

# Plant composition of three woodland communities of variable condition in the western Riverina, New South Wales, Australia

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**Abstract:** We examined differences in floristics among three regionally-threatened woodland communities in the western Riverina: Blackbox (*Eucalyptus largiflorens*), Bimble box-Pine (*Eucalyptus populnea-Callitris glaucophylla*) and Boree (*Acacia pendula*) between 2001 and 2004. Our aim was to examine possible relationships between the diversity and biomass of groundstorey vegetation, and remnant condition and rainfall both among communities and across years. The three woodland communities varied widely in their plant species composition, with only 22% of the 358 species common to all communities. Seven species, mainly exotic grasses and forbs, contributed 25% of the total cover across all sites and times. Blackbox communities had the greatest number of exotic and annual species. There were poor relationships between condition and diversity, richness, evenness or abundance of groundstorey plant species within 400 m<sup>2</sup> quadrats. Overall, sites in better condition tended to support a greater cover of native plants and a lower cover of exotic plants (Blackbox only). There were only weak relationships between rainfall and biomass. The marked variation in species diversity in relation to changing seasonal conditions and within similar condition classes highlights the difficulties of developing benchmarks for separating the effects of management, and seasonal and longer-term climate change.

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## Introduction

Over the past century the wheat-sheep belt of south-eastern Australia has undergone substantial modification, predominantly through the clearing of vegetation for agriculture. Fertile soils of the western slopes of the Great Dividing Range have suffered dramatic reductions in natural vegetation, with up to 95% removed in some districts (Murray-Darling Basin Ministerial Council 1987, Walker et al. 1993). The removal of large areas of native woodland is exacerbated by the fact that <1% of the native vegetation communities in the NSW Southwest Slopes Bioregion are formally reserved (Thackway & Cresswell 1995) and only small areas of woodland in the eastern sections of the Riverina Bioregion are reserved (Eardley 1999). In particular, fertile soils supporting box woodlands on flat and gently undulating slopes have been extensively cleared for agriculture, with a result that <2% of the original extent of *Eucalyptus melliodora* woodlands remains (Sheahan 1998). Similarly <0.1% of the original grassy white box (*Eucalyptus albens*) woodlands remain in near-natural condition (Prober & Thiele 1995).

Most remnants are also severely degraded, and intact communities with native groundstorey and shrub layers are now extremely rare (Lunt 1991, Curtis & Wright 1993, Prober & Thiele 1995, Spooner et al. 2004). Degradation

of vegetation is associated with increased land degradation (Bird et al. 1992), with increasing woodland fragmentation, increasing numbers of isolated trees, declining tree health, reduced tree recruitment, loss of understorey plants, rising water tables causing salinity and waterlogging, soil erosion, deterioration of soil structure, invasion by exotic plant species and an increase in unpalatable understorey species (Yates & Hobbs 1997). This loss of native vegetation is also associated with a decline in ecosystem function, the ability of the landscape to cycle nutrients, resist erosion and to produce biomass, and therefore a reduction in the quality of habitat for plants and animals. With ongoing clearing, fragmented patches of woodland are increasingly being isolated from related patches, resulting in habitat discontinuity (Bennett 1990). Smaller remnants have higher edge to area ratios, meaning that they are almost entirely edge habitat. Edges may have differences in micro-climate variables, wildlife species and differences in plant structure and composition (Bennett 1990). They are more susceptible to invasion by feral plants and animals (Loney & Hobbs 1991) and consequently tend to support a greater number of weedy plants (Panetta & Hopkins 1991).

In the Murrumbidgee Irrigation Area (MIA) in the western Riverina region of southern NSW, the Bimble box (*Eucalyptus populnea*) – Pine (*Callitris glaucophylla*) and Boree (*Acacia pendula*) communities are regarded

as Endangered, i.e. there is < 10% of pre-European extent remaining, and the Blackbox (*Eucalyptus largiflorens*) community is Depleted i.e. 30–50% of pre-European extent remaining (WRRVMC 2001, Benson et al. 2006). The Blackbox community corresponds mainly with ID13 and ID16, but there are also smaller areas of ID15 of the New South Wales Vegetation Classification (Benson 2006, Benson et al. 2006). The Boree community corresponds with ID26, and the Bimble box-Pine community mainly with ID82 of the Vegetation Classification (Benson et al. 2006). The MIA was originally developed as an irrigation district in the middle of the 20<sup>th</sup> century, and has been extensively cleared to support horticulture, orchards, and more recently, rice farming. Blackbox and Boree communities have suffered substantially from clearing for irrigation because the fine-textured soils on which they occur are highly suitable for irrigation. Bimble box-Pine communities tend to occur on the higher level undulating plains and footslopes, and are generally less suitable for irrigated agriculture. However they have been subjected to overgrazing and vegetation removal to increase carrying capacities for sheep grazing.

