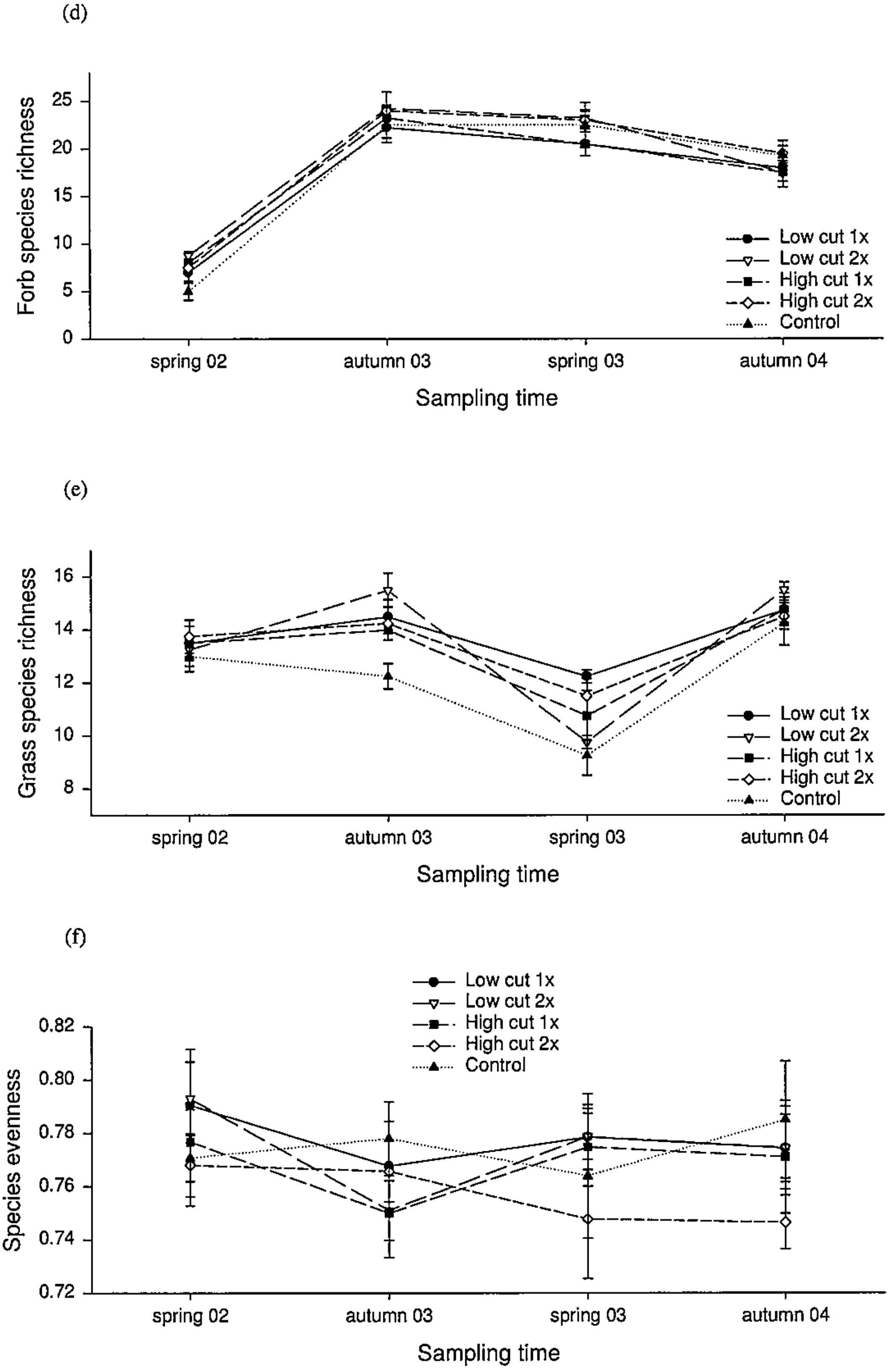
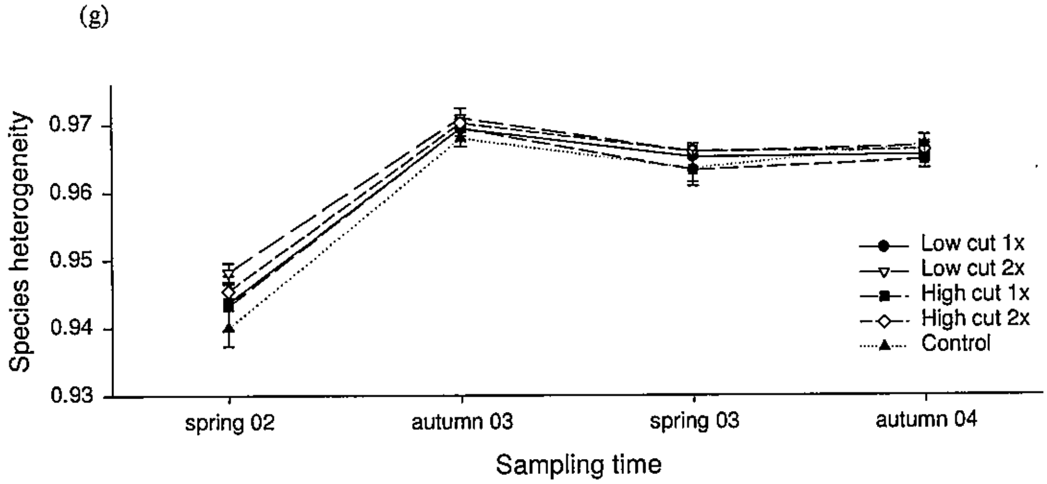


Fig. 6.3. (continued)



6.3.2 The influence of disc ploughing

No significant interactions between sampling time and ploughing were detected (Table 6.3). Total, introduced and forb richness and species heterogeneity varied significantly between the three autumn sampling periods irrespective of ploughing (Fig. 6.4a,c,d,g). These three richness measures and heterogeneity were higher during autumn 2003 when the early occurrence of winter-growing introduced forbs was recorded. Species such as **Medicago polymorpha*, **M. truncatula*, **Hedypnois rhagadioloides*, **Sonchus oleraceus* and **Physalis lanceifolia* were common in this part of the Reserve in autumn 2003 but not 2004 (Appendix 5.5).

Significant effects of disc ploughing were recognised for species evenness and heterogeneity (Table 6.3). Evenness and heterogeneity were lower at ploughed sites (Fig. 6.4f,g). Total and native species richness were marginally reduced by ploughing (Table 6.3, Fig. 6.4a,b). Interestingly, the effects of ploughing were more obvious in autumn 2004 than in 2003 (Fig. 6.4a,b,e,f,g). Species evenness and heterogeneity were significantly lower at ploughed sites in 2004 ($F_{1,7} = 10.84$, $P = 0.013$ and $F_{1,7} = 6.89$, $P = 0.034$, respectively). In addition, grass species richness was marginally lower at ploughed sites in 2004 ($F_{1,7} = 4.16$, $P = 0.081$). Grass species such as *Astrebla lappacea, Enteropogon acicularis, Eragrostis parviflora* and *Thellungia advena* were present in certain ploughed quadrats in 2003 but disappeared from some of those quadrats in 2004.

Table 6.2. Mean (± SE) frequency score per quadrat (i.e. out of five) for individual species with significantly different ($P < 0.002$ after Bonferroni adjustment) scores between the different mowing treatments. Differences in frequency between the initial sampling (pre-treatment) and other sampling times (autumn 2003 and 2004) were analysed with generalised linear models (binomial error structure). $n = 4$ quadrats for all

	Sampling time	Control	Low cut, once	Low cut, twice	High cut, once	High cut, twice	Deviance (χ^2)	*P*
Favoured by mowing (relative to controls)								
Panicum queenslandicum	Pre-treatment	3.0 ± 1.08	3.0 ± 1.08	2.8 ± 1.11	3.8 ± 0.95	2.8 ± 1.31		
	Aut 03	1.8 ± 0.75	3.5 ± 0.96	4.0 ± 0.58	4.0 ± 0.41	3.3 ± 0.25	5.26	<0.001
Chloris truncata	Pre-treatment	4.3 ± 0.48	3.5 ± 0.65	2.8 ± 0.85	2.3 ± 0.75	3.5 ± 0.96		
	Aut 03	0.8 ± 0.25	2.5 ± 1.19	2.0 ± 0.71	1.3 ± 0.48	1.5 ± 0.65	6.53	<0.001
	Aut 04	3.5 ± 0.65	4.5 ± 0.29	5.0 ± 0.00	4.5 ± 0.29	5.0 ± 0.00	7.11	<0.001
Favoured by one or more mowing treatments								
Eclipta platyglossa	Pre-treatment	0.0 ± 0.00	0.8 ± 0.48	0.5 ± 0.50	0.3 ± 0.25	0.0 ± 0.00		
	Aut 03	0.3 ± 0.25	1.8 ± 1.18	2.0 ± 1.15	1.8 ± 1.18	0.0 ± 0.00	8.86	<0.001
Vittadinia cuneata	Pre-treatment	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00		
	Aut 03	0.0 ± 0.00	0.3 ± 0.25	1.5 ± 0.50	1.5 ± 0.87	1.3 ± 0.63	3.24	0.006†
Portulaca oleracea	Pre-treatment	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00		
	Aut 04	1.0 ± 0.41	1.8 ± 0.63	3.5 ± 0.87	2.0 ± 0.91	1.0 ± 0.41	4.65	<0.001

Table 6.2. (continued)

	Sampling time	Control	Low cut, once	Low cut, twice	High cut, once	High cut, twice	Deviance (χ^2)	*P*
Disadvantaged by one or more mowing treatments								
Boerhavia dominii	Pre-treatment	0.3 ± 0.25	1.3 ± 0.48	3.0 ± 0.71	2.3 ± 0.85	1.0 ± 0.00		
	Aut 03	3.8 ± 0.63	3.8 ± 0.48	3.5 ± 0.87	4.0 ± 0.71	3.3 ± 0.48	4.12	<0.001
Asperula cunninghamii	Pre-treatment	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00		
	Aut 03	3.8 ± 1.25	4.0 ± 0.41	1.5 ± 1.19	3.8 ± 1.25	3.5 ± 0.96	3.94	0.001
Panicum buncei	Pre-treatment	3.8 ± 0.75	2.5 ± 0.65	2.3 ± 1.11	2.3 ± 0.95	2.5 ± 0.29		
	Aut 03	1.0 ± 0.71	2.3 ± 0.63	1.5 ± 1.19	1.8 ± 0.75	1.3 ± 0.63	5.05	<0.001
Oxalis perennans	Pre-treatment	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	0.3 ± 0.25		
	Aut 03	1.5 ± 0.65	1.5 ± 0.65	0.5 ± 0.29	1.5 ± 0.96	3.0 ± 0.82	5.15	<0.001
	Aut 04	3.8 ± 0.63	1.8 ± 0.63	0.8 ± 0.48	2.0 ± 0.71	3.5 ± 0.87	5.43	<0.001
Haloragis aspera	Pre-treatment	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00		
	Aut 03	3.0 ± 1.22	0.5 ± 0.50	2.3 ± 1.11	2.5 ± 1.44	0.5 ± 0.29	5.16	<0.001
	Aut 04	3.5 ± 1.19	0.8 ± 0.48	2.0 ± 1.22	2.0 ± 1.22	0.3 ± 0.25	5.06	<0.001

[†] = Not significant after Bonferroni adjustment.

Table 6.3. Repeated measures ANOVA table showing differences in species richness and evenness measures in response to disc ploughing, sampling time and the interaction between the two effects

Variable		Total		Native		Introduced	
	d.f.	*F*	*P*	*F*	*P*	*F*	*P*
Between-subjects							
Ploughing treatment	1	4.17	0.081	4.77	0.065	2.06	0.194
Covariate (Autumn 2002 sampling)	1	0.55	0.481	0.72	0.424	0.00	0.958
Residual	7	2.28		2.11		1.11	
Within-subjects							
Time	1	41.29	<0.001	4.76	0.061	174.53	<0.001
Time*Ploughing treatment	1	0.74	0.414	0.32	0.586	0.22	0.654
Residual	8						

Variable		Forb		Grass		Evenness		Heterogeneity	
	d.f.	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Between-subjects									
Ploughing treatment	1	2.36	0.168	2.55	0.154	12.26	0.010	6.70	0.036
Covariate (Autumn 2002 sampling)	1	3.73	0.095	1.96	0.204	0.53	0.492	0.00	0.981
Residual	7	1.36		3.89		2.41		3.03	
Within-subjects									
Time	1	70.47	<0.001	2.00	0.195	1.46	0.261	55.32	<0.001
Time*Ploughing treatment	1	1.36	0.277	1.38	0.274	2.21	0.175	3.12	0.115
Residual	8								

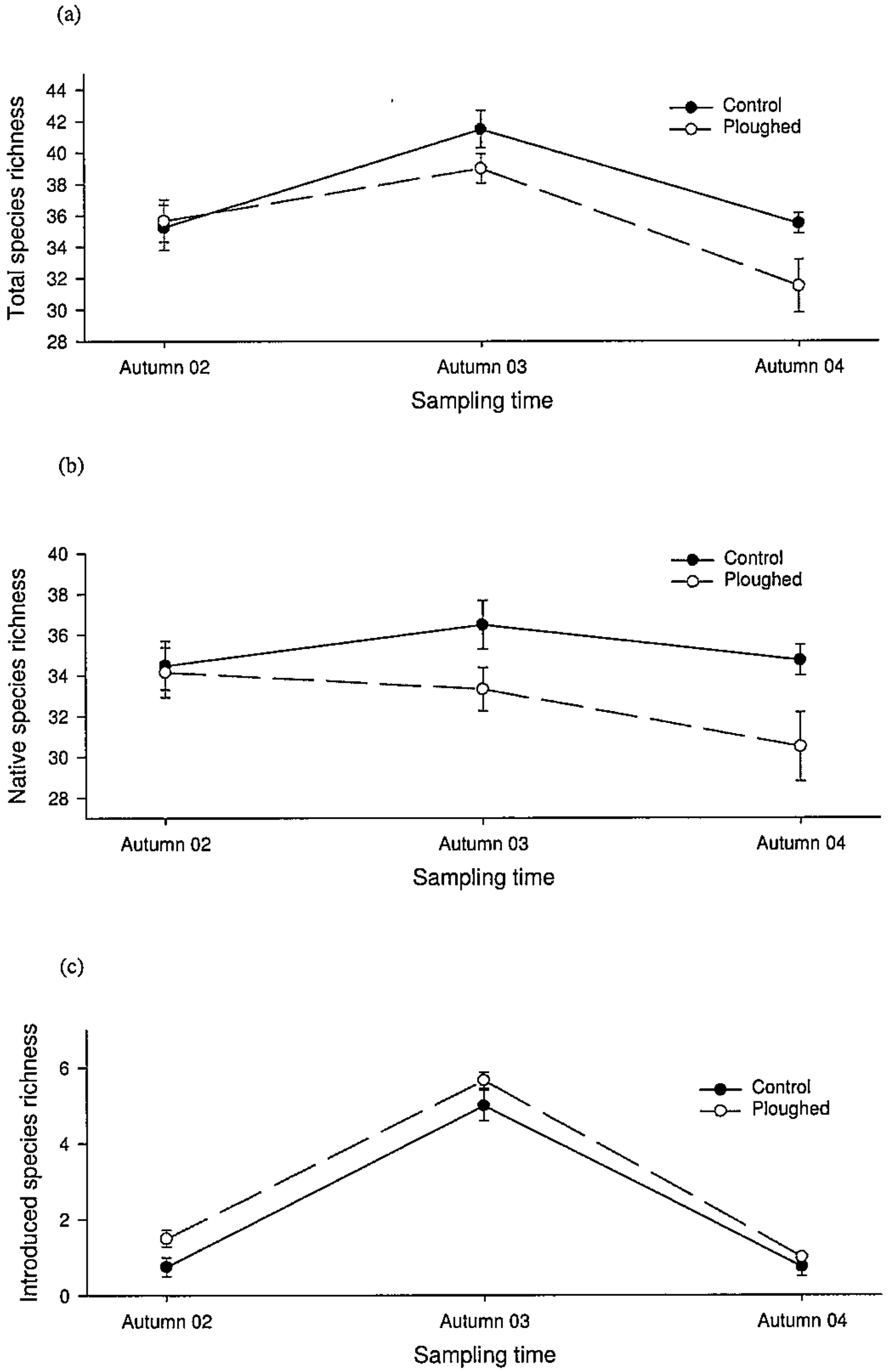


Fig. 6.4. Changes in mean (± SE) species richness, evenness and heterogeneity through time at disc ploughed and control quadrats (*n* = 6 for ploughed, *n* = 4 for controls). Variables: (a) total; (b) native; (c) introduced; (d) forb; and (e) grass species richness; (f) species evenness; and (g) species heterogeneity.

Fig. 6.4. (continued)

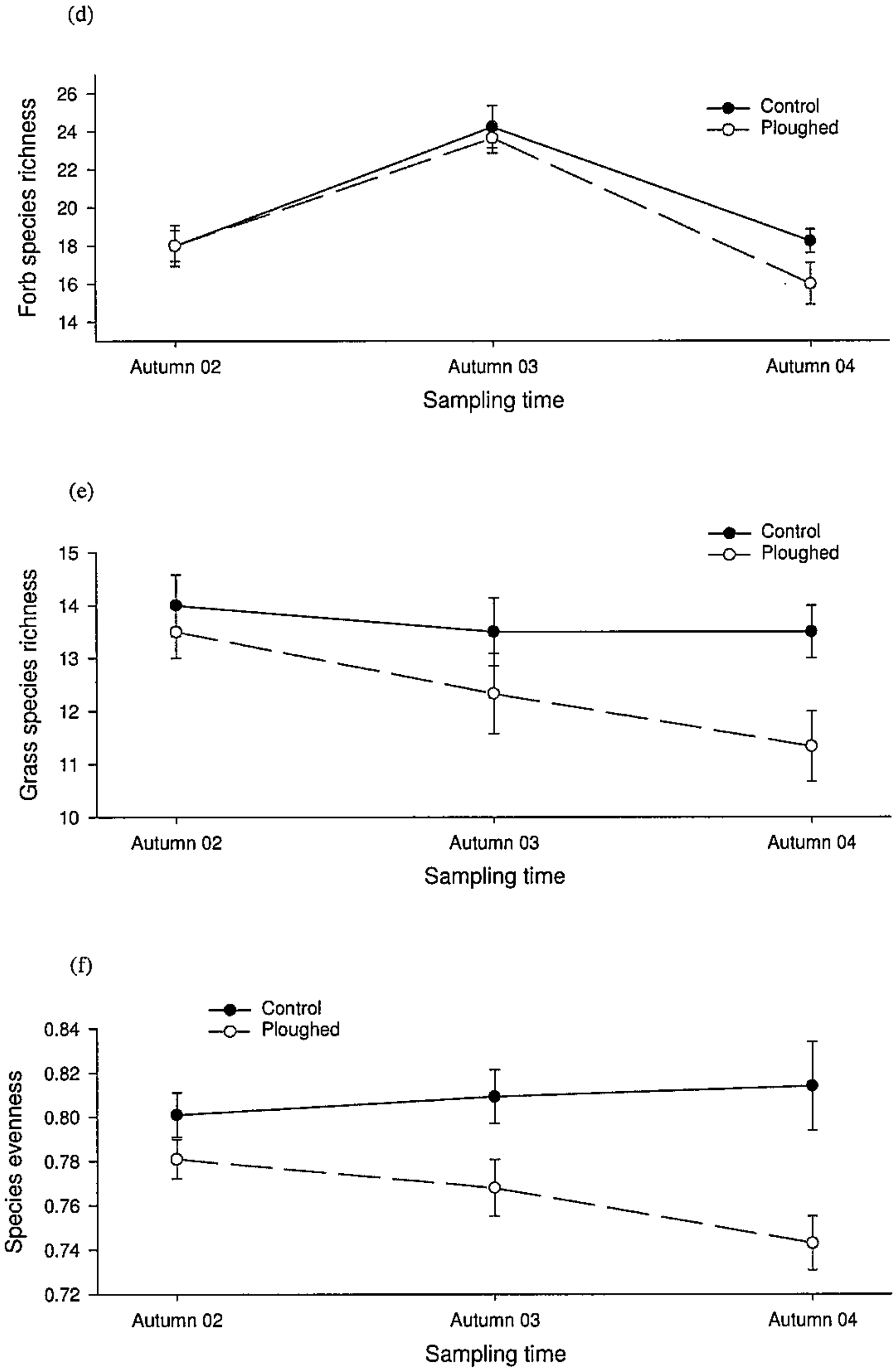
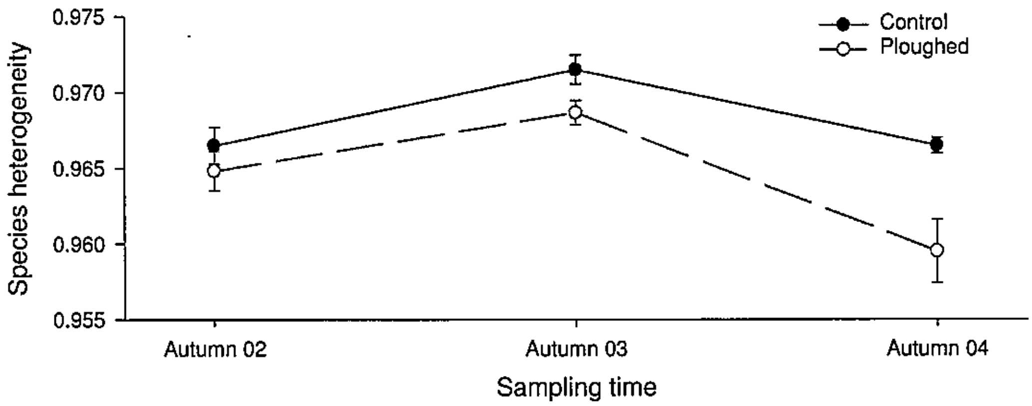


Fig. 6.4. (continued)

(g)



While percentage bare ground was not measured in this study, bare ground was obviously higher at ploughed sites (Fig. 6.5).

Frequencies of all species recorded in ploughed and control quadrats are provided in Appendix 6.3. A similar number of species increased and decreased in frequency at ploughed sites; hence it is not surprising that there was no statistically significant change in total species richness at ploughed sites. Grass species were particularly responsive to disc ploughing (Table 6.4). Species that responded positively to ploughing (i.e. were more frequent at ploughed sites) included *Boerhavia dominii, Chloris truncata, Eragrostis parviflora, Panicum decompositum, P. buncei, Sporobolus caroli* and *Digitaria divaricatissima* (Table 6.4). Species that responded negatively to ploughing included *Aristida leptopoda, Astrebla elymoides, Enteropogon acicularis, Goodenia fascicularis, Oxalis perennans* and *Thellungia advena* (Table 6.4). *Themeda avenacea* also decreased at ploughed sites ($P = 0.01$), but not significantly after Bonferroni adjustment. The response of certain species differed 1 and 2 years after cultivation. For example, the significant decrease in frequency of *Astrebla elymoides* and *Enteropogon acicularis* was only recognised in 2004, while the decrease in *Thellungia advena* frequency was only recognised in 2003 (Table 6.4). Similarly, higher frequencies at ploughed sites were recognised for *Chloris truncata, Eragrostis parviflora* and *Panicum decompositum* in 2003 only, and for *Digitaria divaricatissima* in 2004 only (Table 6.4).

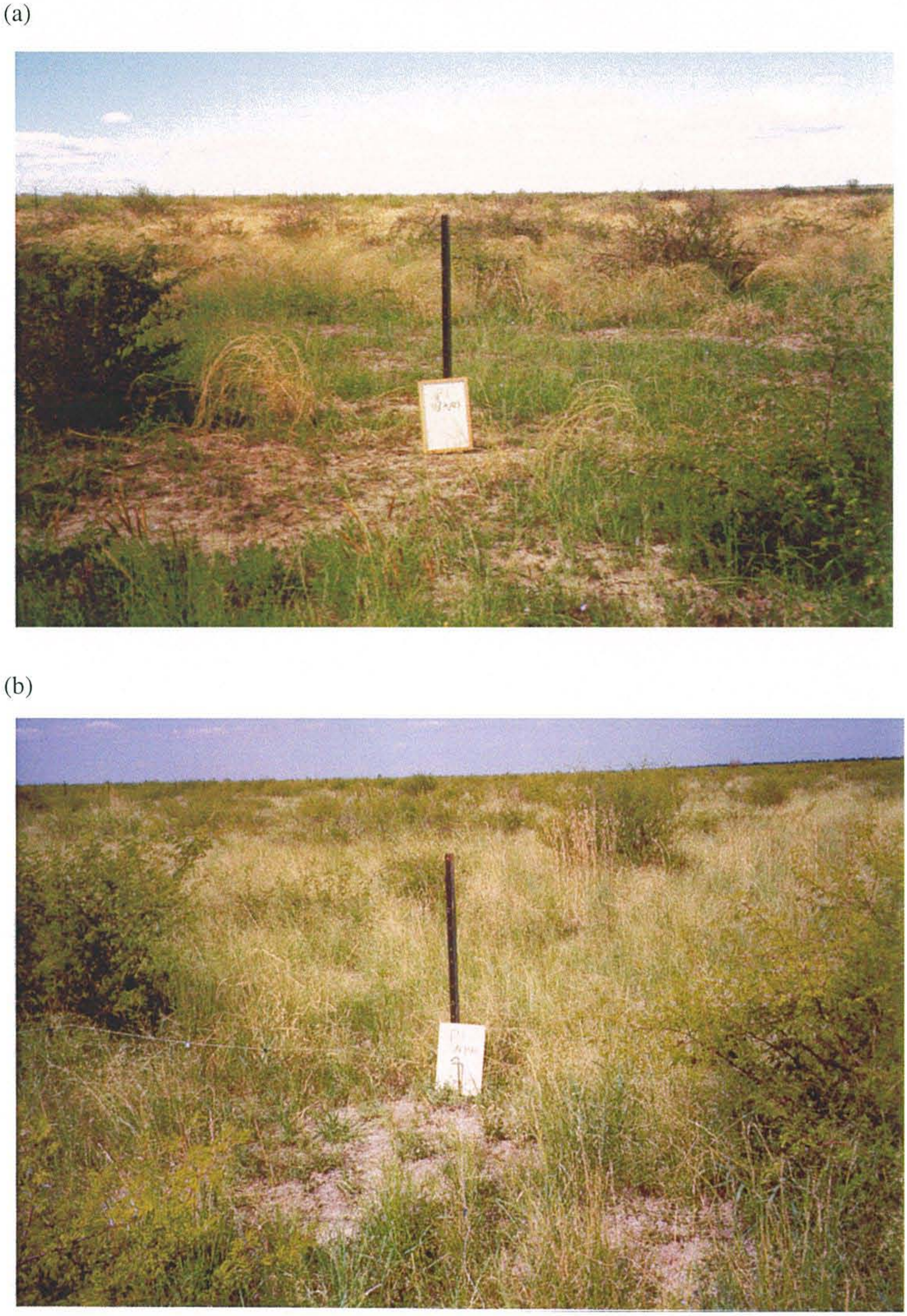


Fig. 6.5. A ploughed site 1 year (a) and 2 years (b) after disc ploughing. The amount of bare ground was higher at ploughed sites than control sites. Note also the difference in grass cover within and outside the ploughed area.

Table 6.4. Mean (± SE) frequency score per quadrat (i.e. out of five) for individual species with significantly different ($P < 0.002$ after Bonferroni adjustment) scores between ploughed (n = 6) and control (n = 4) sites. Differences in frequency between the initial sampling (pre-treatment) and other sampling times (autumn 2003 and 2004) were analysed with generalised linear models (binomial error structure)

	Sampling time	Ploughed	Control	Deviance (χ^2)	P
Favoured by ploughing					
Eragrostis parviflora	Pre-treatment	1.0 ± 0.37	0.3 ± 0.25		
	Aut 03	4.3 ± 0.42	0.0 ± 0.00	29.11	<0.001
Panicum decompositum	Pre-treatment	1.8 ± 0.60	2.5 ± 1.04		
	Aut 03	2.8 ± 0.54	2.3 ± 0.85	9.17	0.002
Chloris truncata	Pre-treatment	4.8 ± 0.17	5.0 ± 0.00		
	Aut 03	4.7 ± 0.33	3.0 ± 0.41	8.42	$0.004^{\dagger}$
Digitaria divaricatissima	Pre-treatment	3.3 ± 0.49	4.5 ± 0.29		
	Aut 04	4.5 ± 0.34	3.3 ± 0.48	7.90	$0.005^{\dagger}$
Boerhavia dominii	Pre-treatment	1.5 ± 0.50	3.8 ± 0.63		
	Aut 03	4.0 ± 0.45	3.8 ± 0.75	13.16	<0.001
	Aut 04	4.0 ± 0.37	3.5 ± 0.65	19.50	<0.001

Table 6.4. (continued)

	Sampling time	Ploughed	Control	Deviance (χ^2)	*P*
Panicum buncei	Pre-treatment	2.3 ± 0.88	4.0 ± 0.71		
	Aut 03	3.7 ± 0.80	2.3 ± 0.75	14.60	<0.001
	Aut 04	4.2 ± 0.83	4.0 ± 0.41	7.74	0.005[†]
Sporobolus caroli	Pre-treatment	2.2 ± 0.48	4.5 ± 0.29		
	Aut 03	4.0 ± 0.37	3.8 ± 0.63	7.74	0.005[†]
	Aut 04	5.0 ± 0.00	4.3 ± 0.48	16.4	<0.001
Disadvantaged by ploughing					
Thellungia advena	Pre-treatment	2.5 ± 0.43	1.5 ± 0.29		
	Aut 03	0.3 ± 0.21	1.8 ± 0.25	10.3	0.001
Enteropogon acicularis	Pre-treatment	1.3 ± 0.33	0.8 ± 0.25		
	Aut 04	0.2 ± 0.17	1.3 ± 0.63	7.90	0.005[†]
Aristida leptopoda	Pre-treatment	4.0 ± 0.82	4.8 ± 0.25		
	Aut 03	1.2 ± 0.83	4.3 ± 0.25	12.35	<0.001
	Aut 04	1.0 ± 0.52	3.8 ± 0.25	8.20	0.004[†]
Astrebla elymoides	Pre-treatment	4.5 ± 0.50	5.0 ± 0.00		
	Aut 03	3.7 ± 0.76	5.0 ± 0.00	5.47	0.019[†]
	Aut 04	2.2 ± 0.70	4.8 ± 0.25	11.69	<0.001

Table 6.4. (continued)

	Sampling time	Ploughed	Control	Deviance (χ^2)	*P*
Oxalis perennans	Pre-treatment	3.3 ± 0.67	3.0 ± 0.91		
	Aut 03	0.8 ± 0.31	2.5 ± 0.87	9.51	0.002
	Aut 04	0.3 ± 0.21	2.8 ± 0.85	13.92	<0.001
Goodenia fascicularis	Pre-treatment	1.8 ± 0.79	0.8 ± 0.48		
	Aut 03	3.2 ± 0.87	4.5 ± 0.29	11.71	<0.001
	Aut 04	3.2 ± 1.01	4.5 ± 0.50	11.71	<0.001

† = Not significant after Bonferroni adjustment.

6.4 Discussion

6.4.1 The influence of mowing

In 2004, approximately 12 months after the last mowing treatment, there were no differences in richness, evenness or heterogeneity between mown and control sites (Table 6.2). This accords with earlier findings in this thesis that species richness and evenness in these grasslands are relatively insensitive to disturbance by grazing and fire (Chapters 3, 4 and 5; Tables 3.20, 4.7; Fig. 5.4). The reasons for the lack of change in richness in response to grazing (or grazing exclusion) have been discussed in previous chapters and appear to be related to: (1) the composition of these grasslands (i.e. a high proportion of perennial species that are not tall and competitive, and that are able to resprout vegetatively after grazing); (2) seasonal variations in perennial grass density (i.e. abundance of *Astrebla elymoides*) allowing recruitment of interstitial species at times of reduced perennial grass dominance in the absence of grazing; and (3) the relatively open nature of these grasslands (also allowing recruitment of interstitial species in the absence of grazing). The resilience of most species to grazing is probably related to their ability to adapt to drought, fire and native herbivore grazing over evolutionary history.

There was a short-term increase in grass species richness at mown sites (Fig. 6.3e; $P = 0.001$). This is perhaps surprising, as a reduction in plant height by mowing or grazing often favours forbs over grasses (Trémont & McIntyre 1994; McIntyre & Lavorel 2001). However, this is not always the case. For example, Collins *et al.* (1998) reported that mowing maintained a number of annual grasses on annually burnt sites, and that such grasses would have disappeared otherwise. The short-term increase in grass species richness in the current study appeared to be a result of increasing frequency of the annual grasses, like *Chloris truncata*, and increases in the incidence of grasses like *Eragrostis parviflora, Panicum queenslandicum, Digitaria divaricatissima* and *Thellungia advena*. While mowing could be used to encourage certain, less frequently occurring grasses within the Reserve, it does not appear necessary unless these species start to show a decline in abundance due to competition with dominant grass species.

Mowing once or twice in a year at two different heights had no influence on total and native species richness in the present study (Fig. 6.3). Zechmeister *et al.* (2003) reported significant negative correlations between plant species richness and mowing intensity in Austrian meadows. However, mowing frequency was higher in meadows sampled by

Zechmeister *et al.* (2003) than in the present study. Continued heavy defoliation may be more likely to influence species richness and composition than mowing sites twice over the course of one year. For example, Hodgkinson *et al.* (1989) reported that *Themeda australis* was less able to withstand sustained heavy defoliation compared to the introduced grass **Cenchrus ciliaris*. It is well known that continuous heavy grazing promotes the abundance of annual species and forbs (e.g. Trémont 1994; McIntyre & Lavorel 1994b; McIntyre & Lavorel 2001). However, frequent mowing (4-6 times per year) did not increased the cover of annual herbs, relative to moderately grazed sites in Tasmania (Verrier & Kirkpatrick 2005), perhaps due to the previously mentioned differences between mowing and grazing.

No species was completely eliminated by the mowing treatments, and those that decreased in frequency are likely to recover over time, without continued mowing. Hence, it is not surprising that there were no differences in total species richness between mown and control sites. Repeated mowing for a number of years may be required before the changes in frequency documented here would result in changes in total or native species richness. Even then, richness may not be altered if the number of species that become locally extinct is balanced by the colonisation of new species. Further, differences in richness may not be detected due to the large number of species recorded within control quadrats. While frequencies of certain species were higher at mown sites, such species were still present at control sites (but often not common). Hence changes in richness might only be detected within small quadrats where less frequent species are less likely to be recorded (Stohlgren *et al.* 1999; Clarke 2003; Chapter 4). Further analysis is required to test this hypothesis.

The mowing treatments did not accurately simulate livestock grazing, because of the lack of selectivity, lack of nutrient input (from dung and urine) and lack of trampling effects (Jameson 1963; Snaydon 1981; Brown & Stuth 1993; Sun & Liddle 1993; Hoffman 2003). It is also unlikely that native grasslands in the region would only be grazed once or twice in a given year. Even mowing sites twice, low to the ground (80-90% utilisation) was probably equivalent to less intensive grazing than at many grazed sites in the regional vegetation survey (Chapter 3). Therefore, the applicability of these results to grazing systems should be treated with caution. Beadle (1948) reported that *Astrebla, Dichanthium* and *Eulalia* disappear under heavy stocking and are replaced by species like *Sporobolus caroli* and *Eragrostis setifolia*. With increasing degeneration, annuals, including a number of winter-growing species become increasingly common (Beadle 1948). More intensive mowing or livestock grazing treatments are recommended to determine whether similar changes in composition occur on the Moree Plains.

Mowing grassland, followed by removal of cut litter, often results in the same changes that may be brought about by fire (Daubenmire 1968; Scanlan 1980). However, this is not always the case, as Shaw (1957) reported markedly different composition after burning and mowing *Eucalyptus-Heteropogon* savanna in Queensland. Comparisons between mowing and burning are also complicated because mowing fails to create gaps of bare ground for seedling regeneration, whereas burning always creates some bare ground. The responses of species to mowing and fire reported in the current research were often inconsistent. For example, *Panicum buncei* was less frequent at mown sites but responded positively to fire; and *Vittadinia cuneata* increased in frequency at mown sites but responded negatively to autumn burning. Only *Portulaca oleracea* increased significantly in frequency in response to both fire and mowing, while *Oxalis perennans* decreased in frequency in response to both fire and mowing. Slashing or mowing rather than burning large areas of Kirramingly Nature Reserve is not recommended as an alternative method of grass removal. Slashing would result in a thick mulch layer, assuming grass is left on the ground, and this may prevent seedling establishment and may smother low-growing plants (Lunt 1993). Slashing machinery may also carry seeds of weed species from other areas, and could possibly allow invasion of the Reserve by new introduced species.

