

Floristic patterns along an east–west gradient in grassy box woodlands of Central New South Wales

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Abstract: Temperate grassy box woodlands are the predominant native vegetation of the 'wheat-sheep' belt of south-eastern Australia. In New South Wales, a number of different eucalypt species form the overstorey of these woodlands, with changes in dominance from *Eucalyptus melliodora* (Yellow Box) and *Eucalyptus albens* (White Box) in the east to *Eucalyptus microcarpa* (Grey Box) and *Eucalyptus populnea* (Poplar Box) in the west. Most grassy Box woodlands have now been cleared or modified for agriculture, and their conservation is dependent on adequate knowledge of the distribution, ecology and management needs of remaining woodlands. In this study we describe the understorey flora of high quality remnants of grassy Box woodlands along an east-west gradient in central New South Wales, comparing sites with a history of minimal livestock grazing (cemeteries) with sites with a history of intermittent livestock grazing (travelling stock reserves). With some important exceptions relating to *Eucalyptus melliodora*, dominant overstorey eucalypts were good indicators of understorey changes along the east-west gradient. A particular disjunction, involving changes in the dominant grasses from *Themeda australis* and *Poa sieberiana* to *Austrostipa scabra*, *Austroanthonia* and *Enteropogon* species, distinguishes 'eastern' (*Eucalyptus melliodora*, *Eucalyptus albens*) from 'western' (*Eucalyptus microcarpa*, *Eucalyptus populnea*) Box woodlands, and has significant implications for understorey management. Notable changes in subsidiary species included changes in the main genera of shrubs and daisies, and a number of trends at the family level. Families such as Dilleniaceae, Haloragaceae, Epacridaceae and Ranunculaceae were more frequent or diverse in eastern Box woodlands, and gave way to species of the families Malvaceae, Chenopodiaceae, Myoporaceae, Amaranthaceae and Brassicaceae in the west. Intermittent grazing influenced understorey composition in all box woodlands sampled, although influences in western Box woodlands were less pronounced. Effects of grazing included a decline in shrub abundance and loss of a range of native perennials across all woodlands, changes to the dominant grasses and a considerable increase in exotic annuals in the east, and a decline in native grass diversity and increase in native annuals in the west.

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Introduction

Temperate grassy box woodlands are the predominant native vegetation of the productive soils of the 'wheat-sheep' belt of south-eastern Australia. Before European settlement, they occupied millions of hectares on the Tablelands, Slopes and Plains of New South Wales, on the Wimmera and Northern Plains of Victoria, and on the Darling Downs of southern Queensland (AUSLIG 1990a, Keith 2002).

In central NSW, a number of different eucalypt species form the overstorey of grassy box woodlands, with changes in dominance broadly reflecting rainfall and temperature gradients with distance inland. Yellow Box (*Eucalyptus melliodora*) and Red Gum (*Eucalyptus blakelyi*) are dominant on the Tablelands, and form mosaics with White Box (*Eucalyptus albens*) in the eastern Slopes regions. Grey Box (*Eucalyptus microcarpa*) and occasionally Fuzzy Box (*Eucalyptus conica*) become dominant further to the west, especially on alluvial red brown earths, and Bimble Box (*Eucalyptus populnea*) forms large tracts of woodland still further west (Beadle 1948, Moore 1953a). Black Box (*Eucalyptus largiflorens*) also forms distinct communities on heavy alluvial soils in western NSW (Beadle 1948), but these were not a subject of this study.

Grassy box woodlands are distinguished from shrub woodlands by the presence of a well-developed grass and forb layer and the lack of a dense shrub layer, although scattered or patchy shrubs may be present. Woodlands with a grassy understorey predominate on the better soils in the White Box, Yellow Box and Red Gum regions, and some of the Grey and Bimble Box regions (Moore 1953a, Moore 1993, Prober 1996). Box woodlands with a more shrubby understorey predominate in lower rainfall areas in the west, especially in the Bimble Box areas (Beadle 1948, Beeston et al. 1980, Moore 1993), and on shallower or lower nutrient soils in more eastern woodlands (Prober 1996, Keith 2002). Understorey types tend to intergrade on intermediate sites, but at the extremes the shrubby and grassy understoreys may share few species. This study focused on woodlands with a grassy understorey.

Owing to the productive nature of the soils they grow on, most of the grassy box woodlands have been cleared for agriculture, and uncleared areas have been modified to varying degrees by livestock grazing or other disturbance. As a result, grassy box woodlands have been classified as one of the most poorly conserved ecological communities in Australia (Specht 1981, Benson 1991), and some types have been listed as endangered ecological communities in NSW

(White Box, Yellow Box, Blakely's Red Gum Woodland under the *NSW Threatened Species Conservation Act 1995*), the Australian Capital Territory (Yellow Box and Red Gum Woodland under the *Nature Conservation Act 1980*) and nationally (Grassy White Box Woodlands under the *Environment Protection and Biodiversity Conservation Act 1999*). Efforts to conserve the grassy Box woodlands are increasing, and include remnant fencing programs (McDonald 2000), extension programs (Elix & Lambert 1998), coordinated protection and management of remnants through the Grassy Box Woodlands Conservation Management Network (Prober et al. 2001), and legislative controls (e.g. state vegetation clearance controls and threatened ecological community listings).

The success of such conservation efforts in the box woodlands is dependent on adequate ecological knowledge, including an understanding of environmental and management-induced patterns in floristic and faunal composition. Currently such information is patchy, and detailed information is completely lacking for some of the box woodlands and for many fauna groups. Most botanical studies of grassy box woodlands in NSW have focused on regional vegetation classification and mapping (e.g. Moore 1953a, Beadle 1948, Costin 1954, Moore 1970, Sivertsen & Metcalfe 1995, Austin et al. 2000, Keith 2002). These studies were largely based on overstorey species, but provide general descriptions of understorey composition and some include more detailed discussion of perceived changes in the understorey resulting from European settlement (Beadle 1948, Moore 1953b, Costin 1954, Moore 1970). Prober and Thiele (1995) and Prober (1996) undertook broadscale analyses of environmental and management induced variation in the understorey of grassy White Box woodlands throughout their range in NSW. However, relationships between understorey, environment and management across the different box woodland types are still poorly understood.

In this study, we sampled the understorey flora of grassy Yellow Box (*Eucalyptus melliodora*), Red Gum (*Eucalyptus blakelyi*), White Box (*Eucalyptus albens*), Grey Box (*Eucalyptus microcarpa*) and Bimble Box (*Eucalyptus populnea*) woodlands along an east-west gradient in central NSW. As these ecological communities are highly disturbed across their range, we focused on data from the least-disturbed remnants available, comparing cemetery remnants (with a history of minimal or no livestock grazing) with some of the least disturbed travelling stock routes and reserves (TSRs, with a history of intermittent livestock grazing). Our aims were to describe natural patterns in native understorey composition across the gradient, to assess relationships between understorey and overstorey composition, and to compare the effects of these two broadly differing management regimes across the range of woodland types. It was also important to begin identification of significant remnants and contribute to an improved understanding of the native understorey in Grey and Bimble Box Woodlands, where conservation efforts are particularly hindered through lack of such information.

Methods

Sampling strategy

Floristic data were collected for 82 grassy box woodland remnants across an east-west gradient in central NSW, representing a general decline in rainfall from 800 mm on the Tablelands to 400 mm on the Western Plains (AUSLIG 1990b). Sampling extended from Hall (Australian Capital Territory, 120 km inland) to Nymagee (506 km inland), with most samples concentrated within the region defined approximately by the towns Condobolin, Narrandera, Canberra and Wellington (Fig. 1). Sites were spread across a relatively broad latitudinal range and included outliers at Nymagee and Trangie (Fig. 1), in order to capture information from rare, little-disturbed cemetery remnants.

Given the rarity of high quality native understorey in the highly disturbed and fragmented grassy woodlands characteristic of this region, our sampling strategy focused on seeking out sites with relatively good-condition native understorey. Earlier studies in grassy woodlands and

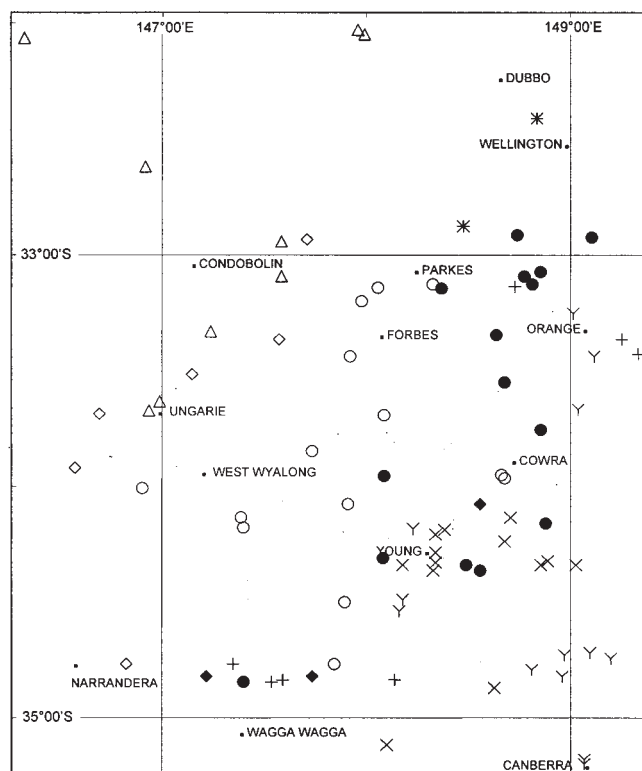


Fig. 1. Map showing the distribution of sites sampled and their dominant overstorey eucalypts:

- ∇ *Eucalyptus melliodora* & *Eucalyptus blakelyi* (Yellow Box, Red Gum)
- +
- × *Eucalyptus albens* & *Eucalyptus melliodora* (White Box, Grey Box)
- *Eucalyptus albens* (White Box)
- ◆ *Eucalyptus albens* & *Eucalyptus microcarpa* (White Box, Grey Box)
- *Eucalyptus microcarpa* (Grey Box)
- ◇ *Eucalyptus microcarpa* & *Eucalyptus populnea* (Grey Box, Bimble Box)
- △ *Eucalyptus populnea* (Bimble Box)
- * *Eucalyptus conica* (Fuzzy Box)

grasslands have shown that little-used country cemeteries, roadsides and TSRs are important refugia for woodland and grassland flora (Stuwe & Parsons 1977, Prober & Thiele 1995), thus site selection was restricted to remnants in either cemeteries (with a history of minimal grazing by livestock), or TSRs and roadsides, which generally have a history of intermittent livestock grazing.