Apart from some National Parks and State Forests (e.g. Cocoparra National Park, Binya State Forest), few large tracts of intact woodland remain in the MIA. Many of the smaller patches have been severely degraded due to a combination of overgrazing, selective clearing, removal of the shrub layer and alterations to natural flooding regimes due to changing irrigation practices. Close to the irrigation areas, saline water tables occur within the rooting zone of trees. Consequently the trees are generally in poor health (Harrison 2001, Eldridge 2002). Similarly, many large and generally intact remnants are characterised by a depauperate groundstorey vegetation community, largely though overgrazing. Overgrazing causes palatable native forbs and tall perennial grasses to be replaced by small tussock-grasses and then introduced annual grasses and herbs (Moore 1970, Lunt 1991, Prober et al. 2002), ultimately increasing the proportion of annual exotic plants at the expense of natives and perennials (e.g. Grice & Barchia 1992, Navie & Rogers 1997).

Here we report on a study of the floristics of three regionally important woodland communities in the southern Riverina for which little information is available. The aims of this study are threefold: (1) to examine differences in floristics among the vegetation communities and across years, (2) to examine possible relationships between remnant condition and the attributes of the groundstorey vegetation, and (3) to explore possible relationships between rainfall and groundstorey vegetation.

## Methods

### Study sites

The study was part of a larger biodiversity monitoring program designed to assess condition, in the context of biodiversity, in seven vegetation communities in the western

Riverina. The study was conducted at 42 remnant patches of Blackbox, Bimble box-Pine and Boree within 30 km of Griffith in south-western New South Wales, Australia (34° 05–35° E, 145° 35–146° 08' S). The Blackbox community is restricted to plains, floodplains and relict drainage channels, often with a characteristic gilgai pattern ranging from small crabholes about 30 cm across to wide melon holes and sinkholes up to 20 m across and 1 m deep. Soils are predominantly medium to heavy grey clays (Ug5.24, Ug5.25, Ug5.28; Northcote, 1992), sometimes overlain by clay loams and loams. Slopes were generally less than 1%. Erosion was typically low on the clay soils (<5%), and restricted to the boundary between sandy soils which occur on the margins of the aeolian country. The soils are stable and generally fertile, with high levels of organic carbon (mean = 5.9%).

The Bimble box-Pine community occurs over extensive areas of slightly undulating plains, footslopes and midslopes on deep, loamy calcareous earths (Gn2.12, Gn2.13; Northcote 1992). Often the soil profile has calcareous material at depth. Adjacent to the ranges, soil profiles are dominated by colluvial material eroded from the higher slopes. In many places rock outcrops occurred over 5–10% of the site. On steeply sloping country with little vegetation cover, calcareous red earths are moderately susceptible to gullying, rilling and water sheeting. The soil surface is often dominated by biological soil crusts at cover levels up to 60% (Eldridge 2002). The Boree community occurs on floodplains with gilgai to 1 m across, elevated plains with source-bordering dunes, or the levees of prior streams. Soils range from compacted grey clays (Ug5.24, Ug5.28) to sandy and loamy duplex soils on the prior stream levees (Dr2, Db2, Db4). Boree (*Acacia pendula*) occurs at relatively low densities (< 50 trees ha<sup>-1</sup>). Shrubs such as cassia (*Senna artemisioides*) and hopbush (*Dodonaea viscosa*) occur in moderately high densities at some sites. Common groundstorey species (by cover) included burr medic (*Medicago polymorpha* var. *vulgaris*), climbing saltbush (*Einhadia nutans*), great brome (*Bromus diandrus*), ruby saltbush (*Enchytraea tomentosa*) and corrugated sida (*Sida corrugata*).

### Site selection

We compiled a list of potential woodland sites by digitising onto maps clearly-defined remnants of native woodland vegetation greater than 1 ha in area. The vegetation community characterising these remnants was identified using local knowledge and some ground-truthing. We then used a simple matrix of eight attributes to guide our selection of potential monitoring sites. These attributes were: patch size, connectivity (distance to the nearest patch of similar vegetation), depth to the water table, degree of grazing, tree health, extent of shrub regeneration, extent of tree regeneration, and weediness. The value of each attribute was rated from 0 to 3, with higher ratings corresponding to healthier or more intact sites. For a potential site, the

values for each attribute were summed, and expressed as a percentage of 24, the maximum score for any site. For example, a 23 ha site (rated 2 for size), 70 m distant from the next nearest patch (rated 2 for connectivity), with water table at 1.7 m (rated 1 for water table depth), ungrazed (rated 3 for grazing status), with healthy tree canopies (rating = 3), abundant tree regeneration (rating = 3), few shrubs (rating = 1) and < 10% weeds (rating = 3) would receive an overall score of  $2 + 2 + 1 + 3 + 3 + 3 + 1 + 3 (=18)$  out of a possible score of 24; therefore a value 75 %. A final decision on which sites to monitor from within each woodland community was made by examining the site scores obtained using the process described above. As the aim of the study was to select sites with a range of intactness or condition, we selected sites with a wide range of scores.

