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OPTIMUM TIME FOR SAMPLING FLORISTIC DIVERSITY IN TROPICAL EUCALYPT WOODLANDS OF NORTHERN QUEENSLAND

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Abstract

The timing of vegetation sampling in highly seasonal environments is one of the critical factors in determining the proportion of the flora captured in a single sampling. Four sites were located within a 20 km radius of Mareeba, north Queensland and sampled every three months for three years. The sites were located in a variety of eucalypt communities and across an altitudinal range from 380 to 840 m above sea level. In these eucalypt communities experiencing highly seasonal rainfall typical of the tropical savannas, vegetation sampling in the early dry season (May) maximises the diversity of flora recorded. The ANOVA analysis showed a significant effect of month of sampling for the number of ground taxa recorded ($P<0.005$). There was significant variation ($P<0.005$) in species diversity between the sites but in all four study sites the May sampling recorded greater than 84% of the total recorded flora, whereas the November samplings accounted for between 21% and 56% of the flora. This supports the experience of other researchers that a May sampling is near optimum for sampling the ground layer floristic diversity in tropical eucalypt woodlands.

Most vegetation survey and mapping data are of necessity collected at less than ideal times of the year due to access and resource issues. Care must be exercised in using data collected in the dry season, as only a limited proportion of the total ground flora is likely to be recorded. Studies designed to capture the full florisitic inventory of species present in these highly seasonal environments need to budget resources and plan to access these environments in the late wet season.

Keywords: sampling, floristic diversity, vegetation, savannas, woodlands

Introduction

Sampling design is a critical component of any vegetation survey project. Because field work is expensive, it is important to maximise the return on investment (Mueller-Dombois and Ellenberg 1974, Austin and Heyligers 1991, Kent and Coker 1994). Adequacy of sampling for vegetation survey, mapping and modelling is a key issue for the utility of site data collected and the outputs produced (Austin 1991, Neldner *et al.* 1995). The timing of vegetation sampling in highly seasonal environments is one of the critical factors in determining the proportion of the flora captured in a single sampling. Observations of short-lived annual or short growing season perennial plants are generally the most affected by timing of sampling, whereas perennial woody plants are generally apparent at any time of the year.

Australia's tropical savannas

The tropical savannas in Australia are one of the most widespread landscape patterns and cover a large proportion of northern Australia (Fox *et al.* 2001). This includes much of continental Australia north of a line between Rockhampton on the east coast, and Broome on the west coast (Fig. 1).These tropical savannas occur within three major rainfall zones; the semi-arid zone which