Selection of sample sites within the two landuse classes was subjective, as high quality areas are rare and unpredictable in their occurrence, and random sampling would often lead to sampling of weedy sites with a limited suite of native plants. All cemeteries marked on 1:100 000 topographic maps within the region were visited, as well as others located through local information. These were sampled if they retained apparently little-disturbed native vegetation with relatively low weed abundance, but rejected if they were unfenced or clearly disturbed through cemetery operations or livestock grazing.

TSR samples were selected after reconnaissance surveys of a wide range of travelling stock reserves throughout the main study region, including the most promising areas based on floristic information from vegetation maps (Moore 1953a, Beadle 1948), unpublished surveys (A. Nowlandt, R. Rehwinkel pers. comm.) and local Rural Lands Protection Boards. We aimed for good coverage of the region and at least 8 TSR samples of grassy woodland per overstorey type (see below). Within these criteria, we sampled the highest quality sites, as judged by low weed abundance and high native cover and richness, that we could locate within the time available.

As described above, sampling was stratified on landuse (TSR/roadside, cemetery), and to ensure the range of overstorey species was represented (Bimble Box, Grey Box, White Box, Tablelands Yellow Box/Red Gum, Slopes Yellow Box/Red Gum). Owing to the paucity of high quality cemetery remnants, samples included sites with mixtures of these overstorey species, and resulted in a minimum of 7 cemetery and 8 TSR samples containing each overstorey species. The final sample included 33, 32, 31, 23 and 15 sites containing Yellow Box, Red Gum, White Box, Grey Box and Bimble Box respectively (including mixed sites), and 39 cemetery, 5 roadside and 38 TSR remnants. Several Fuzzy Box sites were also sampled, but these were not sufficient for describing understorey in these woodlands. It was not within the scope of this study to stratify on environmental variables such as lithology or soil type, but these variables were used in subsequent data analyses.

Sampling methodology

Small, well defined remnants such as most cemeteries and smaller TSRs were surveyed across their full extent, provided they were relatively uniform in soil type, topography and overstorey. Anomalous areas such as creek lines, swamps or graves were excluded. For larger, more continuous sites, particularly travelling stock routes and roadsides, relatively

uniform sections were selected, with selections favouring areas of lowest exotic species abundance. Where possible we chose to sample larger areas rather than smaller quadrats because this was more effective for detecting native species that are often sparse in grazed sites, and because it provided a more complete record of discrete remnants, and thus was valuable for conservation planning and management purposes. This led to a high variation in plot sizes (0.04 to 56 ha, mostly 0.1 to 5 ha) that required consideration during data interpretation. However, correlations between plot size and relevant floristic data were generally very weak (see results).

Each survey area was visited once, in most cases during spring (1991–2001), and all species of higher plants observed within it were recorded. The survey area was traversed over its widest dimensions, until few new species were being added to the list. After traversing the survey area, a subjective abundance measure was allocated to each species, using the following scale: 1, rare; 2, uncommon; 3, occasional; 4, common; 5, very common (as per Prober & Thiele 1995). One of us (SMP) allocated abundance measures at all sites, to maximize consistency of scoring. Taxonomy follows Wheeler et al. (2002) for grasses, Bayer (2001) for *Xerochrysum*, and Harden (1990–3) for other species.

The following environmental attributes were recorded for each site: latitude, longitude, elevation, topographic class (an ordered sequence from hilly, undulating-hilly, undulating, gently undulating, to flat), landuse (TSR, roadside, cemetery), degree of tree clearing (wooded, thinned, almost fully cleared), lithology (according to 1:250 000 geological map sheets), and soil resource class (arable, suitable for grazing only, unsuitable for agriculture, according to the 1:1000 000 dyeline of Soil Resources Sheets 1 and 2, Soil Conservation Service of NSW). Rainfall in the study region generally declines, and temperature generally increases, with distance inland (Moore 1953a, AUSLIG 1990b, Austin et al. 2000), thus distance of the site from the coast was estimated from maps as a surrogate measure of these climatic influences. For interpreting analyses of understorey data, sites were classified into the following overstorey groups, based on the combinations that occurred in final set of samples: *Eucalyptus blakelyi/melliodora*, *Eucalyptus melliodora*, *Eucalyptus albens/blakelyi/melliodora*, *Eucalyptus albens*, *Eucalyptus albens/microcarpa*, *Eucalyptus microcarpa*, *Eucalyptus microcarpa/Eucalyptus populnea*, *Eucalyptus populnea*, *Eucalyptus conica*. While these groups are discrete classes, they formed an approximate east–west sequence that could be used for vector fitting (see below). Botanical region of occurrence (Southern Tablelands, Central Tablelands, South Western Slopes, Central Western Slopes, South Western Plains) was determined from Harden (1990–3).

Richness and relative abundance of various plant groups (natives, exotics, native shrubs, native annuals, native plant families) were calculated from the floristic data. Relative abundance was estimated by summing abundance scores for species within each group, and expressing this as a

percentage of the sum of abundance scores for all species at a site. Relative rather than absolute sum of abundance scores was used to help correct for variation between samples in total cover and in sample area.

Data analysis

Classification of floristic data

Floristic data were subjected to the UPGMA cluster analysis procedure of PC-Ord (McCune & Mefford 1999), using the Bray-Curtis coefficient of dissimilarity. The Bray-Curtis similarity measure excludes shared species absences when calculating distances between pairs of plots. This renders the analysis less sensitive to species richness of sites, which may be affected by the variation in plot sizes in our dataset. Tree species were excluded from analyses because understorey patterns, including correlations with overstorey type, were the main interest of the study.

Ordination of floristic data

Ordination techniques were used to explore patterns in the full data set, and in two data sub-sets ('eastern' and 'western' Box woodland) determined from the full analysis.

For all data sets, quantitative floristic data (excluding tree species) were standardized to equal maxima and used to produce a distance matrix using the Bray-Curtis coefficient of dissimilarity (Faith et al. 1987). Non-metric multi-dimensional scaling (nMDS) analyses were performed on the distance matrices using the software package DECODA (Minchin 1989), and results were transferred to PC-ORD (McCune & Mefford 1999) for plotting and visual analysis. Preliminary analyses were performed in one to five dimensions using 10 random starts and global nMDS, and the 'minimum stress' solutions from each of these analyses were used as single starting configurations for hybrid nMDS in the respective dimensions. The two-dimensional hybrid nMDS solution was chosen for the analysis of the full data set, as recovery of ecological gradients was only minimally increased in higher dimensions. Three dimensions were necessary to best explain patterns in the two data subsets.

Correlations of environmental attributes with the distribution of sites on the final ordinations were examined by plotting each directly onto the ordination and, where appropriate, by calculating vectors of maximum correlation (R_{\max} , see Prober & Austin 1991) using the vector-fitting procedure of DECODA. Monte-Carlo tests, using 1000 random permutations of the data, were used to estimate the significance of each vector correlation. Where appropriate, vectors were used to order sites and species into two way tables indicating species contributing to relevant trends.

Species diversity statistics

We generally avoided analysis of species diversity statistics in this study, because of the complicating influence of plot size. However, as correlations between plot size and floristic and environmental variables were generally very weak (see

results), we present some comparisons of diversity of specific plant groups (plant families, annual natives and shrubs) with environmental variables.

Results

A total of 538 species from 82 plant families was recorded from the 82 survey sites, including 368 native and 170 exotic species. The most frequently recorded species included the natives *Elymus scaber*, *Austrostipa scabra*, *Lomandra filiformis* and *Bulbine bulbosa*, and the exotics *Hypochaeris radicata*, *Lolium* spp., *Bromus molliformis* and *Echium plantagineum*, which all occurred in over 60% of sites. Species with the highest mean abundance were the native grasses *Austrostipa scabra*, *Themeda australis* and *Poa sieberiana*, and the exotics *Lolium* spp. and *Hypochaeris radicata* (mean abundance 2 to 2.4). Native plant species richness ranged from 24 to 76 species per sample (mean 43). All sites contained exotic plants (range 5 to 53 species, mean 25), suggesting that no remnants of grassy Box woodland in the region have escaped the influences of European settlement.

Ordination of the full dataset indicated two major trends in the floristic data, the first relating to climatic gradients and lithological changes along the east-west gradient, and the second relating to landuse (Table 1). Analyses of data subsets were generally consistent with the full analysis, and thus are discussed in more detail only where exceptions or improved resolution were noted. Similarly, the UPGMA cluster analyses generally reflected the most prominent trends indicated by the ordination. Note also that, while exotic species showed significant trends on the ordination, similar ordination results were obtained when exotics were excluded from analyses.