Five species occurred at higher frequencies at mown sites than at control sites after mowing (Table 6.2). Two of these were grasses (*Chloris truncata* and *Panicum queenslandicum*) and three were forbs (*Vittadinia cuneata, Eclipta platyglossa* and *Portulaca oleracea*). All of these species except *Panicum queenslandicum* are annual or short-lived species. Only perennials, including one grass (*Panicum buncei*) and four forbs (*Boerhavia dominii*, *Asperula cunninghamii*, *Haloragis aspera* and *Oxalis perennans*), were disadvantaged by one or more mowing treatments (Table 6.2). These changes in species composition are supported by findings of previous authors that annual species are favoured by disturbance that removes the grass canopy (e.g. Lunt 1990a, 1993; McIntyre *et al.* 1995; Collins *et al.* 1998; McIntyre & Lavorel 2001; Abule *et al.* 2005). Most of the forb and grass species that increased in frequency (all except *Panicum queenslandicum*) were small in stature or procumbent species, supporting the hypothesis that small species are favoured over large species by mowing or grazing (Lunt 1993; Trémont & McIntyre 1994; Metzger *et al.* 2005). Further, McIntyre and Lavorel (2001) reported that short plants were associated with more intense grazing, and Noy-Meir *et al.* (1989), reported that mostly small, prostrate and rosette plants increased in response to grazing. Similarly, Belsky (1992) reported that disturbance caused annual and short perennial species to increase and tall perennials to decrease in cover.

Given the differences between mowing treatments applied here and livestock grazing for production, it is possible that some of the above changes in frequency may be magnified at sites that have been ungrazed or grazed by livestock for some time. In support of this *Asperula cunninghamii, Panicum buncei* and *Oxalis perennans* were negatively affected by at least one mowing treatment and were more frequent at ungrazed sites in either the regional survey (Chapter 3) or the Kirramingly Nature Reserve survey (Chapter 4). In addition, *Portulaca oleracea* was more frequent at mown sites and was more common at grazed sites in the survey at Kirramingly Nature Reserve (Chapter 4). However, not all responses were consistent. Two species (*Panicum queenslandicum* and *Vittadinia cuneata*) were favoured by at least one mowing treatment but were more frequent at certain ungrazed sites in the regional survey (Chapter 3). Other species that were favoured by at least one mowing treatment (*Chloris truncata* and *Eclipta platyglossa*) were not consistently more frequent at grazed sites in the regional survey.

It is interesting that *Panicum buncei* appeared to be sensitive to mowing and grazing and was less frequent at previously cultivated sites in the Kirramingly Nature Reserve survey (Chapter 4), yet increased in frequency at disc-ploughed sites (Table 6.4) and at burnt sites (Chapter 5). This highlights the varied response of species to differing disturbances. Perhaps this species is less able to recover vegetatively after defoliation, but can reproduce rapidly from seed soon after the vegetation cover is removed. Some lack of consistency between this experiment and the regional survey is to be expected given: (1) the differences between mowing and livestock grazing already mentioned; (2) the range of different management histories and environmental variables at sites sampled in the regional vegetation survey; and (3) the fact that species respond inconsistently to grazing under different conditions (Vesk & Westoby 2001). Some responses observed in the current chapter are consistent with other studies. For example, *Chloris truncata* is known to tolerate moderate to heavy grazing (Biddiscombe 1953; Campbell 1989). Biddiscombe

(1953) reported that *Chloris truncata* became dominant under prolonged heavy grazing (4.8 sheep/ha).

6.4.2 The influence of disc ploughing

The reduction in species heterogeneity and marginal reductions in total and native species richness at ploughed sites (Table 6.3; Fig. 6.4a,b,g) supports findings in Chapters 3 and 4, where total and native species richness was significantly lower at certain sites with a history of cultivation (Tables 3.24, 4.7). It is not surprising that disc ploughing narrow strips within Kirramingly Nature Reserve had a relatively small effect (i.e. a reduction of <5 species) on total and native species richness, given that once-off disc ploughing may not be adequate to kill all species originally present, the nearby seed sources surrounding each ploughed area and the seed banks within the soil. In addition, recovery of ploughed quadrats at Kirramingly Nature Reserve was not affected by the invasion of introduced weeds, which can prolong early-successional stages (Belsky 1986b), and the negative effects of ploughing on certain species may be balanced by colonisation by other species (Fulbright 2004). Belsky (1986b) reported that small ploughed grassland plots in the Serengeti National Park regained much of their original cover and composition within 1-3 years. Rice and Penfound (1954) reported similar findings, suggesting formerly undisturbed grassland can return to its previous composition and abundance in the second year after once-off ploughing.

In an experiment in Texas by Fulbright (2004), control and disc-ploughed plots had similar total species richness during the first 3 years after ploughing, but species richness at ploughed plots exceeded that at control plots during the fourth and fifth year after ploughing. Annual forbs generally increased in response to disc ploughing while perennial grasses decreased (Fulbright 2004). Forb species richness was not significantly influenced by disc ploughing in the current experiment, but grass species richness was marginally reduced by disc ploughing in 2004 (Fig. 6.4e). Differences in response to ploughing may be due to natural differences in the basal area of perennial grasses between these different grasslands. Monitoring of ploughed sites in the future is necessary to determine whether there are increases in species richness over a longer period of time.

Caution is required in comparing the effects of once-off disc ploughing of small areas in a nature reserve with whole paddocks ploughed for agricultural production. Cultivation for agricultural production may differ due to: (1) the depth of cultivation; (2) application of fertiliser and weed sprays; (3) the number of consecutive cultivations; and (4) the lack of seed sources nearby, or within the soil, to re-colonise cultivated areas. Despite this, the disturbance mechanism is similar, because it results in the death of most species (unless they are able to re-establish from root stock), and an increase in the amount of bare ground. Unfortunately, the effects of repeated ploughing could not be investigated in this short-term study. However, the effects of repeated ploughing on an annual basis should be investigated if ploughing is to be used in the maintenance of containment lines at Kirramingly Nature Reserve. While Fulbright (2004) reported that disc ploughing areas once, increased herbaceous richness, repeated ploughing on an annual basis resulted in a decline in species richness.

In an experiment in Mediterranean grasslands in Spain, ploughing initially reduced the number of species, but after 4 years the original diversity had recovered where grazing was present (Montalvo *et al.* 1993). Grazing, as a plant dispersal mechanism is probably not important in the current experiment, given the small areas ploughed and the probability that seed of many species may have remained in the soil and can be transported short distances by the wind and ants. The small scale of the disturbance and the once-off treatment undoubtedly assisted the fast recovery of most species (Belsky 1986b). Proximity to neighbouring grazing and cultivated paddocks may have an influence on the vegetation after ploughing around the borders of Kirramingly Nature Reserve, as there could be dispersal of seeds (of species absent in the Reserve) from neighbouring commercial paddocks to the Reserve containment lines. Hence there is potential for weed invasion. All ploughed quadrats in the current experiment were at least 100 m from the neighbouring property, and so may not be representative of the long-term containment lines that border the Reserve. It may be particularly important to determine the effects of nearby cultivation to native grasslands in this region, given the extent of fragmentation of native grasslands on the Moree Plains.

The significant reduction in species evenness at ploughed sites was interesting as we might expect evenness to increase in response to removal of the canopy of the dominant grasses (e.g. Wright 2001). The reduction in evenness and heterogeneity at ploughed sites was more pronounced in 2004 than in 2003 (Fig. 6.4f,g). Evenness and heterogeneity were reduced because certain species did not recover well after cultivation (Table 6.4) and other species favoured by ploughing became more abundant (i.e. those species able to rapidly colonise bare ground). Therefore, reductions in bare ground (i.e. competition) may have limited the establishment of less common species (especially if seed banks were initially low). Römermann *et al.* (2005) also reported higher species evenness in undisturbed grassland than in areas cultivated more than 10 years previously in France.

More species were responsive to ploughing than to mowing treatments. Six native grasses (*Chloris truncata, Eragrostis parviflora, Panicum buncei, P. decompositum, Sporobolus caroli* and *Digitaria divaricatissima*) and one native forb (*Boerhavia dominii*) occurred at higher frequencies in response to disc ploughing. Three of these are annual or short-lived species (*C. truncata, E. parviflora* and *S. caroli*). The increased frequency of annuals at ploughed sites supports the findings of McIntyre *et al.* (1995) who reported greater numbers of therophytes at soil-disturbed sites. This is not surprising as recently ploughed sites provide a good environment for species to colonise from seed (Belsky 1986a). In addition, annual species generally have larger seed banks than perennials (Fenner 1985; Lunt 1990b). Four species (*E. parviflora, P. buncei, B. dominii* and *S. caroli*) that were favoured by ploughing were also favoured by fire (Chapter 5; Table 5.9). These species appear to benefit from disturbance that results in increased bare ground.

Four native grasses (*Aristida leptopoda, Astrebla elymoides, Enteropogon acicularis* and *Thellungia advena*) and two native forbs (*Goodenia fascicularis* and *Oxalis perennans*) were more frequent at unploughed sites than ploughed sites. These species are perennial and this supports the findings of McIntyre *et al.* (1995), who reported that vegetatively resprouting species are more common at undisturbed sites. Many perennial species at Kirramingly Nature Reserve are able to resprout vegetatively after fire (Chapter 5) and mowing. Such species are probably less able to survive ploughing that destroys root systems and growing points at or below the soil surface. Belsky (1986a) reported that vegetatively sprouting plants occurred at greater densities in shallowly ploughed plots than in deeply disturbed plots, due to removal of underground organs.

The differences in species responses over time, after ploughing, are not surprising given the differing abilities of species to colonise areas after disturbance. Annual species, such as *Chloris truncata* and *Eragrostis parviflora*, were favoured by ploughing in the short-term, while perennials, such as *Digitaria divaricatissima*, were favoured 2 years after ploughing. Establishment of perennial species without large soil seed banks is obviously limited by dispersal and perhaps dormancy mechanisms. The decrease in *Astrebla elymoides* at cultivated sites between 2003 and 2004 was surprising (Table 6.4). This species was very abundant and seeded prolifically in the Reserve in 2003 (Chapter 5). Perhaps seedling *A. elymoides* established in ploughed quadrats in 2003, but did not survive to 2004. It is also possible that some *A. elymoides* plants were able to grow from roots beneath the surface and, hence, were not all killed by disc ploughing initially, but for some reason died before sampling in 2004. Bellotti *et al.* (1986) suggested that natural regeneration of *Astrebla* spp. may occur after cropping for only short periods (i.e. 2-3 years). However, cropping for more than 10 years is likely to diminish *Astrebla* spp. seed banks and regeneration of *Astrebla* grassland may take many years (Chapters 3 and 4; Bellotti *et al.* 1986).

The lack of similar responses of species to ploughing in this experiment and previously cultivated sites in previous surveys (Chapters 3 and 4) is not unexpected given that species' responses to cultivation vary depending on the time since cultivation. Sites in surveys over the region and at Kirramingly Nature Reserve were sampled at least 2 years after cultivation. Hence an initial increase in annual species may not be obvious several years after cultivation if perennials replace annual species. Two of the perennial grass species (*Aristida leptopoda* and *Enteropogon acicularis*) that decreased in frequency at disc-ploughed sites (Table 6.6) were relatively common in areas of the Reserve that had been cultivated at least 13 years previously (Chapter 4). It is likely that these two species were able to re-establish in cultivated areas some time after cultivation, as they have open panicles that can be dispersed by the wind.

While ploughing is not a natural disturbance on the Moree Plains, it appears that some species are able to persist and even increase in frequency in response to ploughing. This is probably related to their adaptations to survive other forms of disturbance (i.e. fire, grazing, flooding and drought). In addition, the grey clay soils shrink and swell frequently (Campbell 1989) so the flora may be pre-adapted to natural movement of the soil.

6.4.3 Conclusions

Frequencies of a greater number of species varied (positively and negatively) in response to ploughing than they did to mowing. However, both forms of disturbance influenced species frequencies. Both disturbances resulted in an increase in frequencies of annuals, perhaps due to favourable colonisation conditions and stored soil seed banks. Neither disturbance resulted in an influx of introduced species. The two different disturbance mechanisms investigated in this chapter had contrasting effects on grass species richness. Ploughing resulted in a marginal reduction in grass richness, while mowing resulted in a short-term increase in grass richness. Annual and short-statured species, like *Chloris truncata, Vittadinia cuneata, Eclipta platyglossa* and *Portulaca oleracea* were more frequent at mown sites. Some annual grasses were more frequent at ploughed sites (e.g. *Chloris truncata, Eragrostis parviflora* and *Sporobolus caroli*) while perennial grasses, such as *Astrebla elymoides, Aristida leptopoda* and *Enteropogon acicularis*, were less frequent at ploughed sites. These perennial species probably rely heavily on vegetative reproduction for persistence and may take some time to re-establish in ploughed sites from seed.

While there was no evidence that small mowed and ploughed areas were invaded by introduced species there is a potential threat of invasion of such species into the Reserve from surrounding properties and machinery (i.e. for slashing or ploughing). Hence mowing or ploughing small areas for containment lines could have a negative effect on native plant diversity in the Reserve. While this potential threat can be minimised by ensuring machinery is clean and monitoring the Reserve boundaries, controlled fire would be a more appropriate method for hazard reduction (Chapter 5). Mowing or ploughing large areas of the Reserve for a reduction in perennial grass canopy is not recommended. If disturbance for removal of grass canopy and litter is necessary, controlled burning is a more natural method and appears to have little influence on species composition and richness (Chapter 5).

CHAPTER SEVEN

General discussion and synthesis

7.1 Introduction

Disturbance is one of the main factors controlling diversity and species composition (Connell 1978; Collins & Barber 1985; Collins *et al.* 1995; Mackey & Currie 2000; Mackey & Currie 2001). This thesis has focussed on disturbances due to grazing, cultivation, flooding and fire. In this final chapter, I summarise the response of grasslands on the Moree Plains to these different types of disturbance. Based on similarities and differences to other grasslands in Australia and elsewhere, general trends in response to disturbance and the applicability of findings reported for these grasslands, are discussed. The ability of existing ecological theory, such as the intermediate disturbance hypothesis (Connell 1978) to predict species diversity patterns on the Moree Plains, is also discussed. McIntyre and Lavorel (1994b) defined three groups of species (intolerant species, tolerant species and disturbance specialists) based on their responses to disturbance in temperate grasslands. Similar groups of species associated with different types of disturbance or lack of disturbance may be recognised on the Moree Plains.

Little research has been conducted on the native grassland communities of the Moree Plains. Rather than defining plant communities (Clarke *et al.* 1998; Hunter & Earl 1999), this thesis has focussed on the influences of management, particularly for *Astrebla* spp. and *Dichanthium sericeum* dominated grasslands. While it is difficult to predict plant successional pathways from the data obtained in the time span of this project, some attempt has been made to summarise knowledge in a model of transitional stages to aid in management for conservation of plant diversity. Some of the major management issues concerning native grasslands on the Moree Plains are discussed, mostly from a biodiversity conservation perspective. Recommendations regarding grassland management of Kirramingly Nature Reserve are suggested and avenues for future research are also suggested for these grasslands.

The objectives of this chapter are to:

1. Summarise the response of the Moree Plains grasslands and their species to different types of disturbance.

2. Relate the findings of this research to other grasslands and existing ecological theory.
3. Develop a conceptual model using data obtained in this thesis to aid in the management of these grasslands.
4. Discuss the management of native grasslands on the Moree Plains and at Kirramingly Nature Reserve.
5. Recommend avenues for further research and monitoring of these native grassland communities.

7.2 Ecological relevance of findings

7.2.1 Comparisons of Moree Plains grasslands to other grasslands

Mitchell grasslands are considered resilient communities (Orr & Holmes 1984). The ability of *Astrebla* grasslands on the Moree Plains to recover from natural disturbances (e.g. fire) supports this. Some important features of these grasslands in their response to disturbance (or lack of disturbance) are: (1) the resilience of most native species to livestock grazing, kangaroo grazing and mowing (Sections 3.3.4, 4.3.3, 5.3.2 and 6.3.1), but perhaps not over-grazing (Francis 1935; Beadle 1948; Williams & Roe 1975; Orr 1980a; Phelps & Bosch 2002); (2) the lack of decline in species richness when livestock grazing is removed for several years (i.e. at least 8 years; Section 4.3.3); (3) their capacity to recover after fire, without major changes in composition (Section 5.3.2); (4) the resilience of most native species to flooding (Section 3.3.4), although *Astrebla lappacea* is an exception (Section 3.3.4); (5) the ability of most native species to recover after once-off disc ploughing (Section 6.3.2), but with more pronounced changes in composition and a reduction in native species richness after extended periods of cultivation (Sections 3.3.4 and 4.3.4); and (6) their resilience to drought (Sections 3.3.2 and 5.4.1).

Some characteristics of grassland ecosystems that are important in determining their response to disturbances include rainfall, soil fertility, height and competitiveness of dominant grasses, and the relative proportions of perennial and annual species present (Groves & Williams 1981; Milchunas *et al.* 1988; McIntyre & Lavorel 1994b; McIvor 1998; Olff & Ritchie 1998; McIntyre & Lavorel 2001; Vesk *et al.* 2004). Accordingly, my results for native grasslands on the Moree Plains might be applicable to other grasslands where the: (1) climate is semi-arid and the timing of rainfall unpredictable, but generally higher in warmer months; (2) soil is fertile and has good water-holding capacity (e.g. clay soils); (3) dominant grasses are medium-sized tussock grasses that do not form dense swards that result in competitive exclusion of interstitial species; and (4) majority of species are 'tolerant' perennial species that are able to resprout after disturbances like fire, drought and grazing. Some of these characteristics are related. For example, the ability to tolerate grazing is related to the good regrowth opportunities owing to the high nutrient availability in fertile soils (Anderson & Briske 1995; Olff & Ritchie 1998). Differences in the basal area of grasses, numbers of growing points, rapidity of tiller development and growth probably also influence the response of physiognomically similar grasslands to distrubance.

Olff and Ritchie (1998) divided grassland response to grazing into four categories based on environmental gradients of precipitation and soil fertility. The Moree Plains grasslands fit their category of grasslands in dry environments on fertile soils. This is because: (1) the competitively dominant plant species tend to be palatable (e.g. *Astrebla* spp. and *Dichanthium sericeum*); (2) most plant species are able to tolerate grazing (Sections 3.3.4 and 4.3.3) due to their abilities to regrow after grazing; (3) rainfall appears to be the major limiting resource (e.g. Section 3.3.2); and (4) exclusion of grazing has only weak positive effects on diversity (Sections 3.3.4 and 4.3.3) due to the occurrence of some grazing-intolerant species that may remain in infrequently grazed parts of the landscape. The East African savannas are an example of an ecosystem that shares similar characteristics (Olff & Ritchie 1998). Based on community responses recognised by Milchunas *et al.* (1988), the grasslands on the Moree Plains respond similarly to semi-arid grasslands with an evolutionary history of grazing.

These grasslands differ from those on fertile soils where precipitation is not a major limiting resource. In such grasslands the dominant grasses are often tall and productive and competition for light is important in the absence of grazing (Olff & Ritchie 1998). An Australian example is the *Themeda*-dominated grasslands that occur on fertile clay soils in Victoria. In these grasslands, removal of perennial grass cover is important for maintaining native species richness (e.g. Lunt 1990a, 1994; Morgan 1998). Hence the differences between Australian grasslands on fertile soils are probably related to the amounts and reliability of rainfall. In semi-arid regions of Australia, where there is bare ground between tussocks, recruitment may not be space limited, but instead occurs episodically in response to rainfall (Landsberg *et al.* 2002; Vesk *et al.* 2004). In such grasslands, coexistence may be controlled more by below-ground competition than by interactions above ground (Milchunas *et al.* 1988; Stohlgren *et al.* 1999). The fact that *Astrebla* tussocks can be distant from each other at the surface but have overlapping root systems (Everist 1964) supports this idea.

The native grasslands on the Moree Plains also responded to ploughing in a similar way to East African grasslands (Belsky 1986a,b). The recovery of a relatively high number of native species and the absence of a major increase in introduced species after ploughing or cultivation on the Moree Plains (Sections 3.3.4, 4.3.4 and 6.3.2) differs to grassland recovery in southern Australia where annual and introduced species become dominant (Stuwe 1986). After cultivation ceases in Mediterranean regions, the vegetation is composed mostly of annual species, although perennial grass species and shrubs can establish over time (Seligman 1996). In some cases, ruderal 'weed-fields' are maintained after cultivation for many decades by grazing (Seligman 1996). In southern Australia, where rainfall is winter dominant, the inability to cope with disturbances like cultivation and heavy grazing has probably enhanced invasions and the eventual dominance by weeds (Milchunas *et al.* 1988).

Following fire at Kirramingly Nature Reserve, most species were able to resprout (Section 5.3.7). The resilience of these grasslands to other forms of disturbance (e.g. grazing and drought) is aided by the high proportion of perennial species that are able to resprout. Fire-stimulated changes in species composition were not as obvious in grasslands at Kirramingly Nature Reserve (Section 5.3.5) as in temperate grasslands (Lunt 1990a, 1997; Lunt & Morgan 1999) or arid hummock grasslands (Suijdendorp 1981) of Australia. In southern Australia, fire may encourage certain native species (e.g. *Themeda australis*) but it often promotes annuals and introduced species (Lunt 1990a; Milberg & Lamont 1995; Lunt & Morgan 1999). The native grasslands of the Moree Plains and perhaps Mitchell grasslands in general, appear less susceptible to weed invasion after fire than temperate grasslands. However, this may be dependent on season, rainfall and land-use history, and, hence, the presence of weed species in the seed bank.

It is necessary to point out that the important features of the native grasslands on the Moree Plains in their response to disturbance (or lack of disturbance) may not be applicable to Mitchell grasslands elsewhere in Australia. *Astrebla* grasslands on the Moree Plains occur at the edge of their geographical and ecological range and are in many ways unique

(Anon., date unknown). In fact, sites in the east of the study region (Fig. 3.1) occurred outside the range of *Astrebla* dominated communities. Given the extent of Mitchell grasslands in Australia, considerable variation in composition would be expected over such a large range. Annual rainfall in Mitchell grasslands generally varies from 250 to 550 mm, with marked variation in seasonal precipitation from north to south (Partridge 1996). In NSW, the high proportion of winter rainfall (40%) allows growth of winter forbs (e.g. medics; Section 3.3.2), which may be absent in northern Mitchell grasslands (Partridge 1996). In fact, almost half the genera found in Mitchell grasslands in NSW and Queensland are exclusive to either state (Bellotti *et al.* 1986). The amount and season of rainfall is likely to play an important role in how Mitchell grasslands in different regions respond to disturbance.

There is conflict regarding the response of Mitchell grasslands to livestock grazing exclusion. Partridge (1996) suggested that excluding grazing from Mitchell grasslands may result in the death of *Astrebla* spp., which become moribund as old leaves and roots accumulate. Everist and Webb (1975) also suggested that not grazing these grasslands might result in the development of different plant communities and there are conflicting reports regarding the influence of grazing on the recruitment of *Astrebla* spp. (Orr & Evenson 1991a; Campbell *et al.* 1996). While Kirramingly Nature Reserve is grazed by kangaroos, there was no evidence of a decline in *Astrebla* spp. abundance after 8 years of livestock grazing removal at the Reserve (Section 4.3.3). Further, native species richness was consistently higher at Kirramingly than at grazed sites over the Moree Plains (Section 3.3.4). Hence removal of livestock grazing does not result in a decline in *Astrebla* spp. abundance or a decline in richness in *Astrebla* grasslands on the Moree Plains.

7.2.2 Disturbance

Collins & Barber (1985) reported that community diversity is maximised in environments that support the natural disturbance regime. Unfortunately the disturbance history of the Moree Plains prior to European settlement is largely unknown. According to the intermediate disturbance hypothesis, if the interval between disturbances is short relative to the time necessary for competition to exclude less competitive species, the ecosystem remains stable and species richness remains high (Gudrun & Claude 1996; Mackey & Currie 2000). The ability of Moree Plains grasslands to recover quickly after disturbance (e.g. fire), given favourable seasonal conditions (Section 5.3.2), suggests that they are well adapted to frequent natural disturbances. On the other hand, species richness at Kirramingly Nature Reserve (ungrazed by livestock for approximately 8 years) was not reduced through competitive exclusion (Section 4.3.3) and it could be argued that disturbances were relatively infrequent (>8 year frequency) on the Moree Plains. The highly variable climate probably plays an important role in the coexistence of species by negating competitive exclusion most of the time and allowing the smaller species (i.e. forbs) to persist (Section 5.4.5). For example, at Kirramingly Nature Reserve, abundance of the dominant grass species varied over time (Section 5.3.6) such that competitive exclusion may only be noticeable at times when grass density is high (Section 5.4.5).

Grasslands on the Moree Plains did not appear to follow the intermediate disturbance hypothesis (Connell 1978) in response to fire and grazing. This is largely due to the high proportion of perennial species that are able to resprout vegetatively after these disturbances (Section 5.4.2). Neither fire nor grazing (or mowing) resulted in an initial increase in species richness, suggesting there may be relatively few early successional species in these grasslands. However, some early successional species (i.e. annuals) are present and able to persist within these communities. For example, an increase in frequency of certain annual species already present in the area was recorded in response to experimental disturbance (fire, mowing and disc ploughing) at Kirramingly Nature Reserve (Chapters 5 and 6). It is likely that the recruitment of early successional species immediately after disturbance is limited by rainfall and perhaps the rapid recovery of perennial species (i.e. competition).

We might expect cultivated grasslands to follow the intermediate disturbance hypothesis more closely because most perennial species would be less able to resprout vegetatively, assuming growing points at and below the ground are destroyed. If this were the case we might expect to see a quadratic (humped) trend in species richness with time since cultivation. Such a trend was not observed for ploughed sites in the regional vegetation survey (Section 3.3.4; Fig. 3.12). However, ploughed sites in the regional vegetation survey were confounded with other variables (e.g. rainfall and soil type). Disc-ploughed quadrats at Kirramingly Nature Reserve did not show strong support for the intermediate disturbance hypothesis either (Section 6.3.2). Apart from a decrease in the abundance of certain perennial species (Section 6.3.2; Table 6.4), most species that were originally present had reappeared in disc-ploughed quadrats 12 months after ploughing.

I found that some species respond differently to various forms of disturbance on the Moree Plains (i.e. grazing, cultivation, flooding, fire, mowing and disc-ploughing). A summary of the species responses is provided in Table 7.1. No species responded positively or negatively to all forms of disturbance investigated. However, taking into account the responses reported in this thesis, and those in the relevant literature, several taxa are recognised that generally benefit from different kinds of disturbance; for example, *Sclerolaena muricata* var. *muricata, Portulaca oleracea, Chloris truncata, Sporobolus caroli, Panicum decompositum, Salsola kali* and **Medicago* spp. (Table 7.1). Most of these species are annuals or short-lived species (all except *P. decompositum* and *S. muricata* var. *muricata*) or are likely to disperse long distances by wind (e.g. *C. truncata, P. decompositum* and *S. muricata* var. *muricata*). Several taxa were also recognised that preferred relatively undisturbed areas; for example, *Ptilotus semilanatus, Oxalis perennans, Asperula cunninghamii, Themeda avenacea, Thellungia advena* and *Astrebla lappacea*. All of these species are perennials. These findings support the general trend of annuals and wind-dispersed species responding positively to disturbance, and perennials preferring lack of disturbance, as commonly reported in grasslands (e.g. Biddiscombe 1953; Belsky 1986b; Milchunas *et al.* 1989; Noy-Meir *et al.* 1989; Trémont 1994; McIntyre *et al.* 1999; McIntyre & Lavorel 2001).

Table 7.1. Species responding positively and negatively to grazing, cultivation, flooding, fire, mowing and disc ploughing (and source of information for each). Positive and negative responses are possible due to differing intensities of disturbance. Only taxa recorded during surveys carried out in this research are reported. Literature was limited to studies in western NSW and *Astrebla* spp. communities

Disturbance type	Taxa responding positively	Taxa responding negatively
Grazing	**Chapter 3:** *Astrebla elymoides* *Juncus aridicola* *Sclerolaena muricata* var. *muricata* (also Beadle 1948; Campbell 1989) *_Tribulus terrestris_ (also Beadle 1948; Orr 1980b; Cunningham *et al.* 1992) **Chapter 4:** *Maireana decalvens* *Portulaca oleracea* (also Beadle 1948; Williams & Mackey 1983) **Literature:** *Aristida latifolia* (Williams & Mackey 1983) *Aristida leptopoda* (Partridge 1996) *Astrebla lappacea* (Williams & Mackey 1983) *Boerhavia* spp. (Beadle 1948) *Chloris truncata* (Biddiscombe 1953) *Dactyloctenium radulans* (Beadle 1948; Partridge 1996) *Enteropogon acicularis* (Partridge 1996) *Eragrostis setifolia* (Beadle 1948; Partridge 1996) *Eriochloa pseudoacrotricha* (Campbell 1989; Partridge 1996) *_Medicago_ spp. (Beadle 1948; Campbell 1989) *Panicum decompositum* (Campbell 1989; Partridge 1999) *Panicum queenslandicum* (Partridge 1996) *Salsola kali* var. *kali* (Campbell 1989)	**Chapter 3:** *Einadia nutans* subsp. *nutans* *Oxalis perennans* *Panicum buncei* *Panicum queenslandicum* (also Chapter 4) *Ptilotus semilanatus* (also Chapter 4) *_Sonchus oleraceus_ (also Chapter 4) *Themeda avenacea* *Vittadinia cuneata* **Chapter 4:** *Asperula cunninghamii* *Desmodium campylocaulon* *Leiocarpa websteri* *Phyllanthus virgatus* *Wahlenbergia communis* **Literature:** *Astrebla lappacea* (Partridge 1996) *Astrebla* spp. (Beadle 1948) *Crotalaria dissitiflora* (Williams & Mackey 1983) *Dichanthium sericeum* (Beadle 1948; Williams & Mackey 1983) *Eragrostis parviflora* (Campbell 1989) *Eulalia* spp. (Beadle 1948) *Ipomoea lonchophylla* (Orr & Holmes 1984) *Panicum decompositum* (Williams & Mackey 1983) *Thellungia advena* (Cunningham *et al.* 1992)

Table 7.1. (continued)

Disturbance type	Taxa responding positively	Taxa responding negatively
Grazing (*cont.*)	*Sclerolaena birchii* (Bellotti *et al.* 1986) *Sporobolus actinocladus* (Williams & Mackey 1983; Partridge 1996) *Sporobolus caroli* (Beadle 1948; Biddiscombe 1953) **Urochloa panicoides* (Partridge 1999) **Xanthium* spp. (Bellotti *et al.* 1986)	
Cultivation or clearing	**Chapter 3:** **Medicago polymorpha* **Rapistrum rugosum* (also Chapter 4) *Rhynchosia minima* *Salsola kali* var. *kali* (also Bellotti *et al.* 1986; Cunningham *et al.* 1992) **Chapter 4:** *Cucumis melo* *Leptochloa divaricatissima* *Sclerolaena muricata* var. *muricata* (also Campbell 1989) **Literature:** **Avena fatua* (Bellotti *et al.* 1986) *Chloris truncata* (Beadle 1948; Campbell 1989) *Dactyloctenium radulans* (Campbell 1989) *Echinochloa colona* (Cunningham *et al.* 1992) *Eriochloa pseudoacrotricha* (Campbell 1989) **Hordeum leporinum* (Campbell 1989) **Medicago laciniata* (Scriven 1988) *Oxalis perennans* (Beadle 1948) *Panicum decompositum* (Campbell 1989) **Phalaris* spp. (Bellotti *et al.* 1986) *Sclerolaena birchii* (Iwaszkiewicz & Semple 1988)	**Chapter 3:** *Acacia farnesiana* *Astrebla elymoides* *Astrebla lappacea* (also Chapter 4) *Boerhavia dominii* **Conyza bonariensis* *Maireana decalvens* *Neptunia gracilis* *Sclerolaena muricata* var. *villosa* *Sida trichopoda* *Solanum esuriale* *Verbena gaudichaudii* **Chapter 4:** *Asperula cunninghamii* *Austrodanthonia bipartita* *Calotis scabiosifolia* *Chamaesyce drummondii* *Eryngium plantagineum* *Haloragis aspera* *Leiocarpa websteri* *Maireana aphylla* *Panicum buncei* *Panicum queenslandicum* *Ptilotus semilanatus* *Themeda avenacea* **Literature:** *Astrebla* spp. (Campbell 1989) *Aristida latifolia* (Campbell 1989) *Enteropogon acicularis* (Dalton 1988)

Table 7.1. (continued)

Disturbance type	Taxa responding positively	Taxa responding negatively
Flooding	**Chapter 3:** *Cyperus bifax* (also Cunningham *et al.* 1992) *Eleocharis pallens* (also Cunningham *et al.* 1992) *Paspalidium jubiflorum* (also Cunningham *et al.* 1992) **Literature:** *Aristida latifolia* (Campbell 1989) *Dichanthium sericeum* (Cunningham *et al.* 1992) *Diplachne fusca* (Cunningham *et al.* 1992) *Eragrostis setifolia* (Cunningham *et al.* 1992) *Iseilema membranaceum* (Cunningham *et al.* 1992) *Leptochloa digitata* (Cunningham *et al.* 1992) *Marsilea drummondii* (Cunningham *et al.* 1992) *Panicum decompositum* (Campbell 1989) *Salsola kali* var. *kali* (Bellotti *et al.* 1986) *Sclerolaena muricata* (Campbell 1989) *Sporobolus mitchellii* (Cunningham *et al.* 1992)	**Chapter 3:** *Astrebla lappacea* (also Campbell 1989; Bowman *et al.* 1996) *Maireana microphylla* _*Malvastrum americanum_ _*Medicago polymorpha_ _*Medicago truncatula_ *Paspalidium constrictum* _*Rapistrum rugosum_ *Sida trichopoda* **Literature:** *Astrebla pectinata* (Campbell 1989) _*Medicago minima_ (Campbell 1989)
Fire	**Chapter 5:** *Boerhavia dominii* *Eragrostis parviflora* _*Medicago truncatula_ *Panicum buncei* *Portulaca oleracea* (also Wright 2001) *Sporobolus caroli* **Literature:** *Daucus glochidiatus* (Mulham 1985) *Desmodium campylocaulon* (Wright 2001) *Iseilema* spp. (Wright 2001) *Panicum decompositum* (Wright 2001) _*Plantago_ spp. (Mulham 1985) _*Sonchus oleraceus_ (Mulham 1985)	**Chapter 5:** _*Hedypnois rhagadioloides_ *Oxalis perennans* _*Sonchus oleraceus_ *Vittadinia cuneata* **Literature:** *Aristida* spp. (Wright 2001) _*Plantago_ spp. (Mulham 1985) *Sida* spp. (Mulham 1985)

Table 7.1. (continued)

Disturbance type	Taxa responding positively	Taxa responding negatively
Mowing	**Chapter 6:** *Chloris truncata* *Eclipta platyglossa* *Panicum queenslandicum* *Portulaca oleracea* *Vittadinia cuneata*	**Chapter 6:** *Asperula cunninghamii* *Boerhavia dominii* *Haloragis aspera* *Oxalis perennans* *Panicum buncei*
Disc ploughing	**Chapter 6:** *Boerhavia dominii* *Chloris truncata* *Digitaria divaricatissima* *Eragrostis parviflora* *Panicum buncei* *Panicum decompositum* *Sporobolus caroli*	**Chapter 6:** *Aristida leptopoda* *Astrebla elymoides* *Enteropogon acicularis* *Goodenia fascicularis* *Oxalis perennans* *Thellungia advena*

McIntyre and Lavorel (1994b) used their three groups of species (i.e. intolerant species, tolerant species and disturbance specialists) in a model to show changes in community structure with increasing disturbance intensity. On the Moree Plains, disturbance specialists might include those species that consistently increase in response to disturbance, while intolerant species are those that decrease. One difference between McIntyre and Lavorel's (1994b) model for temperate grasslands and the structure of grasslands on the Moree Plains is in the relative proportions of intolerant and tolerant species. On the Moree Plains, the majority of species were judged to be tolerant because their frequencies were not consistently influenced by disturbances (Chapters 3, 4, 5 and 6). There were generally only a small group of intolerant species that became less frequent in response to different disturbances (Table 7.1); however, in temperate grasslands, McIntyre and Lavorel (1994b) reported that the intolerant group of species made up most of the richness at a site. While most species on the Moree Plains can tolerate some forms of disturbance, severe disturbances (e.g. cultivation) can result in the removal of the dominant perennial grasses (i.e. matrix species, such as *Astrebla* spp.) that are able to tolerate natural disturbances (e.g. fire, grazing and drought). Severe anthropogenic disturbances have the greatest effect on the conservation value of these grasslands because certain matrix species (i.e. *Astrebla* spp.) and intolerant interstitial species are replaced by disturbance specialists.

Severe human-induced disturbances that are likely to result in loss of the matrix species include:

(1) Heavy livestock grazing for long periods of time (i.e. over-grazing). This will result in the loss of important matrix species, such as *Astrebla lappacea*, *A. elymoides*, *Dichanthium sericeum*, *Eulalia aurea* and *Themeda avenacea* (Beadle 1948; Phelps & Bosch 2002; Table 7.1), as well as several grazing-sensitive species (Table 7.1).

(2) Several years of cultivation. This will result in the loss of important matrix species, such as *A. lappacea*, *A. elymoides* and *Enteropogon acicularis* (Table 7.1), as well as some species that are sensitive to cultivation (Table 7.1).

(3) Changed flooding regime, resulting in increased flooding frequency. This will result in the loss of the matrix species, *A. lappacea*, and other flood-sensitive species (Table 7.1).