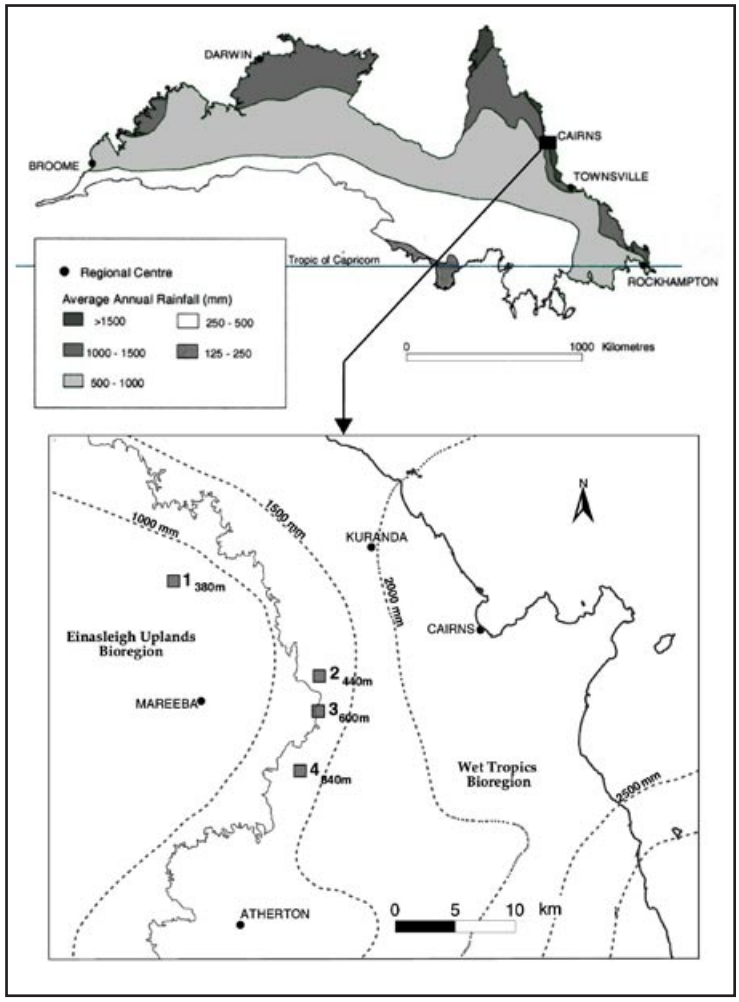

Fig. 1.
Map showing location for four monitoring sites, in relation to Australia's tropical savannas as defined by Fox *et al.* (2001).

receives 250-500 mm rainfall annually, semi-humid which receives 500-1000 mm rainfall and the humid zone which receives greater than 1000 mm annually (Fox *et al.* 2001). This precipitation falls predominantly during the summer wet season (November-April) with very little precipitation during the winter dry season (Fig. 2). The magnitude of the wet season is determined by the positioning and length of the monsoonal trough and the number and intensity of cyclones in the area. Widespread flooding occurs frequently in the summer months, and lowland parts of the country remain inundated for different periods of time. These conditions and the generally unformed roads makes vegetation survey at this time very difficult even in four wheel drive vehicles. Vehicle access is reliable in the winter and spring months. Summer maximum temperatures are consistently high, and the variation and diurnal range increase with distance from the coast.

Australian savanna vegetation comprises open wooded grassy landscapes in which a flush of annual flora, including many forbs, appears after the summer rains and persists only briefly before senescence (Wilson *et al.* 1990, Fox *et al.* 2001). The tall grasses, which proliferate during the wet season, are usually burnt off during the dry season (Allan *et al.* 2001, Williams *et al.* 1999). Fires, which are deliberately lit by either Aboriginals or pastoralists, or naturally lit by lightning strikes, are an important factor when sampling tropical savanna vegetation.

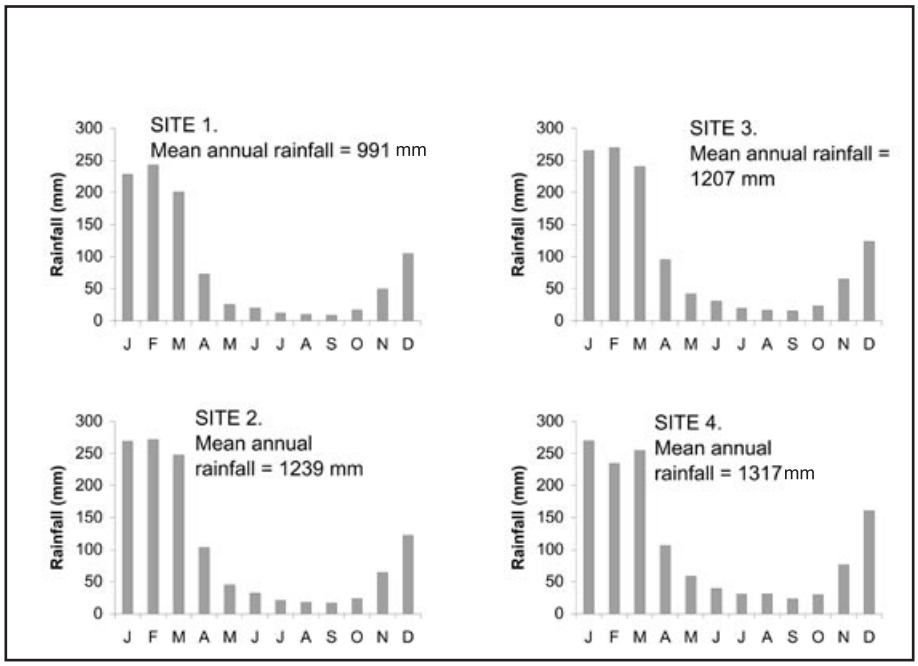

Fig. 2. Mean monthly and annual rainfall for monitoring sites derived from SILO Data Drill system (Jeffrey *et al.* 2001).