Table 1. Correlation (R_{\max}) of environmental and floristic variables with the ordination of the full dataset and the eastern and western data subsets. Significance of correlations are indicated by *($p < 0.001$), **($p < 0.01$), *($p < 0.05$).**

Variables	R_{\max}		
	All data n=82	Eastern n=45	Western n=32
Environmental			
Distance inland	0.84***	0.81***	0.75***
Elevation	0.79***	0.77***	0.35
Topographic class	0.72***	0.26	–
Landuse	0.68***	0.89***	0.69***
Latitude	0.45***	0.58***	0.76***
Soil resource class	0.32*	0.29	0.19
Tree clearing	0.31*	0.35	0.24
Sample area	0.30*	0.46*	0.65*
Floristic			
Overstorey type	0.83***	0.69***	0.73***
Relative exotic species abundance	0.76***	0.87***	0.65**
Relative native shrub abundance	0.73***	0.75***	0.86***
Native shrub richness	0.66***	0.67***	0.84***
Relative native annual abundance	0.63***	0.71***	0.87***
Native annual richness	0.52***	0.69***	0.88***
Native grass richness	0.37**	0.4	0.69***
Total native richness	0.24	0.35	0.76***

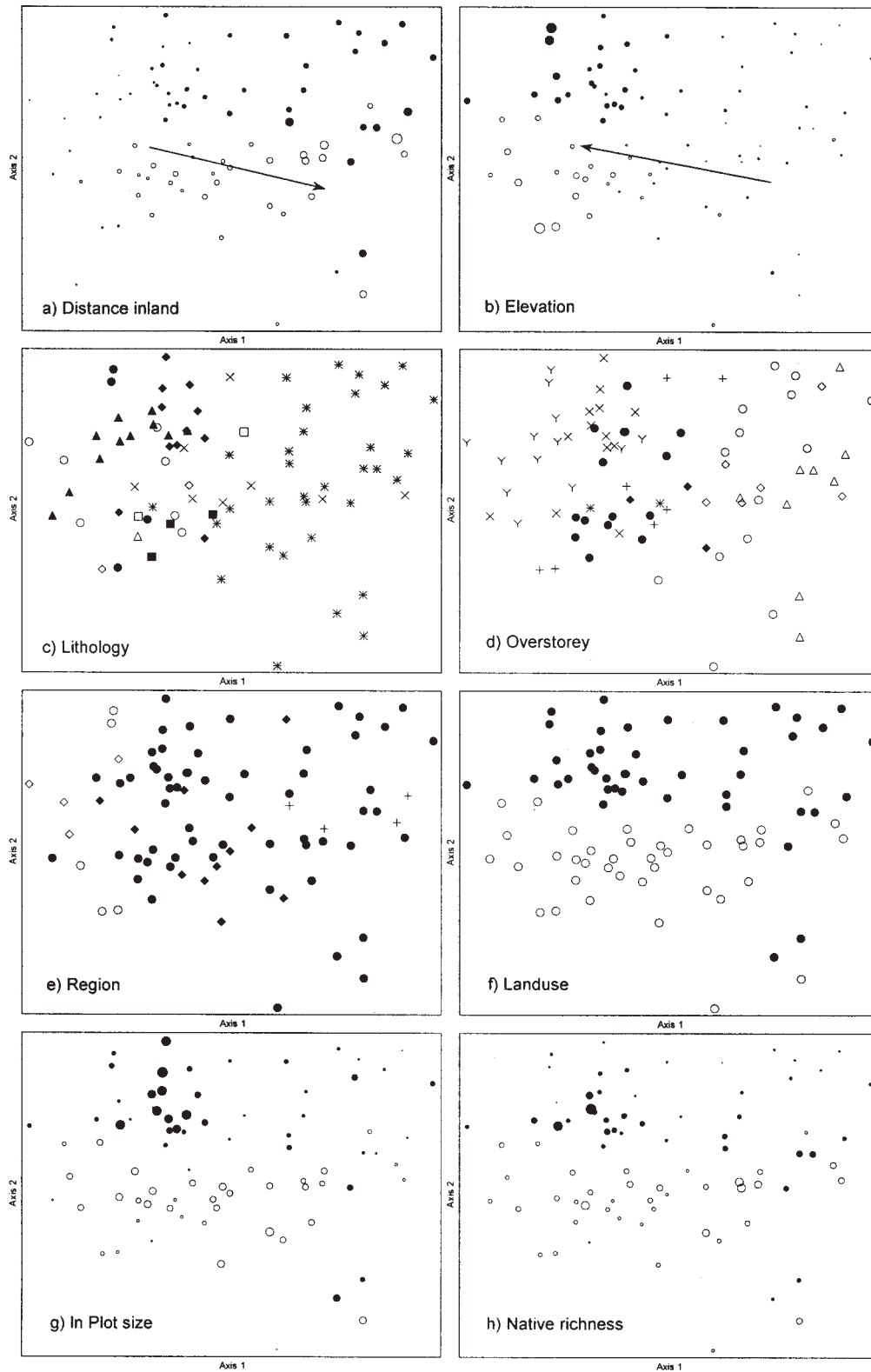


Fig. 2. MDS ordination of the full dataset showing trends in (a) distance inland (indicated by circle size) and landuse (● TSRs and roadsides, ○ cemeteries), (b) elevation (indicated by circle size) and landuse, (c) lithology (igneous: ● alkaline volcanics (basalts), ▲ intermediate to acid volcanics (andesites), ■ intermediate to acid intrusives (porphyry), ◆ acid plutonic (granites); sedimentaries: sandstones, siltstones, ▲ limestones; metamorphics: □ slates, schists, ◇ serpentinites; * recent alluvials (or occasionally colluvial or eluvial); × mixed influences or uncertain), (d) overstorey eucalypts (see Fig. 1 for symbol key), (e) botanical region (◇ Southern Tablelands, ○ Central Tablelands, ◆ South Western Slopes, ● Central Western Slopes, + South Western Plains), (f) landuse (● TSRs and roadsides, ○ cemeteries), (g) plot size (ln, indicated by circle size) and landuse and (h) total native plant richness (indicated by circle size) and landuse. Vectors indicate direction and relative strength of trends in relation to the plotted axes.

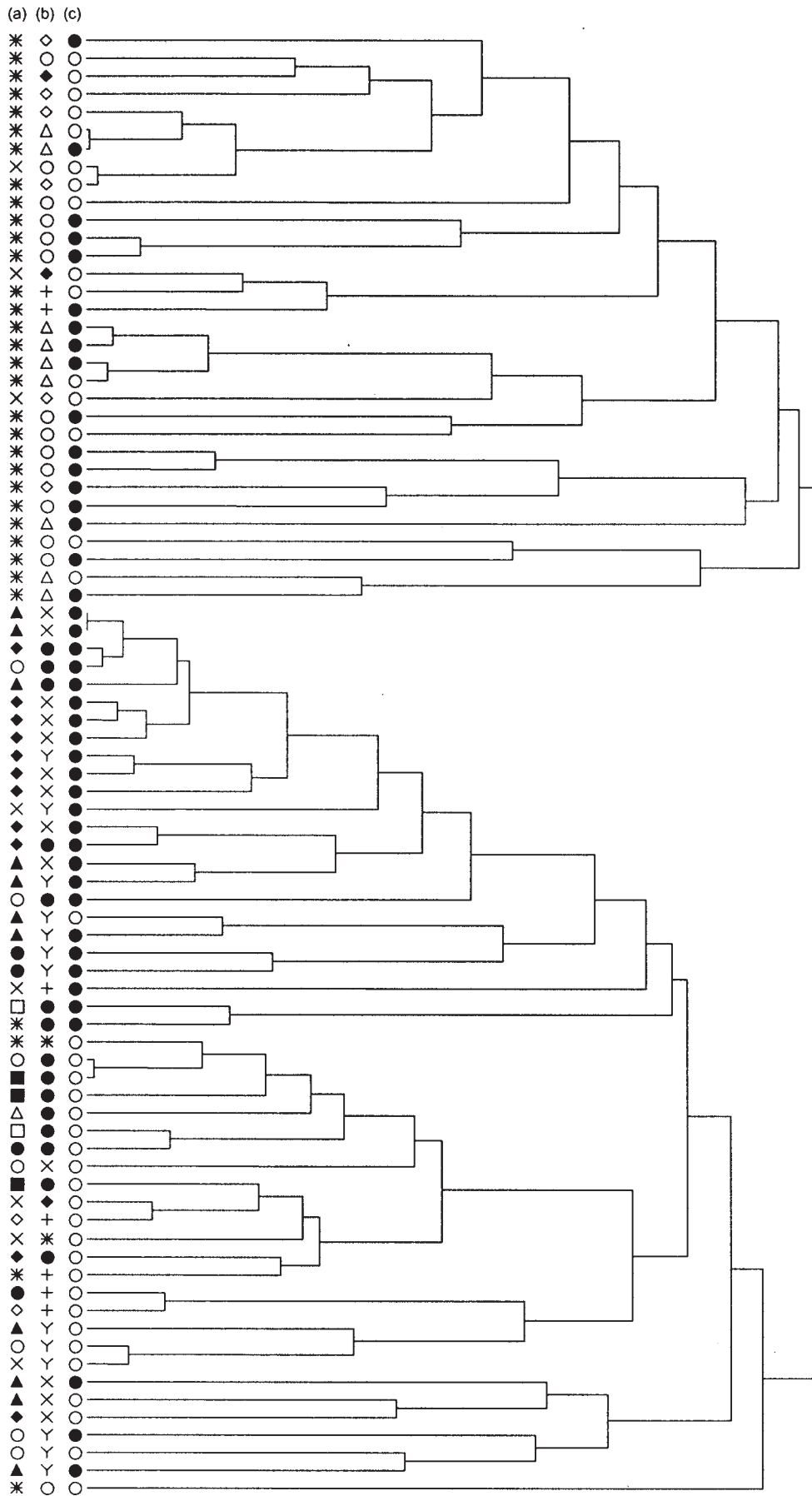


Fig. 3. UPGMA cluster analyses showing (a) lithology, (b) overstorey type and (c) landuse. See Figures 1 and 2 for symbol keys.

Understorey trends related to climate and lithology

As could be expected, the strongest trend on the ordination of the full data set was a distinct change in understorey composition from the Tablelands in the east to the Plains in the west (Fig. 2a). Both climatic and lithological factors are likely to be important environmental determinants of the east-west trends. Increasing aridity is probably the most important of these, as reflected by the high correlation of distance inland with the ordination (Table 1, Fig. 2a). Elevation also declined significantly with distance inland, reflecting a grade from cooler conditions on the Tablelands to warmer conditions in the west (Fig. 2b).

The major influence of lithology was as a major disjunction between eastern and western sites (Fig. 2c). Eastern sites occurred on a range of lithologies, including alkaline and acid volcanics, granites, sediments, serpentinites and metamorphics, but there were no clear relationships between these and understorey composition. In the west, however, almost all sites had soils of Tertiary or Quaternary alluvial (or occasionally colluvial or eluvial) origin, largely corresponding with Red Brown Earths as described in Beadle (1948) and Moore (1953a) (rare in the east). As this lithological change from east to west closely parallels the climatic trends, it is difficult to separate the relative contributions of these two factors in influencing floristic patterns. However, a number of sources of evidence indicate that the change to alluvial soils significantly influenced understorey composition, over and above the climatic trends: 1) some relatively eastern sites had alluvial parent materials and these usually grouped with or were marginal to the more western sites on the ordination, 2) the change in understorey composition along the east-west gradient was most marked between the two main lithological classes (alluvial vs. non-alluvial), as indicated by the two major groups formed on the UPGMA cluster analysis of the floristic data (Fig. 3a & 3) the lithological change closely mapped a change in overstorey from White Box to Grey Box, as discussed below and as described by other authors (Moore 1953a).