It is unlikely that once-off fire or drought on their own will have a long-term effect on matrix species (Sections 3.3.2 and 5.3.2). However, it is hypothesised that an inappropriate fire regime, involving repeated fires in autumn, will encourage winter-growing introduced species and that intense competition with certain species (e.g. **Rapistrum rugosum*) may reduce the abundance of important perennial grasses (e.g. *Dichanthium sericeum* and *Astrebla* spp.).

7.2.3 Transitional stages model

Mitchell grasslands are resilient to natural disturbances (Section 7.2.1; Orr & Holmes 1984). This means that they have a strong tendency to return to their original state after the influence of outside pressures (Harrington *et al.* 1984). Therefore, defining a series of stable states for these grasslands may be pointless. State and transition models have previously been proposed for *Astrebla* spp. and *Dichanthium* spp. grasslands (McArthur *et al.* 1994; Phelps & Bosch 2002). On the Moree Plains, it is unlikely that all of the states defined by McArthur *et al.* (1994) are stable, where a system is considered stable if it persists despite perturbations (Connell & Slatyer 1977). As Stringham *et al.* (2003) point out, grassland states should include many seral stages of the overall grassland community. The ability to define stable states may be further complicated by the seasonal variations in species abundance (e.g. fluctuations in the dominance of *Astrebla* spp. and *Dichanthium sericeum* between years). It may be difficult for managers (especially without experience in the region) to determine whether fluctuations in the dominant species of the community occur in response to management or seasonal influences. Therefore, vegetation states would need to be assessed on several occasions, to take into account the year-to-year variations in species composition (Section 4.3.2). Phelps and Bosch (2002) developed a state and transition model taking into account the variation between years and the fact that some vegetation states are unstable. However, some of the compositional states defined for central western Queensland are different to those on the Moree Plains (i.e. the herbfield states in Phelps and Bosch (2002)).

Conceptual models (e.g. McArthur *et al.* 1994) that depict changes in composition are useful in management (Westoby *et al.* 1989; Whalley 1994). Hence a model with transitional stages (based on grassland composition and richness), rather than 'stable states' is proposed to aid management of native grasslands on the Moree Plains for conservation of plant diversity (Fig. 7.1). The compositional stages in this model have been previously refered to as plant community phases or seral stages within a state, when refering to state and transition models (Stringham *et al.* 2003). In general, disturbances such as moderate grazing and fire on the Moree Plains do not have a major effect on the dominant grasses (matrix species) and composition can recover relatively quickly. However, as discussed in Section 7.2.2, certain disturbances can result in the removal of matrix species and major changes in composition. There needs to be further investigation in order to understand the shifts in botanical composition over longer time frames, and the thresholds (e.g. grazing intensities) required to produce major shifts in botanical composition of these grasslands. Indeed, McArthur *et al.* (1994) suggested that transitions between states are not well understood for *Astrebla* and *Dichanthium* dominated grasslands. Transitions in grassland condition (based on composition and richness) in Figure 7.1 are based on the findings reported in this study and other hypothesised influences (Table 7.2).

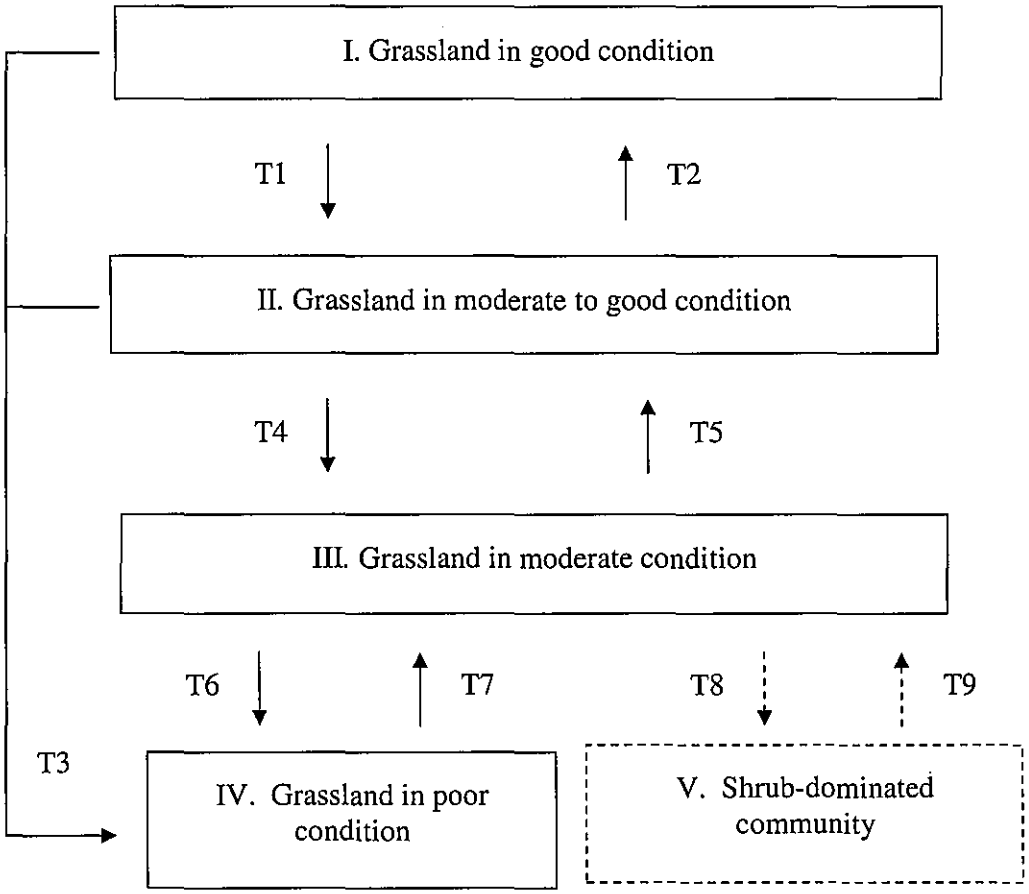


Fig. 7.1. Tranistional stages model for native grasslands on clay soils of the Moree Plains. Each stage was defined by composition and richness (based on sampling 20 by 20-m quadrats in autumn), with detailed definitions provided below. Transitions between stages are based on my findings and hypothesised changes that could not be determined from this study (Table 7.2). Stages and transitions that were not investigated in this study are shown with dashed lines.

Stage characteritics

Stage I. High native species richness in autumn (at least 36 native species per 0.04 ha) with a low number (≤5) and cover (<10%) of introduced species, occurrence of rare species (listed for NSW or nationally), ≥3 native herbaceous species with cover abundance scores ≥3 (i.e. ≥6% cover) and good structural diversity with a mix of forbs, grasses, sub-shrubs and graminoids. Typical grasses might include: *Astrebla elymoides, A. lappacea, Dichanthium sericeum, Aristida leptopoda, Austrodanthonia bipartita, Chloris truncata, Enteropogon acicularis, Panicum decompositum, P. buncei, P. queenslandicum, Digitaria* *divaricatissima, Eragrostis parviflora, Eriochloa pseudoacrotricha, E. crebra, Eulalia aurea, Paspalidium globoideum, Sporobolus caroli, Thellungia advena* and *Themeda avenacea.* Typical forbs might include: *Alternanthera denticulata, Asperula cunninghamii, Boerhavia dominii, Brachycome ciliaris, Calotis scabiosifolia, Chamaesyce drummondii, Convolvulus erubescens, Crotalaria dissitiflora, Cullen tenax, Desmodium campylocaulon, Eclipta platyglossa, Einadia nutans, Eryngium plantagineum, Glycine latifolia, Goodenia fascicularis, Hibiscus trionum, Marsilea drummondii, Mimulus gracilis, Minuria integerrima, Neptunia gracilis, Oxalis perennans, Phyllanthus virgatus, Ptilotus semilanatus, Pycnosorus globosus, Rhynchosia minima, Rostellularia adscendens, Sida trichopoda, Solanum esuriale, Verbena gaudichaudii, Vittadinia cuneata* and *Wahlenbergia communis.* Typical graminoids might include: *Juncus aridicola, J. usitatus, Fimbristylis dichotoma, Eleocharis pallens, Cyperus bifax,* other *Cyperus* spp., *Caesia calliantha, Carex inversa* and *Crinum flaccidum.* Typical sub-shrubs might include: *Atriplex semibaccata, Eremophila debilis, Leiocarpa websteri, Maireana aphylla, M. decalvans, M. microphylla, Sclerolaena muricata* var. *villosa, Swainsona* spp. and *Einadia hastata.* Assuming winter rainfall occurs several annual species (mostly introduced species) become part of the interstitial component (see list of winter annuals below). This includes important pasture species like **Medicago polymorpha* and other **Medicago* spp.

Stage II. Moderate to high native species richness in autumn (at least 30 native species per 0.04 ha) with a low number (≤7) and cover (<15%) of introduced species, the possible occurrence of rare species (e.g. *Desmodium campylocaulon*), ≥3 native herbaceous species with cover abundance scores ≥3 (i.e. ≥6% cover) and good structural diversity with a mix of forbs, grasses, sub-shrubs and graminoids. Composition would be much the same as that for *Stage I*, but without certain grazing-sensitive species. Native taxa such as *Ptilotus semilanatus, Themeda avenacea, Panicum queenslandicum, Vittadinia cuneata, Asperula cunninghamii, Desmodium campylocaulon, Phyllanthus virgatus* and *Swainsona murrayana* are less likely to be recorded in this stage.

Stage III. Moderate native species richness in autumn (15-30 native species per 0.04 ha) with a relatively low number (<10) and cover (<25%) of introduced species, unlikely occurrence of rare species (e.g. *Desmodium campylocaulon*) and often dominated (i.e. species with ≥6% cover) by <3 native herbaceous species. While many of the species typical of *Stage I* may be present, some dominant perennial grass species may be removed due to certain forms of disturbance (see Table 7.1) and others may become more abundant. Grasses that rapidly disperse (i.e. by wind or livestock) will be common at sites recovering from severe disturbances like cultivation. Typical grasses might include: *Dichanthium sericeum, Aristida leptopoda, A. platychaeta, A. latifolia, Chloris truncata, Enteropogon acicularis, Eriochloa pseudoacrotricha, Panicum decompositum, Sporobolus caroli, S. mitchellii, Dactyloctenium radulans, Echinochloa colona, Eragrostis parviflora, E. setifolia, Leptochloa divaricatissima, Paspalidium jubiflorum* and **Urochloa panicoides.* In addition to some of the common (i.e. disturbance-tolerant) forbs, graminoids and sub-shrubs listed above for *Stage I*, other species might include: **Tribulus terrestris, T. micrococcus, Sclerolaena muricata* var. *muricata, Portulaca oleracea, *Medicago spp.*, *Salsola kali* var. *kali, *Xanthium* spp., **Rapistrum rugosum, Cucumis melo, *Malvastrum americanum, *Physalis lanceifolia, Haloragis aspera, Polymeria pusilla* and *Ipomoea lonchophylla.*

Stage IV. Low native species richness in autumn (<20 native species per 0.04 ha), with a high number (>10) or cover (>25%) of introduced and annual species, poor structural diversity (i.e. mostly annual forbs and grasses), no rare species (listed for NSW or nationally) and often dominated (i.e. species with ≥6% cover) by <3 herbaceous species. While some of the species typical of *Stage I* may be present (i.e. disturbance-tolerant species), many species will have been removed. Annual grasses and forbs, and introduced species are likely to be abundant. Typical grasses might include: **Urochloa panicoides, Chloris truncata, Sporobolus caroli, Panicum decompositum, Enteropogon acicularis, Echinochloa colona, *Avena fatua* (winter only) and **Phalaris paradoxa* (winter only). Other typical species might include: *Salsola kali* var. *kali, *Tribulus terrestris, T. micrococcus, Sclerolaena muricata* var. *muricata, S. birchii, Portulaca oleracea, *Rapistrum rugosum, *Cucumis* spp., **Polygonum* spp., *Convolvulus erubescens, Sida trichopoda, Solanum esuriale, *Malvastrum americanum, Boerhavia dominii, Verbena gaudichaudii* and **Lactuca* spp.

Hypothesised Stage V (stable). Shrub-dominated communities (i.e. with >25% cover of woody species, like *Acacia stenophylla* or *A. victoriae*). While shrub-dominated communities were not a focus of this thesis, they are likely to have lower herbaceous richness and grazing value (Booth 1986; Burrows 1986). However, areas with abundant *Acacia farnesiana* might be an exception to this, as this species had no negative impact on plant species richness or composition (Section 4.3.6). Invasion of woody weeds is considered a more serious problem in the northern Mitchell grasslands (Partridge 1996; Radford *et al.* 2001).

Winter annual species. There is a group of annual species that increase in abundance, or are usually only recorded in late autumn, winter or spring on the Moree Plains. They include: **Rapistrum rugosum, *Sonchus oleraceus, *Plantago cunninghamii, *Hedypnois rhagadioloides, Erodium crinitum, *Medicago polymorpha, *Medicago truncatula, *Medicago minima,* other **Medicago* spp., **Conyza bonariensis, *Phalaris paradoxa, Daucus glochidiatus, *Avena fatua, *Calotis hispidula, *Hordeum leporinum, *Calendula arvensis, *Centaurea melitensis, *Cirsium vulgare, *Ciclospermum leptophyllum, *Echium plantagineum, Lachnagrostis filiformis, *Lolium perenne, *Aster subulatus, *Bromus cartharticus, *Silybum marianum* and **Solanum nigrum.* Some of these species may be recorded in any of the above grassland stages but are likely to be more common in *Stages III* and *IV.*

Table 7.2. Known and hypothesised causes for transitions between stages in Fig. 7.1

	Known cause	Hypothesised cause
T1	Livestock grazing for production (Section 3.3.4; Table 7.1). Drought (Section 3.3.2; Fig. 3.6).	
T2	Complete removal of livestock (Section 4.3.3). Conservative livestock grazing (e.g. some sites in the regional vegetation survey).	
T3	Cultivation (Section 3.3.4; Table 7.1).	Extended periods of over-grazing.
T4	Altered flooding regime, resulting in increased flooding frequency (Section 3.3.4; Table 7.1). Drought (Section 3.3.2; Fig. 3.6).	Livestock grazing at high intensity or without rests (i.e. not allowing recruitment of long-lived perennial grasses). Inappropriate fire management. For example, repeated burning in autumn or allowing livestock grazing on recently burnt areas.

Table 7.2. (continued)

	Known cause	Hypothesised cause
T5		Careful grazing management involving frequent spelling and low stocking rates to allow recruitment of all native species (including long-lived perennial grasses). A series of good seasons (i.e. with above average summer rainfall).
T6	Cultivation (Section 3.3.4; Table 7.1). Interactions with grazing and drought (Section 3.3.4).	Extended periods of over-grazing. Inappropriate fire management (e.g. livestock grazing in recently burnt areas).
T7	Careful management after cultivation, involving grazing at strategic times to aid in seed dispersal (Section 3.4.5). Removal of livestock grazing (e.g. Kirramingly Nature Reserve), although this may not be sufficient after extended periods of cultivation.	Restoration involving addition of native seed and removal of introduced species. A series of good seasons (i.e. with above-average summer rainfall) is likely to result in a faster recovery but may need to be combined with careful management.
T8		Mass recruitment of woody weeds due to a series of favourable seasons, over-grazing and/or inappropriate fire regime (Booth & Barker 1981; Walker *et al.* 1981; Hodgkinson *et al.* 1984; Booth 1986; McArthur *et al.* 1994; Archer 1995; Noble 1997).
T9		Control of shrubs using biological, mechanical or chemical means (or a combination) (Bovey *et al.* 1979; Booth 1986).

7.3 Management of native grasslands to encourage diversity

7.3.1 Management of the Moree Plains grasslands

It is encouraging that sensible livestock grazing on the Moree Plains does not result in a major reduction in species richness (Fig. 7.1; Sections 3.3.4 and 4.3.3), although the initial effects of grazing after European settlement are unknown. Some grazing is probably beneficial for promoting spatial heterogeneity (i.e. patches that support different plant assemblages) in the landscape and encouraging certain species favoured by grazing (Table 7.1). However, while certain species are favoured by grazing (e.g. **Tribulus terrestris,* *Dactyloctenium radulans* and **Urochloa panicoides*) there is little evidence to suggest that species will disappear entirely in ungrazed areas on the Moree Plains. Only two species (*Portulaca oleracea* and *Maireana decalvens*) were significantly more frequent at TSR sites than in Kirramingly Nature Reserve (Section 4.3.3) and neither of these species had decreased in frequency in the Reserve since 1998. It is possible, though, that some species disappeared from the Reserve after livestock exclusion in 1996, but prior to initial surveys at the Reserve in 1998.

There are few ungrazed grassland remnants on the Moree Plains (Chapter 3). However, some areas of the Moree Plains should remain ungrazed (e.g. Kirramingly Nature Reserve). Sites at Kirramingly Nature Reserve without a history of cultivation had consistently higher species richness than the majority of sites in the regional vegetation survey (Section 3.3.4). The trend of higher species richness at ungrazed sites in the regional vegetation survey (Fig. 3.9) was supported by trends in the Kirramingly Nature Reserve survey (Fig. 4.6). Grassland reserves like Kirramingly play an important role in the landscape, as they allow the continued persistence of certain grazing-sensitive species (e.g. *Swainsona murrayana*) that have not already been eliminated. It is encouraging that grassland in areas with a history of livestock grazing is able to recover to grassland in good condition, given sufficient rest from livestock grazing (e.g. Kirramingly Nature Reserve). This suggests that some grazing-sensitive species are able to persist in the landscape, but are probably rare, and could become more so over time in grazed areas.

Native grasslands on the Moree Plains that are in moderate to good condition from a plant diversity perspective also contain species considered desirable from a grazing perspective (Appendix 7.1). Grazed grasslands on the Moree Plains are comprised mostly of disturbance-tolerant native species. However, some sites with a history of heavy grazing or cultivation were of lesser grazing value due to the absence of valuable perennial grasses (e.g. *Astrebla* spp.) and higher abundances of disturbance specialists. Heavily grazed or degraded sites on the Moree Plains (i.e. Fig. 7.1, *Stage IV*) are recognised by species of lower grazing value (e.g. **Tribulus terrestris*, **Urochloa panicoides*, **Rapistrum rugosum*, **Xanthium* spp., **Cucumis myriocarpus*, **Polygonum* spp., **Lactuca* spp., *Salsola kali* var. *kali*, *Sclerolaena muricata* var. *muricata* and *S. birchii*). The occurrence of an increasing abundance of these species in a paddock should be a warning sign to land managers that their grassland is becoming (or is already) degraded. Degraded grasslands not only have lower grazing value, but are of poor condition from a plant diversity perspective (Fig. 7.1). Phelps and Bosch (2002) similarly reported lower producivity in unstable states of poor ecological condition in central western Queensland. Hence, if early signs of degradation can be observed by land managers, a change in management is probably necessary. This may require removal of livestock for some time to allow native species to recruit from seed banks, recolonise from surrounding areas, set seed and establish seedlings (Fig. 7.1; Campbell *et al.* 1996).

Spelling and timing of grazing may be very important on the Moree Plains, particularly after disturbance, such as fire or cultivation, and after summer rainfall events. Seedling establishment is likely to be highest after rainfall and after disturbance, yet seedlings can be very sensitive to grazing (Roberts 1978; Campbell *et al.* 1996) and may be preferred by grazing animals due to their high palatability (Leigh & Holgate 1979; Letnic 2004). Recruitment of long-lived perennial grass species (e.g. *Astrebla* spp.) may be rare and highly dependent on seasonal conditions (Williams & Roe 1975; Orr & Holmes 1984). Therefore, allowing recruitment at critical times is crucial for the long-term persistence of such species (Campbell *et al.* 1996). Rotational grazing probably also plays an important role in the recovery of previously cultivated land, through the dispersal of herbaceous seed in livestock dung or attached to livestock exteriors (Section 3.4.5).

Livestock grazing over a number of years is a more severe disturbance than fire (without livestock grazing) in the Moree Plains grasslands, as the composition of the vegetation is more significantly altered (Section 3.3.4). However, fire is not commonly used as a management tool by graziers on the Moree Plains, probably because of the recovery period required without grazing. In fact, fire is generally not promoted in Mitchell grasslands due to the loss of forage value (Orr & Holmes 1984; Partridge 1996). Some managers have suggested fire is not a useful management option as seedlings (and resprouts) recovering after fire are particularly vulnerable to grazing (Roberts 1978). Therefore, livestock grazing immediately after fire could result in the reduced abundance of species that are favoured by livestock and, hence, a loss in grazing value. For this reason, the use of fire should be restricted to areas that are not grazed by livestock (e.g. Kirramingly Nature Reserve) or areas that can be rested from grazing for some time. Assuming areas burnt are large enough (e.g. >20 ha), kangaroo grazing post-fire is unlikely to have a significant impact on species composition or richness (Section 5.3.2). The use of repeated fire in the control of woody shrub abundance in *Astrebla* grasslands requires further investigation. However, one or two burns, 3 years apart, do not affect the abundance of *Acacia farnesiana* or *A. stenophylla* (Section 5.3.7).

Changes in flooding regimes (i.e. flood frequency) associated with diversionary earthworks and irrigation farming will result in changes in grassland composition (Sections 3.3.3 and 3.3.4). Increased flooding frequency is likely to result in the loss of *Astrebla lappacea* and, thus, a reduction in conservation value and grazing value. On the other hand, preventing flooding of areas that naturally flood could result in the loss of species that require flooding to persist (e.g. species responding positively to flooding in Table 7.1).

Revegetation after disturbances like fire and grazing on the Moree Plains is predominantly through vegetative regrowth of perennial species rather than by establishment of seedlings (Chapters 4, 5 and 6). Establishment after long periods of cultivation, however, requires recruitment from seed. Annuals and wind-dispersed species are usually common at cultivated sites (e.g. Fig. 7.1, *Stage IV*). Since many introduced annuals persist in areas due to their large seed banks (Lunt 1990b), they are difficult to eliminate from the assemblage once they have established a seed bank of critical size (Morgan 1994), even after the establishment of native perennials. For example, at Kirramingly Nature Reserve, seasonal periods of high abundance of introduced species in previously cultivated areas (Section 4.3.4) allow these species to replenish their seed banks. The winter-growing introduced species are able to persist in such areas because they grow in winter when competition with native perennial grasses is less intense.

The primary threat to native grasslands on the Moree Plains is cultivation for cropping. The ability of native grasslands to recover after cultivation can be reasonable from a grazing management perspective (Section 3.4.5). Hence the aim for most managers is to establish a productive pasture on previously cultivated areas, rather than to return it to its original condition. However, from a conservation perspective, cultivation of native grasslands on the Moree Plains has a long-lasting negative effect. Surveys at Kirramingly Nature Reserve (Section 4.3.4) supported findings from the regional survey (Section 3.3.4) that cultivation has a negative effect on species richness and composition. Species richness and composition varied more in response to previous cultivation (and disc ploughing) than in response to grazing, fire or mowing (Chapters 3, 4, 5 and 6). Native perennial grasses (e.g. *Astrebla* spp., *Themeda avenacea, Thellungia advena, Enteropogon acicularis, Aristida leptopoda*) declined in abundance in response to cultivation, especially at recently ploughed sites.

Extended periods of cultivation encourage disturbance specialists, including undesirable species (e.g. *Salsola kali* var. *kali, *Rapistrum rugosum, Sclerolaena muricata* var. *muricata, *Tribulus terrestris, *Urochloa panicoides* and **Xanthium occidentale*). Invasion of such species may influence the recovery of previously cultivated areas through competitive exclusion of native species typical of undisturbed areas (Belsky 1986b; Graham & Hutchings 1988a; Römermann *et al.* 2005). Therefore, complete recovery of native grasslands (to their original composition and richness) is unlikely after long periods of cultivation. Restoration of cultivated grasslands to their original composition and richness may require inputs from land managers (e.g. spreading seed of species that are eliminated by cultivation and control of introduced species). To improve the conservation value of cultivated areas infested with introduced species, selective treatment of introduced species with broadleaf herbicides may be necessary. Even then, it may be difficult to restore such areas to native grassland of high conservation value, given the changes in soil fertility associated with cultivation (Section 3.3.4) and their influence on species composition (e.g. Tilman 1986; Gough & Marrs 1990; McLendon & Redente 1991; Kindscher & Tieszen 1998; Wijesuriya & Hocking 1998). Hence it is particularly important to conserve native grasslands on the Moree Plains without a history of cultivation.

7.3.2 Management of Kirramingly Nature Reserve

The evidence to date suggests that removal of perennial grass canopy and litter is unnecessary at Kirramingly Nature Reserve to prevent competitive exclusion of interstitial species (Section 4.3.3). Seasonal variations, drought and possibly kangaroo grazing, appear adequate to regulate perennial grass density and allow recruitment of interstitial species. If after some time, competitive exclusion of species is recognised through monitoring, then use of fire at appropriate times as a disturbance mechanism at Kirramingly Nature Reserve should be the preferred method of biomass removal, rather than livestock grazing, mowing or ploughing. Fire is preferred over livestock grazing due to the possible elimination of grazing-sensitive species (Fig. 7.1), introduction of seeds of introduced species (in livestock dung or on their exteriors) and other possible changes in species composition associated with livestock grazing (e.g. Table 7.1). While mowing or slashing has a relatively small effect on species composition (Section 6.3.1; Table 7.1), it is not recommended over fire due to the possible introduction of weed species on machinery, the costs involved and the need to remove the litter after treatment (Lunt 1993). Ploughing has similar disadvantages in that it is costly and may introduce weed species on machinery and encourage invasion of introduced species from neighbouring properties. In addition, ploughing may result in a decline in some perennial grasses (Table 7.1). Ploughing or slashing, however, has been used to maintain 10-20-m wide fire-breaks around some of the Reserve margins (C. Watt pers. comm., 2002). Hence monitoring of containment lines is important to prevent the invasion of introduced species from outside the Reserve.

Timing of fires at Kirramingly Nature Reserve should be managed to ensure a rapid recovery of vegetation cover; hence, burning in spring, rather than autumn or winter, is recommended (Section 5.3.2). Further, late spring is preferred over early spring, to reduce the chance of establishment of winter-and spring-growing introduced annuals immediately after fire and to kill their seed on the soil surface. It is important that the influence of management continues to be monitored so that declines in native species or increases in introduced species are recognised, and changes in management can occur (see Section 7.4.2).

7.4 Future research and monitoring

7.4.1 Further research

Future research should involve experiments to test some of the hypothesised causes for transitions in grassland composition and richness (see Table 7.2). For example, experimental studies are recommended to further investigate the impacts of livestock grazing on plant diversity in these grassland communities. To prevent deterioration of grassland condition and grazing value, it would be useful to determine the grazing intensities that result in loss of grassland matrix species (e.g. *Astrebla* spp. and *Dichanthium sericeum*) on the Moree Plains. From a biodiversity perspective, it would be worthwhile determining the grazing regimes that result in the loss of grazing-sensitive species. While this thesis has identified several species that respond negatively to grazing (e.g. Table 7.1), it is likely that many of the grazing-sensitive species were not recognised because rare species (e.g. *Swainsona murrayana*) were too infrequent to be analysed.

Studies that focus on infrequently recorded species might help to determine whether they are grazing sensitive, or sensitive to other disturbances.

Further analysis of the effects of time since cultivation on species richness and composition is required. Few Australian studies have dealt with the time required to re-establish plant diversity in grasslands after cultivation (Nadolny & Eldridge 1999 is an exception). Results in Chapter 3 suggest that there is no strong relationship between species richness and time since cultivation (Fig. 3.12). However, this result was undoubtedly influenced by a range of confounding variables at cultivated sites (e.g. soil type, number of years of consecutive cultivations, grazing history post-cultivation, rainfall post-cultivation). At Kirramingly Nature Reserve there was also no obvious increase in native species richness at cultivated sites relative to uncultivated sites between 1998 and 2004 (Section 4.3.4; Fig. 4.9). Hence I recommend experimental work (i.e. without confounding variables) to better determine the time required for species richness and composition to recover after several years of cultivation.

Studies investigating the importance of grazing for seed dispersal after cultivation would be beneficial to determine the species that can establish in previously cultivated areas after dispersal by livestock. Whether previously cultivated sites can be returned to their pre-cultivation composition and richness with careful management assisted by livestock and natural dispersal methods is of interest from a conservation perspective. Location of nearby seed sources (remnants) in the surrounding landscape is likely to influence the speed of recovery (e.g. Hutchings & Booth 1996; Nadolny & Eldridge 1999); however, studies are required to determine the relative importance of nearby seed sources and livestock-assisted dispersal.

The time required for elimination of seed banks in cultivated areas should also be a focus of future research. Persistence of native and introduced seed banks is likely to influence how quickly grasslands can recover after cultivation. Assessing seed banks in previously cultivated areas is recommended, as it will help determine the extent of management interventions required to restore previously cultivated areas. Results in Chapter 4 support previous findings (e.g. Graham & Hutchings 1988a,b; Hutchings & Booth 1996; Römermann *et al.* 2005) that introduced species (particularly annuals) can remain in previously cultivated areas (as a seed bank) for many years. For example, Graham and

Hutchings (1988a,b) reported that in chalk grasslands in Sussex, re-establishment after cultivation from the seed bank and seed rain is likely to result in dominance of weed species. Therefore, it is hypothesised that areas cultivated for extended periods (e.g. >10 years) have a small native perennial seed bank relative to that of introduced and annual species.

Given that fire is not commonly used in management of grazed grasslands on the Moree Plains, the need for understanding fire and livestock grazing interactions is not pressing. While kangaroo grazing post-fire had no impact on species richness or composition (Section 5.3.2), it is likely that more intense livestock grazing does have an effect, but further studies would be required to determine this effect. A better understanding of the natural disturbance regime of these grasslands (pre-European settlement) may be relevant to the management of Kirramingly Nature Reserve in deciding on an appropriate fire regime. Research into the pre-European fire frequency is recommended.

On the Moree Plains, species that benefit from disturbance were generally annuals or had means of long-distance seed dispersal (Section 7.2.2). Potential exists for classification of more detailed plant functional traits (e.g. seed size, dormant bud position, stem/leaf ratio) using existing data sets and analyses to determine whether there are consistent responses of certain plant traits to different types of disturbance (e.g. McIntyre & Lavorel 2001; Vesk *et al.* 2004). The inconsistent responses of species to grazing recognised here (e.g. Chapters 3 and 4) and elsewhere (e.g. Noy-Meir *et al.* 1989; Vesk & Westoby 2001) suggest that use of plant traits for predictive purposes should be done with caution. Vesk *et al.* (2004) reported that prediction of grazing responses with simple traits is less clear in semi-arid and arid regions, because of the sparse vegetation and high diversity of growth forms. It would be worthwhile testing this hypothesis in the Moree Plains grasslands.

Finally, this thesis has only been concerned with vascular plant diversity. There is a need for similar studies to investigate management impacts on both vertebrates and invertebrates.

7.4.2 Further monitoring of established sites

Sites have been established at Kirramingly Nature Reserve to allow long-term monitoring of vegetation composition and richness. Monitoring sites with a range of management histories is suggested to assist in decisions regarding Reserve management (Table 7.3) and will be crucial in recognising species declines and colonisation by introduced species. While there was no evidence of competitive exclusion after livestock removal at Kirramingly Nature Reserve (Section 4.3.3), relatively weak, undetectable competition may be important over longer periods of time (Tokeshi 1999). It is possible that grass density and litter has not reached a critical level whereby species recruitment is limited, since the removal of livestock from the Reserve 8 years ago. Jones *et al.* (1995) reported that botanical changes might only occur after many years (5-10 years or more) in grazing trials due to rainfall variability and other factors such as longevity of individual plants. This is especially relevant to grasslands on the Moree Plains, because recruitment of long-lived grasses (e.g. *Astrebla* spp.) may be infrequent and sporadic (Williams & Roe 1975; Orr & Holmes 1984). It is important that future surveys also consider the strong temporal variations in richness and composition by making use of existing data.

Monitoring of sites at Kirramingly Nature Reserve is likely to influence management decisions (Table 7.3). Monitoring of repeatedly burnt sites is particularly important given that the findings reported in this thesis may have been influenced by the unusually dry winter conditions that prevented the growth of winter annuals (Section 5.4.1). The influence of repeated disc ploughing of Reserve containment lines should also be monitored; however, this will require the addition of new monitoring points. For comparisons between ungrazed sites in the Reserve and grazed sites nearby, new sites should also be established in adjacent privately owned land. This will allow a direct comparison between sites managed for conservation and sites managed entirely for production (i.e. not TSR sites). It is hoped that a long-term monitoring program will be developed between the University of New England and NPWS (Table 7.3). Frequency of monitoring and the number of sites surveyed will depend on NPWS management (i.e. how often, and which sites are burnt). Monitoring of sites established at Kirramingly Nature Reserve will allow adaptive management, as suggested by Clarke *et al.* (1998). For example, if continued fires (on a yearly basis) on the northern boundary of the Reserve result in a reduction in diversity, extinction of certain native species, or an increase in introduced species abundance, alternative management options might be considered.

Table 7.3. Suggested monitoring of established sites at Kirramingly Nature Reserve (and surrounds)

Monitoring required	Frequency	Required for
The influence of a continued fire regime. Monitoring of 32-m² sites on the northern boundary of the Reserve to investigate the influence of repeated burning. Control sites, should if possible, remain unburnt.	2-5 years, depending on fire frequency	Reserve management
The influence of long-term livestock grazing removal. Comparisons between grazed and ungrazed 0.1024-ha sites; preferably with the addition of grazed sites in adjacent privately owned land.	5 years	Reserve management and management of other ungrazed remnants on the Moree Plains
The influence of total vertebrate grazing removal. Comparisons between areas fenced to exclude kangaroos and unfenced areas (32-m² sites).	5 years	Reserve management and management of other ungrazed remnants on the Moree Plains
Recovery of previously cultivated sites. Comparisons between cultivated and uncultivated 0.1024-ha sites over time. Possible experimental treatment of introduced species with broadleaf herbicides in cultivated areas infested with introduced species.	5-10 years	Reserve management and management of other cultivated grasslands on the Moree Plains
Abundance of *Acacia farnesiana* at 0.1024-ha sites over the Reserve.	10 years	Reserve management

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APPENDIX 3.1. Questions asked of land managers to determine the management history of sites sampled in the regional vegetation survey in 2002 and 2003.

Management History Questionnaire

'Management of the native grassland communities on the Moree Plains' PhD research

These questions relate to the management of individual paddocks, where I have set up vegetation survey points. Please fill in one of these for each paddock (survey point) on your property. Answer these to the best of your knowledge in your own time. If you are uncertain about an answer please indicate this.

Property name:

Q1. **When does your continuous knowledge of the management history for the property start?**

Q2(a). **Has the area ever been cultivated?**

Q2(b). **If so, in what year was it last cultivated?**

Q2(c). **How frequently was it cultivated prior to that year (i.e. how many years of continuous cultivation were there)?**

Q3. **Describe the grazing history of the area.**

(a) **Is it currently grazed by sheep or cattle or a mixture of both?**

(b) **Over time, has the area been grazed by predominantly sheep or cattle?**

(c) **Is the area continuously stocked or is it spelled for part of the year?**

(d) **If so, what percentage of the year is it spelled?**

Q4(a). **What is your current average stocking rate (d.s.e)?**

Q4(b). **Does this vary greatly from year to year?**

Q4(c). **Please provide yearly stocking rates (dating back as far as possible) if you have the records.**

Q5(a). **Does the area get flooded?** *Yes / No* *(Please circle)*

Q5(b). **If so, please provide the years when the area was flooded, or how often it floods (e.g. once every 2 years).**

Q5(c). **If possible, estimate how long the area stays inundated for when it floods.**

Q6(a). **Has the area ever been burnt?** *Yes / No* *(Please circle)*

Q6(b). **If so, when and how often was it burnt?**

Q6(c). **Was it burnt in a bushfire or a subscribed burn?**

Q7(a). **What is the average annual rainfall for your property?**

Q7(b). **Approximately how much rain did you receive in the 4 months prior to my vegetation survey?**

Q8. **Please provide any other information on the management of the area that may be useful (for example, if you have ever spread / sowed Mitchell grass seed, if you have ever spread / sowed other grass or legume species, if you have been spraying or cutting weeds, or if you have added nitrogen to the soil).**

Thanks very much for your time.

Tom Lewis
(PhD student, UNE)

If you have any queries or want to know more about the project you can contact me on (02) 6773 5213, or by email at tlewis3@metz.une.edu.au.

You can address completed survey forms to me at:
Ecosystem Management
University of New England
ARMIDALE
NSW 2351
Or fax it to: (02) 6773 2769.

APPENDIX 3.2. All taxa (scientific name, common name and family) recorded during the regional vegetation survey on the Moree Plains in 2002 and 2003. Code refers to labels given in ordination diagrams in the thesis. Also shown are species origin (N, native; I, introduced; U, unknown), growth form (F, forb; G, grass; GR, graminoid; S, shrub; SS, sub-shrub; T, Tree; O, other) and life cycle (P, perennial; A, annual or biennial; S, short-lived perennial). Species percentage frequency (% Freq) for 184 quadrats and mean cover abundance score (CA score) are also provided. Species that have a frequency and cover abundance score of zero were recorded outside quadrats or were only recorded during spring sampling. An # identifies species that were not recorded by Hunter and Earl (1999); ♣ indicates species listed under the *Threatened Species Act* (NSW).