Scores for Blackbox sites ranged from 8% (small degraded sites) to 87% (large and intact), Bimble box-Pine from 43% to 100%, and Boree sites from 38–75%. From this process we selected a total of 20 Blackbox, 13 Bimble box-Pine and nine Boree sites. Equal numbers of Blackbox sites ( $n=5$ ) were ungrazed, lightly grazed, moderately grazed and heavily grazed. For the Bimble box-Pine community, five sites were heavily grazed, two moderate, one light and five ungrazed. Three Boree sites were moderately grazed while the remainder were heavily grazed (two sites), lightly grazed (two sites) or ungrazed (two sites).

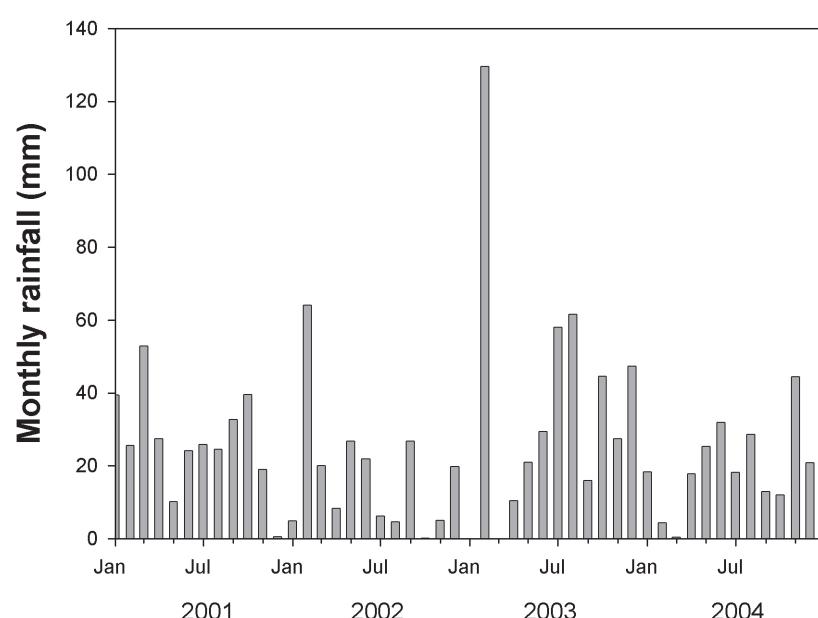
#### The vegetation survey

At each site we established a 20 m by 50 m plot, within which was centrally located a 20 by 20 m plot. The larger plot was selected to be as representative as possible to the site conditions. Projected foliage cover of all vascular

plants was measured, by species, within a 20 m by 20 m plot. The projected foliage cover of all woody plants (shrubs and trees) was measured in a 20 by 50 m plot. Biomass of groundstorey vegetation was assessed using a series of photo-standards developed for grasslands and woodland further west (Eldridge & Koen 2003). Sites were measured in early spring, generally September to October. Monthly rainfall over the period is shown in Figure 1.

#### Site-based condition assessment

Each site was given a subjective score for condition (in the context of biodiversity) when the site was visited, but before measurements were made. The score was based on the senior author's impression of the status of the site, from personal experience with the soils and vegetation of the area, and took into account attributes such as the health of the trees (Wylie et al. 1992) and shrubs, the diversity and floristics of the groundstorey vegetation, the stability of the soil, the presence of weeds and the presence of perennial plants. The scores assigned ranged from very poor condition (rating = 1) to excellent condition (rating = 10). Scores were assigned at each time of measurement. We acknowledge potential problems with a heuristic approach to assessing condition, not the least being the potential for the introduction of personal biases (Oliver et al. 2007). However, in this study all sites were assessed by one observer, and while a different 'expert' might be expected to assess the sites slightly differently, we are confident that the overall ranking would be the same. The Blackbox and Bimble box-Pine sites were measured annually from 2001–2003. Six Boree sites were measured between 2001 to 2003 and an additional three sites added in 2002 and measured thereafter yearly until 2004.



**Fig. 1.** Monthly rainfall (mm) for the four-year period (2001–2004). Measurements were made between September and October in all years.

### Statistical analyses

We used a combination of multivariate and univariate statistics to examine the differences in floristics between the three woodland communities, and relationships between floristics and diversity and other environmental variables. We converted a matrix of 358 columns (plant species) by 126 rows (sites by visits) to a similarity matrix using the 4<sup>th</sup>-root transformation and the Bray-Curtis distance measure using Canonical Analysis of Principal Coordinates CAP statistical package (Anderson 2004). Canonical Analysis of Principal Coordinates combines the use of principal coordinate analysis with either a canonical discriminant analysis (when the hypothesis concerns groups) or a canonical correlation analysis for exploring relationships with environmental or other variables; Anderson and Willis 2003). It tests the significance of these groups, defined *a priori*, using a canonical test statistic. The degree of association of individual species with either Blackbox, Bimble box-Pine or Boree communities was assessed using Indicator-Species Analysis using PC-ORD (McCune & Mefford 1999). Indicator values combine information on relative abundance and frequency of species. For example, when all individuals of a given species are restricted to a particular class, and all samples from the particular class contain an occurrence of that species, then the indicator value is maximal, i.e. IV=100. Species data were randomized among the soil texture, rainfall and forestry practice classes, and a Monte Carlo randomization procedure performed with 1000 iterations in order to determine the statistical significance of the indicator values. The PCORD software was also used to generate information on plant diversity at each site and time, i.e. the number of species, richness and evenness. Relationships between diversity measures between the three communities were examined using one-way ANOVA (Minitab 1997) after using diagnostic tests to check for homogeneity of variance and normality.