Topographic class also changed along the east-west gradient, reflecting a grade from more hilly sites in the east to flatter sites in the west. The significant correlation of topographic class with the ordination of the full data set probably results from its correlation with the other major gradients.

Correlation of overstorey composition with understorey trends

The trend in understorey species composition across the east-west gradient generally paralleled changes in the overstorey (Fig. 2d). Yellow Box and Red Gum, sometimes with Apple Box (*Eucalyptus bridgesiana*), were generally the dominant eucalypts in sites falling to the far left of the ordination. Most of these sites were on the Central or Southern Tablelands, although some were in the far-eastern parts of the Central Western Slopes region (Fig. 2e). Adjacent to these on the ordination were sites on the Western Slopes dominated by

White Box and/or Yellow Box, occasionally with Red Gum. Within the Slopes region there was little distinction in understorey between sites dominated by White or Yellow Box. The grade from Tablelands to Slopes woodlands was not clearly apparent on the cluster analysis (Fig. 3b), even when the eastern sites were analysed separately.

Samples of Grey and Bimble Box Woodland fell clearly to the right of other samples on the ordination (Fig. 2d). The distinction of these 'western' Box woodlands from the 'eastern' Box woodlands (dominated by White Box, Yellow Box or Red Gum) corresponds with the major division on the cluster analysis as described above, with one group containing almost all Grey Box (*Eucalyptus microcarpa*) and Bimble Box (*Eucalyptus populnea*) remnants, and the other containing all White Box (*Eucalyptus albens*) and Red Gum (*Eucalyptus blakelyi*) remnants, and all sites with Yellow Box (*Eucalyptus melliodora*) except for those occurring on the alluvial soils to the west (Fig. 3b). This change from eastern to western woodlands occurs within the Central and South Western Slopes regions (Fig. 2e), and is highly congruent with the change from non-alluvial parent materials to alluvial parent materials (Fig. 3a).

A grade between sites dominated by Grey Box and sites dominated by Bimble Box was apparent on the ordination (Fig. 2d), although these sites were interspersed on the cluster analyses (Fig. 3b), and sites containing both species occurred anywhere along the gradient (for both the full data set and the western data sub-set). This pattern was again related to distance inland, and became more pronounced when sites dominated by combinations of Grey and Bimble Box were ordinated separately (Fig. 4, see next section).

Five of the sites sampled contained Fuzzy Box, two as a dominant and three as a sub-dominant. These sites were scattered across the ordination amongst White and Grey Box sites, and formed no distinct understorey group of their own. However, sample sizes for Fuzzy Box are not considered sufficient to draw any reliable conclusions about the understorey of Fuzzy Box woodlands.

Understorey species contributing to the east-west grade

Floristic changes across the east-west gradient are shown in Table 2. Some species were ubiquitous across the whole sampling region, particularly the natives *Bulbine bulbosa*, *Dianella longifolia*, *Wahlenbergia luteola*, *Triptilodiscus pygmaeus*, *Oxalis perennans* and *Elymus scaber*, and the exotics *Hypochaeris radicata*, *H. glabra*, *Vulpia bromoides*, *Vulpia myuros*, *Trifolium glomeratum* and *Lolium* spp. However, most species (about 90% of those that were recorded with sufficient frequency) showed some relationship with the east-west gradient. These can be classified into three main groups: species distinguishing eastern from western woodlands; species contributing to the grade from the Yellow Box – Red Gum woodlands of the Tablelands to the White and Yellow Box woodlands of the slopes; and species contributing to the grade from Grey to Bimble Box

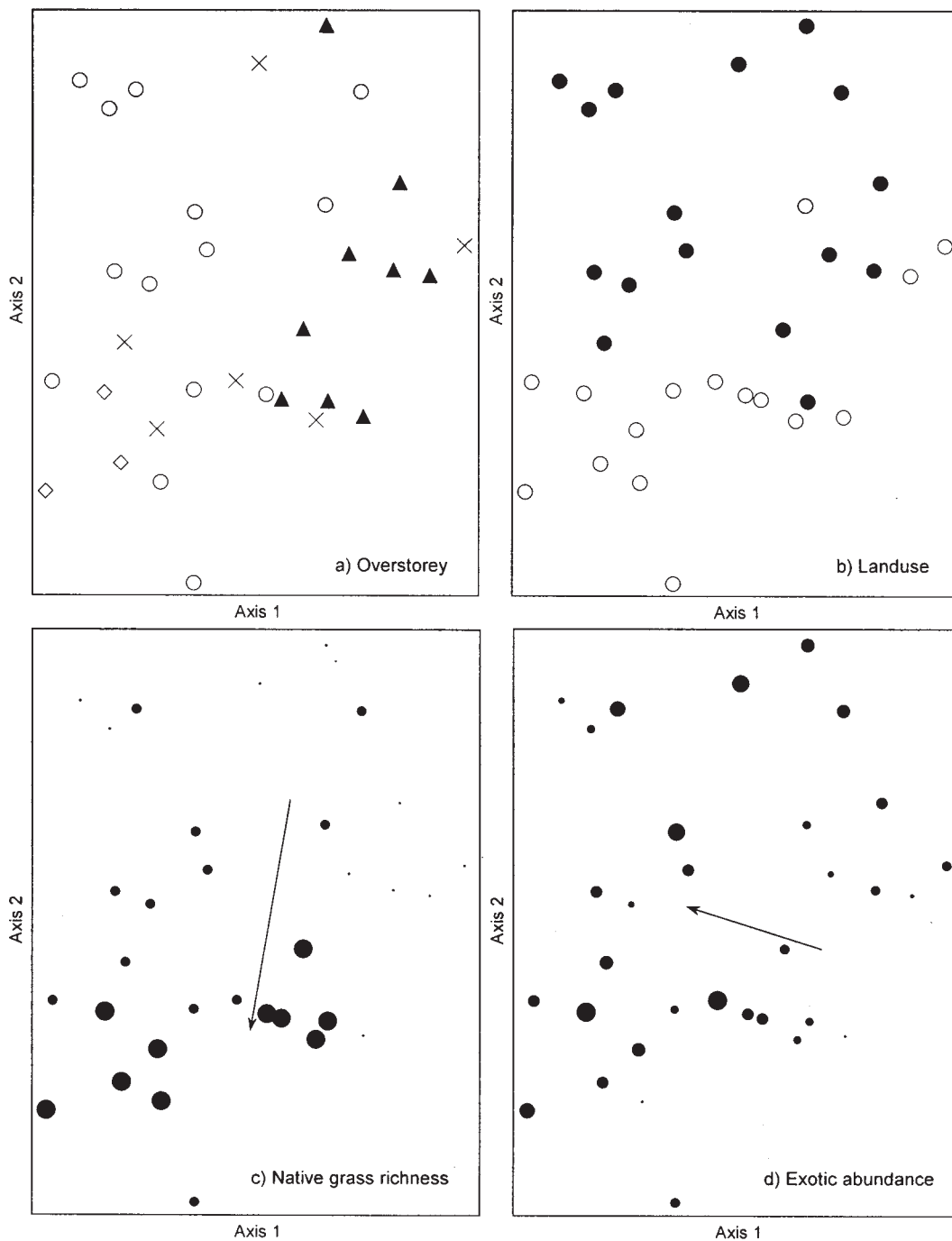


Fig. 4. MDS ordination of Grey and Poplar Box sites showing trends related to (a) overstorey type (◊ *Eucalyptus albens* & *Eucalyptus microcarpa*, ○ *Eucalyptus microcarpa*, × *Eucalyptus microcarpa* & *Eucalyptus populnea*, ▲ *Eucalyptus populnea*), (b) landuse (● TSRs and roadsides, ○ cemeteries), (c) native grass richness (indicated by circle size, range 5–16), (d) relative exotic abundance. Vectors indicate direction and relative strength of trends in relation to the plotted axes.

woodlands. As analysis of the latter data sub-set showed improved resolution of the Grey from Bimble Box woodlands (Fig. 4a), species contributing to that gradient are described using a two-way table resulting from analysis of the western data subset.