Species	**Code**	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**	**% Freq ($n = 184$)**	**CA score ($n = 184$)**
# *Abutilon malvifolium*	Abumal	Malvaceae	Mallow-leaf Lantern-flower	N	F	P	3	0.03
Abutilon oxycarpum	Abuoxy	Malvaceae	Flannel Weed	N	F	P	4	0.04
Acacia farnesiana	Acafar	Fabaceae	Mimosa Bush	U	S	P	60	1.24
Acacia oswaldii	Acaosw	Fabaceae	Miljee	N	T	P	0	0.00
Acacia pendula	Acapen	Fabaceae	Weeping Myall	N	T	P	2	0.02
Acacia salicina	Acasal	Fabaceae	Cooba	N	T	P	2	0.03
Acacia stenophylla	Acaste	Fabaceae	River Cooba	N	T	P	2	0.03
# *Acacia victoriae*	Acavic	Fabaceae	Prickly wattle	N	S	P	1	0.01
Alectryon oleifolius subsp. *canescens*	Aleole	Sapindaceae	Western Rosewood	N	T	P	2	0.02
# *Alternanthera angustifolia*	Altang	Amaranthaceae	Narrow-leaf Joyweed	N	F	A	1	0.02
Alternanthera denticulata	Altden	Amaranthaceae	Lesser Joyweed	N	F	A	43	0.74
Alternanthera nodiflora	Altnod	Amaranthaceae	Common Joyweed	N	F	A	3	0.05
Alternanthera pungens	Altpun	Amaranthaceae	Khaki Weed	I	F	A	1	0.02
Amaranthus macrocarpus var. *macrocarpus*	Amamam	Amaranthaceae	Dwarf Amaranth	N	F	A	3	0.05
Amaranthus macrocarpus var. *pallidus*	Amamap	Amaranthaceae	Dwarf Amaranth	N	F	A	7	0.14
# *Ammi majus*	Ammmaj	Apiaceae	Bishop's Weed	I	F	A	2	0.04
Amyema miquelii	Amymiq	Loranthaceae	Box Mistletoe	N	O	P	1	0.01
# *Anagallis arvensis*	Angarv	Primulaceae	Scarlet Pimpernel	I	F	A,S	0	0.00
Apophyllum anomalum	Apoano	Capparaceae	Warrior Bush	N	S	P	1	0.01

Species	**Code**	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**	**% Freq ($n = 184$)**	**CA score ($n = 184$)**
Aristida latifolia	Arilat	Poaceae	Feathertop Wiregrass	N	G	P	5	0.10
Aristida leichhardtiana	Arilei	Poaceae	Threeawn Grass	N	G	P	0	0.00
Aristida leptopoda	Arilep	Poaceae	White Speargrass	N	G	P	48	1.18
# Aristida personata	Ariper	Poaceae	Purple Wiregrass	N	G	P	1	0.02
Aristida platychaeta	Aripla	Poaceae	Threeawn Grass	N	G	P	7	0.16
Aristida psammophila	Aripsa	Poaceae	Threeawn Grass	N	G	P	3	0.04
Aristida ramosa	Ariram	Poaceae	Purple Wiregrass	N	G	P	10	0.32
Asperula conferta	Aspcon	Rubiaceae	Common Woodruff	N	F	P	14	0.24
Asperula cunninghamii	Aspcun	Rubiaceae	Twining Woodruff	N	F	P	2	0.04
Aster subulatus	Astsub	Asteraceae	Wild Aster	I	F	A	4	0.06
Astrebla elymoides	Astely	Poaceae	Hoop Mitchell Grass	N	G	P	41	1.26
Astrebla lappacea	Astlap	Poaceae	Curly Mitchell Grass	N	G	P	30	0.85
Astrebla pectinata	Astpec	Poaceae	Barley Mitchell Grass	N	G	P	2	0.04
Astrebla squarrosa	Astsqu	Poaceae	Blue Mitchell Grass	N	G	P	2	0.05
Atalaya hemiglauca	Atahem	Sapindaceae	Whitewood	N	T	P	2	0.03
Atriplex leptocarpa	Atrlep	Chenopodiaceae	Slender-fruit Saltbush	N	F	P,S	3	0.04
Atriplex muelleri	Atrmue	Chenopodiaceae	Saltbush	N	F	A	3	0.04
Atriplex semibaccata	Atrsem	Chenopodiaceae	Creeping Saltbush	N	SS	P	16	0.26
Atriplex species B	Atrspe	Chenopodiaceae	Saltbush	N	SS	P	8	0.14
Austrodanthonia bipartita	Ausbip	Poaceae	Wallaby Grass	N	G	P	22	0.34
Austrostipa aristiglumis	Ausari	Poaceae	Plains Grass	N	G	P	14	0.32
Austrostipa scabra	Aussca	Poaceae	Speargrass	N	G	P	1	0.03
Austrostipa verticillata	Ausver	Poaceae	Slender Bamboo Grass	N	G	P	4	0.09
Avena fatua	Avefat	Poaceae	Wild Oats	I	G	A	4	0.04
Bidens pilosa	Bidpil	Asteraceae	Cobbler's Pegs	I	F	P	2	0.04
# Bidens subalternans	Bidsub	Asteraceae	Greater Beggar's Tick	I	F	P	5	0.08
Boerhavia dominii	Boedom	Nyctaginaceae	Tarvine	N	F	P	57	1.09
Bothriochloa biloba	Botbil	Poaceae	Bluegrass	N	G	P	1	0.01
Bothriochloa bladhii	Botbla	Poaceae	Forest Bluegrass	N	G	P	1	0.01
Bothriochloa decipiens	Botdec	Poaceae	Red Grass	N	G	P	6	0.18
Bothriochloa erianthoides	Boteri	Poaceae	Satintop Grass	N	G	P	1	0.01

Species	**Code**	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**	**% Freq (*n* = 184)**	**CA score (*n* = 184)**
Bothriochloa ewartiana	Botewa	Poaceae	Desert Bluegrass	N	G	P	2	0.05
# Brachiaria eruciformis	Braeru	Poaceae	Armgrass	I	G	A	1	0.01
# Brachycome ciliaris var. *ciliaris*	Bracic	Asteraceae	Variable Daisy	N	F	P	5	0.10
# Brachycome ciliaris var. *lanuginosa*	Bracil	Asteraceae	Variable Daisy	N	F	P	0	0.00
# Brachycome ciliaris var. *subintegrifolia*	Bracis	Asteraceae	Variable Daisy	N	F	P	3	0.05
# Brachycome curvicarpa	Bracur	Asteraceae	Curved-seed Daisy	N	F	A	1	0.01
Brachycome heterodonta var. *heterodonta*	Brahet	Asteraceae	Lobed-seed Daisy	N	F	P	6	0.10
Brachycome melanocarpa	Bramel	Asteraceae	Black-seeded Daisy	N	F	P	4	0.07
# Bromus arenarius	Broare	Poaceae	Sand Brome	N	G	A	1	0.01
Bromus catharticus	Brocat	Poaceae	Prairie Grass	I	G	A	2	0.04
Brunoniella australis	Bruaus	Acanthaceae	Blue Trumpet	N	F	P	2	0.05
# Bulbine bulbosa	Bulbul	Asphodelaceae	Bulbine Lily	N	GR	P	0	0.00
Caesia calliantha	Caecal	Anthericaceae	Grass Lily	N	GR	P	0	0.00
Calendula arvensis	Calarv	Asteraceae	Field Marigold	I	F	A	2	0.04
Callitris glaucophylla	Calgla	Cupressaceae	White Cypress Pine	N	T	P	1	0.01
Calostemma purpureum	Calpur	Amaryllidaceae	Garland Lily	N	GR	A	2	0.02
Calotis cuneata var. *cuneata*	Calcuc	Asteraceae	Mountain Burr-daisy	N	F	P	1	0.01
Calotis hispidula	Calhis	Asteraceae	Bogan Flea	N	F	A	1	0.01
Calotis lappulacea	Callap	Asteraceae	Yellow Burr-daisy	N	F	P	3	0.07
Calotis scabiosifolia var. *scabiosifolia*	Calscs	Asteraceae	Rough Burr-daisy	N	F	P	11	0.20
Capparis lasiantha	Caplas	Capparaceae	Nepine	N	S	P	4	0.04
Capparis mitchellii	Capmit	Capparaceae	Wild Orange	N	S	P	0	0.00
Carex inversa	Carinv	Cyperaceae	Knob Sedge	N	GR	P	6	0.09
# Carthamus lanatus	Carlan	Asteraceae	Saffron Thistle	I	F	A	1	0.02
Casuarina cristata	Cascri	Casuarinaceae	Belah	N	T	P	3	0.04
Cenchrus ciliaris	Cencil	Poaceae	Buffel Grass	I	G	P	4	0.09
# Centaurea calcitrapa	Cencal	Asteraceae	Star Thistle	I	F	A	1	0.01
Centaurea melitensis	Cenmel	Asteraceae	Maltese Cockspur	I	F	A	8	0.13
Centaurea solstitialis	Censol	Asteraceae	St Barnaby's Thistle	I	F	A	0	0.00
Centaurium spicatum	Censpi	Gentianaceae	Spike Centaury	N	F	A	1	0.01
Centipeda thespidioides	Centhe	Asteraceae	Desert Sneezeweed	N	F	P	4	0.07

Species	Code	Family	Common name	Origin	Growth form	Life cycle	% Freq (*n* = 184)	CA score (*n* = 184)
# *Chamaecrista nomame*	Chanom	Fabaceae	Chamaecrista	N	F	S,A	1	0.01
Chamaesyce drummondii	Chadru	Euphorbiaceae	Caustic weed	N	F	P	34	0.61
Cheilanthes sieberi subsp. *sieberi*	Chesie	Adiantaceae	Narrow Rock Fern	N	O	P	1	0.02
Chenopodium auricomum	Cheaur	Chenopodiaceae	Golden Goosefoot	N	S	P	1	0.01
# *Chenopodium desertorum*	Chedes	Chenopodiaceae	Desert Goosefoot	N	F	P	1	0.01
# *Chenopodium melanocarpum*	Chemel	Chenopodiaceae	Black Crumbweed	N	F	A	1	0.01
Chenopodium nitrariaceum	Chenit	Chenopodiaceae	Nitre Goosefoot	N	S	P	0	0.00
Chenopodium pumilio	Chepum	Chenopodiaceae	Small Crumbweed	N	F	A	0	0.00
Chloris truncata	Chltru	Poaceae	Windmill Grass	N	G	S,A	61	1.32
Chloris ventricosa	Chlven	Poaceae	Tall Chloris	N	G	P	7	0.14
Chloris virgata	Chlvir	Poaceae	Feathertop Rhodes Grass	I	G	A	1	0.02
Chrysocephalum semipapposum	Chrsem	Asteraceae	Clustered Everlasting	N	F	P	1	0.02
Chrysopogon fallax	Chrfal	Poaceae	Golden-beard Grass	N	G	P	2	0.03
# *Cichorium intybus*	Cicint	Asteraceae	Chicory	I	F	P	0	0.00
Ciclospermum leptophyllum	Ciclep	Apiaceae	Slender Celery	I	F	A	1	0.02
Cirsium vulgare	Cirvul	Asteraceae	Spear Thistle	I	F	A	7	0.10
Citrullus colocynthis	Citcol	Cucurbitaceae	Colocynth	I	F	P	0	0.00
# *Citrullus lanatus*	Citlan	Cucurbitaceae	Wild Melon	I	F	A	3	0.03
# *Commelina cyanea*	Comcya	Commelianaceae	Scurvy Weed	N	GR	P	1	0.01
Commelina ensifolia	Comens	Commelianaceae	Scurvy Grass	N	GR	P	0	0.00
Convolvulus erubescens	Coneru	Convolvulaceae	Australian Bindweed	N	F	P	46	0.80
Convolvulus remotus	Conrem	Convolvulaceae	Bindweed	N	F	P	8	0.17
Conyza bonariensis	Conbon	Asteraceae	Flaxleaf Fleabane	I	F	A	19	0.32
Corymbia tessellaris	Cortes	Myrtaceae	Carbeen	N	T	P	0	0.00
Crinum flaccidum	Crifla	Amaryllidaceae	Darling Lily	N	GR	A	8	0.14
Crotalaria dissitiflora subsp. *dissitiflora*	Crodis	Fabaceae	Grey Rattlepod	N	F	P	5	0.08
# *Crotalaria incana* subsp. *incana*	Croinc	Fabaceae	Woolly Rattlepod	I	SS	P	1	0.02
Cucumis melo subsp. *agrestis*	Cucmel	Cucurbitaceae	Ulcardo Melon	N	F	A	10	0.13
Cucumis myriocarpus subsp. *leptodermis*	Cucmyr	Cucurbitaceae	Paddy Melon	I	F	A	5	0.05
Cullen tenax	Culten	Fabaceae	Emu-foot	N	F	P	32	0.58
Cymbonotus lawsonianus	Cymlaw	Asteraceae	Bears-ear	N	F	P	1	0.01

Species	Code	Family	Common name	Origin	Growth form	Life cycle	% Freq (*n* = 184)	CA score (*n* = 184)
Cymbopogon refractus	Cymref	Poaceae	Barbed-wire Grass	N	G	P	2	0.03
Cynodon dactylon	Cyndac	Poaceae	Couch	N	G	P	5	0.11
Cyperus bifax	Cypbif	Cyperaceae	Downs Nutgrass	N	GR	P	49	1.09
Cyperus concinnus	Cypcon	Cyperaceae	Trim Sedge	N	GR	P	4	0.09
Cyperus fulvus	Cypful	Cyperaceae	Sticky Sedge	N	GR	P	1	0.02
# *Cyperus gracilis*	Cypgra	Cyperaceae	Sedge	N	GR	P	3	0.06
Cyperus lucidus	Cypluc	Cyperaceae	Sedge	N	GR	P	1	0.01
Cyperus victoriensis	Cypvic	Cyperaceae	Sedge	N	GR	P	4	0.09
Dactyloctenium radulans	Dacrad	Poaceae	Button Grass	N	G	A	16	0.31
Datura ferox	Datfer	Solanaceae	Fierce Thornapple	I	F	A	2	0.03
Daucus glochidiatus	Dauglo	Apiaceae	Australian Carrot	N	F	A	7	0.11
Desmodium brachypodum	Desbra	Fabaceae	Large Tick-trefoil	N	F	P	1	0.01
♣ *Desmodium campylocaulon*	Descam	Fabaceae	Creeping Tick-trefoil	N	F	P,A	20	0.39
# *Desmodium varians*	Desvar	Fabaceae	Slender Tick-trefoil	N	F	A	1	0.01
Dianella longifolia	Dialon	Phormiaceae	Flax Lily	N	GR	P	1	0.01
Dichanthium sericeum	Dicser	Poaceae	Queensland Bluegrass	N	G	P	75	2.32
Dichondra repens	Dicrep	Convolvulaceae	Kidney Weed	N	F	P	3	0.06
Digitaria brownii	Digbro	Poaceae	Cotton Panic Grass	N	G	P	3	0.05
# *Digitaria coenicola*	Digcoe	Poaceae	A Finger Panic Grass	N	G	P	3	0.08
Digitaria divaricatissima	Digdiv	Poaceae	Umbrella Grass	N	G	P	28	0.52
Digitaria hystrichoides	Dighys	Poaceae	Umbrella Grass	N	G	P	1	0.01
# ♣ *Digitaria porrecta*	Digpor	Poaceae	A Finger Panic Grass	N	G	P	8	0.16
Diplachne fusca	Dipfus	Poaceae	Brown Beetle Grass	N	G	A	3	0.07
Echinochloa colona	Echcol	Poaceae	Awnless Barnyard Grass	N	G	A	10	0.19
Echium plantagineum	Echpla	Boraginaceae	Paterson's Curse	I	F	A	0	0.00
# *Eclipta platyglossa*	Eclpla	Asteraceae	Yellow Twin-heads	N	F	A	14	0.21
Einadia hastata	Einhas	Chenopodiaceae	Berry Saltbush	N	SS	P	10	0.15
Einadia nutans subsp. *linifolia*	Einnul	Chenopodiaceae	Climbing Saltbush	N	F	P	13	0.22
# *Einadia nutans* subsp. *nutans*	Einnun	Chenopodiaceae	Climbing Saltbush	N	F	P	16	0.29
Einadia polygonoides	Einpol	Chenopodiaceae	Knotweed Goosefoot	N	F	P,A	23	0.33
Eleocharis pallens	Elepal	Cyperaceae	Pale Spikerush	N	GR	P	15	0.35

Species	Code	Family	Common name	Origin	Growth form	Life cycle	% Freq ($n = 184$)	CA score ($n = 184$)
# *Elymus* species A	ElyspA	Poaceae	Wheatgrass	N	G	P	0	0.00
# *Elymus* species B	ElyspB	Poaceae	Wheatgrass	N	G	P	5	0.10
Enchylaena tomentosa	Enctom	Chenopodiaceae	Ruby Saltbush	N	SS	P	4	0.07
Enneapogon gracilis	Enngra	Poaceae	Slender Nineawn	N	G	A,P	3	0.05
# *Enneapogon nigricans*	Ennnig	Poaceae	Niggerheads	N	G	P	1	0.02
Enteropogon acicularis	Entaci	Poaceae	Large Windmill Grass	N	G	P	73	1.72
Eragrostis alveiformis	Eraalv	Poaceae	Granite Lovegrass	N	G	P	9	0.16
Eragrostis benthamii	Eraben	Poaceae	Lovegrass	N	G	P	1	0.01
Eragrostis curvula	Eracur	Poaceae	African Lovegrass	I	G	P	1	0.01
# *Eragrostis falcata*	Erafal	Poaceae	Sickle Lovegrass	N	G	P	1	0.03
Eragrostis lacunaria	Eralac	Poaceae	Purple Lovegrass	N	G	P	1	0.01
Eragrostis leptocarpa	Eralep	Poaceae	Drooping Lovegrass	N	G	S,A	1	0.02
# *Eragrostis leptostachya*	Eralet	Poaceae	Paddock Lovegrass	N	G	P	0	0.00
# *Eragrostis microcarpa*	Eramic	Poaceae	Lovegrass	N	G	P	0	0.00
Eragrostis parviflora	Erapar	Poaceae	Weeping Lovegrass	N	G	A	30	0.57
Eragrostis setifolia	Eraset	Poaceae	Neverfail	N	G	P	4	0.08
Eremophila bignoniiflora	Erebig	Myoporaceae	Eurah	N	S	P	1	0.01
Eremophila debilis	Eredeb	Myoporaceae	Winter Apple	N	SS	P	8	0.11
Eremophila maculata	Eremac	Myoporaceae	Spotted Fuchsia	N	S	P	2	0.03
Eremophila mitchellii	Eremit	Myoporaceae	False Sandalwood	N	T	P	0	0.00
# *Eriochloa australiensis*	Eriaus	Poaceae	Spring Grass	N	G	A	1	0.01
Eriochloa crebra	Ericre	Poaceae	Cup Grass	N	G	P	34	0.69
Eriochloa procera	Eripro	Poaceae	Spring Grass	N	G	P	1	0.02
# *Eriochloa pseudoacrotricha*	Eripse	Poaceae	Early Spring Grass	N	G	S,A	16	0.30
Erodium crinitum	Erocri	Geraniaceae	Blue Storksbill	N	F	A	10	0.15
# *Eryngium plantagineum*	Erypla	Apiaceae	Long Eryngium	N	F	A	7	0.11
Eucalyptus camaldulensis	Euccam	Myrtaceae	River Red Gum	N	T	P	1	0.01
Eucalyptus coolabah	Euccoo	Myrtaceae	Coolibah	N	T	P	2	0.02
Eucalyptus largiflorens	Euclar	Myrtaceae	Black Box	N	T	P	1	0.01
Eucalyptus melanophloia	Eucmel	Myrtaceae	Silver-leaved Ironbark	N	T	P	1	0.01
Eucalyptus populnea subsp. *bimbil*	Eucpop	Myrtaceae	Bimble Box	N	T	P	3	0.03

Species	**Code**	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**	**% Freq ($n = 184$)**	**CA score ($n = 184$)**
Euchiton sphaericus	Eucsph	Asteraceae	Cudweed	N	F	A	10	0.17
Eulalia aurea	Eulaur	Poaceae	Silky Browntop	N	G	P	11	0.26
Euphorbia planiticola	Euppla	Euphorbiaceae	Plains Spurge	N	F	A	4	0.06
# *Fallopia convolvulus*	Falcon	Polygonaceae	Black Bindweed	I	F	A	1	0.01
Fimbristylis dichotoma	Fimdic	Cyperaceae	Common Fringe Rush	N	GR	P	8	0.17
Flindersia maculosa	Flimac	Rutaceae	Leopardwood	N	T	P	1	0.01
Geijera parviflora	Geipar	Rutaceae	Wilga	N	T	P	1	0.01
Geranium solanderi var. *solanderi*	Gersol	Geraniaceae	Native Geranium	N	F	P	2	0.03
Glycine latifolia	Glylat	Fabaceae	Glycine	N	F	P	5	0.11
Glycine tabacina	Glytab	Fabaceae	Variable Glycine	N	F	P	7	0.11
Gomphrena celosioides	Gomcel	Amaranthaceae	Gomphrena Weed	I	F	A	3	0.04
Goodenia fascicularis	Goofas	Goodeniaceae	Silky Goodenia	N	F	P	44	0.79
# *Goodenia glauca*	Googla	Goodeniaceae	Pale Goodenia	N	F	P	1	0.01
Haloragis aspera	Halasp	Haloragaceae	Rough Raspwort	N	F	A,P	1	0.02
Haloragis glauca forma *glauca*	Halgla	Haloragaceae	Grey Raspwort	N	F	A,P	1	0.01
# *Haloragis heterophylla*	Halhet	Haloragaceae	Variable Raspwort	N	F	A,P	2	0.03
Hedypnois rhagadioloides subsp. *cretica*	Hedrha	Asteraceae	Cretan Weed	I	F	A	4	0.09
Helianthus annuus	Helann	Asteraceae	Common Sunflower	I	F	A	1	0.01
Heliotropium amplexicaule	Helamp	Boraginaceae	Blue Heliotrope	I	F	P	1	0.01
Hibiscus brachysiphonius	Hibbra	Malvaceae	Low Hibiscus	N	F	P	2	0.03
Hibiscus trionum	Hibtri	Malvaceae	Bladder Ketmia	N	F	A	14	0.24
Hypochaeris glabra	Hypgla	Asteraceae	Smooth Catsear	I	F	A	1	0.01
Hypochaeris radicata	Hyprad	Asteraceae	Flatweed	I	F	P	1	0.02
# *Hypoxis hygrometrica* var. *hygrometrica*	Hyphyg	Hypoxidaceae	Golden Weather-grass	N	GR	P	2	0.03
Ipomoea lonchophylla	Ipolon	Convolvulaceae	Common Cow-vine	N	F	A	11	0.22
Iseilema membranaceum	Isemem	Poaceae	Small Flinders Grass	N	G	A	15	0.26
# *Jasminum suavissimum*	Jassua	Oleaceae	Jasmine	N	SS	P	1	0.01
Juncus aridicola	Junari	Juncaceae	Rush	N	GR	P	4	0.09
Junsus usitatus	Junusi	Juncaceae	Common Rush	N	GR	P	22	0.34
Lachnagrostis filiformis	Lacfil	Poaceae	Blown Grass	N	G	A	0	0.00
Lactuca saligna	Lacsal	Asteraceae	Willow-leaved Lettuce	I	F	A	7	0.13

Species	**Code**	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**	**% Freq ($n = 184$)**	**CA score ($n = 184$)**
# *Lactuca serriola*	Lacser	Asteraceae	Prickly Lettuce	I	F	A	2	0.03
Lawrencia squamata	Lawsqu	Malvaceae	Thorny Fan-leaf	N	S	P	0	0.00
Leiocarpa brevicompta	Leibre	Asteraceae	Plains Plover-daisy	N	SS	A	10	0.20
Leiocarpa leptolepis	Leilep	Asteraceae	Stalked Plover-daisy	N	SS	P	3	0.05
Leiocarpa panaetioides	Leipan	Asteraceae	Woolly Buttons	N	SS	P	1	0.01
Leiocarpa tomentosa	Leitom	Asteraceae	Woolly Plover-daisy	N	SS	P	1	0.01
Leiocarpa websteri	Leiweb	Asteraceae	Plover-daisy	N	SS	P	40	0.67
# *Lepidium africanum*	Lepafr	Brassicaceae	Peppercress	I	F	A	1	0.01
Lepidium bonariense	Lepbon	Brassicaceae	Cut-leaf Peppercress	I	F	A	2	0.01
Lepidium fasciculatum	Lepfas	Brassicaceae	Bundled Peppercress	N	F	A	1	0.01
Lepidium pseudohyssopifolium	Leppse	Brassicaceae	Peppercress	N	F	A	4	0.07
Leptochloa digitata	Lepdig	Poaceae	Umbrella Canegrass	N	G	P	4	0.05
Leptochloa divaricatissima	Lepdiv	Poaceae	Canegrass	N	G	P	34	0.67
# *Lolium perenne*	Lolper	Poaceae	Perennial Ryegrass	I	G	A	0	0.00
# *Lomandra multiflora*	Lommul	Lomandraceae	Many-flowered Mat-rush	N	GR	P	0	0.00
# *Lotus cruentus*	Lotcru	Fabaceae	Red-flowered Lotus	N	F	P	1	0.01
Lycium ferocissimum	Lycfer	Solanaceae	African Boxthorn	I	S	P	5	0.05
Lysiana exocarpi subsp. *exocarpi*	Lysexo	Loranthaceae	Harlequin Mistletoe	N	S	P	0	0.00
Maireana aphylla	Maiaph	Chenopodiaceae	Cottonbush	N	SS	P	10	0.17
Maireana coronata	Maicor	Chenopodiaceae	Maireana	N	F	P	1	0.01
Maireana decalvans	Maidec	Chenopodiaceae	Black Cottonbush	N	SS	P	15	0.25
Maireana microphylla	Maimic	Chenopodiaceae	Eastern Cottonbush	N	SS	P	8	0.08
# *Malva parviflora*	Malpar	Malvaceae	Small-flowered Mallow	I	F	A	3	0.05
Malvastrum americanum	Malame	Malvaceae	Spiked Malvastrum	I	F	A	43	0.77
Marrubium vulgare	Marvul	Lamiaceae	Horehound	I	F	P	1	0.01
Marsilea drummondii	Mardru	Marsileaceae	Common Nardoo	N	O	P	29	0.53
Medicago laciniata	Medlac	Fabaceae	Cut-leaved Medic	I	F	A	2	0.04
Medicago minima	Medmin	Fabaceae	Woolly Burr Medic	I	F	A	3	0.05
# *Medicago orbicularis*	Medorb	Fabaceae	Button Medic	I	F	A	1	0.02
Medicago polymorpha	Medpol	Fabaceae	Burr Medic	I	F	A	36	0.74
Medicago sativa	Medsat	Fabaceae	Lucerne	I	F	P	1	0.01

Species	Code	Family	Common name	Origin	Growth form	Life cycle	% Freq ($n = 184$)	CA score ($n = 184$)
# *Medicago scutellata*	Medscu	Fabaceae	Snail Medic	I	F	A	2	0.04
Medicago truncatula	Medtru	Fabaceae	Barrel Medic	I	F	A	9	0.18
Melinis repens	Melrep	Poaceae	Red Natal Grass	I	G	A	1	0.01
# *Mentha satureioides*	Mensat	Lamiaceae	Native Pennyroyal	N	F	P	4	0.07
Mimulus gracilis	Mimgra	Scrophulariaceae	Slender Monkey-flower	N	F	P,A	4	0.06
Minuria integerrima	Minint	Asteraceae	Smooth Minuria	N	F	P	16	0.26
Muehlenbeckia florulenta	Mueflo	Polygonaceae	Lignum	N	S	P	3	0.04
Myoporum montanum	Myomon	Myoporaceae	Western Boobialla	N	S	P	2	0.02
Myoporum platycarpum	Myopla	Myoporaceae	Sugarwood	N	S	P	1	0.01
# *Neptunia dimorphantha*	Nepdim	Fabaceae	Sensitive Plant	N	F	P	1	0.01
Neptunia gracilis forma *gracilis*	Nepgra	Fabaceae	Sensitive Plant	N	F	P	57	1.04
# *Nicotiana velutina*	Nicvel	Solanaceae	Velvet Tobacco	N	F	A	1	0.01
Opuntia stricta	Opustr	Cactaceae	Prickly Pear	I	SS	P	5	0.07
Oxalis perennans	Oxaper	Oxalidaceae	Wood Sorrel	N	F	P	48	0.88
# *Panicum antidotale*	Panant	Poaceae	Giant Panic Grass	I	G	P	1	0.02
Panicum buncei	Panbun	Poaceae	Native Panic	N	G	P	18	0.32
# *Panicum coloratum* var. *coloratum*	Pancoc	Poaceae	Coolah Grass	I	G	P	2	0.05
Panicum coloratum var. *makarikariense*	Pancom	Poaceae	Bambatsi Panic	I	G	P	2	0.03
Panicum decompositum	Pandec	Poaceae	Native Millet	N	G	P	75	1.54
Panicum effusum	Paneff	Poaceae	Hairy Panic	N	G	P	1	0.01
Panicum laevinode	Panlae	Poaceae	Pepper Grass	N	G	A	1	0.01
Panicum maximum var. *trichoglume*	Panmat	Poaceae	Green Panic	I	G	P	1	0.01
Panicum queenslandicum var. *queenslandicum*	Panque	Poaceae	Yadbila Grass	N	G	P	17	0.29
Paspalidium aversum	Pasave	Poaceae	Bent Summer-grass	N	G	P	2	0.03
Paspalidium constrictum	Pascon	Poaceae	Knottybutt Grass	N	G	P	14	0.26
Paspalidium distans	Pasdis	Poaceae	Paspalidium	N	G	P	1	0.02
Paspalidium globoideum	Pasglo	Poaceae	Shotgrass	N	G	P	15	0.25
# *Paspalidium gracile*	Pasgra	Poaceae	Slender Panic	N	G	P	1	0.01
Paspalidium jubiflorum	Pasjub	Poaceae	Warrego Grass	N	G	P	11	0.29
Paspalum dilatatum	Pasdil	Poaceae	Paspalum	I	G	P	1	0.02
Phalaris paradoxa	Phapar	Poaceae	Paradoxa Grass	I	G	A	3	0.04

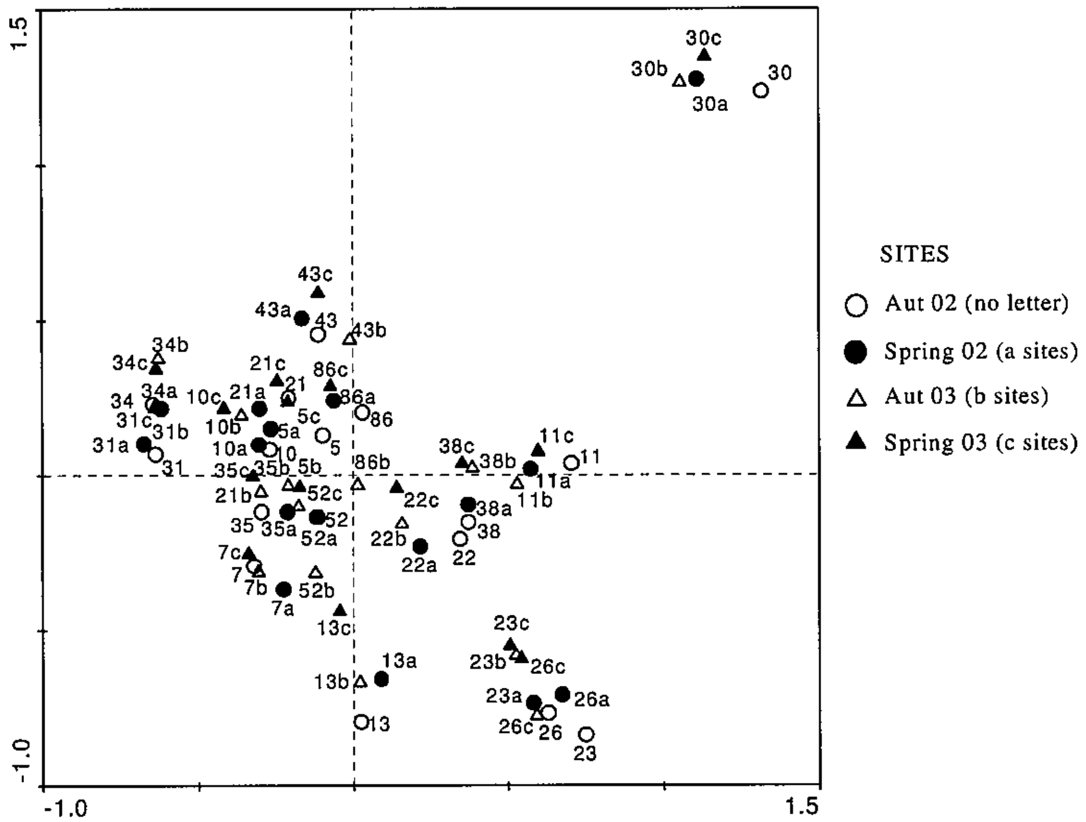
Species	**Code**	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**	**% Freq ($n = 184$)**	**CA score ($n = 184$)**
Phyla canescens	Phycan	Verbenaceae	Lippia	I	F	P	6	0.13
♣ *Phyllanthus maderaspatensis*	Phymad	Euphorbiaceae	Spurge	N	F	P	1	0.01
Phyllanthus virgatus	Phyvir	Euphorbiaceae	Spurge	N	F	P	23	0.41
# *Physalis lanceifolia*	Phylan	Solanaceae	Ground Cherry	I	F	A	7	0.10
Physalis virginiana	Phyvir	Solanaceae	Perennial Ground Cherry	I	F	P	2	0.03
# *Picris hieracioides*	Pichie	Asteraceae	Hawkweed Picris	I	F	A	1	0.01
Pimelea microcephala subsp. *microcephala*	Pimmic	Thymelaeaceae	Shrubby Rice-flower	N	S	P	2	0.04
Pittosporum phylliraeoides	Pitphy	Pittosporaceae	Weeping Pittosporum	N	T	P	0	0.00
Plantago cunninghamii	Placun	Plantaginaceae	Sago-weed	N	F	A	5	0.10
Plantago debilis	Pladeb	Plantaginaceae	Plantain	N	F	A	1	0.01
# *Podolepis muelleri*	Podmue	Asteraceae	Small Copper-wire Daisy	N	F	A	0	0.00
Polygonum arenastrum	Polare	Polygonaceae	Wireweed	I	F	P	1	0.01
Polygonum aviculare	Polavi	Polygonaceae	Wireweed	I	F	P	6	0.11
Polymeria longifolia	Pollon	Convolvulaceae	Clumped Bindweed	N	F	P	3	0.06
Polymeria pusilla	Polpus	Convolvulaceae	Bindweed	N	F	P	11	0.20
Portulaca oleracea	Porole	Portulacaceae	Pigweed	N	F	A	49	0.85
Pratia concolor	Pracon	Lobeliaceae	Poison Pratia	N	F	P	13	0.24
Ptilotus semilanatus	Ptisem	Amaranthaceae	Ptilotus	N	F	P	11	0.19
Pycnosorus globosus	Pynglo	Asteraceae	Pale Billy-buttons	N	F	A	19	0.32
Rapistrum rugosum	Raprug	Brassicaceae	Turnip Weed	I	F	A	50	0.97
Rhagodia spinescens	Rhaspi	Chenopodiaceae	Thorny Saltbush	N	S	P	16	0.26
# *Rhodanthe diffusa*	Rhodif	Asteraceae	Ascending Sunray	N	F	A	0	0.00
Rhynchosia minima	Rhymin	Fabaceae	Rhyncho	N	F	P	21	0.40
Rostellularia adscendens subsp. *adscendens*	Rosads	Acanthaceae	Pink Tongues	N	F	P	4	0.06
Rumex brownii	Rumbro	Polygonaceae	Swamp Dock	N	F	P	11	0.17
Rumex crispus	Rumcri	Polygonaceae	Curled Dock	I	F	P	2	0.03
Rumex crystallinus	Rumcry	Polygonaceae	Shiny Dock	N	F	A	2	0.03
Rumex tenax	Rumten	Polygonaceae	Shiny Dock	N	F	P	8	0.11
Salsola kali var. *kali*	Salkal	Chenopodiaceae	Buckbush	N	SS	A	11	0.16
Salvia reflexa	Salref	Lamiaceae	Mintweed	I	F	A	2	0.04
Schkuhria pinnata var. *abrotanoides*	Schpin	Asteraceae	Dwarf Marigold	I	F	A	1	0.01