## Results

### Community composition

The three woodland communities varied significantly in their plant species composition, and the two canonical test statistics were highly significant ( $P=0.0001$  for both tests, using 9999 permutations; Figure 2). There were some significant differences between years ( $P=0.001$ ), though surprisingly they were not very strong considering the dry conditions in 2002. All years except 2004 different from all other years. Indicator species analysis indicated that *Eucalyptus largiflorens* (IV=100,  $P=0.001$ ), *Hordeum leporinum* (IV=62,  $P=0.001$ ), *Malva parviflora* (IV=52,  $P=0.001$ ) and *Marsilea drummondii* (IV=50,  $P=0.001$ ) were the main indicators of Blackbox sites. *Callitris glaucophylla* (IV=69.4,  $P=0.001$ ), *Cheilanthes sieberi* subsp. *sieberi* (IV=66.5,  $P=0.001$ ) and *Eucalyptus populnea* (IV=52.2,  $P=0.001$ ) were the best indicators of Bimble

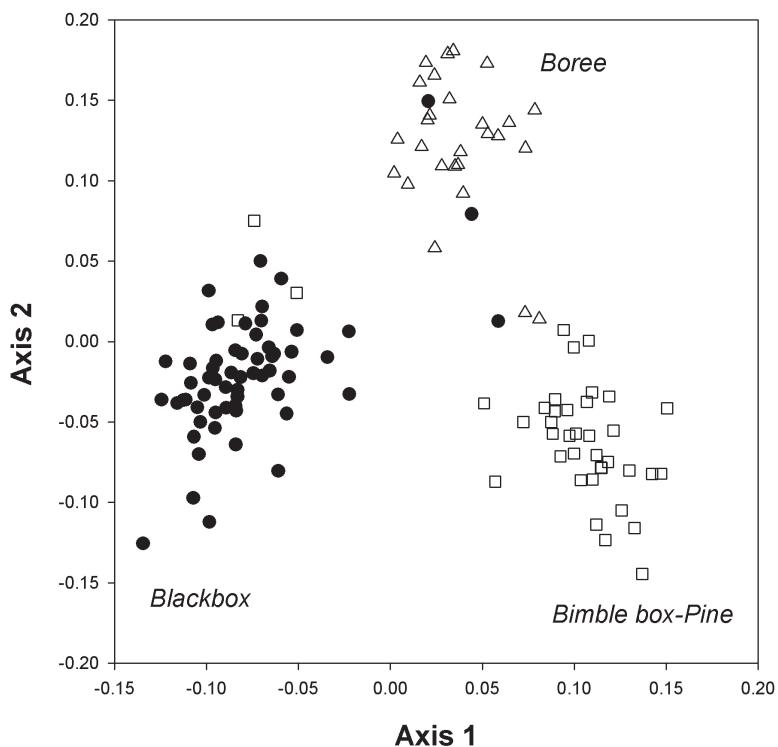
box-Pine sites. The community dominant, *Acacia pendula* (IV=90,  $P=0.001$ ), was a good indicator of Boree sites, along with the chenopod forb *Atriplex semibaccata* (IV=41.3,  $P=0.001$ ). *Avena* spp. (IV=54,  $P=0.005$ ) and *Austrodanthonia caespitosa* (IV=50,  $P=0.009$ ) were strong indicators of 2001, while *Echium plantagineum* (IV=56,  $P=0.029$ ) and *Calotis hispidula* (IV=55,  $P=0.007$ ) were good indicators of 2003.

A total of 358 species was recorded among the three woodland communities over the four years of measurements. Seventy-eight species (22%) were found in all communities, 86 (24%) in two communities and 194 (54%) in only one community. A total of 218 and 240 species was recorded from the Blackbox and Bimble box-Pine communities respectively, and 180 species from the Boree community. About 25% of total cover recorded across all sites and times was contributed by seven species (*Lolium perenne*, *Hordeum leporinum*, *Echium plantagineum*, *Austrostipa scabra*, *Bromus diandrus*, *Sisymbrium* sp., *Arctotheca calendula*), all of which were found in all three communities.