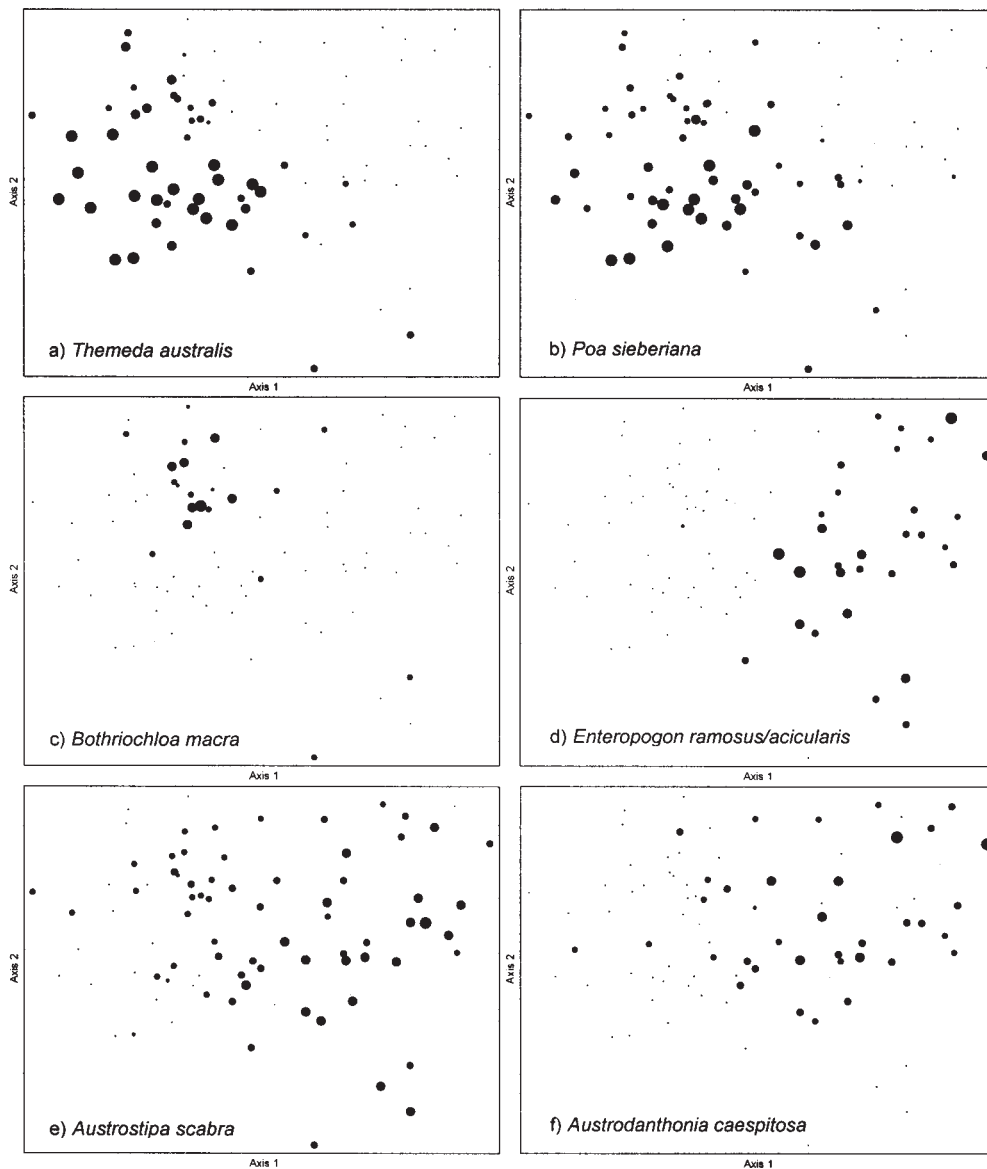


Fig. 5. Trends in dominant grasses. Circle size indicates abundance of:

- (a) *Themeda australis*,
- (b) *Poa sieberiana*,
- (c) *Bothriochloa macra*,
- (d) *Enteropogon ramosus/acicularis*,
- (e) *Austrostipa scabra*,
- (f) *Austroanthonia caespitosa*

Species distinguishing eastern and western box woodlands

Differences in species composition between eastern and western woodlands involved changes in both the dominant grasses and subsidiary species (Table 2). In little disturbed remnants, *Themeda australis* and/or *Poa sieberiana* were the usual dominants in eastern woodlands, whereas in the west, these species were subsidiary or absent. The dominant native grasses in western woodlands were more varied, but generally included *Enteropogon ramosus/acicularis*¹, *Austrostipa scabra* and/or *Austroanthonia* species (Fig. 5, Table 2). The only notable intergrades between these two groups concerned sites with a mix of White and Grey Box, and two remnants on alluvial soils the Junee–Coolamon region, where Yellow Box is often the sole dominant. These sites were generally intermediate on the ordination, and one

¹*Enteropogon ramosus* was the most common, but as they were not regularly distinguishable (especially on grazed sites) they were grouped together for this analysis.

of the latter sites grouped (along with a nearby TSR) with western woodlands on the cluster analysis, despite an understorey dominated by *Themeda australis*.

Total native species richness was similar for eastern and western woodlands, but changes in subsidiary species composition were substantial. A number of these trends in native species were consistent at the family level, with families such as Dilleniaceae (*Hibbertia* spp.), Haloragaceae, Epacridaceae, Ranunculaceae, Rosaceae (particularly *Acaena agnipila*), Orchidaceae (particularly *Microtis unifolia*), Juncaceae and Myrtaceae (mostly *Eucalyptus*) notably more frequent or diverse in eastern woodlands (Table 3).

Western woodlands were characterized by a notable increase in the diversity and abundance of species of the families Goodeniaceae, Crassulaceae, Malvaceae (particularly the forbs *Sida corrugata* and *Sida cunninghamii*), Chenopodiaceae (particularly *Maireana microphylla*, *Maireana enchylaenoides*, *Chenopodium desertorum* and

Atriplex semibaccata) and Myoporaceae. Native species of the families Amaranthaceae (particularly *Ptilotus spathulatus*) and Brassicaceae (e.g. *Menkea australis*) occurred exclusively in western woodlands (Tables 2 & 3).

Other families showed a more even distribution across the east-west gradient (Table 3), but some species within these families were still important for distinguishing eastern from western woodlands (Table 2). In particular, species of the family Asteraceae (daisies) were common across the gradient, but some species (e.g. *Leptorhynchos squamatus*, *Microseris lanceolata*, *Cymbonotus lawsonianus*) were typical of eastern woodlands and others (e.g. *Calotis cuneifolia*, *Vittadinia cervicularis*, *Stuartina muelleri*, *Minuria leptophylla*, *Rhodanthe corymbiflora*) were frequent only in western woodlands.

Bimble and Grey Box woodlands had a generally higher diversity and abundance of native annuals than eastern woodlands. These included the daisies *Rhodanthe corymbiflora* and *Stuartina muelleri* and the lily *Bulbine semibarbata*, as well as a number of species more typical of the Bimble Box Woodlands (see below). Other natives more common in western woodlands included the forb *Wahlenbergia communis*, and the grasses *Aristida benthamii*, *Panicum subxerophilum* and *Paspalidium constrictum*. Other natives showing notable preferences for eastern woodlands included the forbs *Luzula meridionalis*, *Geranium solanderi*, *Asperula conferta*, *Cynoglossum suaveolens*, and *Wahlenbergia stricta*.

Owing to the lack of undisturbed remnants, trends in native shrub abundance across the east-west gradient were difficult to assess (cemetery remnants were often cleared of their mid- and over-storey species at least early in their history, and grazing and thinning in TSRs also affect the shrub layer). From the available data, it appears that shrub diversity and abundance was often higher in western woodlands (particularly evident in cemeteries) than in White Box Woodlands, and perhaps also increased again in the Yellow Box – Red Gum woodlands of the far east (Fig. 6a). Shrub species changed markedly across the gradient, with leguminous shrubs, epacrids and *Cryptandra amara* more common in the east, and shrubs of the family Myoporaceae (especially *Myoporum montanum*), *Senna artemisioides*, *Maireana microphylla* and *Pittosporum phillyreoides* more typical in the west. *Acacia* and *Cassinia* species occurred across the gradient (Table 2).

Exotic species were notably more abundant in the eastern than the western woodlands sampled, both in cemeteries and TSRs (Fig. 6b). A wide variety of exotic species common to eastern woodlands were absent or infrequent in western woodlands (e.g. *Briza minor*, *Plantago lanceolata*, *Cerastium glomeratum*, *Hypericum perforatum*, *Sherardia arvensis*, *Rosa rubiginosa*, *Trifolium subterraneum* and *Anagallis arvensis*). By contrast, few exotic species were characteristic of western woodlands only.

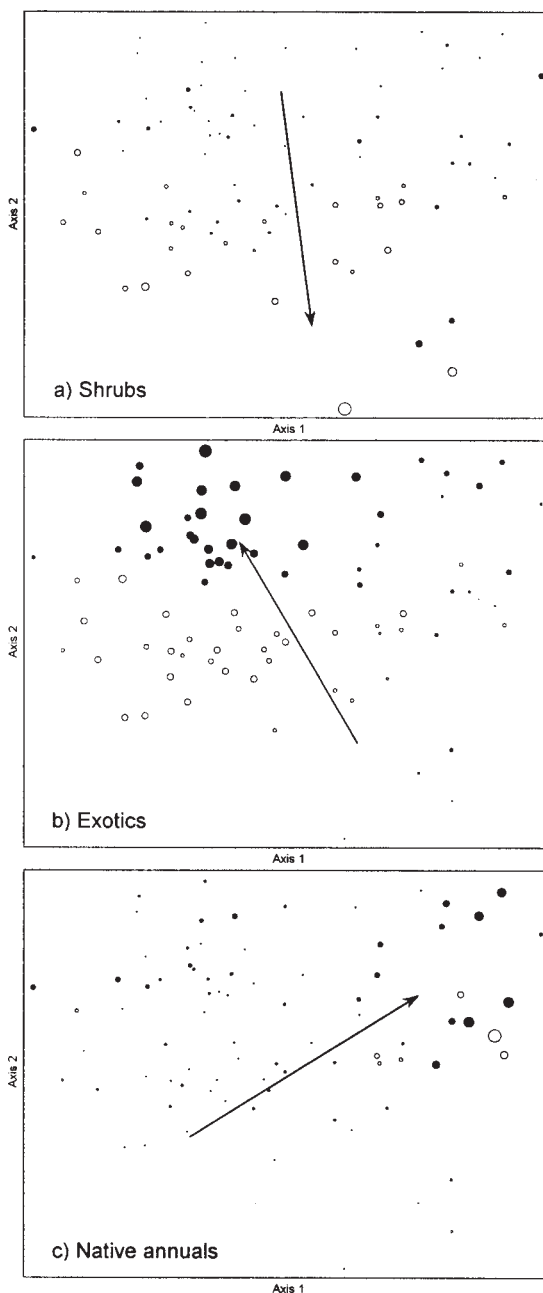


Fig. 6. Trends in plant groups. Circle size indicates: (a) Relative native shrub abundance (b) Relative exotic abundance (c) Relative native annual abundance. Closed circles indicate TSRs and roadsides, open circles indicate cemeteries. Vectors indicate direction and relative strength of trends in relation to plotted axes.

Species contributing to the grade from Yellow Box – Red Gum Woodlands of the Tablelands to White Box, Yellow Box, Red Gum Woodlands of the Slopes

Themeda australis and *Poa sieberiana* were the dominant native grasses in little-disturbed representatives of all eastern woodlands, thus the grade in species composition from the tablelands to the slopes was largely due to subsidiary species (Table 2). Only a small number of species (e.g. the native shrubs *Melichrus urceolatus* and *Daviesia* spp., the native forbs *Ammobium craspedioides* and *Plantago*

(potentially the native *Sclerolaena muricata*) were characteristic of Grey Box woodlands. Most were species that were abundant in eastern woodlands and continued into Grey Box but were uncommon in Bimble Box woodlands (e.g. *Geranium retrorsum*, *Goodenia hederacea*, *Juncus* subg. *genuini*, *Plantago varia* and *Stackhousia monogyna*). Similarly, the grasses *Themeda australis* and *Poa sieberiana* were frequent in Grey Box remnants, but were recorded in only one Bimble Box site without Grey Box (at Trangie and Ungarie respectively).