Species	**Code**	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**	**% Freq ($n = 184$)**	**CA score ($n = 184$)**
Sclerolaena anisacanthoides	Sclani	Chenopodiaceae	Yellow Burr	N	F	P	4	0.07
Sclerolaena birchii	Sclbir	Chenopodiaceae	Galvanized Burr	N	SS	P	5	0.06
Sclerolaena calcarata	Sclcal	Chenopodiaceae	Redburr	N	F	S,P	2	0.02
Sclerolaena limbata	Scllim	Chenopodiaceae	Pearl Copperburr	N	F	P	1	0.03
Sclerolaena longicuspis	Scllon	Chenopodiaceae	Long-spined Poverty Bush	N	SS	P	1	0.01
Sclerolaena muricata var. *muricata*	Sclmum	Chenopodiaceae	Black Rolypoly	N	SS	P	49	0.82
Sclerolaena muricata var. *semiglabra*	Sclmus	Chenopodiaceae	Dark Rolypoly	N	SS	P	1	0.01
Sclerolaena muricata var. *villosa*	Sclmuv	Chenopodiaceae	Grey Rolypoly	N	SS	P	60	1.03
Sclerolaena stelligera	Sclste	Chenopodiaceae	Star Copperburr	N	F	S,P	4	0.07
Sclerolaena tricuspis	Scltri	Chenopodiaceae	Giant Redburr	N	SS	P	1	0.02
# Senecio daltonii	Sendal	Asteraceae	Groundsel	N	F	P	1	0.01
Sesbania cannabina var. *cannabina*	Sescan	Fabaceae	Sesbania Pea	N	SS	A	0	0.00
# Setaria incrassata	Setinc	Poaceae	Purple Pigeon Grass	I	G	P	2	0.05
Sida corrugata	Sidcor	Malvaceae	Corrugated Sida	N	F	P	2	0.03
Sida cunninghamii	Sidcun	Malvaceae	Ridge Sida	N	F	P	8	0.10
# Sida filiformis	Sidfil	Malvaceae	Fine Sida	N	SS	P	1	0.01
Sida rhombifolia	Sidrho	Malvaceae	Paddy's Lucerne	I	SS	P	1	0.01
Sida spinosa	Sidspi	Malvaceae	Sida	N	SS	P	6	0.10
Sida subspicata	Sidsub	Malvaceae	Spiked Sida	N	SS	P	2	0.03
Sida trichopoda	Sidtri	Malvaceae	High Sida	N	F	P	55	0.97
Sigesbeckia australiensis	Sigaus	Asteraceae	Pale Indian Weed	N	F	A	0	0.00
# Sigesbeckia orientalis	Sigori	Asteraceae	Indian Weed	N	F	A	1	0.01
Silybum marianum	Silmar	Asteraceae	Variegated Thistle	I	F	A	3	0.05
Solanum esuriale	Solesu	Solanaceae	Quena	N	F	P	63	1.20
Solanum nigrum	Solnig	Solanaceae	Black-berry Nightshade	I	F	A	0	0.00
# Solenogyne bellioides	Solbel	Asteraceae	Solenogyne	N	F	P	1	0.02
Sonchus oleraceus	Sonole	Asteraceae	Common Sowthistle	I	F	A	22	0.39
Sorghum bicolor	Sorbic	Poaceae	Cultivated Sorghum	I	G	A	1	0.01
Sorghum halepense	Sorhal	Poaceae	Johnson Grass	I	G	S,P	2	0.03
Sporobolus actinocladus	Spoact	Poaceae	Katoora Grass	N	G	S,P	2	0.05
Sporobolus caroli	Spocar	Poaceae	Fairy Grass	N	G	A	33	0.62

Species	Code	Family	Common name	Origin	Growth form	Life cycle	% Freq ($n = 184$)	CA score ($n = 184$)
# Sporobolus contiguous	Spocon	Poaceae	Sporobolus	N	G	P	1	0.01
Sporobolus creber	Spocre	Poaceae	Slender Rat's Tail Grass	N	G	P	3	0.08
Sporobolus mitchellii	Spomit	Poaceae	Rat's Tail Couch	N	G	P	9	0.21
# Stachys arvensis	Staaru	Lamiaceae	Stagger Weed	I	F	A	0	0.00
Stemodia glabella	Stegla	Scrophulariaceae	Stemodia	N	F	P	3	0.05
Swainsona galegifolia	Swagal	Fabaceae	Smooth Darling Pea	N	SS	P	0	0.00
Swainsona greyana	Swagre	Fabaceae	Darling Pea	N	F	P	1	0.01
♣ *Swainsona murrayana*	Swamur	Fabaceae	Slender Darling Pea	N	F	P	1	0.01
Swainsona procumbens	Swapro	Fabaceae	Broughton Pea	N	F	P	0	0.00
# Swainsona queenslandica	Swaque	Fabaceae	Darling Pea	N	SS	P	6	0.08
Swainsona swainsonioides	Swaswa	Fabaceae	Downy Darling Pea	N	F	P	1	0.01
Tetragonia tetragonoides	Tettet	Aizoaceae	New Zealand Spinach	N	F	A	3	0.04
Teucrium racemosum	Teurac	Lamiaceae	Grey Germander	N	F	P	1	0.01
Thellungia advena	Theadv	Poaceae	Coolibah Grass	N	G	P	33	0.61
Themeda avenacea	Theave	Poaceae	Native Oatgrass	N	G	P	8	0.14
Tragus australianus	Traaus	Poaceae	Small Burrgrass	N	G	A	3	0.03
Trianthema triquetra	Tritri	Aizoaceae	Small Hogweed	N	F	A	9	0.14
Tribulus micrococcus	Trimic	Zygophyllaceae	Yellow Vine	N	F	A	20	0.46
Tribulus terrestris	Triter	Zygophyllaceae	Caltrop	I	F	A	8	0.21
Tricoryne elatior	Triela	Anthericaceae	Yellow Autumn-lily	N	GR	P	1	0.01
Tripogon loliiformis	Trilol	Poaceae	Fiveminute Grass	N	G	A	1	0.02
# Urochloa mosambicensis	Uromos	Poaceae	Sabi Grass	I	G	P	1	0.02
Urochloa panicoides	Uropan	Poaceae	Liverseed Grass	I	G	A	23	0.52
Verbena bonariensis	Verbon	Verbenaceae	Purpletop	I	F	P	3	0.05
Verbena gaudichaudii	Vergau	Verbenaceae	Verbena	N	F	P	39	0.71
# Verbena tenuisecta	Verten	Verbenaceae	Mayne's Pest	I	F	P	1	0.01
Vicia monantha	Vicmon	Fabaceae	Spurred Vetch	I	F	A	0	0.00
# Vigna lanceolata var. *lanceolata*	Viglan	Fabaceae	Maloga Bean	N	F	P	1	0.02
Vittadinia cuneata	Vitcun	Asteraceae	Fuzzweed	N	F	A,P	32	0.55
# Vittadinia muelleri	Vitmue	Asteraceae	Vittadinia	N	F	P	1	0.02
Vittadinia pterochaeta	Vitpte	Asteraceae	Rough Fuzzweed	N	F	A	3	0.05

Species	**Code**	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**	**% Freq (n = 184)**	**CA score (n = 184)**
Wahlenbergia communis	Wahcom	Campanulaceae	Tufted Bluebell	N	F	P	27	0.49
Xanthium occidentale	Xanocc	Asteraceae	Noogoora Burr	I	F	A	7	0.11
Xanthium spinosum	Xanspi	Asteraceae	Bathurst Burr	I	F	A	3	0.05
Zaleya galericulata	Zalgal	Aizoaceae	Hogweed	N	F	P,A	1	0.01
Unknown germinants (Asteraceae)							2	0.02
Unknown germinants (other)							3	0.05
Indigofera spp?							1	0.01
Cyperus spp? (germinant)							1	0.02
Lily-like spp (Asphodelaceae or Amaryllidaceae)							1	0.01

APPENDIX 3.3. Ordination (CCA) diagram, for species cover data of the 17 repeatedly surveyed sites in the regional vegetation survey, classified by sampling period. Site numbers labelled on diagram (e.g. sites 7, 7a, 7b and 7c represent the same site, sampled over time).



APPENDIX 3.4a. Species richness at grazed and ungrazed sites on clay soils sampled during the regional vegetation survey. Also shown are the probabilities (from ANOVA, *F* statistic, or the Mann-Whitney test, *U* statistic) associated with a comparison between the two groups of sites.

	Ungrazed (*n* = 18)		Grazed (*n* = 155)			
Species richness	Mean	SE	Mean	SE	Statistic	*P*
Total	34.7	2.32	29.3	0.72	$F = 5.12$	0.025
Native	29.4	2.33	25.2	0.67	$F = 3.45$	0.065
Introduced	5.3	0.59	4.1	0.21	$F = 3.71$	0.056
Forb	17.7	1.12	14.4	0.43	$F = 5.96$	0.016
Grass	11.1	1.07	9.5	0.31	$F = 2.05$	0.154
Graminoid	1.1	0.27	1.3	0.10	$U = 1239$	0.443
Sub-shrub	3.3	0.46	2.5	0.11	$U = 1084$	0.123
Shrub	1.0	0.21	1.0	0.06	$U = 1366$	0.884

APPENDIX 3.4b. Species richness at cultivated and uncultivated sites on clay soils sampled during the regional vegetation survey. Also shown are the probabilities (from ANOVA, *F* statistic, or the Mann-Whitney test, *U* statistic) associated with a comparison between the two groups of sites

	Uncultivated (*n* = 113)		Cultivated (*n* = 58)			
Species richness	Mean	SE	Mean	SE	Statistic	*P*
Total	31.5	0.84	26.5	1.13	$F = 12.59$	<0.001
Native	27.3	0.79	22.2	1.02	$F = 14.77$	<0.001
Introduced	4.2	0.25	4.3	0.33	$F = 0.03$	0.874
Forb	15.5	0.48	13.3	0.71	$F = 7.42$	0.007
Grass	9.9	0.39	9.1	0.49	$F = 1.62$	0.205
Graminoid	1.4	0.11	1.2	0.16	$U = 2992$	0.352
Sub-shrub	3.0	0.14	1.9	0.16	$U = 2066$	<0.001
Shrub	1.2	0.07	0.60	0.10	$U = 1814$	<0.001

APPENDIX 3.4c. Species richness at flooded and not flooded sites on clay soils sampled during the regional vegetation survey. Also shown are the probabilities (from ANOVA, *F* statistic, or the Mann-Whitney test, *U* statistic) associated with a comparison between the two groups of sites

	Not flooded ($n = 88$)		Flooded ($n = 85$)			
Species richness	Mean	SE	Mean	SE	Statistic	*P*
Total	31.6	1.01	28.1	0.93	$F = 5.86$	0.017
Native	26.5	0.96	24.8	0.88	$F = 1.57$	0.213
Introduced	5.1	0.30	3.4	0.24	$F = 20.11$	<0.001
Forb	16.1	0.60	13.4	0.52	$F = 10.17$	0.002
Grass	10.3	0.41	9.0	0.42	$F = 5.42$	0.021
Graminoid	0.9	0.10	1.7	0.13	$U = 2258$	<0.001
Sub-shrub	2.8	0.18	2.4	0.14	$U = 3199$	0.100
Shrub	1.0	0.09	1.0	0.09	$U = 3693$	0.887

APPENDIX 3.5. The effect of repeated cultivation on species richness (mean ± SE (*n*)) at sites sampled during the regional vegetation survey in 2002 and 2003. ANOVA (*F* statistic) was used to test for differences between sites cultivated for >5 years ($n = 42$) and those cultivated for ≤5 years ($n = 20$) for total, native, introduced, forb and grass species richness. The nonparametric Mann-Whitney test (*U* statistic) was used for the variables graminoid, sub-shrub and shrub species richness.

Species richness	Cultivated >5 years	Cultivated ≤5 years	Statistic	*P*
Total	25.1 ± 1.22	28.1 ± 2.18	$F = 1.37$	0.247
Native	20.7 ± 1.12	23.9 ± 1.91	$F = 1.96$	0.167
Introduced	4.4 ± 0.40	4.3 ± 0.58	$F = 0.13$	0.724
Forb	12.3 ± 0.79	14.9 ± 1.28	$F = 2.75$	0.102
Grass	9.0 ± 0.54	8.7 ± 0.92	$F = 0.14$	0.714
Graminoid	1.2 ± 0.20	1.4 ± 0.21	$U = 347.5$	0.278
Sub-shrub	1.8 ± 0.18	2.1 ± 0.31	$U = 382.0$	0.575
Shrub	0.5 ± 0.10	0.8 ± 0.22	$U = 355.5$	0.334

APPENDIX 4.1. All taxa (scientific name, common name and family) recorded during surveys at Kirramingly Nature Reserve. Code refers to labels given in ordination diagrams in the thesis. Also shown are species origin (N, native; I, introduced; U, unknown), growth form (F, forb; G, grass; GR, graminoid; S, shrub; SS, sub-shrub; T, Tree; O, other) and life cycle (P, perennial; A, annual or biennial; S, short-lived perennial). Species percentage frequency in 76 quadrats surveyed between 1998 and 2004 (% Freq); mean frequency score (Mean Freq) per quadrat (i.e. out of 10) and mean cover abundance score (CA score) are also provided. An # before the species name identifies species recorded only in surveys carried out during this research (2001-2004). Species recorded in surveys not carried out by myself are identified by † (1998 only) and ‡ (1999 only).

Species	**Code**	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**	**% Freq**	**Mean Freq**	**CA score**
# *Abutilon oxycarpum*	Abuoxy	Malvaceae	Flannel Weed	N	F	P	7	0.28	0.11
Acacia farnesiana	Acafar	Fabaceae	Mimosa Bush	U	S	P	96	4.62	2.05
Acacia pendula	Acapen	Fabaceae	Weeping Myall	N	T	P	13	0.58	0.34
Acacia stenophylla	Acaste	Fabaceae	River Cooba	N	T	P	11	0.18	0.19
Alectryon oleifolius subsp. *canescens*	Aleole	Sapindaceae	Western Rosewood	N	T	P	3	0.03	0.03
Alternanthera denticulata	Altden	Amaranthaceae	Lesser Joyweed	N	F	A	63	1.76	0.82
Alternanthera nodiflora	Altnod	Amaranthaceae	Common Joyweed	N	F	A	16	0.36	0.20
Amaranthus macrocarpus var. *pallidus*	Amamac	Amaranthaceae	Dwarf Amaranth	N	F	A	9	0.25	0.12
# *Ammannia multiflora*	Ammmul	Lythraceae	Jerry-jerry	N	F	A	1	0.01	0.01
Amyema quandang var. *quandang*	Amyqua	Loranthaceae	Grey Mistletoe	N	O	P	7	0.25	0.09
Aristida latifolia	Arilat	Poaceae	Feathertop Wiregrass	N	G	P	25	0.38	0.30
Aristida leptopoda	Arilep	Poaceae	White Speargrass	N	G	P	93	6.09	2.25
Aristida platychaeta	Aripla	Poaceae	Threeawn Grass	N	G	P	30	1.18	0.47
Asperula cunninghamii	Aspcun	Rubiaceae	Twining Woodruff	N	F	P	47	2.62	0.80
Aster subulatus	Astsub	Asteraceae	Wild Aster	I	F	A	21	0.79	0.32
Astrebla elymoides	Astely	Poaceae	Hoop Mitchell Grass	N	G	P	88	6.53	2.38
Astrebla lappacea	Astlap	Poaceae	Curly Mitchell Grass	N	G	P	53	2.51	1.14
Atalaya hemiglauca	Atahem	Sapindaceae	Whitewood	N	T	P	3	0.16	0.05
Atriplex semibaccata	Atrsem	Chenopodiaceae	Creeping Saltbush	N	SS	P	66	2.82	1.03

Species	**Code**	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**	**% Freq**	**Mean Freq**	**CA score**
‡*Atriplex suberecta*	Atrsub	Chenopodiaceae	Saltbush	N	F	A	9	0.28	0.13
Austrodanthonia bipartita	Ausbip	Poaceae	Wallaby Grass	N	G	P	58	2.25	1.02
Austrostipa aristiglumis	Ausari	Poaceae	Plains Grass	N	G	P	18	0.45	0.28
Avena fatua	Avefat	Poaceae	Wild Oats	I	G	A	9	0.30	0.14
# *Bidens subalternans*	Bidsub	Asteraceae	Greater Beggar's Tick	I	F	P	1	0.01	0.03
Boerhavia dominii	Boedom	Nyctaginaceae	Tarvine	N	F	P	88	6.42	1.66
# *Brachycome ciliaris* var. *ciliaris*	Bracic	Asteraceae	Variable Daisy	N	F	P	14	0.57	0.24
Brachycome ciliaris var. *subintegrifolia*	Bracis	Asteraceae	Variable Daisy	N	F	P	24	1.20	0.40
†*Brassica juncea*	Brajun	Brassicaceae	Indian Mustard	I	F	A	1	0.01	0.01
Bromus cartharticus	Brocar	Poaceae	Prairie Grass	I	G	A	7	0.16	0.11
# *Bulbine bulbosa*	Bulbul	Asphodelaceae	Bulbine Lily	N	GR	P	1	0.01	0.01
Caesia calliantha	Caecal	Anthericaceae	Grass Lily	N	GR	P	4	0.05	0.04
Calotis scabiosifolia var. *scabiosifolia*	Calsca	Asteraceae	Rough Burr-daisy	N	F	P	29	1.12	0.46
Capparis lasiantha	Caplas	Capparaceae	Nepine	N	S	P	9	0.24	0.13
Carex inversa	Carinv	Cyperaceae	Knob Sedge	N	GR	P	4	0.13	0.05
Casuarina cristata	Cascri	Casuarinaceae	Belah	N	T	P	5	0.22	0.21
Centaurea melitensis	Cenmel	Asteraceae	Maltese Cockspur	I	F	A	13	0.45	0.17
# *Centipeda thespidioides*	Centhe	Asteraceae	Desert Sneezeweed	N	F	P	1	0.03	0.03
Chamaesyce drummondii	Chadru	Euphorbiaceae	Caustic weed	N	F	P	74	4.00	1.21
Chloris truncata	Chltru	Poaceae	Windmill Grass	N	G	S,A	91	6.97	1.91
Chloris ventricosa	Chlven	Poaceae	Tall Chloris	N	G	P	16	0.87	0.30
Cirsium vulgare	Cirvul	Asteraceae	Spear Thistle	I	F	A	18	0.72	0.29
‡*Citrullus lanatus* var. *lanatus*	Citlan	Cucurbitaceae	Wild Melon	I	F	A	1	0.01	0.01
Convolvulus erubescens	Coneru	Convolvulaceae	Australian Bindweed	N	F	P	79	4.59	1.33
Conyza bonariensis	Conbon	Asteraceae	Flaxleaf Fleabane	I	F	A	49	2.93	0.90
Crotalaria dissitiflora subsp. *dissitiflora*	Crodis	Fabaceae	Grey Rattlepod	N	F	P	20	0.49	0.25
Cucumis melo subsp. *agrestis*	Cucmel	Cucurbitaceae	Ulcardo Melon	N	F	A	17	0.45	0.24
Cucumis myriocarpus	Cucmyr	Cucurbitaceae	Paddy Melon	I	F	A	8	0.08	0.08
Cullen tenax	Culten	Fabaceae	Emu-foot	N	F	P	53	2.78	0.87
Cynodon dactylon	Cyndac	Poaceae	Couch	N	G	P	5	0.21	0.11
Cyperus bifax	Cypbif	Cyperaceae	Downs Nutgrass	N	GR	P	64	4.20	1.18

Species	**Code**	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**	**% Freq**	**Mean Freq**	**CA score**
# *Cyperus concinnus*	Cypcon	Cyperaceae	Trim Sedge	N	GR	P	3	0.03	0.03
Cyperus fulvus	Cypful	Cyperaceae	Sticky Sedge	N	GR	P	1	0.05	0.01
Dactyloctenium radulans	Dacrad	Poaceae	Button Grass	N	G	A	20	0.70	0.28
Daucus glochidiatus	Daugla	Apiaceae	Australian Carrot	N	F	A	16	0.99	0.28
Desmodium campylocaulon	Descam	Fabaceae	Creeping Tick-trefoil	N	F	P,A	66	3.79	1.16
Dichanthium sericeum	Dicser	Poaceae	Queensland Bluegrass	N	G	P	91	7.24	2.34
Dichondra repens	Dicrep	Convolvulaceae	Kidney Weed	N	F	P	8	0.25	0.12
Digitaria divaricatissima	Digdiv	Poaceae	Umbrella Grass	N	G	P	70	3.64	1.29
† *Digitaria hystrichoides*	Dighys	Poaceae	Umbrella Grass	N	G	P	13	0.70	0.28
# *Diplachne fusca*	Dipfus	Poaceae	Brown Beetle Grass	N	G	A	1	0.03	0.04
† *Diplachne parviflora*	Dippar	Poaceae	Brown Beetle Grass	N	G	A	1	0.03	0.01
Echinochloa colona	Echcol	Poaceae	Awnless Barnyard Grass	N	G	A	3	0.18	0.07
Eclipta platyglossa	Eclpla	Asteraceae	Yellow Twin-heads	N	F	A	20	0.92	0.32
# *Einadia hastata*	Einhas	Chenopodiaceae	Berry Saltbush	N	SS	P	5	0.13	0.07
Einadia nutans subsp. *linifolia*	Einnul	Chenopodiaceae	Climbing Saltbush	N	F	P	67	3.14	1.20
Einadia polygonoides	Einpol	Chenopodiaceae	Knotweed Goosefoot	N	F	P,A	25	0.87	0.38
Eleocharis pallens	Elepal	Cyperaceae	Pale Spikerush	N	GR	P	13	0.92	0.36
Enchylaena tomentosa	Enctom	Chenopodiaceae	Ruby Saltbush	N	SS	P	5	0.13	0.07
Enneapogon gracilis	Enngra	Poaceae	Slender Nineawn	N	G	A,P	11	0.30	0.18
Enteropogon acicularis	Entaci	Poaceae	Large Windmill Grass	N	G	P	79	5.64	1.78
† *Eragrostis cilianensis*	Eracil	Poaceae	Stinkgrass	I	G	A	1	0.01	0.01
Eragrostis leptocarpa	Eralep	Poaceae	Drooping Lovegrass	N	G	A,P	5	0.09	0.05
Eragrostis parviflora	Erapar	Poaceae	Weeping Lovegrass	N	G	A	39	1.37	0.57
Eremophila debilis	Eredeb	Myoporaceae	Winter Apple	N	SS	P	32	0.62	0.39
Eremophila mitchellii	Eremit	Myoporaceae	False Sandalwood	N	T	P	3	0.16	0.08
Eriochloa crebra	Ericre	Poaceae	Cup Grass	N	G	P	8	0.36	0.19
† *Eriochloa procera*	Eripro	Poaceae	Spring Grass	N	G	P	1	0.09	0.04
Eriochloa pseudoacrotricha	Eripse	Poaceae	Early Spring Grass	N	G	A,P	87	7.04	2.03
Eryngium plantagineum	Erypla	Apiaceae	Long Eryngium	N	F	A	25	0.83	0.37
Eucalyptus coolabah subsp. *excerata*	Euccoo	Myrtaceae	Coolibah	N	T	P	0	0.00	0.00
Euchiton sphaericus	Eucsph	Asteraceae	Cudweed	N	F	A	33	1.53	0.58

Species	Code	Family	Common name	Origin	Growth form	Life cycle	% Freq	Mean Freq	CA score
Eulalia aurea	Eulaur	Poaceae	Silky Browntop	N	G	P	38	1.57	0.63
Fimbristylis dichotoma	Fimdic	Cyperaceae	Common Fringe Rush	N	GR	P	3	0.05	0.04
†*Frankenia serpyllifolia*	Fraser	Frankeniaceae	Bristly Sea-heath	N	SS	P	4	0.12	0.07
# *Geranium solanderi* var. *solanderi*	Gersol	Geraniaceae	Native Geranium	N	F	P	4	0.14	0.07
Glycine latifolia	Glylat	Fabaceae	Glycine	N	F	P	24	1.26	0.38
# *Glycine tabacina*	Glytab	Fabaceae	Variable Glycine	N	F	P	3	0.11	0.04
# *Gomphrena celosioides*	Gomcel	Amaranthaceae	Gomphrena Weed	I	F	A	3	0.03	0.03
Goodenia fascicularis	Goofas	Goodeniaceae	Silky Goodenia	N	F	P	66	4.14	1.17
†*Goodenia heteromera*	Goohet	Goodeniaceae	Spreading Goodenia	N	F	P,A	3	0.08	0.03
Haloragis aspera	Halasp	Haloragaceae	Rough Raspwort	N	F	A,P	34	1.74	0.59
‡*Haloragis glauca*	Halgla	Haloragaceae	Grey Raspwort	N	F	P	1	0.01	0.01
Hedypnois rhagadioloides	Hedrha	Asteraceae	Cretan Weed	I	F	A	17	1.43	0.32
Hibiscus trionum	Hibtri	Malvaceae	Bladder Ketmia	N	F	A	13	0.32	0.17
‡*Hordeum leporinum*	Horlep	Poaceae	Barley Grass	I	G	A	4	0.11	0.05
# *Ipomoea lonchophylla*	Ipolon	Convolvulaceae	Common Cow-vine	N	F	A	4	0.13	0.05
Iseilema membranaceum	Isemem	Poaceae	Small Flinders Grass	N	G	A	20	0.62	0.30
Juncus aridicola	Junari	Juncaceae	Rush	N	GR	P	11	0.24	0.13
Juncus usitatus	Junusi	Juncaceae	Common Rush	N	GR	P	28	0.74	0.38
# *Lachnagrostis filiformis*	Lacfil	Poaceae	Blown Grass	N	G	A	3	0.05	0.04
‡*Lactuca serriola*	Lacser	Asteraceae	Prickly Lettuce	I	F	A	7	0.28	0.09
Leiocarpa panaetioides / tomentosa	Leitom	Asteraceae	Woolly Plover-daisy	N	SS	P	37	1.28	0.61
Leiocarpa websteri	Leiweb	Asteraceae	Plover-daisy	N	SS	P	76	2.91	1.20
# *Lepidium bonariense*	Lepbon	Brassicaceae	Cut-leaf Peppercress	I	F	A	4	0.08	0.05
Leptochloa digitata	Lepdig	Poaceae	Umbrella Canegrass	N	G	P	5	0.11	0.10
Leptochloa divaricatissima	Lepdiv	Poaceae	Canegrass	N	G	P	36	1.43	0.64
# *Linum marginale*	Linmar	Linaceae	Native Flax	N	F	P	4	0.36	0.09
‡*Lomandra multiflora*	Lommul	Lomandraceae	Many-flowered Mat-rush	N	GR	P	1	0.01	0.01
Lycium ferocissimum	Lycfer	Solanaceae	African Boxthorn	I	S	P	9	0.24	0.13
Maireana aphylla	Maiaph	Chenopodiaceae	Cottonbush	N	SS	P	61	1.25	0.76
Maireana decalvens	Maidec	Chenopodiaceae	Black Cottonbush	N	SS	P	34	1.13	0.46
Maireana microphylla	Maimic	Chenopodiaceae	Eastern Cottonbush	N	SS	P	55	1.14	0.68

Species	Code	Family	Common name	Origin	Growth form	Life cycle	% Freq	Mean Freq	CA score
Malvastrum americanum	Malame	Malvaceae	Spiked Malvastrum	I	F	A	64	2.78	1.03
Marrubium vulgare	Marvul	Lamiaceae	Horehound	I	F	P	3	0.03	0.03
Marsilea drummondii	Mardru	Marsileaceae	Common Nardoo	N	O	P	20	0.99	0.36
Medicago polymorpha	Medpol	Fabaceae	Burr Medic	I	F	A	22	0.91	0.32
Medicago truncatula	Medtru	Fabaceae	Barrel Medic	I	F	A	5	0.30	0.08
Mimulus gracilis	Mimgra	Scrophulariaceae	Slender Monkey-flower	N	F	P,A	4	0.04	0.04
Minuria integerrima	Minint	Asteraceae	Smooth Minuria	N	F	P	18	0.47	0.24
# Myoporum montanum	Myomon	Myoporaceae	Western Boobialla	N	S	P	7	0.09	0.08
Neptunia gracilis	Nepgra	Fabaceae	Sensitive Plant	N	F	P	82	6.42	1.59
# Nicotiana megalosiphon	Nicmeg	Solanaceae	Long-flowered Tobacco	N	F	A	1	0.01	0.01
Opuntia stricta	Opustr	Cactaceae	Prickly Pear	I	SS	P	11	0.24	0.14
Oxalis perennans	Oxaper	Oxalidaceae	Wood Sorrel	N	F	P	83	5.37	1.43
Panicum buncei	Panbun	Poaceae	Native Panic	N	G	P	58	2.74	1.05
Panicum decompositum	Pandec	Poaceae	Native Millet	N	G	P	88	6.51	2.07
Panicum effusum	Paneff	Poaceae	Hairy Panic	N	G	P	5	0.24	0.05
Panicum queenslandicum var. *queenslandicum*	Panque	Poaceae	Yadbila Grass	N	G	P	62	3.74	1.24
Paspalidium aversum	Pasave	Poaceae	Bent Summer-grass	N	G	P	4	0.16	0.09
Paspalidium constrictum	Pascon	Poaceae	Knottybutt Grass	N	G	P	16	0.62	0.30
Paspalidium globoideum	Pasglo	Poaceae	Shotgrass	N	G	P	34	1.03	0.54
Paspalidium jubiflorum	Pasjub	Poaceae	Warrego Grass	N	G	P	7	0.47	0.17
‡Phalaris aquatica	Phaaqu	Poaceae	Phalaris	I	G	P	1	0.04	0.03
Phalaris paradoxa	Phapar	Poaceae	Paradoxa Grass	I	G	A	9	0.45	0.17
Phyllanthus virgatus	Phyvir	Euphorbiaceae	Spurge	N	F	P	76	4.96	1.34
# Physalis lanceifolia	Phylan	Solanaceae	Ground Cherry	I	F	A	13	0.53	0.20
Physalis virginiana	Phyvir2	Solanaceae	Perennial Ground Cherry	I	F	P	9	0.38	0.14
# Picris hieracioides	Pichie	Asteraceae	Hawkweed Picris	I	F	A	3	0.14	0.05
Pimelea linifolia	Pimlin	Thymelaeaceae	Slender Rice-flower	N	S	P	14	0.24	0.16
Pimelea microcephala	Pimmic	Thymelaeaceae	Shrubby Rice-flower	N	S	P	11	0.28	0.11
Pimelea neo-anglica	Pimneo	Thymelaeaceae	Poison Pimelea	N	S	P	3	0.03	0.03
Pittosporum phylliraeoides	Pitphy	Pittosporaceae	Weeping Pittosporum	N	T	P	3	0.13	0.08
Plantago cunninghamii	Placun	Plantaginaceae	Sago-weed	N	F	A	11	0.30	0.14

Species	**Code**	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**	**% Freq**	**Mean Freq**	**CA score**
‡*Plantago debilis*	Pladeb	Plantaginaceae	Plantain	N	F	A	4	0.14	0.05
# *Podolepis muelleri*	Podmue	Asteraceae	Small Copper-wire Daisy	N	F	A	7	0.08	0.07
Polymeria pusilla	Polpus	Convolvulaceae	Bindweed	N	F	P	1	0.01	0.01
Portulaca oleracea	Porole	Portulacaceae	Pigweed	N	F	A	68	3.72	1.13
Pratia concolor	Pracon	Lobeliaceae	Poison Pratia	N	F	P	21	0.82	0.33
# *Proboscidea louisianica*	Prolou	Martyniaceae	Purple-flowered Devil's Claw	I	F	A	3	0.07	0.04
Ptilotus semilanatus	Ptisem	Amaranthaceae	Ptilotus	N	F	P	57	2.63	0.89
†*Pycnosorus chrysanthus*	Pycchr	Asteraceae	Golden Billy-buttons	N	F	A	5	0.08	0.07
Pycnosorus globosus	Pycglo	Asteraceae	Pale Billy-buttons	N	F	A	33	0.88	0.43
Rapistrum rugosum	Raprug	Brassicaceae	Turnip Weed	I	F	A	30	2.01	0.61
Rhagodia spinescens	Rhaspi	Chenopodiaceae	Thorny Saltbush	N	S	P	21	0.59	0.30
Rhynchosia minima	Rhymin	Fabaceae	Rhyncho	N	F	P	30	1.57	0.55
Rostellularia adscendens	Rosads	Acanthaceae	Pink Tongues	N	F	P	20	0.96	0.29
Rumex crispus	Rumcri	Polygonaceae	Curled Dock	I	F	P	16	0.28	0.18
Rumex crystallinus	Rumcry	Polygonaceae	Shiny Dock	N	F	A	8	0.11	0.08
Salsola kali var. *kali*	Salkal	Chenopodiaceae	Buckbush	N	F	A	4	0.18	0.07
Salvia reflexa	Salref	Lamiaceae	Mintweed	I	F	A	4	0.14	0.07
# *Sclerolaena anisacanthoides*	Sclani	Chenopodiaceae	Yellow Burr	N	F	P	4	0.25	0.09
# *Sclerolaena birchii*	Sclbir	Chenopodiaceae	Galvanized Burr	N	SS	P	1	0.01	0.01
†*Sclerolaena longicuspis*	Scllon	Chenopodiaceae	Long-spined Poverty Bush	N	SS	P	5	0.26	0.09
Sclerolaena muricata var. *muricata*	Sclmum	Chenopodiaceae	Black Rolypoly	N	SS	P	39	2.43	0.84
Sclerolaena muricata var. *villosa*	Sclmuv	Chenopodiaceae	Grey Rolypoly	N	SS	P	83	5.88	1.69
# *Sclerolaena stelligera*	Sclste	Chenopodiaceae	Star Copperburr	N	F	S,P	3	0.03	0.03
‡*Senecio quadridentatus*	Senqua	Asteraceae	Cotton Fireweed	N	F	P	11	0.46	0.16
Setaria incrassata	Setinc	Poaceae	Purple Pigeon Grass	I	G	P	9	0.20	0.11
Sida cunninghamii	Sidcun	Malvaceae	Ridge Sida	N	F	P	9	0.28	0.13
Sida trichopoda	Sidtri	Malvaceae	High Sida	N	F	P	93	6.42	1.73
# *Silybum marianum*	Silmar	Asteraceae	Variegated Thistle	I	F	A	4	0.18	0.07
Solanum esuriale	Solesu	Solanaceae	Quena	N	F	P	86	4.54	1.50
Solanum nigrum	Solnig	Solanaceae	Black-berry Nightshade	I	F	A	7	0.16	0.09
Sonchus oleraceus	Sonole	Asteraceae	Common Sowthistle	I	F	A	41	2.47	0.72

Species	**Code**	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**	**% Freq**	**Mean Freq**	**CA score**
Sporobolus actinocladus	Spoact	Poaceae	Katoora Grass	N	G	S,P	4	0.04	0.04
Sporobolus caroli	Spocar	Poaceae	Fairy Grass	N	G	A	82	5.86	1.81
‡*Sporobolus creber*	Spocre	Poaceae	Slender Rat's Tail Grass	N	G	P	3	0.05	0.03
Sporobolus mitchellii	Spomit	Poaceae	Rat's Tail Couch	N	G	P	7	0.28	0.14
Stemodia glabella	Stegla	Scrophulariaceae	Stemodia	N	F	P	3	0.05	0.03
†*Swainsona luteola*	Swalut	Fabaceae	Dwarf Darling Pea	N	SS	P	1	0.01	0.01
Swainsona murrayana	Swamur	Fabaceae	Slender Darling Pea	N	F	P	5	0.13	0.07
Swainsona queenslandica	Swaque	Fabaceae	Darling Pea	N	SS	P	36	1.00	0.49
Tetragonia tetragonoides	Tettet	Aizoaceae	New Zealand Spinach	N	F	A	4	0.09	0.07
Thellungia advena	Theadv	Poaceae	Coolibah Grass	N	G	P	71	3.82	1.48
Themeda avenacea	Theave	Poaceae	Native Oatgrass	N	G	P	61	2.08	1.02
Tragus australianus	Traaus	Poaceae	Small Burrgrass	N	G	A	1	0.01	0.01
# Trianthema triquetra	Tritri	Aizoaceae	Small Hogweed	N	F	A	11	0.41	0.17
# Tribulus micrococcus	Trimic	Zygophyllaceae	Yellow Vine	N	F	A	3	0.14	0.04
Urochloa panicoides	Uropan	Poaceae	Liverseed Grass	I	G	A	9	0.49	0.20
Ventilago viminalis	Venvim	Rhamnaceae	Supple Jack	N	T	P	3	0.05	0.03
Verbena gaudichaudii	Vergau	Verbenaceae	Verbena	N	F	P	54	1.30	0.70
Vittadinia cuneata	Vitcun	Asteraceae	Fuzzweed	N	F	A,P	76	4.66	1.38
Wahlenbergia communis	Wahcom	Campanulaceae	Tufted Bluebell	N	F	P	63	3.11	1.05
Xanthium spinosum	Xanspi	Asteraceae	Bathurst Burr	I	F	A	11	0.29	0.14

APPENDIX 4.2. Frequency (Freq, number of occurrences / number of quadrats sampled) and mean frequency score per quadrat (Mean FS, mean number of occurrences in 10 concentric sub-quadrats per 1024-m² quadrat) for each species recorded at all surveys carried out over time at Kirramingly Nature Reserve. An * before the species name denotes introduced species.