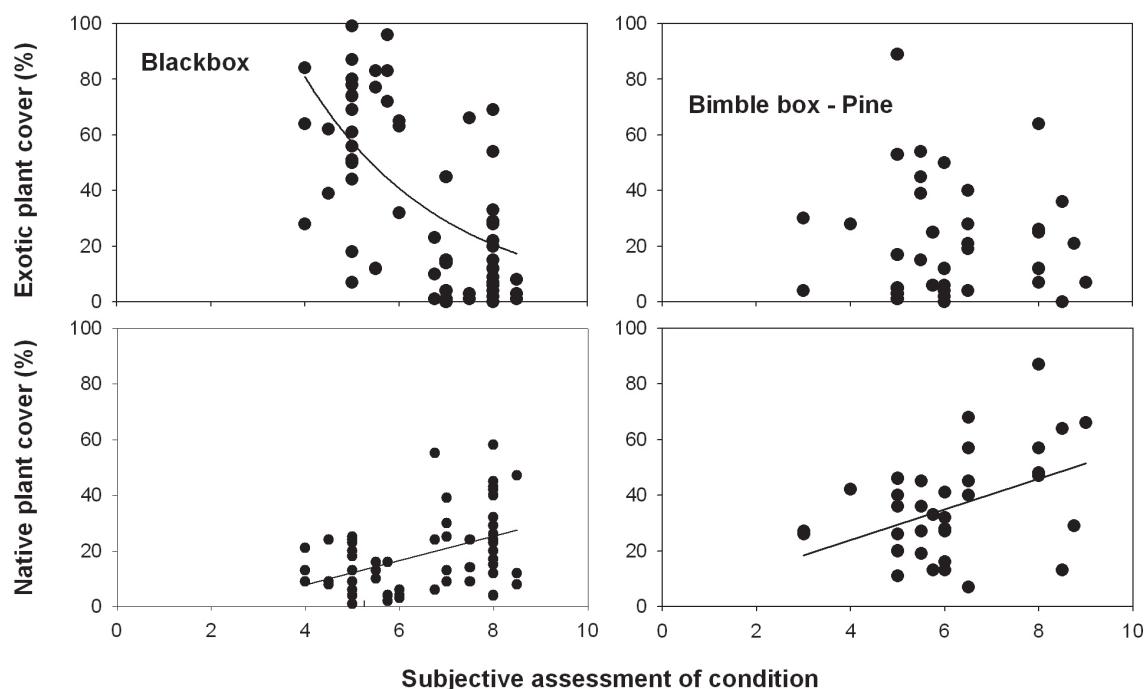
There were significantly fewer species per quadrat in the Blackbox community ( $24.9 \pm 1.37$  mean  $\pm$  SEM) compared with Bimble box ( $32.1 \pm 1.73$ ) or Boree communities ( $30.0 \pm 1.42$ ;  $F_{2,123}=6.79$ ,  $P=0.002$ ). The trend was similar for richness ( $F_{2,123}=10.95$ ,  $P<0.001$ ) and evenness ( $F_{2,123}=8.02$ ,  $P=0.001$ ). Across all vegetation communities there were significantly fewer species per quadrat in 2002 ( $20.0 \pm 1.26$ ) compared with the other years ( $32.3$  to  $35.0$ ;  $F_{3,122}=18.6$ ,  $P<0.001$ ). Blackbox communities supported the highest percentage of exotic species (43.1%) compared with Boree (31.7%) or Bimble box-Pine (26.7%,  $F_{2,123}=10.9$ ,  $P<0.001$ ). The Blackbox community also had a greater proportion of annuals (39.8%) compared with Bimble box-Pine (32.5%;  $F_{2,123}=3.9$ ,  $P<0.023$ ). Bimble box-Pine sites supported twice the number of perennial grass species (7.8 species) compared with the Blackbox sites (4.9 species;  $F_{2,123}=13.2$ ,  $P<0.001$ ).

### Plant cover and diversity in relation to condition and tree cover

Over all communities and across all sampling dates, there was a moderately positive relationship between the condition scores and the cover of exotic plants found within a quadrat ( $F_{1,124}=32.2$ ,  $P<0.001$ ,  $R^2=0.20$ ). Analyses for the Blackbox sites only revealed that increasing condition was associated with a declining cover of exotic plants ( $F_{2,57}=20.2$ ,  $P<0.001$ ,  $R^2=0.43$ ; Figure 3). Further, when condition scores were amalgamated into three groups that were determined, *a priori*, to correspond to obviously differences in condition (i.e.  $<5.1$  = poor condition score,  $5.1$ – $6.9$  = average condition,  $>6.9$  = good condition), exotic plant cover averaged 17% on good condition sites compared with 62% on poor and 51% on average condition sites ( $F_{2,57}=4.35$ ,  $P=0.017$ ). Native plant cover increased slightly with increases in condition ( $F_{1,58}=15.0$ ,  $P<0.001$ ,  $R^2=0.19$ ), but the range of cover increase was very small (Figure 3).



**Fig. 2.** Plot of the first two canonical axes produced by the CAP analysis showing the separation of the three woodland communities in relation to the 358 plant species. Closed circle = Blackbox community, triangle = Boree community, open circle = Bimble box-Pine community.



**Fig. 3.** Relationships between the subjective assessment of condition (increasing number equates with a healthier site) and the cover of exotic and native groundstorey plants in Blackbox and Bimble box-Pine communities. Relationships for Boree community were not significant.