A greater number of species was typical of the Bimble Box sites of this study. These included annual daisies such as *Isoetopsis graminifolia*, *Calotis hispidula*, *Actinobole uliginosum*, *Brachycome lineariloba* and *Hyalosperma semisterile*, a range of other native annuals (e.g. *Menkea australis*, *Calandrinia eremaea* and *Erodium crinitum*) and native perennials (e.g. *Goodenia cycloptera*, *Maireana humillima* and *Thyridolepis mitchelliana*), and the exotic species *Sisymbrium orientale* and *Medicago laciniata*.

Trends related to landuse

The second major trend on the ordination was related to Landuse (Table 1, Fig. 2f). Across the whole of the east–west gradient, cemetery remnants were usually distinct from roadside and TSR remnants. This trend was most prominent for eastern sites (Fig. 2f), and for these sites was also apparent (with some exceptions) on the UPGMA cluster analysis (Fig. 3c). In Grey and Bimble Box sites the distinction became more blurred, with some mixing of roadsides and TSRs with cemetery remnants on the ordination (Fig. 4b), and poor distinction of cemeteries and TSRs on the cluster analysis (Fig. 3c).

Species involved in distinguishing the landuse classes varied according to position on the east–west gradient, so are best described using the two-way tables derived from separate analyses of eastern and western woodlands (Tables 5, 6). As well, more general differences were apparent for relative shrub abundance and native annual abundance (Fig. 6, Table 1). While relative shrub abundance was generally low, it was often higher in cemeteries than TSRs (Fig. 6a). By contrast, native annuals were uncommon in cemeteries, but increased in TSRs, particularly in the west (Fig. 6c, Table 1). For example *Triptilodiscus pygmaeus* and *Daucus glochidiatus* were frequent in TSRs in the east (Table 5), but not in eastern cemeteries. Native annuals typical of western TSRs included the daisies *Brachycome* spp., *Rhodanthe corymbiflora* and *Stuartina muelleri*, and other forbs such as *Menkea australis*, *Bulbine semibarbata* and *Plantago turrifera* (Table 6).

In eastern woodlands, cemeteries were also distinguished by a markedly lower relative exotic species abundance (Fig. 6b), dominance by *Themeda australis* and/or *Poa sieberiana*, and a range of native species that were infrequent (e.g. *Pimelea glauca*, *Templetonia stenophylla*, *Chrysocephalum semipapposum*, *Cryptandra amara*, *Pimelea curviflora*), or declined notably (e.g. *Dianella revoluta*, *Ranunculus*

lappaceus, *Linum marginale*, *Dichelachne micrantha*, *Microseris lanceolata*, *Dianella longifolia* and *Chrysocephalum apiculatum*) in grazed sites (Table 5).

In eastern TSRs, the dominant grasses of cemeteries were replaced by a mixture of exotic species and native grasses such as *Bothriochloa macra*, *Aristida ramosa*, *Austrodanthonia* spp. and *Austrostipa scabra*. The latter three of these grasses were common in western woodlands, but it is of interest that *Bothriochloa macra*, highly abundant in grazed eastern woodlands, was common neither in western woodlands nor little-grazed eastern woodlands, raising an interesting question as to the original ecological range of this species in the region (Fig. 5c). A range of natives appeared to tolerate light grazing in TSRs (e.g. *Lomandra filiformis*, *Plantago varia*, *Acaena agnipila*, *Goodenia pinnatifida*, *Convolvulus erubescens*, *Hydrocotyle laxiflora*, *Dichopogon fimbriatus*, *Hypericum gramineum* and a number of others not shown) or benefit from it (e.g. *Wurmbea dioica*, *Arthropodium minus* and *Solenogyne dominii*), but a large number of exotic species also increased in TSRs (Table 5). Although they include a number of Yellow Box – Red Gum and tableland remnants, these results are generally concurrent with our earlier studies of grassy White Box woodlands (Prober & Thiele 1995, Prober 1996), and a more detailed discussion of these trends is given in those papers.

In western woodlands, no clear change in dominant native grasses was involved in the distinction between roadside, TSR and cemetery remnants (Table 6). *Enteropogon ramosus/ acicularis*, *Austrostipa scabra*, and *Austrodanthonia* species (especially *Austrodanthonia setacea* and *Austrodanthonia caespitosa*) were moderate to common at most sites (Fig. 5d–f). Their relative abundances varied from site to site, but one or a combination of these, most commonly *Austrostipa scabra*, were the general dominants in both cemeteries and TSRs.

There was, however, a pattern of declining diversity of grasses related to landuse (Fig. 4c). The diversity of native grasses in western cemeteries was remarkably high (mean 11.2, range 5–16), and was usually lower in grazed sites (mean 7.5, range 5–11). This reflected a decline in frequency or abundance of grasses such as *Themeda australis*, *Thyridolepis mitchelliana*, *Poa sieberiana* and *Austrodanthonia bipartita/fulva* (syn. *Austrodanthonia linkii*), and to a lesser extent, *Austrodanthonia auriculata* and *Austrostipa bigeniculata* (Table 6). As well there appeared to have been some change in the local distribution and structure of the grasses resulting from management (personal observation, Biddiscombe 1953). In cemeteries that appeared most natural (less invasion by dense *Callitris* regrowth, greater structural diversity, low exotic species abundance) the most common grass species often occurred as large tussocks in distinct clumps or patches (particularly for *Austrostipa scabra*, *Austrodanthonia* spp., *Themeda australis* and *Poa sieberiana*). These were interspersed with clumps of shrubs and patches of bare ground, and other natives were scattered sparsely or in small patches

Table 6. Two-way table indicating changes in floristic composition in relation to landuse in western woodlands.

Sites are arranged according to the landuse vector, and species according to their weighted average location along this vector. All species occurring in more than 14 sites are included, as well as selected others. T=TSR, R=roadside, C=cemetery; *denotes introduced species. *Enteropogon ramosus* and *Enteropogon acicularis* both occurred in the survey region.

	TTTTTRTCTTTRCTR	CCTCCCCCTCCCCC
<i>Sclerolaena muricata</i>	1-212-1-----	-----
<i>Brachycome ciliaris</i>	3-23-----2	-----
<i>Medicago truncatula*</i>	3-222-1---2	-----1
<i>Brachycome lineariloba</i>	-2-1---2---2	-----
<i>Rhodanthe corymbiflora</i>	3-143212---31--	4-----1---
<i>Asperula cunninghamii</i>	2-2121---2	-----3---
<i>Menkea australis</i>	-2-1---2---2	2-----
<i>Maireana microphylla</i>	12213-1-4-23---1	---1-1-11---
<i>Atriplex semibaccata</i>	-22222-1---21---	---1-112---
<i>Wahlenbergia communis</i>	22-222-21---2-22	1-----1---2---
<i>Arthropodium minus</i>	-11-213--32--2-	-1-----2---
<i>Carex inversa</i>	-32--1-1---2-222	-----2----
<i>Wurmbea dioica</i>	-1---2---2-12-	-----
<i>Medicago laciniata*</i>	-413-2-31---213-	3-4-----2---
<i>Bulbine semibarbata</i>	-2---12232--32	-----
<i>Plantago turrifera</i>	21-1---2---21212	2-----1---
<i>Arctotheca calendula*</i>	-223-231-13-23-	-----2-1-2
<i>Hordeum leporinum*</i>	222311-2---22-	---2-21-1-2-2-
<i>Goodenia pinnatifida</i>	2233222232-2221	22-22--21-22--12
<i>Austrodanthonia setacea/spp.</i>	2-52-352432-4-2	-3-4----222--3
<i>Crassula sieberiana</i>	-112-122322-3-31	2---1-23-2---
<i>Vittadinia cuneata</i>	11213-2---2-2213	2---23-1-4-3-2---
<i>Lolium spp.*</i>	3534223224342435	-233233142443--
<i>Austrodanthonia caespitosa</i>	53235--3-4-3234	22-2334433322--
<i>Calotis lappulacea</i>	-2-22232132233-	2-32-----223-
<i>Convolvulus erubescens</i>	21-12-1-111----	2-111113---22---
<i>Sida corrugata</i>	1-222-2221212-12	21-212223112---
<i>Elymus scaber</i>	32323123-2212223	-2--323222222-2
<i>Oxalis perennans</i>	3-21222222-2-22	2122-1222-2321-1
<i>Eucalyptus microcarpa</i>	3-33324-3435-3-1	-5-33333--322-33
<i>Stuartina muelleri</i>	---2-111-12-12-	2-----12-----
<i>Bromus molliformis*</i>	---2-222-3-221	---2-1221-1---
<i>Echium plantagineum*</i>	1212123221322221	1-32-221212311-2
<i>Calandrinia eremaea</i>	---2---21---211-	2-----221---
<i>Eucalyptus populnea</i>	-3-3---4----3334	1-4--2-133-2-2--
<i>Enteropogon ramosus/acicularis</i>	452223232233334	234544353344-3-3
<i>Einadia nutans</i>	-2122--221233222	1321223322-13--
<i>Austrostipa scabra</i>	3-24334444345242	4434434434443433
<i>Avena fatua/barbata*</i>	321-222-32-2-3	-32333333-234-2
<i>Triptilodiscus pygmaeus</i>	---21312-2-2221	2---122-4313---
<i>Vulpia bromoides*</i>	2-2-3122-43-222-	-2-3444344--5-2-
<i>Hypochaeris radicata*</i>	-222-22222-2-22	21-212-332332-2
<i>Chenopodium desertorum</i>	2-12--22-2221-	222222122-2-41-
<i>Daucus gluchidiatus</i>	---21-22222-3-2-	2-1-2-2133-3-2-1
<i>Calotis cuneifolia</i>	2-1-2--322322332	2---4-2-3233-333
<i>Austrostipa bigeniculata</i>	2---14---2-----	-2--323343251--
<i>Lomandra filiformis</i>	-1-1-21-232---1	-211-12222233-2-
<i>Trifolium arvense*</i>	-2---3-2-----2	1-212222212---
<i>Sonchus oleraceus*</i>	-21-1---1-1-1-2	-221-1-13112-2-2
<i>Bromus diandrus*</i>	---21-2-2-2-----	-3-322321-3-3-2-
<i>Eremophila debilis</i>	-1-1--1-21-31-11	-211-212222-11-
<i>Myoporum montanum</i>	3-----2---1	-2-4-2-23---32-
<i>Dianella longifolia</i>	-2-----2-12112	222-3-122-2223-
<i>Cheilanthes sieberi</i>	---222-122321	212222222223222
<i>Austrodanthonia auriculata</i>	---21-2-2-22-4-	-2-3354433321---
<i>Bulbine bulbosa</i>	---4-124-2-12	-212222122-231-3
<i>Wahlenbergia luteola</i>	---1-2--22-231-	2222221-22222-22
<i>Aristida behriana</i>	---2---2-2-21-2	--222232321---
<i>Dodonea viscosa</i>	2---11---2-3---	-32-41--2-32-343
<i>Dichondra repens</i>	-----1-1-1-2	-21--21-----2-
<i>Xerochrysum bracteatum</i>	-----3---3131	2---22-3223--2
<i>Callitris glaucophylla</i>	---11-1-2232333	32-142255552433
<i>Acacia deanii</i>	---2-2-2-2---	-1-2-3-2232-2-3
<i>Senna artemisioides</i>	-----1-2---32-	-2-22322-3-33-
<i>Tricoryne elatior</i>	-----21---2	1112-2222223---
<i>Hydrocotyle laxiflora</i>	-----12-1-12	1---11-3-12--3
<i>Bromus rubens*</i>	-----	2--22-21-1---
<i>Aira elegantissima*</i>	-----21---2	---321232324-2-
<i>Dichopogon fimbriatus</i>	-----23---2	--22-232232-3
<i>Chrysocephalum semipapposum</i>	-----	---122-122---
<i>Austrodanthonia bipartita/fulva</i>	-----2----	-2222---2-122
<i>Dianella revoluta</i>	-----213---	-223-1---324443
<i>Poa sieberiana</i>	-----2-1-1	-4-24-123-334-32
<i>Thyridolepis mitchelliana</i>	-----	1-2---1213-2-1-
<i>Brachychiton populneus</i>	-----11---	1-1-1-1-1-12211
<i>Aristida ramosa</i>	---1-----3	-1-----2---3-23
<i>Chrysocephalum apiculatum</i>	-----1-1	22-2---221333222
<i>Lomandra multiflora</i>	-----2----	--22-2111212-22
<i>Glycine clandestina</i>	-----1-	1---11-11121-1
<i>Geranium retrorsum</i>	-----	-2-2--2-1-2-2-
<i>Stackhousia monogyna</i>	-----	2-221-22-223-3
<i>Pimelea curviflora</i>	-----	---2-2---1-1-
<i>Themeda australis</i>	-----	---32-----225333
<i>Microseris lanceolata</i>	-----	-----1---32--3