Sampling period	Feb-Mar 1998 ($n = 22$)		Nov 1999 ($n = 8$)		Dec 2001 ($n = 6$)		Feb-Mar 2002 ($n = 25$)		Mar 2004 ($n = 15$)	
Species	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS
Abutilon oxycarpum	0	0.0	0	0.0	17	0.5	8	0.6	13	0.3
Acacia farnesiana	91	4.7	100	5.0	100	3.8	96	4.6	100	4.7
Acacia pendula	14	0.5	0	0.0	33	1.7	12	0.5	13	0.6
Acacia stenophylla	9	0.1	0	0.0	33	0.5	8	0.2	13	0.3
Alectryon oleifolius subsp. *canescens*	5	0.0	0	0.0	0	0.0	4	0.0	0	0.0
Alternanthera denticulata	55	1.3	13	0.1	67	2.0	72	2.0	93	2.9
Alternanthera nodiflora	18	0.3	50	1.6	0	0.0	8	0.2	7	0.1
Amaranthus macrocarpus var. *pallidus*	23	0.5	0	0.0	0	0.0	4	0.2	7	0.2
Ammannia multiflora	0	0.0	0	0.0	0	0.0	0	0.0	7	0.1
Amyema quandang var. *quandang*	5	0.2	0	0.0	17	0.8	8	0.3	7	0.1
Aristida latifolia	18	0.5	0	0.0	83	1.0	28	0.4	20	0.3
Aristida leptopoda	86	4.1	100	3.6	100	6.0	92	7.4	100	8.1
Aristida platychaeta	36	1.6	38	0.6	0	0.0	28	1.3	33	1.1
Asperula cunninghamii	36	1.5	63	4.5	50	2.5	48	3.3	53	2.1
**Aster subulatus*	5	0.0	50	0.9	17	0.7	40	1.9	0	0.0
Astrebla elymoides	82	6.0	75	3.6	100	8.2	84	6.2	100	8.7
Astrebla lappacea	50	2.5	0	0.0	17	0.7	64	2.4	80	4.9
Atalaya hemiglauca	5	0.2	0	0.0	0	0.0	4	0.3	0	0.0
Atriplex semibaccata	59	1.7	13	0.3	83	3.7	80	4.0	73	3.5
Atriplex suberecta	0	0.0	88	2.6	0	0.0	0	0.0	0	0.0
Austrodanthonia bipartita	41	2.0	50	1.9	50	1.0	80	3.2	53	1.7
Austrostipa aristiglumis	18	0.3	13	0.3	17	0.5	24	0.7	13	0.3
**Avena fatua*	0	0.0	50	1.6	33	1.5	4	0.0	0	0.0

Sampling period	Feb-Mar 1998 ($n = 22$)		Nov 1999 ($n = 8$)		Dec 2001 ($n = 6$)		Feb-Mar 2002 ($n = 25$)		Mar 2004 ($n = 15$)	
Species	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS
**Bidens subalternans*	0	0.0	0	0.0	0	0.0	4	0.0	0	0.0
Boerhavia dominii	86	5.9	100	6.8	83	6.0	88	7.2	87	6.0
Brachycome ciliaris var. *ciliaris*	0	0.0	0	0.0	50	3.0	8	0.2	40	1.4
Brachycome ciliaris var. *subintegrifolia*	23	1.1	13	0.1	50	2.7	24	1.3	20	1.1
**Brassica juncea*	5	0.0	0	0.0	0	0.0	0	0.0	0	0.0
**Bromus cartharticus*	0	0.0	13	0.1	17	0.3	12	0.4	0	0.0
Bulbine bulbosa	0	0.0	0	0.0	0	0.0	1	0.0	0	0.0
Caesia calliantha	0	0.0	25	0.4	17	0.2	0	0.0	0	0.0
Calotis scabiosifolia var. *scabiosifolia*	0	0.0	25	0.5	33	0.5	40	1.6	53	2.5
Capparis lasiantha	14	0.4	0	0.0	0	0.0	12	0.4	7	0.1
Carex inversa	5	0.2	0	0.0	0	0.0	4	0.1	7	0.3
Casuarina cristata	9	0.4	0	0.0	0	0.0	8	0.4	0	0.0
**Centaurea melitensis*	0	0.0	50	1.4	17	0.2	20	0.9	0	0.0
Centipeda thespidioides	0	0.0	0	0.0	0	0.0	4	0.1	0	0.0
Chamaesyce drummondii	59	2.9	88	5.4	100	4.7	68	4.2	87	4.3
Chloris truncata	86	6.0	100	9.0	100	5.5	88	7.2	100	7.7
Chloris ventricosa	14	0.7	75	5.6	0	0.0	12	0.2	0	0.0
**Cirsium vulgare*	0	0.0	50	1.4	50	2.3	28	1.2	0	0.0
**Citrullus lanatus* var. *lanatus*	0	0.0	13	0.1	0	0.0	0	0.0	0	0.0
Convolvulus erubescens	68	4.3	100	9.4	83	3.7	68	3.7	100	4.3
**Conyza bonariensis*	32	2.2	63	4.6	50	3.2	84	4.6	7	0.1
Crotalaria dissitiflora subsp. *dissitiflora*	14	0.5	38	0.6	17	0.5	12	0.3	33	0.8
Cucumis melo subsp. *agrestis*	27	0.8	0	0.0	0	0.0	12	0.2	33	0.7
**Cucumis myriocarpus*	9	0.1	13	0.1	17	0.2	8	0.1	0	0.0
Cullen tenax	9	0.3	75	6.9	100	3.5	64	3.5	67	2.8
Cynodon dactylon	9	0.3	0	0.0	0	0.0	4	0.2	7	0.2
Cyperus bifax	45	2.5	75	4.4	67	4.2	64	4.9	87	5.5
Cyperus concinnus	0	0.0	0	0.0	17	0.2	0	0.0	7	0.1
Cyperus fulvus	5	0.2	0	0.0	0	0.0	0	0.0	0	0.0

Sampling period	Feb-Mar 1998 ($n = 22$)		Nov 1999 ($n = 8$)		Dec 2001 ($n = 6$)		Feb-Mar 2002 ($n = 25$)		Mar 2004 ($n = 15$)	
Species	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS
Dactyloctenium radulans	23	0.3	0	0.0	0	0.0	4	0.0	60	3.0
Daucus glochidiatus	0	0.0	100	6.5	67	3.8	0	0.0	0	0.0
Desmodium campylocaulon	50	2.6	63	2.5	100	5.7	64	4.0	80	5.2
Dichanthium sericeum	77	5.8	100	6.6	100	8.5	92	7.7	100	8.4
Dichondra repens	5	0.1	0	0.0	17	0.8	12	0.2	7	0.4
Digitaria divaricatissima	45	2.4	75	2.6	67	3.7	76	3.4	93	6.3
Digitaria hystrichoides	0	0.0	13	0.3	0	0.0	0	0.0	0	0.0
Diplachne fusca	0	0.0	0	0.0	0	0.0	0	0.0	7	0.1
Diplachne parviflora	5	0.1	0	0.0	0	0.0	0	0.0	0	0.0
Echinochloa colona	0	0.0	13	0.5	0	0.0	4	0.4	0	0.0
Eclipta platyglossa	0	0.0	38	1.3	0	0.0	32	1.6	27	1.4
Einadia hastata	0	0.0	0	0.0	0	0.0	4	0.1	20	0.5
Einadia nutans subsp. *linifolia*	55	2.1	38	0.9	50	2.8	88	5.0	73	2.9
Einadia polygonoides	0	0.0	88	4.1	17	1.2	20	0.5	40	0.9
Eleocharis pallens	14	1.0	0	0.0	33	3.2	12	0.9	13	0.5
Enchylaena tomentosa	0	0.0	13	0.3	0	0.0	0	0.0	20	0.5
Enneapogon gracilis	18	0.5	0	0.0	0	0.0	12	0.4	7	0.1
Enteropogon acicularis	68	4.5	0	0.0	100	8.0	96	7.0	100	7.1
**Eragrostis cilianensis*	5	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Eragrostis leptocarpa	14	0.2	0	0.0	17	0.3	0	0.0	0	0.0
Eragrostis parviflora	9	0.2	13	0.1	33	1.8	56	1.6	73	3.1
Eremophila debilis	9	0.1	25	0.3	33	0.5	36	0.8	60	1.3
Eremophila mitchellii	5	0.2	0	0.0	0	0.0	4	0.3	0	0.0
Eriochloa crebra	5	0.3	0	0.0	0	0.0	4	0.0	27	1.3
Eriochloa procera	0	0.32	0	0.0	0	0.0	0	0.0	0	0.0
Eriochloa pseudoacrotricha	77	5.9	88	5.9	83	6.7	88	7.6	93	8.5
Eryngium plantagineum	14	0.5	50	2.4	17	0.8	32	1.0	20	0.3
Eucalyptus coolabah subsp. *excerata*	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Euchiton sphaericus	5	0.4	50	3.5	83	2.8	56	2.5	7	0.1

Sampling period	Feb-Mar 1998 (*n* = 22)		Nov 1999 (*n* = 8)		Dec 2001 (*n* = 6)		Feb-Mar 2002 (*n* = 25)		Mar 2004 (*n* = 15)	
Species	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS
Eulalia aurea	23	1.4	38	2.1	50	0.5	40	1.6	53	1.9
Fimbristylis dichotoma	0	0.0	13	0.4	0	0.0	0	0.0	7	0.1
Frankenia serpyllifolia	14	0.4	0	0.0	0	0.0	0	0.0	0	0.0
Geranium solanderi var. *solanderi*	0	0.0	0	0.0	17	1.2	4	0.1	7	0.1
Glycine latifolia	41	2.2	13	0.5	0	0.0	24	1.0	27	1.3
Glycine tabacina	0	0.0	0	0.0	0	0.0	0	0.32	0	0.0
**Gomphrena celosioides*	0	0.0	0	0.0	0	0.0	8	0.1	0	0.0
Goodenia fascicularis	18	0.5	100	9.4	100	5.3	72	4.4	93	5.9
Goodenia heteromera	9	0.3	0	0.0	0	0.0	0	0.0	0	0.0
Haloragis aspera	0	0.0	75	3.4	50	2.3	40	2.0	47	2.7
Haloragis glauca	0	0.0	13	0.1	0	0.0	0	0.0	0	0.0
**Hedypnois rhagadioloides*	0	0.0	100	9.6	83	5.3	0	0.0	0	0.0
Hibiscus trionum	5	0.0	0	0.0	0	0.0	8	0.1	47	1.3
**Hordeum leporinum*	0	0.0	38	1.0	0	0.0	0	0.0	0	0.0
Ipomoea lonchophylla	0	0.0	0	0.0	0	0.0	4	0.0	13	0.6
Iseilema membranaceum	23	0.5	0	0.0	0	0.0	16	0.3	40	1.8
Juncus aridicola (subsecundus)	9	0.1	0	0.0	0	0.0	24	0.6	0	0.0
Juncus usitatus	9	0.1	38	0.5	50	3.0	36	0.9	27	0.5
Lachnagrostis filiformis	0	0.0	0	0.0	17	0.3	4	0.1	0	0.0
**Lactuca serriola*	0	0.0	63	2.6	0	0.0	0	0.0	0	0.0
Leiocarpa panaetioides / tomentosa	0	0.2	0	0.0	0	0.2	0	0.2	0	0.2
Leiocarpa websteri	68	2.9	88	2.4	33	2.3	68	2.9	80	3.5
**Lepidium bonariense*	0	0.0	0	0.0	0	0.0	4	0.1	13	0.3
Leptochloa digitata	5	0.0	0	0.0	0	0.0	8	0.2	7	0.1
Leptochloa divaricatissima	27	1.0	25	0.6	17	0.5	52	2.2	33	1.6
Linum marginale	0	0.0	0	0.0	33	3.2	4	0.3	0	0.0
Lomandra multiflora	0	0.0	13	0.1	0	0.0	0	0.0	0	0.0
**Lycium ferocissimum*	5	0.1	0	0.0	17	0.3	16	0.4	7	0.2
Maireana aphylla	68	1.2	50	1.9	33	0.7	64	1.4	60	0.9

Sampling period	Feb-Mar 1998 ($n = 22$)		Nov 1999 ($n = 8$)		Dec 2001 ($n = 6$)		Feb-Mar 2002 ($n = 25$)		Mar 2004 ($n = 15$)	
Species	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS
Maireana decalvens	36	0.9	0	0.0	33	1.7	44	1.6	33	1.1
Maireana microphylla	55	1.2	38	0.9	50	1.2	52	1.1	73	1.3
**Malvastrum americanum*	59	2.5	63	1.6	50	2.3	64	2.8	80	3.9
**Marrubium vulgare*	5	0.0	0	0.0	0	0.0	4	0.0	0	0.0
Marsilea drummondii	23	1.2	0	0.0	17	0.8	24	1.5	20	0.3
**Medicago truncatula*	0	0.0	38	2.5	17	0.5	0	0.0	0	0.0
**Medicago polymorpha*	5	0.5	50	2.0	100	6.2	8	0.1	27	0.3
Mimulus gracilis	0	0.0	13	0.1	0	0.0	0	0.0	13	0.1
Minuria integerrima	14	0.5	38	0.6	50	1.3	8	0.3	20	0.3
Myoporum montanum	0	0.0	0	0.0	17	0.2	8	0.2	13	0.1
Neptunia gracilis	45	2.4	100	7.6	100	9.7	92	7.6	100	8.5
Nicotiana megalosiphon	0	0.0	0	0.0	0	0.0	0	0.0	7	0.1
**Opuntia stricta*	9	0.2	0	0.0	0	0.0	8	0.2	27	0.5
Oxalis perennans	45	1.6	100	7.5	100	7.3	100	7.8	93	4.9
Panicum buncei	36	2.0	63	1.8	17	0.2	64	3.2	93	4.7
Panicum decompositum	86	6.1	63	2.9	100	7.5	88	6.6	100	8.5
Panicum effusum	14	0.8	0	0.0	17	0.2	0	0.0	0	0.0
Panicum queenslandicum var. *queenslandicum*	32	1.2	88	6.5	83	1.8	64	4.3	80	5.9
Paspalidium aversum	9	0.5	0	0.0	0	0.0	4	0.1	0	0.0
Paspalidium constrictum	27	0.9	0	0.0	17	0.8	16	0.8	7	0.2
Paspalidium globoideum	9	0.1	38	0.6	0	0.0	44	1.6	67	2.1
Paspalidium jubiflorum	9	0.5	0	0.0	0	0.0	8	0.6	7	0.7
**Phalaris aquatica*	0	0.0	13	0.4	0	0.0	0	0.0	0	0.0
**Phalaris paradoxa*	0	0.0	50	2.9	17	0.7	8	0.3	0	0.0
Phyllanthus virgatus	64	3.4	100	4.3	83	5.3	72	5.4	87	6.8
**Physalis lanceifolia*	0	0.0	0	0.0	17	0.7	4	0.0	53	2.3
**Physalis virginiana*	23	1.0	0	0.0	0	0.0	8	0.3	0	0.0
**Picris hieracioides*	0	0.0	0	0.0	0	0.0	8	0.4	0	0.0

Sampling period	Feb-Mar 1998 ($n = 22$)		Nov 1999 ($n = 8$)		Dec 2001 ($n = 6$)		Feb-Mar 2002 ($n = 25$)		Mar 2004 ($n = 15$)	
Species	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS
Pimelea linifolia	14	0.3	25	0.5	17	0.2	16	0.2	0	0.0
Pimelea microcephala	5	0.0	0	0.0	17	0.5	8	0.3	33	0.6
Pimelea neo-anglica	5	0.0	0	0.0	0	0.0	4	0.0	0	0.0
Pittosporum phylliraeoides	5	0.2	0	0.0	0	0.0	4	0.2	0	0.0
Plantago cunninghamii	0	0.0	13	0.9	67	1.3	12	0.3	0	0.0
Plantago debilis	0	0.0	38	1.4	0	0.0	0	0.0	0	0.0
Podolepis muelleri	0	0.0	38	0.5	0	0.0	8	0.1	0	0.0
Polymeria pusilla	5	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Portulaca oleracea	86	4.3	25	0.5	33	2.0	56	2.9	100	6.6
Pratia concolor	5	0.1	50	1.3	17	0.8	24	1.3	27	0.9
**Proboscidea louisianica*	0	0.0	0	0.0	0	0.0	0	0.0	13	0.3
Ptilotus semilanatus	55	2.5	63	3.4	50	2.0	48	2.5	67	2.9
Pycnosorus chrysanthus	9	0.2	0	0.0	17	0.2	4	0.0	0	0.0
Pycnosorus globosus	14	0.2	100	3.1	33	1.7	28	0.8	33	0.5
**Rapistrum rugosum*	0	0.0	63	5.4	67	3.2	48	3.5	13	0.2
Rhagodia spinescens	14	0.4	0	0.0	33	0.8	24	0.8	33	0.9
Rhynchosia minima	23	0.7	0	0.0	50	3.7	28	1.9	47	2.3
Rostellularia adscendens	23	1.1	13	0.3	17	0.3	20	1.1	20	1.1
**Rumex crispus*	23	0.3	0	0.0	50	1.2	16	0.3	0	0.0
Rumex crystallinus	0	0.0	38	0.6	0	0.0	12	0.1	0	0.0
Salsola kali var. *kali*	5	0.1	0	0.0	0	0.0	4	0.2	7	0.4
**Salvia reflexa*	5	0.1	0	0.0	0	0.0	4	0.2	7	0.3
Sclerolaena anisacanthoides	0	0.0	0	0.0	0	0.0	4	0.2	13	1.0
Sclerolaena birchii	0	0.0	0	0.0	0	0.0	4	0.0	0	0.0
Sclerolaena longicuspis	18	0.9	0	0.0	0	0.0	0	0.0	0	0.0
Sclerolaena muricata var. *muricata*	27	2.0	38	2.8	33	2.7	48	2.6	47	2.5
Sclerolaena muricata var. *villosa*	82	6.4	75	5.6	67	5.0	80	6.1	93	5.3
Sclerolaena stelligera	0	0.0	0	0.0	0	0.0	0	0.0	13	0.1
Senecio quadridentatus	0	0.0	100	4.4	0	0.0	0	0.0	0	0.0

Sampling period	Feb-Mar 1998 ($n = 22$)		Nov 1999 ($n = 8$)		Dec 2001 ($n = 6$)		Feb-Mar 2002 ($n = 25$)		Mar 2004 ($n = 15$)	
Species	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS	Freq	Mean FS
**Setaria incrassata*	9	0.4	25	0.4	17	0.2	4	0.0	7	0.1
Sida cunninghamii	0	0.0	13	0.3	17	0.2	20	0.7	0	0.0
Sida trichopoda	91	5.2	100	5.9	100	5.5	88	6.3	100	9.1
**Silybum marianum*	0	0.0	0	0.0	17	1.2	8	0.3	0	0.0
Solanum esuriale	64	2.7	100	5.1	100	5.2	88	4.8	100	6.3
**Solanum nigrum*	0	0.0	25	0.3	17	0.7	8	0.2	0	0.0
**Sonchus oleraceus*	14	0.2	100	8.4	100	8.5	56	2.6	0	0.0
Sporobolus actinocladus	5	0.0	0	0.0	0	0.0	0	0.0	13	0.1
Sporobolus caroli	77	6.6	75	3.6	50	2.7	84	5.9	100	7.1
Sporobolus creber	0	0.0	25	0.5	0	0.0	0	0.0	0	0.0
Sporobolus mitchellii	9	0.5	0	0.0	0	0.0	8	0.4	7	0.1
Stemodia glabella	5	0.1	0	0.0	0	0.0	0	0.0	7	0.1
Swainsona luteola	5	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Swainsona murrayana	0	0.0	13	0.3	50	1.3	0	0.0	0	0.0
Swainsona queenslandica	23	0.6	38	0.5	50	1.0	40	1.5	40	1.0
Tetragonia tetragonoides	5	0.0	0	0.0	0	0.0	8	0.2	0	0.0
Thellungia advena	68	3.5	13	0.6	50	1.7	88	4.8	87	5.1
Themeda avenacea	59	1.9	50	2.3	67	2.3	60	2.1	67	2.2
Tragus australianus	5	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Trianthema triquetra	0	0.0	0	0.0	17	1.5	8	0.2	33	1.1
Tribulus micrococcus	0	0.0	0	0.0	0	0.0	0	0.0	13	0.7
**Urochloa panicoides*	9	0.5	0	0.0	0	0.0	16	0.8	7	0.3
Ventilago viminalis	5	0.0	0	0.0	0	0.0	8	0.1	0	0.0
Verbena gaudichaudii	45	1.2	25	0.3	83	2.0	68	1.8	47	0.9
Vittadinia cuneata	45	2.0	100	6.4	67	4.3	84	5.7	100	5.9
Wahlenbergia communis	50	2.0	88	5.6	67	2.5	56	3.0	80	3.8
**Xanthium spinosum*	9	0.4	13	0.3	0	0.0	8	0.3	20	0.3

APPENDIX 4.3. Frequency (Freq, number of occurrences / number of quadrats sampled) and mean frequency score per quadrat (FS, mean number of occurrences in 10 concentric sub-quadrats per 1024-m² quadrat) for each species recorded within 15 repeatedly sampled quadrats in different management units in 1998, 2002 and 2004 at Kirramingly Nature Reserve. An * before the species name denotes introduced species. Note: Species with frequencies of zero have been recorded in surveys at the Reserve but were not recorded in the 15 quadrats surveyed through time.

Management unit	Uncultivated, ungrazed						Cultivated, ungrazed						Grazed, uncultivated					
	1998		2002		2004		1998		2002		2004		1998		2002		2004	
Species	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS
Abutilon oxycarpum	0	0.0	0	0.0	11	0.1	0	0.0	0	0.0	0	0.0	0	0.0	40	2.8	33	1.0
Acacia farnesiana	93	4.9	93	4.6	100	4.7	100	5.8	100	4.8	100	4.0	75	3.3	100	4.4	100	5.3
Acacia pendula	14	0.3	7	0.1	11	0.1	0	0.0	0	0.0	0	0.0	25	2.0	40	2.4	33	2.7
Acacia stenophylla	14	0.2	14	0.3	22	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Alectryon oleifolius subsp. *canescens*	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	25	0.3	20	0.2	0	0.0
Alternanthera denticulata	57	1.1	71	2.0	100	2.6	75	2.8	67	1.8	67	0.7	25	0.3	80	2.4	100	6.3
Alternanthera nodiflora	21	0.3	14	0.5	11	0.2	25	0.5	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Amaranthus macrocarpus var. *pallidus*	14	0.4	0	0.0	11	0.3	25	0.5	0	0.0	0	0.0	50	0.5	20	1.2	0	0.0
Ammannia multiflora	0	0.0	0	0.0	11	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Amyema quandang var. *quandang*	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	25	1.0	40	1.6	33	0.7
Aristida latifolia	14	0.6	29	0.4	22	0.2	0	0.0	50	0.7	33	0.7	50	0.5	0	0.0	0	0.0
Aristida leptopoda	79	4.6	86	8.1	100	9.3	100	3.0	100	8.0	100	8.7	100	3.8	100	4.4	100	4.0
Aristida platychaeta	43	1.8	36	2.1	22	0.9	0	0.0	17	0.2	33	0.3	50	2.8	20	1.0	67	2.3
Asperula cunninghamii	57	2.4	79	5.4	78	3.4	0	0.0	0	0.0	0	0.0	0	0.0	20	0.6	33	0.3
**Aster subulatus*	7	0.1	36	1.7	0	0.0	0	0.0	67	4.0	0	0.0	0	0.0	20	0.2	0	0.0
Astrebla elymoides	86	7.4	86	8.2	100	9.3	50	1.8	100	4.2	100	6.0	100	5.5	60	2.8	100	9.7
Astrebla lappacea	57	2.7	71	2.4	100	6.6	25	0.3	50	0.8	33	0.7	50	3.8	60	3.8	67	4.3
Atalaya hemiglauca	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	25	1.0	20	1.6	0	0.0
Atriplex semibaccata	57	1.6	64	2.6	56	1.7	50	1.8	100	7.0	100	8.0	75	2.3	100	4.0	100	4.7
Atriplex suberecta	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Austrodanthonia bipartita	50	2.7	79	3.5	78	2.6	0	0.0	83	1.7	0	0.0	50	1.3	80	3.2	33	1.0

Management unit	Uncultivated, ungrazed						Cultivated, ungrazed						Grazed, uncultivated					
Species	1998		2002		2004		1998		2002		2004		1998		2002		2004	
	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS
Austrostipa aristiglumis	21	0.4	21	0.5	11	0.3	0	0.0	0	0.0	0	0.0	25	0.3	60	2.2	33	0.7
**Avena fatua*	0	0.0	0	0.0	0	0.0	0	0.0	17	0.2	0	0.0	0	0.0	0	0.0	0	0.0
**Bidens subalternans*	0	0.0	0	0.0	0	0.0	0	0.0	17	0.2	0	0.0	0	0.0	0	0.0	0	0.0
Boerhavia dominii	86	5.9	86	6.2	89	6.1	100	8.0	100	9.0	100	7.7	75	3.5	80	7.0	67	4.0
Brachycome ciliaris var. *ciliaris*	0	0.0	14	0.3	22	0.6	0	0.0	0	0.0	67	1.0	0	0.0	0	0.0	67	4.3
Brachycome ciliaris var. *subintegrifolia*	21	0.9	29	1.8	33	1.9	0	0.0	17	0.2	0	0.0	50	3.3	20	1.4	0	0.0
**Brassica juncea*	0	0.0	0	0.0	0	0.0	25	0.3	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
**Bromus cartharticus*	0	0.0	0	0.0	0	0.0	0	0.0	33	1.2	0	0.0	0	0.0	20	0.4	0	0.0
Bulbine bulbosa	0	0.0	0	0.08	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Caesia calliantha	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Calotis scabiosifolia var. *scabiosifolia*	0	0.0	50	1.5	67	3.7	0	0.0	0	0.0	0	0.0	0	0.0	60	2.2	67	1.7
Capparis lasiantha	7	0.1	0	0.0	0	0.0	25	0.8	0	0.0	0	0.0	25	0.8	60	1.8	33	0.3
Carex inversa	7	0.3	7	0.2	11	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Casuarina cristata	7	0.4	7	0.5	0	0.0	0	0.0	0	0.0	0	0.0	25	0.5	20	0.6	0	0.0
**Centaurea melitensis*	0	0.0	21	1.5	0	0.0	0	0.0	33	0.5	0	0.0	0	0.0	0	0.0	0	0.0
Centipeda thespidioides	0	0.0	7	0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Chamaesyce drummondii	57	2.9	79	5.1	89	5.2	75	2.8	17	0.7	67	1.7	50	2.8	100	6.2	100	4.0
Chloris truncata	79	5.4	79	6.8	100	7.0	100	7.0	100	8.5	100	8.3	100	7.0	100	6.6	100	9.0
Chloris ventricosa	21	1.1	0	0.0	0	0.0	0	0.0	17	0.5	0	0.0	0	0.0	40	0.6	0	0.0
**Cirsium vulgare*	0	0.0	21	0.9	0	0.0	0	0.0	50	2.8	0	0.0	0	0.0	20	0.2	0	0.0
**Citrullus lanatus* var. *lanatus*	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Convolvulus erubescens	71	4.8	71	3.9	100	4.8	100	5.8	83	5.8	100	4.0	25	1.3	40	1.4	100	3.0
**Conyza bonariensis*	36	2.2	93	5.2	11	0.2	50	4.5	100	6.5	0	0.0	0	0.0	40	0.6	0	0.0
Crotalaria dissitiflora subsp. *dissitiflora*	21	0.7	21	0.4	44	1.2	0	0.0	0	0.0	33	0.3	0	0.0	0	0.0	0	0.0
Cucumis melo subsp. *agrestis*	21	0.8	7	0.1	22	0.6	75	1.8	33	0.7	100	2.0	0	0.0	0	0.0	0	0.0
**Cucumis myriocarpus*	14	0.1	7	0.1	0	0.0	0	0.0	17	0.2	0	0.0	0	0.0	0	0.0	0	0.0
Cullen tenax	7	0.4	71	4.9	78	4.1	0	0.0	67	2.8	67	1.0	25	0.3	40	1.0	33	0.7
Cynodon dactylon	14	0.5	7	0.5	11	0.3	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Cyperus bifax	57	3.3	79	6.5	100	7.7	25	0.8	33	2.8	67	0.7	25	1.3	60	2.8	67	3.7
Cyperus concinnus	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	33	0.3

Management unit	Uncultivated, ungrazed						Cultivated, ungrazed						Grazed, uncultivated					
Species	1998		2002		2004		1998		2002		2004		1998		2002		2004	
	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS
Cyperus fulvus	7	0.3	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Dactyloctenium radulans	21	0.3	0	0.0	33	0.9	25	0.5	0	0.0	100	7.3	25	0.3	20	0.2	100	5.0
Daucus glochidiatus	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Desmodium campylocaulon	64	3.3	86	5.6	100	6.8	25	0.3	50	1.3	67	2.3	25	2.5	20	2.0	33	3.3
Dichanthium sericeum	79	7.0	86	8.2	100	8.6	75	1.8	100	7.7	100	7.7	75	5.8	100	5.8	100	8.7
Dichondra repens	0	0.0	14	0.3	0	0.0	0	0.0	0	0.0	0	0.0	25	0.8	20	0.2	33	2.0
Digitaria divaricatissima	43	2.7	79	3.3	100	6.0	50	2.3	83	3.7	67	6.3	50	1.5	60	3.2	100	7.3
Digitaria hystrichoides	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Diplachne fusca	0	0.0	0	0.0	11	0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Diplachne parviflora	7	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Echinochloa colona	0	0.0	0	0.0	0	0.0	0	0.0	17	1.7	0	0.0	0	0.0	0	0.0	0	0.0
Eclipta platyglossa	0	0.0	43	2.8	44	2.3	0	0.0	33	0.3	0	0.0	0	0.0	0	0.0	0	0.0
Einadia hastata	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	67	2.0	0	0.0	20	0.6	33	0.3
Einadia nutans subsp. *linifolia*	36	1.9	86	3.7	78	2.6	75	3.3	100	8.3	100	6.3	100	1.5	80	5.0	33	0.7
Einadia polygonoides	0	0.0	7	0.2	44	0.7	0	0.0	50	1.3	33	0.7	0	0.0	20	0.6	33	1.7
Eleocharis pallens	21	1.5	21	1.7	22	0.9	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Enchylaena tomentosa	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	33	0.3	0	0.0	0	0.0	67	2.3
Enneapogon gracilis	21	0.6	7	0.3	11	0.2	0	0.0	17	0.7	0	0.0	25	0.8	20	0.2	0	0.0
Enteropogon acicularis	71	4.6	93	5.7	100	6.8	50	4.0	100	8.8	100	9.7	75	4.8	100	8.6	100	5.3
**Eragrostis cilianensis*	7	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Eragrostis leptocarpa	21	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Eragrostis parviflora	7	0.2	57	1.4	78	3.0	0	0.0	67	2.7	33	1.0	25	0.3	40	1.2	100	5.7
Eremophila debilis	7	0.1	29	0.6	67	1.4	0	0.0	67	1.7	67	1.7	25	0.3	20	0.4	33	0.7
Eremophila mitchellii	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	25	1.3	20	1.4	0	0.0
Eriochloa crebra	0	0.0	0	0.0	22	0.8	0	0.0	17	0.2	67	4.0	0	0.0	0	0.0	0	0.0
Eriochloa procera	0	0.0	0	0.0	0	0.0	25	1.8	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Eriochloa pseudoacrotricha	79	5.8	93	8.2	100	9.1	75	7.3	83	7.7	67	5.7	75	5.0	80	5.6	100	9.7
Eryngium plantagineum	21	0.7	57	1.8	33	0.6	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Eucalyptus coolabah subsp. *excerata*	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Euchiton sphaericus	7	0.6	57	2.5	11	0.1	0	0.0	83	3.8	0	0.0	0	0.0	20	0.4	0	0.0

Management unit	Uncultivated, ungrazed						Cultivated, ungrazed						Grazed, uncultivated					
Species	1998		2002		2004		1998		2002		2004		1998		2002		2004	
	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS
Eulalia aurea	29	2.1	50	2.7	56	2.7	0	0.0	50	0.5	67	0.7	25	0.5	0	0.0	33	1.0
Fimbristylis dichotoma	0	0.0	0	0.0	11	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Frankenia serpyllifolia	14	0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	25	1.5	0	0.0	0	0.0
Geranium solanderi var. *solanderi*	0	0.0	7	0.2	11	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Glycine latifolia	50	2.8	36	1.3	33	2.0	25	2.0	0	0.0	0	0.0	25	0.3	20	0.6	33	0.3
Glycine tabacina	0	0.0	0	0.0	0	0.0	0	0.0	17	0.2	0	0.0	0	0.0	40	1.4	0	0.0
**Gomphrena celosioides*	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	40	0.4	0	0.0
Goodenia fascicularis	14	0.2	64	2.9	100	4.7	25	1.3	83	5.8	67	6.7	25	0.8	80	5.6	100	8.7
Goodenia heteromera	7	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	25	0.3	0	0.0	0	0.0
Haloragis aspera	0	0.0	50	3.5	67	4.1	0	0.0	0	0.0	33	1.3	0	0.0	60	1.0	0	0.0
Haloragis glauca	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
**Hedypnois rhagadioloides*	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Hibiscus trionum	0	0.0	7	0.1	44	0.8	25	0.3	17	0.3	67	4.0	0	0.0	0	0.0	33	0.3
**Hordeum leporinum*	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Ipomoea lonchophylla	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	67	3.0	0	0.0	20	0.2	0	0.0
Iseilema membranaceum	21	0.4	7	0.2	33	0.9	25	1.0	33	0.8	67	5.3	25	0.5	20	0.2	33	1.0
Juncus aridicola	14	0.2	29	0.9	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	40	0.4	0	0.0
Juncus usitatus	14	0.2	43	1.3	44	0.9	0	0.0	50	1.0	0	0.0	0	0.0	0	0.0	0	0.0
Lachnagrostis filiformis	0	0.0	7	0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
**Lactuca serriola*	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Leiocarpa panaetioides / tomentosa	17	0.4	23	0.3	22	0.3	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Leiocarpa websteri	79	3.6	86	3.3	100	4.6	75	2.8	67	3.0	33	2.0	25	0.5	20	0.2	67	1.7
**Lepidium bonariense*	0	0.0	7	0.2	11	0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	33	0.7
Leptochloa digitata	7	0.1	14	0.4	11	0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Leptochloa divaricatissima	29	1.2	29	1.4	33	1.1	25	0.3	83	3.2	33	3.0	25	0.8	80	3.8	33	1.7
Linum marginale	0	0.0	7	0.6	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Lomandra multiflora	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
**Lycium ferocissimum*	0	0.0	14	0.5	0	0.0	0	0.0	0	0.0	0	0.0	25	0.5	40	1.0	33	1.0
Maireana aphylla	79	1.5	86	2.4	78	1.3	25	0.3	33	0.3	33	0.3	75	1.0	40	0.4	33	0.3
Maireana decalvens	29	0.4	36	0.8	33	0.6	0	0.0	17	0.2	0	0.0	100	3.5	100	5.4	67	4.0

Management unit	Uncultivated, ungrazed						Cultivated, ungrazed						Grazed, uncultivated					
Species	1998		2002		2004		1998		2002		2004		1998		2002		2004	
	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS
Maireana microphylla	50	1.3	50	0.9	78	1.3	25	0.5	50	0.5	33	0.3	100	1.5	60	2.4	100	2.3
**Malvastrum americanum*	64	2.3	64	2.5	78	3.7	25	1.0	67	1.8	100	5.0	75	4.5	60	4.4	67	3.7
**Marrubium vulgare*	0	0.0	0	0.0	0	0.0	25	0.3	17	0.2	0	0.0	0	0.0	0	0.0	0	0.0
Marsilea drummondii	36	1.9	36	2.5	33	0.6	0	0.0	0	0.0	0	0.0	0	0.0	20	1.0	0	0.0
**Medicago truncatula*	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
**Medicago polymorpha*	7	0.7	7	0.1	22	0.2	0	0.0	17	0.2	33	0.3	0	0.0	0	0.0	33	0.3
Mimulus gracilis	0	0.0	0	0.0	22	0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Minuria integerrima	14	0.4	14	0.6	22	0.3	25	1.0	0	0.0	0	0.0	0	0.0	0	0.0	33	0.7
Myoporum montanum	0	0.0	0	0.0	0	0.0	0	0.0	17	0.2	33	0.3	0	0.0	20	0.6	33	0.3
Neptunia gracilis	50	2.2	93	7.9	100	8.3	50	4.3	100	8.2	100	9.7	25	1.0	80	5.6	100	8.0
Nicotiana megalosiphon	0	0.0	0	0.0	11	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
**Opuntia stricta*	7	0.2	14	0.5	44	0.9	0	0.0	0	0.0	0	0.0	25	0.3	0	0.0	0	0.0
Oxalis perennans	57	2.4	100	7.5	100	6.2	25	0.3	100	10.0	100	5.3	25	0.3	100	5.2	67	0.7
Panicum buncei	36	2.0	79	3.4	100	4.8	25	0.5	33	2.2	67	4.0	50	3.3	60	3.4	100	5.0
Panicum decompositum	86	6.6	93	6.9	100	8.7	100	7.0	100	8.0	100	9.3	75	3.3	60	3.6	100	7.0
Panicum effusum	14	1.0	0	0.0	0	0.0	25	0.8	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Panicum queenslandicum var. *queenslandicum*	43	1.5	86	6.6	100	8.2	0	0.0	50	2.5	33	3.3	25	1.3	20	0.2	67	1.3
Paspalidium aversum	7	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	25	1.0	20	0.4	0	0.0
Paspalidium constrictum	29	1.0	7	0.3	0	0.0	0	0.0	17	0.7	0	0.0	50	1.3	40	2.4	33	1.0
Paspalidium globoideum	7	0.1	36	0.6	44	1.4	0	0.0	50	2.0	100	4.3	25	0.5	60	2.8	100	1.7
Paspalidium jubiflorum	14	0.7	7	0.8	11	1.1	0	0.0	17	1.0	0	0.0	0	0.0	0	0.0	0	0.0
**Phalaris aquatica*	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
**Phalaris paradoxa*	0	0.0	0	0.0	0	0.0	0	0.0	33	1.2	0	0.0	0	0.0	0	0.0	0	0.0
Phyllanthus virgatus	71	4.0	86	7.3	100	8.7	50	3.8	83	4.0	67	6.0	50	0.8	20	1.2	67	2.0
**Physalis lanceifolia*	0	0.0	0	0.0	56	1.3	0	0.0	17	0.2	100	7.7	0	0.0	0	0.0	0	0.0
**Physalis virginiana*	21	1.0	0	0.0	0	0.0	50	2.0	33	1.2	0	0.0	0	0.0	0	0.0	0	0.0
**Picris hieracioides*	0	0.0	7	0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	20	1.6	0	0.0
Pimelea linifolia	14	0.4	14	0.2	0	0.0	0	0.0	0	0.0	0	0.0	25	0.5	40	0.6	0	0.0
Pimelea microcephala	7	0.1	7	0.3	33	0.7	0	0.0	0	0.0	0	0.0	0	0.0	20	0.8	67	1.0