For the Bimble box-Pine sites there was no significant relationship between exotic plant cover and condition, but increases in condition were associated with increased cover of native plants ( $F_{1,34}=8.4$ ,  $P=0.006$ ,  $R^2=0.18$ ; Figure 3). Good condition Bimble box-Pine sites supported 40% more groundstorey species ( $F_{2,36}=3.72$ ,  $P=0.034$ ) and 48% more native groundstorey species ( $F_{2,36}=5.44$ ,  $P=0.009$ ) compared with sites in poor or average condition (Table 3). Overall, Bimble box-Pine community sites in better condition tended to produce more plant biomass ( $F_{1,37}=12.2$ ,  $P=0.001$ ,  $R^2=0.23$ ), but these trends were not evident on Blackbox or Boree sites.

Increases in tree cover were associated with declines in the diversity of understorey plants in 2001 ( $F_{1,37}=4.42$ ,  $P=0.042$ ), though the predictive power was very poor (8%), and 2002 ( $F_{1,40}=18.81$ ,  $P<0.001$ ,  $R^2=0.30$ ). Relationships were not significant in 2003 (Figure 4).

#### Rainfall effects

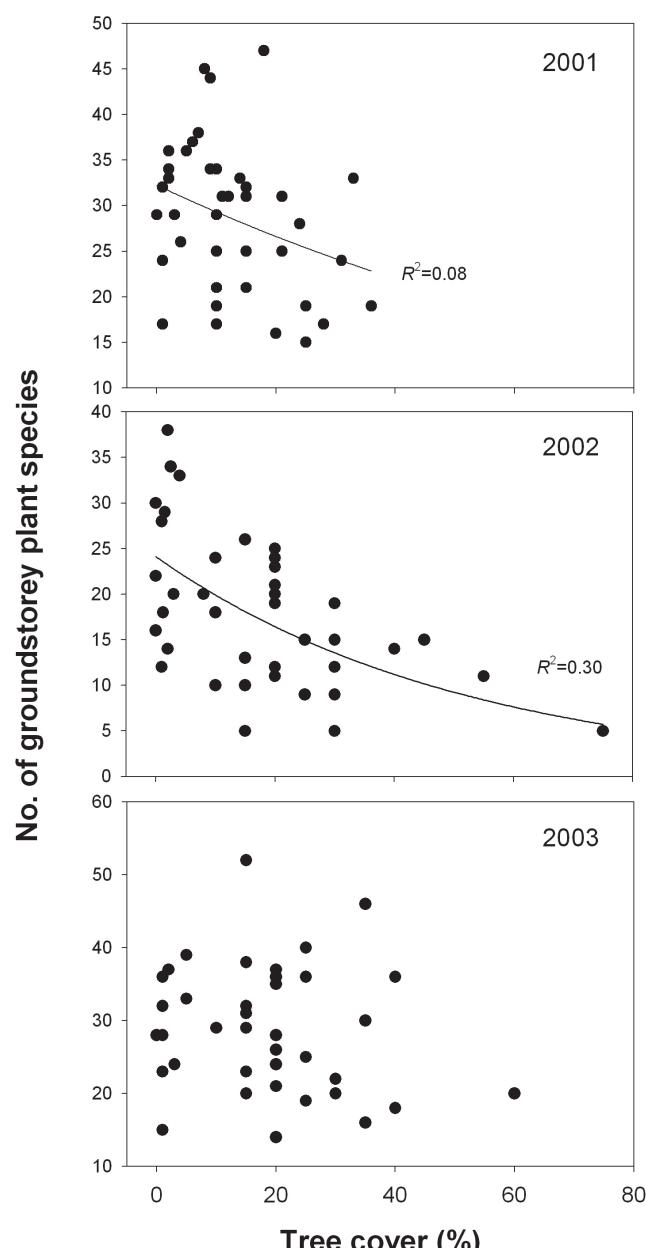
We expected strong relationships between rainfall and measures of quadrat-based diversity, cover and biomass. However, rainfall 3 and 6 months prior to measurements explained 22% and 26% respectively of the variation in the total number of groundstorey plants recorded per quadrat in the Blackbox community ( $F_{1,58}=17.7-21.2$ ,  $P<0.001$ ). However, for the Bimble box-Pine and Boree communities, no significant relationships could be detected between rainfall and plant diversity for lag periods up to 12 months prior to field survey.

Pooled across all sites and sampling dates, we were unable to predict the biomass of groundstorey plants using rainfall 3–, 6– or 12–months prior to measurements. Similarly, no trends were apparent when the data were analysed separately for poor, average or good condition sites (e.g. Blackbox sites). We did, however, find that for the Blackbox community, increases in rainfall over and above 90 mm received during the previous 3 months were associated with increased biomass, but only at the good condition sites ( $F_{1,11}=7.2$ ,  $P=0.02$ ,  $R^2=0.34$ ). There were no similar responses for poor or average condition sites, and for both Bimble box-Pine and Boree communities, biomass was largely independent of rainfall in the past 3 months.