throughout. This structure and patchiness was less apparent in grazed remnants and in cemeteries that were regularly mown, where a more continuous, low sward was formed.

A range of other subsidiary native species also contributed to the distinction between Grey and Bimble Box cemeteries (and less-disturbed TSRs) and grazed remnants (Table 6). A few of these, such as the abovementioned grasses *Thyridolepis mitchelliana*, *Austrodanthonia bipartita/fulva*, and the shrub *Senna artemisioides* were frequent only in Grey and/or Bimble Box woodlands. Others, such as *Themeda australis*, *Poa sieberiana*, *Dianella revoluta* and *Chrysocephalum semipapposum*, were the same as species distinguishing little grazed sites in eastern woodlands, although the two grasses rarely dominated western sites and all were generally more robust in the east. A third prominent group contained common eastern species that showed greater tolerance of grazing in eastern woodlands, but were largely restricted to cemeteries in the west. These included the perennial forbs *Stackhousia monogyna*, *Geranium retrorsum*, *Glycine clandestina*, *Lomandra multiflora*, *Chrysocephalum apiculatum*, *Dichopogon fimbriatus* and *Tricoryne elatior*.

Other native species of western woodlands were more typical of grazed Bimble and Grey Box sites than cemeteries. These were mostly species that were not found elsewhere in our sampling i.e. were infrequent in eastern woodlands, and included the annuals noted above and perennials such as *Sclerolaena muricata* and *Asperula cunninghamii*.

By contrast with the eastern woodlands, relative exotic species abundance was not notably higher in the TSRs and roadsides surveyed than in cemeteries in western woodlands (Fig. 4d), rather was generally lower than eastern woodlands (Fig. 6b). This result is likely to have been partly influenced by our sampling strategy — in the west there were fewer discrete TSRs available and thus our sampling was biased towards smaller, less weedy sections of Travelling Stock Routes (Fig. 2g); high exotic species abundance is still common in poorer remnants of Grey and Bimble Box woodlands (personal observation). Nevertheless it does indicate that at least some TSRs in western woodlands have relatively low exotic species abundance, and points to a need for greater survey effort in western TSRs.

Exotic species composition showed some trends related to landuse. Some exotic species were more typical of cemeteries e.g. *Aira elegantissima* and *Bromus rubens*, and others more typical of TSRs e.g. *Medicago truncatula*, *Arctotheca calendula* and *Medicago laciniata*. Most, however, occurred relatively evenly across landuse classes. Some of these were moderately abundant at many sites (*Lolium spp.*, *Avena fatua*, *Vulpia bromoides*), while others were frequent but usually uncommon (e.g. *Hordeum leporinum*, *Bromus molliformis*, *Echium plantagineum*, *Medicago minima*, *Hypochaeris radicata*).

Finally, a number of interactions were notable between the landuse and the east–west gradients. As noted earlier, a number of native species that were frequent across both landuse classes in the east were found only in cemeteries in the west. The reverse generally did not occur (i.e. few species were ubiquitous in the west but limited to cemeteries in the east.) As well, few species that were ubiquitous in the east were restricted to TSRs in the west.

However, some species that were common across landuse classes in the west were favoured in TSRs in the east — these included some of the more prominent grass species (e.g. *Austrodanthonia auriculata*, *Austrodanthonia setacea*, *Austrostipa bigeniculata*, *Austrostipa scabra*), the native annuals *Triptilodiscus pygmaeus* and *Daucus glochidiatus*, the native perennials *Maireana microphylla*, *Dichondra repens* and *Crassula sieberiana*, and exotic annuals such as *Hordeum leporinum* and *Lepidium africanum*.

These trends suggest that typically eastern species become more susceptible to grazing under drier conditions, and conversely, that some western species are better able to compete in the east when the natural dominants are diminished by grazing. Consequently, we suggest that grazed sites have a more western character, and indeed, five TSR samples that were in close proximity to cemetery samples invariably fell further to the right (‘west’) on the ordination than the respective cemetery remnants (not shown).

Other trends in the floristic data

Environmental variables

The only other major environmental trend in the floristic data was related to latitude. The correlation with latitude was relatively low for the full and eastern data sets (Table 1), but nevertheless is likely to represent part of a north–south climatic grade as described for grassy White Box woodlands in an earlier study (Prober 1996). A higher correlation with latitude was obtained for the western data subset, equal in magnitude to that observed for the east–west trends within these western woodlands (Table 1). The relationship with latitude is likely to have increased in western woodland sites because a wider latitudinal range was sampled (owing to low availability of little-disturbed cemetery remnants). As well, there was some confounding of latitude with distance inland for western woodlands, as Bimble Box does not occur as far south as Grey Box.

Vector correlations of the ordination with the variables tree clearing and soil resource class were marginally significant in the full data set (only), but were generally very low. High levels of tree clearing were more common in cemetery remnants, especially in the east, thus tree clearing may have made some contribution to the differences in understorey between cemeteries, roadsides and TSRs.

Soil resource class generally varied only from ‘arable’ to ‘suitable for grazing’ in the set of sites in the present study, and the slight correlation of this variable with the ordination

of the full data set can be attributed to the relative increase in arable sites on the alluvial soils in the west, and decrease in arable sites on the tablelands. Soil resource class was noted as an important determinant of understorey in grassy White Box woodlands in an earlier study that sampled a broader range of soil resource classes (Prober 1996), but sampling remnants with shallow or infertile soils was beyond the scope of the present study.

Influence of plot size

Correlation of plot size with the ordination of the full data set (Table 1) was low and showed no consistent relationship with the east–west or landuse gradients (Fig. 2g), indicating a minimal influence of this variable on analyses of this data set. In the two data subsets, the relationships between plot size and the ordinations were stronger (Table 1) and somewhat related to landuse (Fig. 2g), suggesting that landuse trends described for these ordinations were potentially influenced by plot size. This is highly unlikely, however, because the relationships between plot size and landuse were reversed for the different data sets, with TSR samples on average larger than cemetery samples in the eastern data subset, and cemetery samples often larger than TSR samples in the western data subset (Fig. 2g). Despite this reversal, eastern TSRs grouped with western TSRs in the main analysis, indicating greater influence of environmental factors.

Further indication that plot size did not significantly influence the environmental trends described is the lack of significant correlations between native species richness and plot size in all data sets ($r=0.17$, 0.20 and 0.35 for the full, eastern and western datasets respectively). Likewise, correlation of native richness with the ordinations was not significant for the full and eastern datasets (Table 1, Fig. 2h). Correlation with the ordination of the western dataset was significant but did not reflect patterns in plot size (vectors of maximum correlation for native richness and plot size were 72° apart).

Discussion

Natural floristic patterns in grassy box woodlands

Understorey composition varied considerably across the east–west gradient sampled, with a notable change in the natural dominant grasses from *Themeda australis* and *Poa sieberiana* to *Austrostipa scabra*, *Enteropogon ramosus/acicularis* and *Austrodanthonia* spp., and with few species occurring consistently across the whole gradient (approximately 10% of natives and 10% of exotic species, Table 2). This contrasts with patterns recorded across the north–south extent of Grassy White Box Woodlands in NSW, where the dominant grasses of little-disturbed sites (*Themeda australis* and *Poa sieberiana*) varied little, and only around 50% of subsidiary species varied with the gradient (Prober 1996), despite a much wider geographical range (900 km cf. 400 km in this study).