Management unit	Uncultivated, ungrazed						Cultivated, ungrazed						Grazed, uncultivated					
Species	1998		2002		2004		1998		2002		2004		1998		2002		2004	
	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS
Pimelea neo-anglica	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	25	0.3	20	0.2	0	0.0
Pittosporum phylliraeoides	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	25	1.0	20	1.2	0	0.0
Plantago cunninghamii	0	0.0	14	0.4	0	0.0	0	0.0	17	0.5	0	0.0	0	0.0	0	0.0	0	0.0
Plantago debilis	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Podolepis muelleri	0	0.0	14	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Polymeria pusilla	7	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Portulaca oleracea	79	2.9	43	2.4	100	5.2	100	5.8	50	0.7	100	7.3	100	7.8	100	7.6	100	10.0
Pratia concolor	7	0.1	36	1.8	44	1.4	0	0.0	17	0.2	0	0.0	0	0.0	0	0.0	0	0.0
**Proboscidea louisianica*	0	0.0	0	0.0	11	0.4	0	0.0	0	0.0	33	0.3	0	0.0	0	0.0	0	0.0
Ptilotus semilanatus	64	3.4	71	4.2	78	4.6	25	0.3	17	0.3	33	0.3	50	1.5	20	0.6	67	0.7
Pycnosorus chrysanthus	0	0.0	0	0.0	0	0.0	50	1.0	17	0.2	0	0.0	0	0.0	0	0.0	0	0.0
Pycnosorus globosus	14	0.3	36	1.2	33	0.3	25	0.3	33	0.5	33	0.3	0	0.0	0	0.0	33	1.3
**Rapistrum rugosum*	0	0.0	36	2.2	11	0.1	0	0.0	100	8.3	33	0.7	0	0.0	20	0.6	0	0.0
Rhagodia spinescens	7	0.1	21	0.5	33	0.4	0	0.0	0	0.0	0	0.0	50	1.8	60	2.6	67	3.0
Rhynchosia minima	21	0.4	36	2.9	67	2.7	25	2.0	33	1.7	33	3.3	25	0.3	0	0.0	0	0.0
Rostellularia adscendens	36	1.8	36	1.4	33	1.9	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
**Rumex crispus*	36	0.5	14	0.2	0	0.0	0	0.0	33	0.5	0	0.0	0	0.0	0	0.0	0	0.0
Rumex crystallinus	0	0.0	14	0.2	0	0.0	0	0.0	17	0.2	0	0.0	0	0.0	0	0.0	0	0.0
Salsola kali var. *kali*	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	25	0.5	20	1.2	33	2.0
**Salvia reflexa*	7	0.1	7	0.4	11	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Sclerolaena anisacanthoides	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	20	0.8	67	5.0
Sclerolaena birchii	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	20	0.2	0	0.0
Sclerolaena longicuspis	14	0.8	0	0.0	0	0.0	50	2.3	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Sclerolaena muricata var. *muricata*	21	1.3	36	1.4	33	1.4	75	6.5	100	7.2	100	5.7	0	0.0	20	0.2	33	2.7
Sclerolaena muricata var. *villosa*	93	7.3	86	6.2	100	6.0	75	5.0	67	4.7	100	4.3	50	4.5	80	6.6	67	4.3
Sclerolaena stelligera	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	67	0.7
Senecio quadridentatus	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
**Setaria incrassata*	0	0.0	0	0.0	0	0.0	50	2.3	17	0.2	33	0.3	0	0.0	0	0.0	0	0.0
Sida cunninghamii	0	0.0	14	0.5	0	0.0	0	0.0	17	0.2	0	0.0	0	0.0	40	2.2	0	0.0
Sida trichopoda	100	4.8	86	6.9	100	9.0	75	5.8	83	4.2	100	8.3	75	6.0	100	6.8	100	10.0

Management unit	Uncultivated, ungrazed						Cultivated, ungrazed						Grazed, uncultivated					
Species	1998		2002		2004		1998		2002		2004		1998		2002		2004	
	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS	Freq	FS
**Silybum marianum*	0	0.0	7	0.1	0	0.0	0	0.0	17	1.0	0	0.0	0	0.0	0	0.0	0	0.0
Solanum esuriale	64	2.6	86	4.3	100	6.2	75	3.8	83	5.7	100	6.7	50	1.8	100	4.6	100	6.0
**Solanum nigrum*	0	0.0	7	0.2	0	0.0	0	0.0	17	0.5	0	0.0	0	0.0	0	0.0	0	0.0
**Sonchus oleraceus*	21	0.4	64	2.9	0	0.0	0	0.0	83	3.0	0	0.0	0	0.0	0	0.0	0	0.0
Sporobolus actinocladus	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	25	0.3	0	0.0	67	0.7
Sporobolus caroli	79	6.3	86	5.1	100	5.6	50	5.0	83	6.3	100	9.0	100	9.5	80	7.6	100	10.0
Sporobolus creber	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Sporobolus mitchellii	14	0.7	14	0.8	11	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Stemodia glabella	7	0.2	0	0.0	11	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Swainsona luteola	7	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Swainsona murrayana	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Swainsona queenslandica	36	0.9	57	2.2	56	1.6	0	0.0	17	0.2	0	0.0	0	0.0	20	0.2	33	0.3
Tetragonia tetragonoides	7	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	40	1.2	0	0.0
Thellungia advena	71	3.8	86	5.1	89	6.9	50	2.8	100	4.0	67	1.0	75	3.5	80	4.4	100	4.0
Themeda avenacea	79	2.4	93	3.5	100	3.2	0	0.0	0	0.0	0	0.0	50	1.8	40	1.0	33	1.3
Tragus australianus	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	25	0.3	0	0.0	0	0.0
Trianthema triquetra	0	0.0	7	0.2	22	0.8	0	0.0	0	0.0	0	0.0	0	0.0	20	0.6	100	3.3
Tribulus micrococcus	0	0.0	0	0.0	11	0.1	0	0.0	0	0.0	33	3.3	0	0.0	0	0.0	0	0.0
**Urochloa panicoides*	14	0.8	14	0.6	11	0.6	0	0.0	17	0.8	0	0.0	0	0.0	20	1.6	0	0.0
Ventilago viminalis	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	25	0.3	40	0.6	0	0.0
Verbena gaudichaudii	57	1.6	64	1.6	56	1.1	25	0.5	67	1.0	33	0.3	25	0.3	80	1.8	33	0.7
Vittadinia cuneata	36	1.3	79	5.7	100	6.1	75	4.8	83	6.7	100	7.3	50	2.0	100	4.8	100	4.0
Wahlenbergia communis	57	2.6	71	4.2	89	4.2	25	1.3	50	2.2	67	3.7	50	0.8	20	0.2	67	2.7
**Xanthium spinosum*	14	0.6	0	0.0	22	0.3	0	0.0	33	1.2	33	0.7	0	0.0	0	0.0	0	0.0

APPENDIX 5.1. All taxa (scientific name, common name and family) recorded during surveys carried out for fire experiments in the north-west management unit of Kirramingly Nature Reserve, 2002-2004. Code refers to labels given in ordination diagrams in the thesis. Also shown are species origin (N, native; I, introduced; U, unknown), growth form (F, forb; G, grass; GR, graminoid; S, shrub; SS, sub-shrub) and life cycle (P, perennial; A, annual or biennial; S, short-lived perennial).

Species	**Code**	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**
Acacia farnesiana	Acafar	Fabaceae	Mimosa Bush	U	S	P
Acacia stenophylla	Acaste	Fabaceae	River Cooba	N	S	P
Alternanthera denticulata	Altden	Amaranthaceae	Lesser Joyweed	N	F	A
Amaranthus macrocarpus	Amamac	Amaranthaceae	Dwarf Amaranth	N	F	A
Aristida latifolia	Arilat	Poaceae	Feathertop Wiregrass	N	G	P
Aristida leptopoda	Arilep	Poaceae	White Speargrass	N	G	P
Aristida platychaeta	Aripla	Poaceae	Threeawn Grass	N	G	P
Asperula cunninghamii	Aspcun	Rubiaceae	Twining Woodruff	N	F	P
Aster subulatus	Astsub	Asteraceae	Wild Aster	I	F	A
Astrebla elymoides	Astely	Poaceae	Hoop Mitchell Grass	N	G	P
Astrebla lappacea	Astlap	Poaceae	Curly Mitchell Grass	N	G	P
Atriplex semibaccata	Atrsem	Chenopodiaceae	Creeping Saltbush	N	SS	P
Austrodanthonia bipartita	Ausbip	Poaceae	Wallaby Grass	N	G	P
Boerhavia dominii	Boedom	Nyctaginaceae	Tarvine	N	F	P
Brachycome ciliaris var. *subintegrifolia*	Bracis	Asteraceae	Variable Daisy	N	F	P
Brachycome ciliaris var. *ciliaris*	Bracil	Asteraceae	Variable Daisy	N	F	P
Caesia calliantha	Caecal	Anthericaceae	Grass Lily	N	GR	P
Calotis hispidula	Calhis	Asteraceae	Bogan Flea	N	F	A
Calotis scabiosifolia var. *scabiosifolia*	Calsca	Asteraceae	Rough Burr-daisy	N	F	P
Chamaesyce drummondii	Chadru	Euphorbiaceae	Caustic Weed	N	F	P
Chloris truncata	Chltru	Poaceae	Windmill Grass	N	G	S,A
Convolvulus erubescens	Coneru	Convolvulaceae	Australian Bindweed	N	F	P
Conyza bonariensis	Conbon	Asteraceae	Flaxleaf Fleabane	I	F	A
Crotalaria dissitiflora subsp. *dissitiflora*	Crodis	Fabaceae	Grey Rattlepod	N	F	P

Species	Code	Family	Common name	Origin	Growth form	Life cycle
Cucumis melo subsp. *agrestis*	Cucmel	Cucurbitaceae	Ulcardo Melon	N	F	A
Cucumis myriocarpus	Cucmyr	Cucurbitaceae	Paddy Melon	I	F	A
Cullen tenax	Culten	Fabaceae	Emu-foot	N	F	P
Cyperus bifax	Cypbif	Cyperaceae	Downs Nutgrass	N	GR	P
Dactyloctenium radulans	Dacrad	Poaceae	Button Grass	N	G	A
Daucus glochidiatus	Dauglo	Apiaceae	Australian Carrot	N	F	A
Desmodium campylocaulon	Descam	Fabaceae	Creeping Tick-trefoil	N	F	P
Dichanthium sericeum	Dicser	Poaceae	Queensland Bluegrass	N	G	P
Digitaria divaricatissima	Digdiv	Poaceae	Umbrella Grass	N	G	P
Eclipta platyglossa	Eclpla	Asteraceae	Yellow Twin-heads	N	F	A
Einadia nutans subsp. *linifolia*	Einnul	Chenopodiaceae	Climbing Saltbush	N	F	P
Einadia polygonoides	Einpol	Chenopodiaceae	Knotweed Goosefoot	N	F	A,P
Eleocharis pallens	Elepal	Cyperaceae	Pale Spikerush	N	GR	P
Enteropogon acicularis	Entaci	Poaceae	Large Windmill Grass	N	G	P
Eragrostis parviflora	Erapar	Poaceae	Weeping Lovegrass	N	G	A
Eremophila debilis	Eredeb	Myoporaceae	Winter Apple	N	SS	P
Eriochloa pseudoacrotricha	Eripse	Poaceae	Early Spring Grass	N	G	S,A
Erodium crinitum	Erocri	Geraniaceae	Blue Storksbill	N	F	A
Eryngium plantagineum	Erypla	Apiaceae	Long Eryngium	N	F	S,A
Euchiton sphaericus	Eucsph	Asteraceae	Cudweed	N	F	A
Eulalia aurea	Eulaur	Poaceae	Silky Browntop	N	G	P
Fimbristylis dichotoma	Fimdic	Cyperaceae	Common Fringe Rush	N	GR	P
Glycine tabacina	Glytab	Fabaceae	Variable Glycine	N	F	P
Goodenia fascicularis	Goofas	Goodeniaceae	Silky Goodenia	N	F	P
Haloragis aspera	Halasp	Haloragaceae	Rough Raspwort	N	F	P
Hedypnois rhagadioloides	Hedrha	Asteraceae	Cretan weed	I	F	A
Hibiscus trionum	Hibtri	Malvaceae	Bladder Ketmia	N	F	A
Iseilema membranaceum	Isemem	Poaceae	Small Flinders Grass	N	G	A
Juncus usitatus	Junusi	Juncaceae	Common Rush	N	GR	P
Leiocarpa tomentosa	Leitom	Asteraceae	Woolly Plover-daisy	N	SS	P
Leiocarpa websteri	Leiweb	Asteraceae	Plover-daisy	N	SS	P
Lepidium bonariense	Lepbon	Brassicaceae	Cut-leaf Peppercress	I	F	A

Species	**Code**	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**
Leptochloa divaricatissima	Lepdiv	Poaceae	Canegrass	N	G	P
Lomandra multiflora	Lommul	Lomandraceae	Many-flowered Mat-rush	N	GR	P
Maireana aphylla	Maiaph	Chenopodiaceae	Cottonbush	N	SS	P
Maireana decalvens	Maidec	Chenopodiaceae	Black Cottonbush	N	SS	P
Maireana microphylla	Maimic	Chenopodiaceae	Eastern Cottonbush	N	SS	P
Malvastrum americanum	Malame	Malvaceae	Spiked Malvastrum	I	F	A
Medicago polymorpha	Medpol	Fabaceae	Burr Medic	I	F	A
Medicago truncatula	Medtru	Fabaceae	Barrel Medic	I	F	A
Minuria integerrima	Minint	Asteraceae	Smooth Minuria	N	F	P
Neptunia gracilis	Nepgra	Fabaceae	Sensitive Plant	N	F	P
Oxalis perennans	Oxaper	Oxalidaceae	Wood Sorrel	N	F	P
Panicum buncei	Panbun	Poaceae	Native Panic	N	G	P
Panicum decompositum	Pandec	Poaceae	Native Millet	N	G	P
Panicum queenslandicum var. *queenslandicum*	Panque	Poaceae	Yadbilla Grass	N	G	P
Paspalidium globoideum	Pasglo	Poaceae	Shotgrass	N	G	P
Phyllanthus virgatus	Phyvir	Euphorbiaceae	Spurge	N	F	P
Physalis lanceifolia	Phylan	Solanaceae	Ground Cherry	I	F	A
Pimelea microcephala	Pimmic	Thymelaeaceae	Shrubby Rice-flower	N	S	P
Plantago cunninghamii	Placun	Plantaginaceae	Sago-weed	N	F	A
Podolepis muelleri	Podmue	Asteraceae	Small Copper-wire Daisy	N	F	A
Portulaca oleracea	Porole	Portulacaceae	Pigweed	N	F	A
Pratia concolor	Pracon	Lobeliaceae	Poison Pratia	N	F	P
Ptilotus semilanatus	Ptisem	Amaranthaceae	Ptilotus	N	F	P
Pycnosorus globosus	Pycglo	Asteraceae	Pale Billy-buttons	N	F	A
Rapistrum rugosum	Raprug	Brassicaceae	Turnip Weed	I	F	A
Rhagodia spinescens	Rhaspi	Chenopodiaceae	Thorny Saltbush	N	S	P
Rhodanthe diffusa	Rhodif	Asteraceae	Ascending Sunray	N	F	A
Rhynchosia minima	Rhymin	Fabaceae	Rhyncho	N	F	P
Rostellularia adscendens	Rosads	Acanthaceae	Pink Tongues	N	F	P
Sclerolaena muricata var. *villosa*	Sclmuv	Chenopodiaceae	Grey Rolypoly	N	SS	P
Sida cunninghamii	Sidcun	Malvaceae	Ridge Sida	N	F	P
Sida trichopoda	Sidtri	Malvaceae	High Sida	N	F	P

Species	Code	Family	Common name	Origin	Growth form	Life cycle
Silybum marianum	Silmar	Asteraceae	Variegated Thistle	I	F	A
Solanum esuriale	Solesu	Solanaceae	Quena	N	F	P
Sonchus oleraceus	Sonole	Asteraceae	Common Sowthistle	I	F	A
Sporobolus caroli	Spocar	Poaceae	Fairy Grass	N	G	A
Sporobolus mitchellii	Spomit	Poaceae	Rat's Tail Couch	N	G	P
Stemodia glabella	Stegla	Scrophulariaceae	Stemodia	N	F	P
Swainsona murrayana	Swamur	Fabaceae	Slender Darling Pea	N	F	P
Swainsona queenslandica	Swaque	Fabaceae	Darling Pea	N	SS	P
Thellungia advena	Theadv	Poaceae	Coolibah Grass	N	G	P
Themeda avenacea	Theave	Poaceae	Native Oatgrass	N	G	P
Trianthema triquetra	Tritri	Aizoaceae	Small Hogweed	N	F	A
Verbena gaudichaudii	Vergau	Verbenaceae	Verbena	N	F	P
Vittadinia cuneata	Vitcun	Asteraceae	Fuzzweed	N	F	A,P
Wahlenbergia communis	Wahcom	Campanulaceae	Tufted Bluebell	N	F	P
Xanthium spinosum	Xanspi	Asteraceae	Bathurst Burr	I	F	A

APPENDIX 5.2. Mean frequency score per quadrat (number of occurrences in five concentric sub-quadrats per 32-m² quadrat) for each species, averaged across all five sampling times (autumn 2002, spring 2002, autumn 2003, spring 2003 and autumn 2004). Species frequencies at each sampling times (averaged across treatments) are provided in Appendix 5.5. S02g, burnt in spring 2002 and grazed by kangaroos; S02ng, burnt in spring 2002 and ungrazed; A99S02g, burnt in autumn 1999 and spring 2002 and grazed by kangaroos; A02ng, burnt in autumn 2002 and ungrazed; A02g, burnt in autumn 2002 and grazed by kangaroos; burnt in autumn 1999 and autumn 2002 and grazed by kangaroos; Cng, not burnt and not grazed; Cg, not burnt and grazed by kangaroos; A99g, burnt in autumn 1999 only and grazed by kangaroos; Distg, Distant unburnt sites subject to kangaroo grazing. An * before the species name denotes introduced species.

Treatment **Species**	**S02g** (*n* = 4)	**S02ng** (*n* = 4)	**A99S02g** (*n* = 4)	**A02ng** (*n* = 4)	**A02g** (*n* = 4)	**A99A02g** (*n* = 4)	**Cng** (*n* = 4)	**Cg** (*n* = 4)	**A99g** (*n* = 4)	**Distg** (*n* = 6)
Acacia farnesiana	2.55	3.10	2.20	1.60	2.60	1.20	2.55	1.70	1.60	1.53
Acacia stenophylla	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alternanthera denticulata	0.25	0.25	0.30	0.25	0.20	0.55	0.35	0.25	0.35	0.65
Amaranthus macrocarpus	0.00	0.20	0.00	0.10	0.00	0.00	0.00	0.00	0.05	0.05
Aristida latifolia	0.00	0.15	0.25	0.15	0.00	0.05	0.00	0.00	0.15	0.00
Aristida leptopoda	3.70	4.10	3.70	3.45	3.05	2.05	4.25	4.25	4.20	4.58
Aristida platychaeta	1.05	1.65	1.25	0.70	0.10	1.00	1.50	1.60	2.20	0.00
Asperula cunninghamii	0.35	1.40	1.50	1.85	1.55	0.85	2.65	2.00	1.70	1.65
**Aster subulatus*	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
Astrebla elymoides	5.00	4.65	4.30	3.75	4.00	4.05	4.80	4.95	4.65	5.00
Astrebla lappacea	0.85	0.90	0.25	0.55	0.25	0.35	0.00	0.00	0.10	1.58
Atriplex semibaccata	0.00	0.00	0.00	0.05	0.00	0.15	0.00	0.00	0.00	0.40
Austrodanthonia bipartita	0.15	0.20	0.00	0.10	0.05	0.00	1.30	0.00	0.10	0.10
Boerhavia dominii	3.50	2.40	1.90	3.75	2.70	0.45	2.40	3.00	1.95	1.78
Brachycome ciliaris var. *subintegrifolia*	1.15	1.10	1.65	0.90	0.65	1.65	0.75	0.80	1.85	0.00
Brachycome ciliaris var. *ciliaris*	0.70	0.35	0.30	0.20	0.05	0.75	0.55	0.00	1.05	1.83
Caesia calliantha	0.05	0.05	0.05	0.00	0.20	0.00	0.15	0.10	0.10	0.00
Calotis hispidula	0.00	0.05	0.10	0.05	0.05	0.10	0.05	0.10	0.20	0.05

Treatment	**S02g**	**S02ng**	**A99S02g**	**A02ng**	**A02g**	**A99A02g**	**Cng**	**Cg**	**A99g**	**Distg**
Species	(*n* = 4)	(*n* = 4)	(*n* = 4)	(*n* = 4)	(*n* = 4)	(*n* = 4)	(*n* = 4)	(*n* = 4)	(*n* = 4)	(*n* = 6)
Calotis scabiosifolia var. *scabiosifolia*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.03
Chamaesyce drummondii	2.85	2.75	3.60	2.65	1.85	3.15	2.45	3.65	3.05	1.13
Chloris truncata	4.00	3.55	4.80	3.50	2.90	4.05	2.80	3.95	4.50	1.98
Convolvulus erubescens	4.00	3.75	3.80	3.95	3.40	3.50	2.85	3.20	3.95	3.28
**Conyza bonariensis*	0.05	0.15	0.05	0.05	0.35	0.15	0.05	0.00	0.05	0.48
Crotalaria dissitiflora subsp. *dissitiflora*	0.65	0.35	0.90	0.95	0.70	0.00	0.10	0.60	0.10	0.08
Cucumis melo subsp. *agrestis*	0.05	0.05	0.00	0.00	0.00	0.10	0.00	0.00	0.05	0.00
**Cucumis myriocarpus*	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
Cullen tenax	3.75	4.05	3.85	3.50	3.85	4.60	2.90	4.40	4.00	3.85
Cyperus bifax	2.25	0.40	2.90	1.90	2.65	3.60	1.55	2.30	2.70	3.80
Dactyloctenium radulans	0.15	0.05	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00
Daucus glochidiatus	0.25	0.40	0.55	0.40	0.00	0.80	0.15	0.35	1.30	0.58
Desmodium campylocaulon	2.05	2.25	2.90	4.00	3.70	3.70	3.55	3.70	3.60	1.63
Dichanthium sericeum	4.75	3.55	4.75	3.85	2.90	3.75	3.05	3.65	4.80	2.98
Digitaria divaricatissima	0.85	2.80	3.50	1.55	1.05	2.00	2.35	3.40	3.85	1.03
Eclipta platyglossa	0.40	0.00	0.35	0.20	0.20	1.05	0.50	0.00	0.30	0.73
Einadia nutans subsp. *linifolia*	0.95	0.90	0.70	0.75	1.80	0.55	2.60	0.70	1.10	2.93
Einadia polygonoides	0.10	0.00	0.00	0.00	0.00	0.05	0.05	0.10	0.00	0.05
Eleocharis pallens	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enteropogon acicularis	1.90	1.65	0.65	1.60	1.45	1.10	1.30	1.05	1.00	2.83
Eragrostis parviflora	1.15	0.55	1.90	1.35	1.70	2.90	0.30	0.20	2.00	0.38
Eremophila debilis	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.13
Eriochloa pseudoacrotricha	4.65	4.65	4.60	3.55	3.50	3.45	3.70	4.45	4.05	4.03
Erodium crinitum	0.35	0.45	0.15	0.50	0.00	0.50	0.20	0.00	0.25	0.13
Eryngium plantagineum	0.95	0.05	2.30	2.80	3.20	3.05	0.60	2.60	1.35	0.83
Euchiton sphaericus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.15
Eulalia aurea	2.10	4.15	3.90	2.80	1.85	3.90	3.70	4.40	2.75	1.75
Fimbristylis dichotoma	0.00	0.20	0.45	0.00	0.00	0.00	0.05	0.10	0.00	0.00
Glycine tabacina	0.00	0.00	0.95	0.00	0.00	0.00	0.00	0.05	0.00	0.00
Goodenia fascicularis	2.15	2.10	2.85	2.00	1.50	1.90	2.00	2.95	2.05	1.40
Haloragis aspera	0.30	0.30	1.45	1.15	1.95	0.00	2.20	2.20	0.00	0.55

Treatment Species	S02g (*n* = 4)	S02ng (*n* = 4)	A99S02g (*n* = 4)	A02ng (*n* = 4)	A02g (*n* = 4)	A99A02g (*n* = 4)	Cng (*n* = 4)	Cg (*n* = 4)	A99g (*n* = 4)	Distg (*n* = 6)
**Hedypnois rhagadioloides*	0.90	0.75	1.30	0.95	1.00	1.40	0.95	1.25	1.60	0.10
Hibiscus trionum	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.03
Iseilema membranaceum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Juncus usitatus	0.25	0.05	0.05	0.05	0.00	0.00	0.10	0.00	0.00	0.15
Leiocarpa tomentosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Leiocarpa websteri	0.45	0.45	0.90	0.35	0.20	0.15	0.15	0.30	1.05	0.98
**Lepidium bonariense*	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Leptochloa divaricatissima	0.45	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.10	0.95
Lomandra multiflora	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
Maireana aphylla	1.45	0.25	0.45	0.00	0.00	1.30	1.00	0.25	2.00	0.60
Maireana decalvens	0.30	1.05	0.25	0.95	1.20	0.00	0.00	0.50	0.35	0.00
Maireana microphylla	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
**Malvastrum americanum*	0.05	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.03
**Medicago polymorpha*	1.55	1.50	1.00	1.20	1.40	1.45	1.25	1.40	1.60	2.00
**Medicago truncatula*	1.80	1.95	1.70	1.90	1.60	1.45	2.05	1.85	1.55	0.95
Minuria integerrima	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Neptunia gracilis	3.65	3.40	3.70	3.80	4.15	4.00	3.35	3.80	3.35	3.60
Oxalis perennans	1.25	2.10	1.15	1.05	2.20	1.60	2.35	2.00	2.60	3.90
Panicum buncei	2.40	2.25	0.95	1.70	1.25	1.25	2.60	2.90	1.80	1.98
Panicum decompositum	2.80	1.65	1.40	2.45	2.10	1.80	1.05	1.95	1.70	2.58
Panicum queenslandicum var. *queenslandicum*	4.20	3.80	4.30	3.00	2.90	3.25	2.45	3.55	4.00	1.90
Paspalidium globoideum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18
Phyllanthus virgatus	2.70	3.60	3.35	3.00	3.10	2.10	3.40	3.00	3.90	2.90
**Physalis lanceifolia*	0.10	0.00	0.15	0.25	0.00	0.30	0.00	0.10	0.55	0.03
Pimelea microcephala	0.00	0.00	0.35	0.00	0.05	0.00	0.25	0.35	0.00	0.00
Plantago cunninghamii	0.60	0.20	0.40	0.35	0.05	0.65	0.20	0.05	0.50	1.18
Podolepis muelleri	0.05	0.05	0.50	0.15	0.10	0.10	0.45	0.30	0.35	0.00
Portulaca oleracea	1.75	1.60	0.85	1.00	0.50	1.30	0.20	0.95	1.20	0.73
Pratia concolor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00
Ptilotus semilanatus	1.45	2.65	3.10	3.15	1.80	1.70	1.60	2.15	2.15	0.93

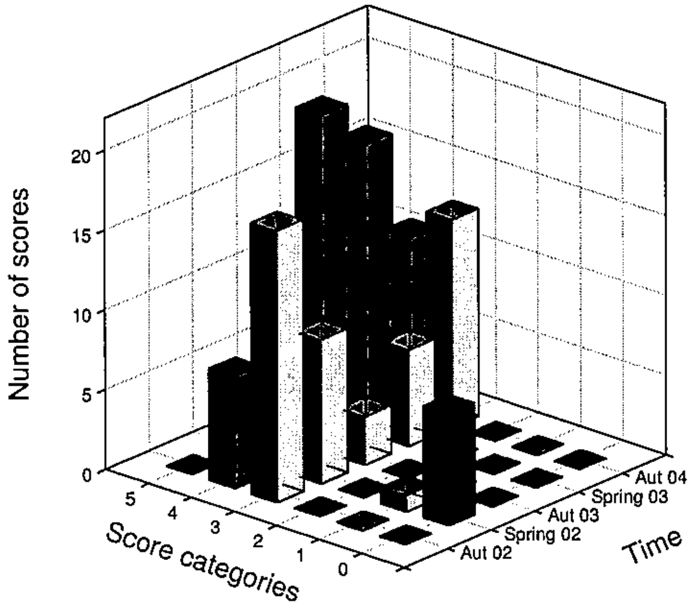
Treatment **Species**	**S02g** ($n = 4$)	**S02ng** ($n = 4$)	**A99S02g** ($n = 4$)	**A02ng** ($n = 4$)	**A02g** ($n = 4$)	**A99A02g** ($n = 4$)	**Cng** ($n = 4$)	**Cg** ($n = 4$)	**A99g** ($n = 4$)	**Distg** ($n = 6$)
Pycnosorus globosus	0.20	0.05	0.40	0.20	0.05	0.85	0.20	0.10	0.60	0.10
**Rapistrum rugosum*	1.05	0.70	0.35	0.45	0.75	0.10	0.90	0.75	1.30	1.68
Rhagodia spinescens	0.15	0.00	0.20	0.05	0.00	0.10	0.35	0.00	0.15	0.00
Rhodanthe diffusa	0.00	0.00	0.05	0.00	0.15	0.25	0.00	0.05	0.05	0.05
Rhynchosia minima	0.10	0.15	0.10	0.00	1.35	0.00	0.25	0.10	0.55	0.00
Rostellularia adscendens	0.00	0.25	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
Sclerolaena muricata var. *villosa*	1.65	1.60	1.10	1.65	1.45	0.50	1.30	0.50	1.95	1.68
Sida cunninghamii	0.70	0.05	0.00	1.15	0.00	0.00	0.20	0.00	0.00	0.00
Sida trichopoda	3.60	3.85	3.55	3.80	3.65	4.10	2.30	3.05	3.50	2.98
**Silybum marianum*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15
Solanum esuriale	1.20	1.50	0.50	3.10	1.00	1.85	1.15	2.40	1.50	1.33
**Sonchus oleraceus*	0.50	1.05	0.40	0.65	0.75	0.10	1.65	1.55	1.15	2.00
Sporobolus caroli	3.10	4.25	3.25	2.35	2.15	1.70	3.20	3.80	2.95	1.33
Sporobolus mitchellii	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Stemodia glabella	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
Swainsona murrayana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00
Swainsona queenslandica	0.80	0.20	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00
Thellungia advena	0.75	2.15	1.15	0.15	1.00	1.80	0.60	1.40	2.45	1.83
Themeda avenacea	1.30	0.75	1.00	1.30	1.85	1.60	2.30	1.45	1.20	1.60
Trianthema triquetra	0.40	0.40	0.00	0.00	0.00	0.05	0.00	0.00	0.10	0.03
Verbena gaudichaudii	0.45	0.05	0.00	0.00	0.00	0.00	0.35	0.00	0.00	0.58
Vittadinia cuneata	1.55	2.10	1.30	2.00	1.65	1.55	1.30	2.70	2.40	1.00
Wahlenbergia communis	1.85	2.05	2.00	2.45	1.40	1.55	1.50	2.50	1.70	0.90
**Xanthium spinosum*	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX 5.3. Contrasts (unplanned, one degree of freedom) used to identify differences in species richness and evenness variables between fire treatments at certain times (autumn 2002, spring 2002 and autumn 2003) after looking at graphs (Fig. 5.6) to determine where contrasts were necessary. No differences in richness were apparent between areas previously burnt in May 1999 and unburnt areas (Burnt 1999 *vs* unburnt), prior to 2002 burning treatments. Differences in richness were apparent between sites burnt in autumn 2002 and unburnt sites (Burnt autumn 2002 *vs* unburnt) in spring 2002, and between sites burnt only in autumn 1999 and all other burnt and unburnt sites (Burnt autumn 1999 only *vs* all other treatments) in autumn 2003 (refer to Fig. 5.6).

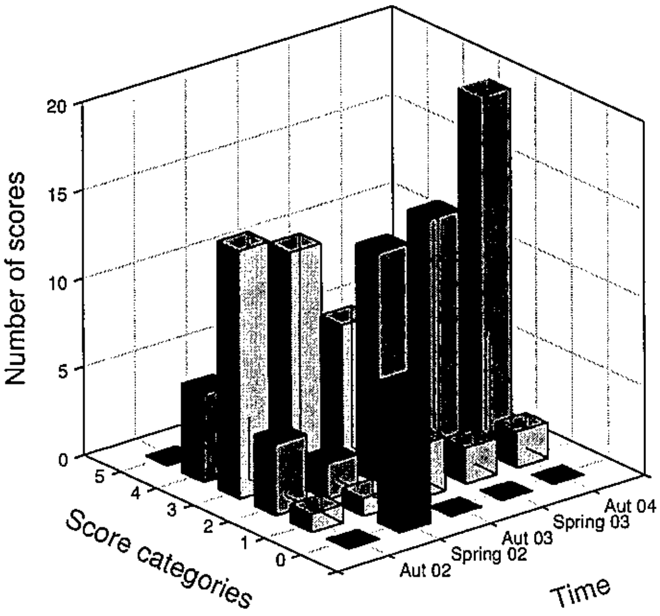
Variable		Total		Native		Introduced		Forb		Grass		Evenness		Heterogeneity	
Time / Contrast	d.f.	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Autumn 2002 Burnt 1999 *vs* unburnt	1, 23	0.02	0.880	0.05	0.834	0.04	0.851	0.10	0.758	0.08	0.786	0.06	0.468	0.22	0.658
Spring 2002 Burnt autumn 2002 *vs* unburnt	1, 23	88.68	<0.001	87.87	<0.001	1.00	0.356	5.99	0.050	61.47	<0.001	7.10	0.037	46.30	<0.001
Autumn 2003 Burnt autumn 1999 only *vs* all other treatments	1, 23	7.37	0.035	3.12	0.128	12.50	0.012	19.25	0.005	0.01	0.936	0.13	0.728	8.31	0.028

APPENDIX 5.4. Changes in the abundance of three common grasses over time in a fire experiment at Kirramingly Nature Reserve. Fire treatment had little influence on the abundance of these species (except in spring 2002), so treatments (i.e. sites either grazed by kangaroos or ungrazed and burnt spring 2002, autumn 2002 or unburnt) were averaged over time. The species are: (a) *Astrebla elymoides*, (b) *Dichanthium sericeum* and (c) *Eriochloa pseudoacrotricha*. Refer to Table 3.1 for the projected cover associated with each cover score.