#### Discussion

In our study we detected large differences in floristics between the three vegetation communities with a strong group fidelity, and only 22% overlap in species across the three vegetation communities. The overlapping group came from a wide variety of plant types, including some annual, often weedy European exotics such as *Medicago* spp., *Vulpia* spp., *Avena*, *Sisymbrium* and *Arctotheca calendula*, but also the ubiquitous perennial native grasses and forbs such as *Austrodanthonia*, *Austrostipa*, *Enteropogon*, *Chloris*, *Oxalis perennans*, and the sub-shrubs *Maireana* spp. and *Einadia nutans* var. *nutans*. The high level of agreement

for the majority of plant species (78%) suggests to us that inherent abiotic differences between the communities (e.g. soil texture and depth, parent material and geomorphic location) account for the major differences in the distribution of species. Averaged across all years, the families Poaceae, Chenopodiaceae and Brassicaceae dominated the understorey of Blackbox communities, Poaceae, Asteraceae and Cupressaceae understorey of Bimble box-Pine sites, and Poaceae, Fabaceae and Chenopodiaceae the understorey Boree sites. This is similar to results from other studies in southern NSW (e.g. Porteniers 1993, Sivertsen & Metcalfe 1995) for the Riverine Plain and southern wheat belt regions respectively.



**Fig. 4.** The diversity of groundstorey plant species in relation to tree cover (%) in 2001, 2002 and 2003. Data for the three communities have been pooled.

Rainfall had only a weak influence on plant diversity and biomass, but consistently fewer species, and a greater proportion of perennials and native plants were recorded in all communities in 2002 compared with 2001 or 2003 (Table 1). Seasonal conditions were exceptionally dry in 2002, with Griffith receiving only 46% (193 mm) of its average annual rainfall. The groundstorey vegetation was dominated almost exclusively by the aggressive cool-season annuals *Echium plantagineum*, *Hordeum leporinum*, *Avena* spp., *Bromus diandrus*, *Sisymbrium irissoides*, *Vulpia* spp. and *Carthamus lanatus*, and this trend was consistent across the three vegetation communities. We expect that other cool-season native annuals such as *Goodenia*, *Rhodanthe*, *Atriplex*, *Calocephalus*, *Pseudognaphalium*, *Cotula* and *Harmsiodoxa* spp., which were common in other years, would have disappeared more rapidly in 2002 because of a lack of sufficient soil moisture to sustain them into the spring.

That we failed to find any reasonable relationships between rainfall and diversity, or rainfall and biomass, is surprising given the generally widely-accepted relationship between increasing rainfall amount and increasing plant production

(e.g. Noble & Crisp 1981, Southgate et al. 1996, du Plessis 1999). Extensive data on the relationships between rainfall and biomass production for well-managed semi-arid grazing lands suggest an efficiency of 30–60 g plant dry matter m<sup>-2</sup> mm<sup>-1</sup> rainfall (Le Houérou 1984). As these relationships have been developed over long time periods, their predictive power in understandably likely to be low in specific years or at specific locations. We posited that potentially there could have been interactions between grazing and biomass production, such that any reductions in biomass at grazed sites might have negated potential increases at lightly grazed (ungrazed) sites. Also, there were large populations of kangaroos in many remnants, and consequently, heavy grazing pressure during dry times. However, partitioning sites by grazing intensity failed to improve the relationships between rainfall and biomass production

Tree density could have been an important determinant of the effect of rainfall on biomass and diversity, particularly in landscapes where grazing by domestic herbivores is low or absent (e.g. Chilcott et al. 1997, Gibbs et al. 1999, Ludwig et al. 2001, Dorrough et al. 2006). While we found that increasing tree cover had no apparent effect on understorey

**Table 1.** Attributes of the vegetation in the three woodland communities. <sup>a</sup> condition of the tree canopy assessed after Wylie et al. (1992); maximum score = 6 (fully foliaged), minimum score = 1 (dead, defoliated).

Attribute	Vegetation community									
	Blackbox			Bimble box-Pine			Boree			
	2001	2002	2003	2001	2002	2003	2001	2002	2003	2004
No. of species	30.1	15.3	29.2	35.3	23.9	37.0	33.7	24.8	32.1	35.0
% perennials	60.6	68.8	51.2	66.4	71.1	65.2	61.3	67.4	60.8	62.2
% natives	55.4	64.7	50.6	68.2	78.3	73.5	64.3	71.3	68.9	66.5
Tree condition <sup>a</sup>	4.5	3.9	4.8	5.3	5.0	5.0	5.0	5.1	5.0	5.9

**Table 2.** Mean ( $\pm$  standard error of the mean; SEM) and range of species richness for all groundstorey plants and native groundstorey plants in 400 m<sup>2</sup> quadrats from poor (condition score <5.1), average (5.1–6.9) and good (>6.9) sites in the three woodland communities. For a particular community, different subscripts indicate a significant difference in the number of species between condition classes at  $P<0.05$ . <sup>#</sup> includes native and exotic species.