With some important exceptions, dominant overstorey eucalypts were good indicators of natural understorey composition. The change from eastern woodlands (Yellow Box, White Box or Red Gum) to western woodlands (Grey or Bimble Box) was concurrent with the change in dominant grasses, and associated with notable changes in subsidiary native species, including an increase in the diversity and abundance of native annuals, species of the families Chenopodiaceae, Myoporaceae, Malvaceae, Brassicaceae and Amaranthaceae, and changes in the main genera of shrubs and daisies. As described by Moore (1970), the change from eastern to western woodlands occurs approximately at the 500 mm rainfall isohyet, and is likely to be determined by edaphic as well as climatic factors. This distinction is largely consistent with other studies (C. Moore 1953a, R. Moore 1970, 1993, Beadle 1981, Keith 2002), although Austin et al. (2000) grouped White Box with Grey Box over significant areas of woodland within the Central Lachlan region.

Working in the western division of NSW, Beadle (1948) similarly stressed the relationship of Grey Box and Bimble Box–White Pine (*Callitris glaucophylla*) associations with the Red-Brown Earths (the typical soils of the alluvial parent materials in this study). He suggested, however, that the pre-European herbaceous stratum in these woodlands was sparse, and that clearing of timber had led to rapid migration of native species from both the east (e.g. *Austrostipa scabra*) and the west (Asteraceae).

We cannot conclusively refute this claim, as most remnants of this study had been disturbed to some degree through grazing, tree thinning and/or mowing, and there is observational evidence that dense overstorey can reduce the density of the herbaceous layer (personal observation). However, as previously noted, species such as *Austrostipa scabra* were more characteristic of western woodlands of this study than of little-grazed eastern woodlands, so it is likely that this was naturally the case. As well, some of the western cemeteries were well wooded, but still showed a high diversity of understorey species. Even for cemeteries with a sparser overstorey, it is not parsimonious to assume that grazing-sensitive eastern species had migrated long distances to these small sites after they were cleared. We suggest instead that the density of the eucalypt canopy was originally variable, allowing patches of denser understorey where the canopy was more open. We interpret the patterns of understorey composition in western woodlands as consistent with a naturally more westerly distribution of many 'eastern' species before the influence of grazing, as suggested by Moore (1970), and an increase in or influx of some (particularly annual) native species, potentially from further west, under grazing.

The occurrence of the other major overstorey tree species recorded in this study, *Callitris glaucophylla*, did not concur with the distinction between eastern and western woodlands (Table 2). Rather, it became frequent in the western parts of the White Box woodlands and continued through to Bimble Box woodlands, concurrent with the grade in understorey

species. Beadle (1948) noted that this species is found over a wide range of climatic and soil conditions, but is confined to soils of a sandy nature. Our sampling was insufficient to determine whether any understorey patterns can be specifically related to *Callitris glaucophylla* or its relationship with sands.

Eastern box woodlands

Changes in understorey within eastern and western woodlands were less distinct than changes between these woodlands. In eastern woodlands, the relationship between understorey and overstorey composition was complicated by the occurrence of Yellow Box and Red Gum across the grade. The understorey of Yellow Box/Red Gum remnants reflected their position on the east–west gradient, grouping more closely with White Box remnants when on the Western Slopes, and becoming more distinct when occurring beyond the main eastern limit of White Box. Thus, for the eastern woodlands included in this study, the regional presence or absence of White Box provided a better indicator of understorey composition than the locally dominant eucalypt.

This is consistent with other studies (Moore 1953a, Keith 2002) that treated White and Yellow Box woodlands of the Slopes as a single unit, and recognized a separate community for the Yellow Box of the Tablelands. The use of botanical region or bioregion is a practical means of separating these groups (Fig 2e), although some sites in the eastern parts of the slopes region were beyond the main distribution of White Box and could be grouped with Tablelands woodlands. Some White Box communities are also known from the Central Tablelands, and it remains to be tested whether the understorey of these are more closely related to other woodlands on the Tablelands, or to White Box woodlands on the Slopes.

Other studies have used different or finer groupings within White and Yellow Box woodlands of the Tablelands and Slopes regions. Moore (1970), Beadle (1981) and Bower and Semple (1993) considered Yellow Box woodlands on the Slopes separately from White Box woodlands, grouping them with Yellow Box woodlands on the Tablelands. For the Central Lachlan region, Austin et al. (2000) included White Box in four major alliances, broadly consistent with a grade from east to west, according to their co-occurrence with combinations of Apple Box, Red Gum, Yellow Box, Grey Box and *Callitris glaucophylla*. For the southern tablelands and adjoining eastern fringe of the western slopes, Thomas et al. (2000) recognized a number of variants of White Box, Yellow Box and/or Red Gum woodlands based on existing floristic composition, including a broad distinction between those in south-west of the region from those to the north and east.

Western box woodlands

Our sampling of western woodlands was not adequate for detecting the likely range of variation within them, for example Austin et al. (2000) recognized a Yellow Box/Grey

Box community as distinct from other Grey Box communities. Nevertheless, our data suggest that the change from Grey to Bimble Box parallels a grade in understorey composition associated with an increase in a range of chenopods, annual daisies and other natives, and the loss of a range of species more typical of eastern woodlands (although sites with mixed overstorey fell anywhere along this gradient, Fig. 4a). This is consistent with the general distinction made between Bimble and Grey Box woodlands made by earlier workers (e.g. Beadle 1948, Moore et al. 1970, Beadle 1981, Austin et al. 2000), although differs from the approach of Sivertsen & Metcalfe (1995) for the Forbes–Cargelligo region, where they made no major distinction between Grey and Bimble Box woodlands.

More generally, Bimble Box woodlands have been treated in greater detail across their range by other workers (Beadle 1948, Biddiscombe 1953, Beeston et al. 1980), who have described a wide range of both shrubby and grassy Bimble Box communities across a range of soil types. Comprehensive studies of understorey patterns within Grey Box communities, however, are still lacking.

Management issues

The change in dominant grasses from eastern to western woodlands has important management implications. In little-disturbed grasslands and grassy woodlands of more productive regions of south-eastern Australia, burning and slashing are considered important management tools for encouraging the dominance of *Themeda australis* while also maintaining high species richness (Lunt & Morgan 2001). Burning and slashing are likely to be less important for remnants dominated by other grasses, although they could be used to influence the relative dominance of different grasses. For example, based on observations in railway exclosures in Bimble Box woodlands, Biddiscombe (1953) suggested that annual burning at the beginning of summer favoured the persistence of *Themeda australis* while suppressing *Austrostipa scabra* and *Paspalidium gracile*. As aboriginal burning regimes in these woodlands are poorly known, it remains unclear whether *Themeda australis* was more abundant throughout them before European settlement.

The floristic composition and abundance of native shrubs in pre-European woodlands is of particular significance for woodland restoration. Shrubs can provide important fauna habitat, e.g. as cover for a range of bird species (Seddon et al. 2001), and dense shrub plantings are often promoted across the woodland regions. On the other hand, dense plantings of shrubs in areas where they were originally sparse are of questionable value for the conservation of the original ecological community and may disadvantage some herbaceous species and associated fauna. Although our data were limited by lack of completely undisturbed remnants, some patterns in shrub species composition and abundance were apparent across the range of woodlands sampled. As observed by earlier workers (e.g. Moore 1953a), shrub

abundance was generally low, but was higher in cemeteries than TSRs, and was quite high in two western cemeteries that had been cleared of trees (Fig. 6a). Medium and large shrubs (e.g. *Senna artemisioides* and *Myoporum montanum*) were naturally more abundant in western woodlands than in the east, consistent with the observation of Beadle (1948) that shrubs commonly form a prominent stratum in Grey Box woodlands north of Narrandera. Small to medium shrubs (e.g. *Cryptandra amara*, epacrids) were more abundant on the tablelands than in White and Yellow Box woodlands of the western slopes, where shrub abundance was particularly low.

A significant difference in understorey composition between cemetery and TSR/roadside remnants, probably reflecting effects of intermittent grazing by livestock, was evident across the range of Box woodlands studied. However, the distinction was weaker in the west, and some of the species involved were different for eastern and western woodlands. As discussed in more detail in Prober & Thiele (1995), grazing in eastern woodlands has led to changes in the dominant grasses, decline in a range of natives, and a significant increase in exotic species abundance.

In western woodlands, a suite of native species were less frequent in TSRs and, consistent with observations by Beadle (1948), there was an increase in native annuals and unpalatable species such as *Maireana microphylla* in grazed sites. However, for the western woodlands surveyed, there was no notable increase in exotic species abundance in the lightly grazed remnants surveyed, and no obvious change in the dominant grasses. Regarding the latter, Biddiscombe (1953) described increasing dominance of *Austrostipa scabra* under light grazing, and increasing *Enteropogon ramosus/ acicularis* then *Chloris truncata* under heavier grazing pressures. These effects were not evident from our data, but an increase in *Austrostipa scabra* and *Enteropogon ramosus/ acicularis* is consistent with the loss of the more diverse combination of grasses found in cemeteries. For example, *Poa sieberiana*, originally a dominant of eastern woodlands, was remarkably frequent in cemetery remnants of western woodlands (recorded in 12 of 16), and was notably absent from grazed sites. This is consistent with Moore (1959), who noted that *Themeda australis* and *Poa sieberiana* were originally prominent in these woodlands. We recorded *Chloris truncata* in only five sites, at low abundance, perhaps reflecting the lack of heavily grazed sites in our survey.

Finally, it remains unclear whether the reduced distinction between cemeteries and TSRs in western woodlands indicates that the western cemeteries are more disturbed than eastern cemeteries (e.g. through rabbit grazing; high levels of dense *Callitris* regrowth were also observed in many western cemeteries), that some western TSRs have been less affected by grazing than eastern TSRs, or perhaps most likely, a combination of the two. A more extensive rangewide study of native understorey in these woodlands, particularly those dominated by Grey Box, would be valuable.

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