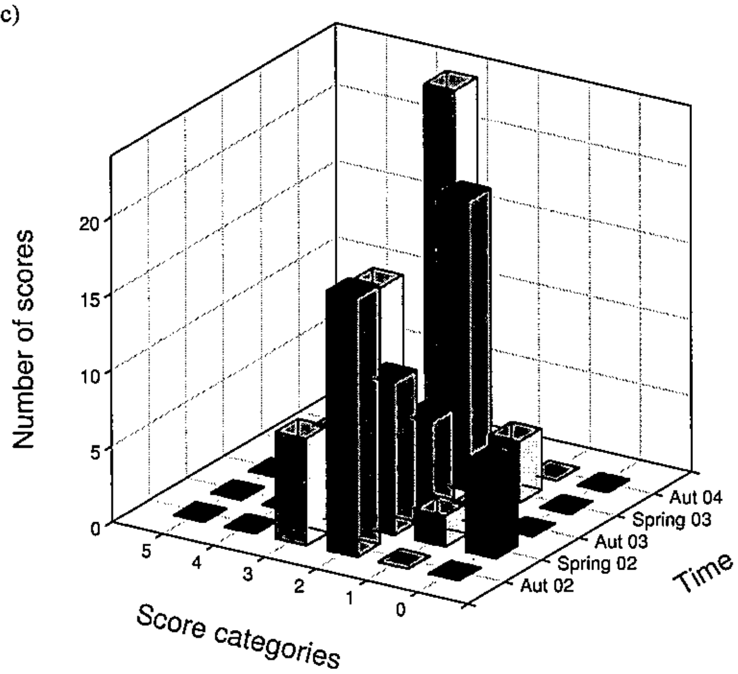
(a)



(b)



(c)


Number of scores
0
5
10
15
20
5
4
3
2
1
0
Score categories
Aut 02
Spring 02
Aut 03
Spring 03
Aut 04
Time

APPENDIX 5.5. Mean frequency score per quadrat (number of occurrences in five concentric sub-quadrats per 32-m² quadrat) for each species, averaged across all fire and grazing treatments (i.e. see Appendix 5.2). *n* = 44 at all times. An * before the species name denotes introduced species.

Species \ Sampling period	Autumn 02	Spring 02	Autumn 03	Spring 03	Autumn 04
Acacia farnesiana	2.00	1.98	2.00	2.07	2.02
Acacia stenophylla	0.00	0.00	0.00	0.02	0.02
Alternanthera denticulata	0.48	0.00	0.86	0.00	0.50
Amaranthus macrocarpus	0.00	0.00	0.20	0.00	0.00
Aristida latifolia	0.11	0.05	0.05	0.02	0.11
Aristida leptopoda	4.34	3.25	3.98	3.68	3.80
Aristida platychaeta	1.23	0.89	0.86	0.89	1.16
Asperula cunninghamii	2.61	0.05	2.05	2.18	0.91
**Aster subulatus*	0.02	0.00	0.00	0.00	0.00
Astrebla elymoides	4.77	3.55	4.89	4.84	4.75
Astrebla lappacea	0.52	0.45	0.98	0.30	0.66
Atriplex semibaccata	0.16	0.07	0.07	0.09	0.07
Austrodanthonia bipartita	0.43	0.20	0.09	0.07	0.16
Boerhavia dominii	2.68	0.86	3.14	1.93	3.02
Brachycome ciliaris var. *subintegrifolia*	2.59	0.02	0.27	1.43	0.45
Brachycome ciliaris var. *ciliaris*	1.36	0.07	0.73	0.68	0.61
Caesia calliantha	0.00	0.00	0.23	0.07	0.02
Calotis hispidula	0.00	0.00	0.34	0.02	0.00
Calotis scabiosifolia var. *scabiosifolia*	0.00	0.00	0.02	0.02	0.02
Chamaesyce drummondii	2.32	0.41	3.55	3.30	3.27
Chloris truncata	4.27	2.95	3.05	2.89	4.11
Convolvulus erubescens	2.89	2.34	4.55	4.75	3.18
**Conyza bonariensis*	0.84	0.00	0.00	0.00	0.00
Crotalaria dissitiflora subsp. *dissitiflora*	0.59	0.05	0.66	0.16	0.59
Cucumis melo subsp. *agrestis*	0.00	0.00	0.11	0.00	0.00
**Cucumis myriocarpus*	0.00	0.00	0.02	0.00	0.00
Cullen tenax	4.07	3.61	4.70	4.77	2.20
Cyperus bifax	3.57	0.00	3.30	2.18	3.61
Dactyloctenium radulans	0.00	0.00	0.14	0.00	0.02
Daucus glochidiatus	0.05	0.00	0.41	1.98	0.00
Desmodium campylocaulon	3.80	0.00	4.07	2.89	4.11
Dichanthium sericeum	4.34	3.16	3.80	3.48	3.86
Digitaria divaricatissima	2.93	2.20	1.77	0.73	3.00
Eclipta platyglossa	0.66	0.07	0.50	0.39	0.41
Einadia nutans subsp. *linifolia*	1.91	1.27	1.07	1.34	1.64
Einadia polygonoides	0.02	0.02	0.05	0.07	0.02
Eleocharis pallens	0.00	0.00	0.05	0.00	0.00
Enteropogon acicularis	1.57	1.02	2.27	1.25	1.77
Eragrostis parviflora	1.09	0.30	2.36	0.50	1.57
Eremophila debilis	0.07	0.07	0.02	0.05	0.05
Eriochloa pseudoacrotricha	4.66	3.43	4.52	2.73	4.95
Erodium crinitum	0.00	0.00	0.68	0.52	0.00
Eryngium plantagineum	1.68	1.45	1.95	2.36	0.98
Euchiton sphaericus	0.16	0.00	0.00	0.00	0.00

Species \ Sampling period	Autumn 02	Spring 02	Autumn 03	Spring 03	Autumn 04
Eulalia aurea	3.50	2.55	3.11	2.93	2.93
Fimbristylis dichotoma	0.00	0.00	0.16	0.00	0.20
Glycine tabacina	0.11	0.00	0.11	0.11	0.11
Goodenia fascicularis	1.16	0.02	2.91	3.23	2.82
Haloragis aspera	0.84	0.00	1.39	1.43	1.18
**Hedypnois rhagadioloides*	0.00	0.00	0.98	3.70	0.00
Hibiscus trionum	0.00	0.00	0.05	0.00	0.05
Iseilema membranaceum	0.00	0.00	0.02	0.00	0.00
Juncus usitatus	0.25	0.09	0.00	0.00	0.02
Leiocarpa tomentosa	0.05	0.00	0.00	0.00	0.00
Leiocarpa websteri	0.80	0.11	0.55	0.66	0.59
**Lepidium bonariense*	0.00	0.00	0.00	0.02	0.00
Leptochloa divaricatissima	0.48	0.43	0.11	0.02	0.18
Lomandra multiflora	0.00	0.00	0.02	0.00	0.00
Maireana aphylla	0.73	0.68	0.73	0.73	0.73
Maireana decalvens	0.48	0.27	0.43	0.41	0.50
Maireana microphylla	0.02	0.02	0.02	0.00	0.02
**Malvastrum americanum*	0.02	0.00	0.00	0.00	0.05
**Medicago polymorpha*	0.00	0.00	4.61	2.82	0.00
**Medicago truncatula*	0.00	0.00	3.32	4.73	0.02
Minuria integerrima	0.02	0.00	0.00	0.00	0.00
Neptunia gracilis	4.95	2.34	4.95	1.18	4.93
Oxalis perennans	3.82	0.27	2.11	2.45	2.30
Panicum buncei	2.32	1.61	2.20	0.61	2.82
Panicum decompositum	2.43	1.59	2.55	0.82	2.64
Panicum queenslandicum var. *queenslandicum*	4.00	2.61	3.82	0.77	4.82
Paspalidium globoideum	0.07	0.00	0.00	0.00	0.09
Phyllanthus virgatus	3.70	0.00	3.59	3.77	4.36
**Physalis lanceifolia*	0.00	0.00	0.64	0.00	0.05
Pimelea microcephala	0.14	0.11	0.07	0.07	0.07
Plantago cunninghamii	0.02	0.00	0.43	1.98	0.00
Podolepis muelleri	0.00	0.00	0.00	0.93	0.00
Portulaca oleracea	0.48	0.00	1.14	0.34	2.95
Pratia concolor	0.00	0.00	0.05	0.00	0.05
Ptilotus semilanatus	2.52	1.27	1.98	2.09	1.95
Pycnosorus globosus	0.80	0.05	0.05	0.23	0.18
**Rapistrum rugosum*	0.32	0.00	2.66	1.43	0.00
Rhagodia spinescens	0.05	0.05	0.07	0.16	0.14
Rhodanthe diffusa	0.00	0.00	0.00	0.30	0.00
Rhynchosia minima	0.20	0.00	0.36	0.23	0.39
Rostellularia adscendens	0.16	0.00	0.14	0.14	0.14
Sclerolaena muricata var. *villosa*	1.57	0.82	1.32	1.27	1.86
Sida cunninghamii	0.18	0.16	0.23	0.16	0.23
Sida trichopoda	2.57	0.84	4.55	4.43	4.59
**Silybum marianum*	0.00	0.00	0.07	0.07	0.00
Solanum esuriale	1.68	0.32	2.07	1.41	2.18
**Sonchus oleraceus*	0.00	0.00	2.07	3.30	0.00
Sporobolus caroli	3.18	2.27	2.48	1.39	4.05
Sporobolus mitchellii	0.02	0.02	0.00	0.00	0.00
Stemodia glabella	0.00	0.00	0.02	0.00	0.00
Swainsona murrayana	0.00	0.00	0.00	0.02	0.00

Species \ Sampling period	Autumn 02	Spring 02	Autumn 03	Spring 03	Autumn 04
Swainsona queenslandica	0.14	0.14	0.09	0.11	0.09
Thellungia advena	1.64	1.32	1.45	1.25	1.20
Themeda avenacea	1.64	1.02	1.50	1.45	1.64
Trianthema triquetra	0.00	0.00	0.23	0.00	0.23
Verbena gaudichaudii	0.43	0.00	0.07	0.32	0.09
Vittadinia cuneata	1.61	0.00	1.89	3.43	1.50
Wahlenbergia communis	2.00	0.30	3.34	1.18	1.73
**Xanthium spinosum*	0.00	0.00	0.02	0.00	0.00

APPENDIX 6.1. Contrasts (one degree of freedom) carried out at each sampling time (spring 2002, autumn 2003, spring 2003 and autumn 2004) for species richness and evenness variables in a mowing experiment at Kirramingly Nature Reserve. Comparisons were made between: (1) mowed sites and controls (M *vs* C); (2) sites mowed twice and sites mowed once (2x *vs* 1x); and (3) high-cut sites and low-cut sites (H *vs* L).

Variable		Total		Native		Introduced		Forb		Grass		Evenness		Heterogeneity	
Time / Contrast	d.f.	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Spring 2002															
M *vs* C	1, 19	12.86	0.003	13.01	0.003	0.25	0.625	16.43	0.001	0.48	0.499	0.36	0.558	2.92	0.109
2x *vs* 1x		2.19	0.161	2.65	0.126	1.25	0.282	0.84	0.374	0.00	0.976	0.04	0.836	1.46	0.247
H *vs* L		0.00	0.975	0.02	0.889	1.25	0.282	0.01	0.927	0.15	0.703	1.43	0.252	0.40	0.539
Autumn 2003															
M *vs* C	1, 19	2.41	0.143	1.82	0.199	0.85	0.373	0.51	0.489	16.38	0.001	1.47	0.245	2.90	0.111
2x *vs* 1x		1.96	0.184	2.92	0.110	4.61	0.050	1.14	0.304	1.32	0.270	0.00	0.950	1.14	0.304
H *vs* L		0.12	0.739	0.47	0.504	4.61	0.050	0.12	0.739	2.62	0.128	0.01	0.918	0.15	0.705
Spring 2003															
M *vs* C	1, 19	0.17	0.685	0.32	0.579	0.73	0.406	0.14	0.716	7.14	0.018	0.06	0.810	0.74	0.404
2x *vs* 1x		1.75	0.207	1.88	0.192	0.00	0.965	3.87	0.069	1.84	0.197	0.45	0.511	1.24	0.284
H *vs* L		0.06	0.812	0.07	0.799	0.00	0.965	0.01	0.912	0.03	0.860	0.80	0.386	0.37	0.550
Autumn 2004															
M *vs* C	1, 19	0.78	0.391	0.56	0.466	1.05	0.323	0.73	0.408	1.14	0.303	1.05	0.323	0.94	0.384
2x *vs* 1x		0.64	0.436	0.69	0.419	0.36	0.560	0.40	0.539	0.21	0.652	0.53	0.477	1.50	0.240
H *vs* L		0.01	0.917	0.08	0.776	2.08	0.171	0.33	0.575	0.82	0.380	0.81	0.382	0.29	0.597

APPENDIX 6.2. All taxa (scientific name, common name and family) recorded during mowing experiments at Kirramingly Nature Reserve. Also shown are species origin (N, native; I, introduced; U, unknown), growth form (F, forb; G, grass; GR, graminoid; S, shrub; SS, sub-shrub) and life cycle (P, perennial; A, annual or biennial; S, short-lived perennial). Mean frequency score per quadrat (number of occurrences in five concentric sub-quadrats per 32-m^2 quadrat) for each species in each treatment ($n = 4$, for all treatments), averaged across all sampling times (spring 2002, autumn 2003, spring 2003 and autumn 2004) is also provided. Treatments were: control (C); low cut, once (LC1); low cut, twice (LC2); high cut, once (HC1) and high cut, twice (HC2). These treatments are defined in Section 6.2.1.

Species	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**	**C**	**LC1**	**LC2**	**HC1**	**HC2**
Acacia farnesiana	Fabaceae	Mimosa Bush	U	S	P	2.56	1.44	1.19	1.38	2.81
Acacia stenophylla	Fabaceae	River Cooba	N	S	P	0.00	0.00	0.00	0.06	0.00
Alternanthera denticulata	Amaranthaceae	Lesser Joyweed	N	F	A	0.31	0.19	0.50	0.25	0.31
Aristida latifolia	Poaceae	Feathertop Wiregrass	N	G	P	0.00	0.00	0.63	0.00	0.13
Aristida leptopoda	Poaceae	White Speargrass	N	G	P	4.25	2.88	3.88	3.50	4.56
Aristida platychaeta	Poaceae	Threeawn Grass	N	G	P	1.50	1.69	1.69	0.00	1.31
Asperula cunninghamii	Rubiaceae	Twining Woodruff	N	F	P	2.31	2.13	1.13	2.38	2.44
Astrebla elymoides	Poaceae	Hoop Mitchell Grass	N	G	P	4.81	5.00	5.00	5.00	4.94
Astrebla lappacea	Poaceae	Curly Mitchell Grass	N	G	P	0.00	0.13	0.13	0.63	0.00
Austrodanthonia bipartita	Poaceae	Wallaby Grass	N	G	P	1.13	0.00	0.19	0.38	0.06
Boerhavia dominii	Nyctaginaceae	Tarvine	N	F	P	2.06	2.38	3.31	2.63	2.44
Brachycome ciliaris var. *subintegrifolia*	Asteraceae	Variable Daisy	N	F	P	0.38	0.63	0.38	0.50	0.31
Brachycome ciliaris var. *ciliaris*	Asteraceae	Variable Daisy	N	F	P	0.31	0.75	0.38	0.06	0.00
Caesia calliantha	Anthericaceae	Grass Lily	N	GR	P	0.19	0.06	0.06	0.19	0.06
Calotis hispidula	Asteraceae	Bogan Flea	N	F	A	0.06	0.00	0.00	0.06	0.00
Calotis scabiosifolia var. *scabiosifolia*	Asteraceae	Rough Burr-daisy	N	F	P	0.00	0.00	0.06	0.00	0.06
Chamaesyce drummondii	Euphorbiaceae	Caustic Weed	N	F	P	2.50	2.50	3.44	2.50	3.75
Chloris truncata	Poaceae	Windmill Grass	N	G	S,A	2.44	3.00	3.25	2.25	3.13
Convolvulus erubescens	Convolvulaceae	Australian Bindweed	N	F	P	2.75	3.69	3.25	3.75	3.75
Crotalaria dissitiflora subsp. *dissitiflora*	Fabaceae	Grey Rattlepod	N	F	P	0.13	0.31	0.44	0.75	1.19
Cucumis melo subsp. *agrestis*	Cucurbitaceae	Ulcardo Melon	N	F	A	0.00	0.00	0.00	0.00	0.06

Species	Family	Common name	Origin	Growth form	Life cycle	C	LC1	LC2	HC1	HC2
Cullen tenax	Fabaceae	Emu-foot	N	F	P	2.63	3.81	3.75	3.75	3.63
Cyperus bifax	Cyperaceae	Downs Nutgrass	N	GR	P	1.25	1.75	2.63	1.38	1.38
Daucus glochidiatus	Apiaceae	Australian Carrot	N	F	A	0.19	0.06	0.25	0.63	0.50
Desmodium campylocaulon	Fabaceae	Creeping Tick-trefoil	N	F	P	3.19	3.31	3.19	3.25	2.94
Dichanthium sericeum	Poaceae	Queensland Bluegrass	N	G	P	2.88	4.00	3.19	3.50	4.38
Digitaria divaricatissima	Poaceae	Umbrella Grass	N	G	P	2.44	3.69	3.06	2.38	3.25
Eclipta platyglossa	Asteraceae	Yellow Twin-heads	N	F	A	0.31	1.31	1.25	1.13	0.19
Einadia nutans subsp. *linifolia*	Chenopodiaceae	Climbing Saltbush	N	F	P	2.56	0.88	1.13	0.75	1.38
Einadia polygonoides	Chenopodiaceae	Knotweed Goosefoot	N	F	A,P	0.06	0.00	0.19	0.06	0.19
Eleocharis pallens	Cyperaceae	Pale Spikerush	N	GR	P	0.00	0.06	0.06	0.06	0.00
Enteropogon acicularis	Poaceae	Large Windmill Grass	N	G	P	1.38	1.81	2.13	1.81	1.75
Eragrostis parviflora	Poaceae	Weeping Lovegrass	N	G	A	0.25	0.38	0.81	0.63	0.44
Eremophila debilis	Myoporaceae	Winter Apple	N	SS	P	0.00	0.25	0.00	0.00	0.06
Eriochloa pseudoacrotricha	Poaceae	Early Spring Grass	N	G	S,A	3.50	3.75	3.63	4.06	3.75
Erodium crinitum	Geraniaceae	Blue Storksbill	N	F	A	0.25	0.13	0.00	0.00	0.31
Eryngium plantagineum	Apiaceae	Long Eryngium	N	F	S,A	0.56	0.81	1.50	1.88	1.19
Eulalia aurea	Poaceae	Silky Browntop	N	G	P	3.63	4.44	3.81	3.44	4.25
Fimbristylis dichotoma	Cyperaceae	Common Fringe Rush	N	GR	P	0.06	0.00	0.00	0.00	0.00
Goodenia fascicularis	Goodeniaceae	Silky Goodenia	N	F	P	2.25	3.13	2.44	2.44	3.06
Haloragis aspera	Haloragaceae	Rough Raspwort	N	F	P	2.56	0.56	1.56	1.75	0.38
Hedypnois rhagadioloides	Asteraceae	Cretan weed	I	F	A	1.19	1.25	1.25	1.19	1.25
Hibiscus trionum	Malvaceae	Bladder Ketmia	N	F	A	0.00	0.00	0.06	0.00	0.00
Juncus usitatus	Juncaceae	Common Rush	N	GR	P	0.06	0.06	0.00	0.00	0.00
Leiocarpa websteri	Asteraceae	Plover-daisy	N	SS	P	0.19	0.06	0.13	0.19	0.19
Lepidium bonariense	Brassicaceae	Cut-leaf Peppercress	I	F	A	0.00	0.00	0.00	0.06	0.00
Leptochloa divaricatissima	Poaceae	Canegrass	N	G	P	0.19	0.13	0.25	0.00	0.00
Lomandra multiflora	Lomandraceae	Many-flowered Mat-rush	N	GR	P	0.06	0.00	0.00	0.06	0.00
Maireana aphylla	Chenopodiaceae	Cottonbush	N	SS	P	1.06	1.00	0.75	1.38	0.25
Maireana decalvens	Chenopodiaceae	Black Cottonbush	N	SS	P	0.00	0.00	0.56	0.00	0.19
Malvastrum americanum	Malvaceae	Spiked Malvastrum	I	F	A	0.00	0.00	0.00	0.00	0.06

Species	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**	**C**	**LC1**	**LC2**	**HC1**	**HC2**
Medicago polymorpha	Fabaceae	Burr Medic	I	F	A	1.56	1.75	1.31	1.81	1.50
Medicago truncatula	Fabaceae	Barrel Medic	I	F	A	2.56	2.50	2.19	2.44	2.25
Neptunia gracilis	Fabaceae	Sensitive Plant	N	F	P	2.94	3.50	3.31	3.38	3.06
Oxalis perennans	Oxalidaceae	Wood Sorrel	N	F	P	2.19	0.94	0.69	1.50	2.25
Panicum buncei	Poaceae	Native Panic	N	G	P	2.31	2.31	1.63	2.06	2.13
Panicum decompositum	Poaceae	Native Millet	N	G	P	1.06	2.88	2.06	1:94	1.94
Panicum queenslandicum var. *queenslandicum*	Poaceae	Yadbilla Grass	N	G	P	2.31	2.88	3.06	3.25	2.88
Phyllanthus virgatus	Euphorbiaceae	Spurge	N	F	P	3.25	3.19	3.25	3.19	3.50
Physalis lanceifolia	Solanaceae	Ground Cherry	I	F	A	0.00	0.19	0.19	0.19	0.13
Pimelea microcephala	Thymelaeaceae	Shrubby Rice-flower	N	S	P	0.19	0.00	0.25	0.00	0.31
Plantago cunninghamii	Plantaginaceae	Sago-weed	N	F	A	0.25	0.25	0.50	0.50	0.25
Podolepis muelleri	Asteraceae	Small Copper-wire Daisy	N	F	A	0.56	0.00	0.31	0.06	0.06
Portulaca oleracea	Portulacaceae	Pigweed	N	F	A	0.25	0.63	1.25	0.69	0.31
Ptilotus semilanatus	Amaranthaceae	Ptilotus	N	F	P	1.25	1.63	2.06	1.25	1.69
Pycnosorus globosus	Asteraceae	Pale Billy-buttons	N	F	A	0.19	0.00	0.00	0.00	0.25
Rapistrum rugosum	Brassicaceae	Turnip Weed	I	F	A	1.13	1.25	1.31	1.19	1.25
Rhagodia spinescens	Chenopodiaceae	Thorny Saltbush	N	S	P	0.38	0.25	0.31	0.25	0.00
Rhodanthe diffusa	Asteraceae	Ascending Sunray	N	F	A	0.00	0.00	0.06	0.00	0.06
Rhynchosia minima	Fabaceae	Rhyncho	N	F	P	0.25	0.88	0.94	0.88	0.56
Rostellularia adscendens	Acanthaceae	Pink Tongues	N	F	P	0.94	0.94	0.00	0.19	0.00
Sclerolaena muricata var. *villosa*	Chenopodiaceae	Grey Rolypoly	N	SS	P	1.19	0.44	1.88	0.38	0.94
Sida cunninghamii	Malvaceae	Ridge Sida	N	F	P	0.25	0.00	0.25	0.00	0.06
Sida trichopoda	Malvaceae	High Sida	N	F	P	2.44	2.56	3.31	3.19	2.44
Solanum esuriale	Solanaceae	Quena	N	F	P	1.06	0.75	1.44	1.13	1.94
Sonchus oleraceus	Asteraceae	Common Sowthistle	I	F	A	2.06	1.69	1.75	2.31	2.00
Sporobolus caroli	Poaceae	Fairy Grass	N	G	A	3.13	2.94	3.75	2.94	3.50
Stemodia glabella	Scrophulariaceae	Stemodia	N	F	P	0.06	0.00	0.00	0.00	0.00
Swainsona queenslandica	Fabaceae	Darling Pea	N	SS	P	0.25	0.00	0.00	0.00	0.00

Species	**Family**	**Common name**	**Origin**	**Growth form**	**Life cycle**	**C**	**LC1**	**LC2**	**HC1**	**HC2**
Thellungia advena	Poaceae	Coolibah Grass	N	G	P	0.56	1.50	0.94	2.25	0.50
Themeda avenacea	Poaceae	Native Oatgrass	N	G	P	2.25	2.38	1.88	1.06	2.25
Tripogon loliiformis	Poaceae	Fiveminute Grass	N	G	A	0.00	0.00	0.06	0.00	0.00
Verbena gaudichaudii	Verbenaceae	Verbena	N	F	P	0.25	0.00	0.06	0.06	0.13
Vittadinia cuneata	Asteraceae	Fuzzweed	N	F	A,P	1.38	0.88	2.50	1.69	1.88
Wahlenbergia communis	Campanulaceae	Tufted Bluebell	N	F	P	1.38	1.56	1.63	1.13	1.63

APPENDIX 6.3. All taxa (scientific name, common name and family) recorded in disc ploughed and unploughed (control) sites at Kirramingly Nature Reserve. Also shown are species origin (N, native; I, introduced; U, unknown), growth form (F, forb; G, grass; GR, graminoid; S, shrub; SS, sub-shrub) and life cycle (P, perennial; A, annual or biennial; S, short-lived perennial). Mean frequency score per quadrat (number of occurrences in five concentric sub-quadrats per 32-m² quadrat) for each species in each treatment, averaged across all sampling times (autumn 2002, autumn 2003 and autumn 2004) is also provided.

Species	Family	Common name	Origin	Growth form	Life cycle	Control ($n = 4$)	Ploughed ($n = 6$)
Acacia farnesiana	Fabaceae	Mimosa Bush	U	S	P	1.70	2.39
Alternanthera denticulata	Amaranthaceae	Lesser Joyweed	N	F	A	0.25	0.39
Aristida latifolia	Poaceae	Feathertop Wiregrass	N	G	P	0.00	0.28
Aristida leptopoda	Poaceae	White Speargrass	N	G	P	4.25	2.06
Aristida platychaeta	Poaceae	Threeawn Grass	N	G	P	1.60	0.44
Asperula cunninghamii	Rubiaceae	Twining Woodruff	N	F	P	2.00	2.61
Astrebla elymoides	Poaceae	Hoop Mitchell Grass	N	G	P	4.95	3.44
Astrebla lappacea	Poaceae	Curly Mitchell Grass	N	G	P	0.00	0.22
Boerhavia dominii	Nyctaginaceae	Tarvine	N	F	P	3.00	3.17
Brachycome ciliaris var. *subintegrifolia*	Asteraceae	Variable Daisy	N	F	P	0.80	1.11
Caesia calliantha	Anthericaceae	Grass Lily	N	GR	P	0.10	0.00
Calotis hispidula	Asteraceae	Bogan Flea	N	F	A	0.10	0.06
Calotis scabiosifolia var. *scabiosifolia*	Asteraceae	Rough Burr-daisy	N	F	P	0.05	0.00
Chamaesyce drummondii	Euphorbiaceae	Caustic Weed	N	F	P	3.65	2.94
Chloris truncata	Poaceae	Windmill Grass	N	G	S,A	3.95	4.78
Convolvulus erubescens	Convolvulaceae	Australian Bindweed	N	F	P	3.20	2.94
Conyza bonariensis	Asteraceae	Flaxleaf Fleabane	I	F	A	0.00	0.22
Crotalaria dissitiflora subsp. *dissitiflora*	Fabaceae	Grey Rattlepod	N	F	P	0.60	0.00
Cucumis melo subsp. *agrestis*	Cucurbitaceae	Ulcardo Melon	N	F	A	0.00	0.17
Cullen tenax	Fabaceae	Emu-foot	N	F	P	4.40	4.28
Cyperus bifax	Cyperaceae	Downs Nutgrass	N	GR	P	2.30	3.33
Daucus glochidiatus	Apiaceae	Australian Carrot	N	F	A	0.35	0.06

Species	Family	Common name	Origin	Growth form	Life cycle	Control ($n = 4$)	Ploughed ($n = 6$)
Desmodium campylocaulon	Fabaceae	Creeping Tick-trefoil	N	F	P	3.70	4.67
Dichanthium sericeum	Poaceae	Queensland Bluegrass	N	G	P	3.65	4.78
Digitaria divaricatissima	Poaceae	Umbrella Grass	N	G	P	3.40	3.67
Eclipta platyglossa	Asteraceae	Yellow Twin-heads	N	F	A	0.00	1.00
Einadia nutans subsp. *linifolia*	Chenopodiaceae	Climbing Saltbush	N	F	P	0.70	0.39
Einadia polygonoides	Chenopodiaceae	Knotweed Goosefoot	N	F	A,P	0.10	0.00
Enteropogon acicularis	Poaceae	Large Windmill Grass	N	G	P	1.05	0.67
Eragrostis parviflora	Poaceae	Weeping Lovegrass	N	G	A	0.20	2.67
Eremophila debilis	Myoporaceae	Winter Apple	N	SS	P	0.00	0.06
Eriochloa pseudoacrotricha	Poaceae	Early Spring Grass	N	G	S,A	4.45	4.72
Erodium crinitum	Geraniaceae	Blue Storksbill	N	F	A	0.00	0.11
Eryngium plantagineum	Apiaceae	Long Eryngium	N	F	S,A	2.60	2.28
Euchiton sphaericus	Asteraceae	Cudweed	N	F	A	0.05	0.00
Eulalia aurea	Poaceae	Silky Browntop	N	G	P	4.40	2.28
Fimbristylis dichotoma	Cyperaceae	Common Fringe Rush	N	GR	P	0.10	0.00
Glycine tabacina	Fabaceae	Variable Glycine	N	F	P	0.05	0.00
Goodenia fascicularis	Goodeniaceae	Silky Goodenia	N	F	P	2.95	2.72
Haloragis aspera	Haloragaceae	Rough Raspwort	N	F	P	2.20	1.11
Hedypnois rhagadioloides	Asteraceae	Cretan weed	I	F	A	1.25	1.33
Hibiscus trionum	Malvaceae	Bladder Ketmia	N	F	A	0.10	0.00
Juncus usitatus	Juncaceae	Common Rush	N	GR	P	0.00	0.11
Leiocarpa websteri	Asteraceae	Plover-daisy	N	SS	P	0.30	0.28
Maireana aphylla	Chenopodiaceae	Cottonbush	N	SS	P	0.25	0.06
Maireana decalvens	Chenopodiaceae	Black Cottonbush	N	SS	P	0.50	0.28
Maireana microphylla	Chenopodiaceae	Eastern Cottonbush	N	SS	P	0.00	0.17
Medicago polymorpha	Fabaceae	Burr Medic	I	F	A	1.40	1.44
Medicago truncatula	Fabaceae	Barrel Medic	I	F	A	1.85	1.22
Neptunia gracilis	Fabaceae	Sensitive Plant	N	F	P	3.80	4.94
Oxalis perennans	Oxalidaceae	Wood Sorrel	N	F	P	2.00	1.50
Panicum buncei	Poaceae	Native Panic	N	G	P	2.90	3.39
Panicum decompositum	Poaceae	Native Millet	N	G	P	1.95	2.50

Species	Family	Common name	Origin	Growth form	Life cycle	Control ($n = 4$)	Ploughed ($n = 6$)
Panicum queenslandicum var. *queenslandicum*	Poaceae	Yadbilla Grass	N	G	P	3.55	4.72
Phyllanthus virgatus	Euphorbiaceae	Spurge	N	F	P	3.00	3.83
Physalis lanceifolia	Solanaceae	Ground Cherry	I	F	A	0.10	0.67
Pimelea microcephala	Thymelaeaceae	Shrubby Rice-flower	N	S	P	0.35	0.00
Plantago cunninghamii	Plantaginaceae	Sago-weed	N	F	A	0.05	0.00
Podolepis muelleri	Asteraceae	Small Copper-wire Daisy	N	F	A	0.30	0.00
Portulaca oleracea	Portulacaceae	Pigweed	N	F	A	0.95	1.28
Pratia concolor	Lobeliaceae	Poison Pratia	N	F	P	0.20	0.00
Ptilotus semilanatus	Amaranthaceae	Ptilotus	N	F	P	2.15	2.39
Pycnosorus globosus	Asteraceae	Pale Billy-buttons	N	F	A	0.10	0.11
Rapistrum rugosum	Brassicaceae	Turnip Weed	I	F	A	0.75	0.22
Rhagodia spinescens	Chenopodiaceae	Thorny Saltbush	N	S	P	0.00	0.28
Rhodanthe diffusa	Asteraceae	Ascending Sunray	N	F	A	0.05	0.00
Rhynchosia minima	Fabaceae	Rhyncho	N	F	P	0.10	1.78
Sclerolaena muricata var. *villosa*	Chenopodiaceae	Grey Rolypoly	N	SS	P	0.50	1.06
Sida trichopoda	Malvaceae	High Sida	N	F	P	3.05	4.00
Solanum esuriale	Solanaceae	Quena	N	F	P	2.40	1.67
Sonchus oleraceus	Asteraceae	Common Sowthistle	I	F	A	1.55	0.50
Sporobolus caroli	Poaceae	Fairy Grass	N	G	A	3.80	3.72
Stemodia glabella	Scrophulariaceae	Stemodia	N	F	P	0.00	0.78
Swainsona murrayana	Fabaceae	Slender Darling Pea	N	F	P	0.05	0.00
Thellungia advena	Poaceae	Coolibah Grass	N	G	P	1.40	1.00
Themeda avenacea	Poaceae	Native Oatgrass	N	G	P	1.45	0.44
Trianthema triquetra	Aizoaceae	Small Hogweed	N	F	A	0.00	0.06
Vittadinia cuneata	Asteraceae	Fuzzweed	N	F	A,P	2.70	0.89
Wahlenbergia communis	Campanulaceae	Tufted Bluebell	N	F	P	2.50	2.56

APPENDIX 7.1. Grazing value of some taxa occurring in the Mitchell grasslands of the Moree Plains. Information on grazing value was obtained from Beadle 1948; Campbell 1989; Cunningham _et al._ 1992; Partridge 1996, 1999. Refer to Appendix 3.2 for species common names. Most species grow during warmer weather or throughout the year unless otherwise indicated. Introduced pasture grasses that are occasionally sown on the Moree Plains (e.g. *_Cenchrus ciliaris,_ *_Setaria incrassata_) are not included. * denotes introduced species.

Grasses	**Forbs / graminoids / sub-shrubs**
Desirable	**Desirable**
Astrebla elymoides	_Atriplex_ spp.
Astrebla lappacea	_Crotalaria dissitiflora_
Other _Astrebla_ spp. (_pectinata_ or _squarrosa_)	_Cullen tenax_
Austrodanthonia bipartita	_Daucus glochidiatus_ (winter active)
Dichanthium sericeum	_Desmodium campylocaulon_
Eulalia aurea	_Glycine latifolia_
Sporobolus caroli	_Glycine tabacina_
	*_Medicago polymorpha_ (winter active)
	*_Medicago truncatula_ (winter active)
	Other *_Medicago_ spp. (winter active)
	Neptunia gracilis
Intermediate or little value	**Intermediate or little value**
Austrostipa aristiglumis	_Alternanthera_ spp.
*_Avena fatua_ (winter active)	_Amaranthus macrocarpus_
Chloris truncata	_Asperula_ spp.
Dactyloctenium radulans	_Boerhavia dominii_
Digitaria divaricatissima	_Brachycome_ spp.
Digitaria porrecta	_Carex inversa_
Diplachne fusca	_Convolvulus erubescens_
Echinochloa colona	*_Conyza bonariensis_ (winter active)
Enneapogon gracilis	_Crinum flaccidum_
Enteropogon acicularis	_Cucumis_ spp.
Eragrostis alveiformis	_Eclipta platyglossa_
Eragrostis parviflora	_Einadia_ spp.
Eragrostis setifolia	_Eremophila debilis_
Eriochloa crebra	_Erodium crinitum_ (winter active)
Eriochloa pseudoacrotricha	_Euchiton sphaericus_
*_Hordeum leporinum_ (winter active)	_Goodenia fascicularis_
Iseilema membranaceum	_Haloragis aspera_
Leptochloa divaricatissima	*_Hedypnois rhagadioloides_ (winter active)
Panicum buncei	_Hibiscus trionum_

Grasses	Forbs / graminoids / sub-shrubs
Panicum decompositum	*Ipomoea lonchophylla*
Panicum queenslandicum	*Leiocarpa* spp.
Paspalidium constrictum	*Lepidium* spp. (winter active)
Paspalidium globoideum	*Maireana* spp.
Paspalidium jubiflorum	**Malvastrum americanum*
**Phalaris paradoxa* (winter active)	*Marsilea drummondii*
Sporobolus actinocladus	*Minuria integerrima*
Sporobolus mitchellii	*Oxalis perennans*
Thellungia advena	*Phyllanthus virgatus*
Themeda avenacea	**Plantago* spp. (winter active)
**Urochloa panicoides*	*Polymeria pusilla*
	Portulaca oleracea
	Ptilotus semilanatus
	Pycnosorus globosus
	Rhynchosia minima
	Sida trichopoda
	Solanum esuriale
	**Sonchus oleraceus* (winter active)
	Swainsona spp.
	Verbena gaudichaudii
	Vittadinia cuneata
	Wahlenbergia communis
Undesirable	**Undesirable**
Aristida latifolia	*Calotis scabiosifolia*
Aristida leptopoda	**Centaurea* spp. (winter active)
Aristida platychaeta	*Chamaesyce drummondii*
Cynodon dactylon	**Cirsium vulgare* (winter active)
Leptochloa digitata	*Cyperus* spp.
Tragus australianus	*Eleocharis pallens*
	Fimbristylis dichotoma
	Juncus spp.
	**Malva parviflora* (winter active)
	**Opuntia stricta*
	**Phyla canescens*
	**Polygonum* spp.
	**Rapistrum rugosum* (winter active)
	Salsola kali
	Sclerolaena muricata
	Other *Sclerolaena* spp. (see Campbell 1989)
	Tribulus micrococcus
	**Tribulus terrestris*
	**Xanthium* spp.