Condition	All groundstorey plants <sup>#</sup>				Native groundstorey plants			
	Mean	SEM	Min	Max	Mean	SEM	Min	Max
<b>Bimble box-Pine</b>								
Poor	25.1 <sup>a</sup>	3.2	14	52	17.9 <sup>a</sup>	2.6	8	40
Average	26.7 <sup>a</sup>	1.7	16	36	17.8 <sup>a</sup>	1.3	9	31
Good	35.3 <sup>b</sup>	3.2	19	45	26.4 <sup>b</sup>	2.0	13	33
<b>Blackbox</b>								
Poor	22.4 <sup>a</sup>	1.7	5	37	9.8 <sup>a</sup>	1.2	2	21
Average	19.7 <sup>a</sup>	2.3	10	36	10.9 <sup>a</sup>	2.0	3	28
Good	23.8 <sup>a</sup>	2.5	5	47	15.2 <sup>b</sup>	1.3	4	27
<b>Boree</b>								
Poor	28.7 <sup>a</sup>	6.3	20	41	18.7 <sup>a</sup>	3.8	13	26
Average	34.7 <sup>a</sup>	2.7	15	42	24.7 <sup>a</sup>	1.7	15	31
Good	28.8 <sup>a</sup>	1.7	16	39	19.6 <sup>a</sup>	1.3	15	39

biomass, there were moderate effects on diversity. We detected general declines in diversity with increasing tree cover for all communities and years, but none of the relationships was significant ( $P>0.05$ ) when data for the three communities were examined separately. However, when we grouped together data for all woodland sites, increasing tree cover was associated with weak exponential declines in groundstorey plant diversity in 2001, no significant relationship in 2003, but a relatively strong relationships for the dry year of 2002 ( $R^2=0.30$ ; Figure 4). This is an important and interesting finding, and suggests that the effect of tree cover on understorey diversity is moderated by available soil moisture. In below-average rainfall years, trees appeared to be competing with groundstorey plants, probably for moisture, as this is a critically-limiting resource in semi-arid environments. Observations of dense swards of annual grasses and forbs, particularly *Avena* spp. and *Sisymbrium* spp. under tree canopies in average or high rainfall years suggests a groundstorey plant response to moisture, but probably also nitrogen and carbon, which are known to accumulate under tree canopies (Prober *et al.* 2002, Eldridge & Wong 2004). It is unlikely that trees diminished nitrogen levels greatly, given the fact that many plants recorded in the dry year were annual Mediterranean weeds, which would be expected to have had a high demand for soil nitrate.

Undoubtedly, understorey plants would have benefited from being close to trees by being able to access water drawn from deeper layers by hydraulic lift (Caldwell & Richards 1989). Pools of organic matter would have contributed to greater carbon, nitrogen, phosphorus and potassium pools under trees compared with in the open (Prober *et al.* 2002, Eldridge & Wong 2004), the result of stem flow processes, the trapping of dust, and increases in litter and soil organic matter at the base of trees (Munzbergova & Ward 2002), all of which are processes mediated directly by the trees themselves (Deans *et al.* 1999). This will eventually lead to the development of fertile patches around the trees, areas of enhanced soil nutrients (Gersper & Holowaychuk, 1971, Rhoades, 1997), which in agricultural areas, are often dominated by a halo of dense annual grasses (Prober *et al.* 2002). Our data suggest that the extent to which understorey plants benefited from proximity to tree canopies depends on seasonal conditions.

This study also highlights the relationships between condition assessed at the site level and the diversity of groundstorey plants. In the Blackbox community in particular, quadrats from sites in good condition supported about 50% more native plants compared with those from poor or average condition sites (Table 2). However, the relationships were very weak for the Bimble box-Pine sites. While we acknowledge that condition is highly subjective and often value-laden and context-dependent (Oliver 2002), our subjective assessment of condition was nonetheless highly correlated with indicators of functional, highly organised landscapes (Eldridge 2002). Apart from a greater proportion of native plants, quadrats in good condition sites had significantly greater cover of perennial plants, greater foliage and basal cover of perennial

grasses, and more patches in the landscape, all characteristics that we would attribute to healthy sites. Although there were a few large patches of Blackbox in the study area, many sites were small and adjacent to cultivated farms, and although effectively ungrazed, were severely degraded due to their small size and proximity to roads. The Boree sites were similar, occurring as very small, highly degraded patches, with their present status less than 30% of its pre-European extent (WRRVMC 2001).

The study can improve our understanding of the variability in species cover and diversity across three important woodland communities of variable condition in the Riverina. We showed that an extensive cover of native plants is a useful indicator of condition for Blackbox sites, while exotic plant cover is indicative of degraded sites, particularly in the Bimble box-Pine community (Figure 3). However, plant diversity was less informative, and while there were differences in mean diversity between good and poor condition sites (Table 2) the range in diversity for Blackbox sites (4–27 species per quadrat for good condition sites) was close to that of poor condition sites (2–21 species per quadrat; Table 2). The marked variation in species diversity in different seasons, and the large overlap in diversity for sites of different condition highlights the difficulties of developing benchmarks for separating out the effects of management from seasonal effects and longer-term climate change. This reinforces the view that benchmarking of these communities will not be easy.

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