Previous research on vegetation sampling in Australia's tropical savannas

Taylor and Dunlop (1985) sampled woodland and monsoon forest in the Northern Territory in March when most herbs were fertile, and identification to species level was practical. They sampled again in May to coincide with the fertile period of the herbs in the lowlands and wetlands. The earlier sampling date generally provides higher quality plant specimens, but it is frequently difficult to access many areas in the wet season because of poor roads and flooding. Rice and Westoby (1983) sampled woodlands near McArthur River and in Arnhem Land in April and May, as the lowlands are often flooded during the wet season. They commented that the exact stage of the season might make species richness measurements vary. The Department of Natural Resources (1997) recommended that the best time to monitor is at the end of the growing season each year (March to May), because plants are easier to identify when they are fertile. It is generally also the time when stocking rate decisions need to be made. The North Australia Pastoral Company Pty Limited (NAPCO), which has large properties in the tropical savannas, monitors pasture and range condition in April or May, as this is the most accurate time to estimate wet season growth (Ritchie and Anderson 1998). Ash *et al.* (2002) sampled the pastures in eucalypt woodlands in the southern Einasleigh Uplands at the end of each growing season (April-May) and also at the end of the dry season. The timing of this monitoring was based on long-term experience with the climate of the area.

Due to the high proportion of annual species, tropical savanna communities can undergo significant year to year changes in botanical composition. The germination/establishment requirements of the various annual species mean that floristic compositon can vary with the timing, duration and intensity of the wet season (Grubb *et al.* 1982). This wet season variability is difficult to account for in the design of vegetation surveys.

One of the issues of repeat sampling is the comparability of subsequent measurements particularly when conducted by different individuals. Murphy and Lodge (2002) found that visual estimates

of ground and canopy (standing herbage greater than 5 cm high) cover were highly correlated with objective ground cover estimates by the mapped area, digital image analysis and point quadrat methods. Vanha-Majamaa *et al.* (2000) and Murphy and Lodge (2002) concluded that visual estimation is an efficient (quick and cheap) and highly reliable method and very suitable for monitoring ground cover.

Aim of this study

The aim of this study was to examine the effect of time of sampling on the floristic and structural information collected, and determine the most effective time for sampling vegetation in the monsoonal savannas of northern Queensland. This study was designed to provide information on the relative value (in terms of percentage floristic diversity capture) and limits to the use of data collected at different times of the year.

Methods

Field sampling

The vegetation survey and mapping methods adopted by the Queensland Herbarium have been summarised and fully discussed by Neldner (1993) and the site sampling methods by Neldner *et al.* (2004). In summary, a single 50 m transect was established at each site and permanently marked at both ends with steel pickets. All vascular plant species occurring within the area 5 m on either side of the centre line were recorded. The height of all woody species was measured using a clinometer, projective foliage cover (PFC) using a line intercept method (Mueller-Dombois and Ellenberg 1974), stem density by counts within the plot, and basal area using the Bitterlich method (Grosenbraugh 1952). All ground layer species present in the plot were recorded, and PFC of each species was visually estimated in 0.5 m^2 quadrats located every 5 m along the transect. Neldner provided the visual estimates for all samplings, and hence removed any issues of observor comparability.

The initial sampling occurred on 1 November 1991. Repeat sampling of the tree PFC and the ground layer occurred on or near the first day of February (mid-wet season when vehicle access can be impossible in most remote areas), May (mid-Autumn when most roads are generally passable), August (mid-dry season when all roads are passable and many areas have already been burnt), and November (end of dry season, start of summer storms) in 1992, 1993 and 1994 inclusive. Photographs of the site were taken at each sampling, and voucher specimens collected, identified and lodged at the Queensland Herbarium. Plant nomenclature follows Henderson (2002) and any subsequent taxonomic changes recognised by the Queensland Herbarium.

Study sites

Four sites were located within a 20 km radius of Mareeba (see Fig. 1). The sites were located in a variety of eucalypt communities and across an altitudinal range from 380 to 840 m above sea level. This gradient was reflected by average annual rainfall ranging from 992 to 1317 mm (see Fig. 2). The mean monthly and annual rainfall of all four sites was modelled using the SILO Data Drill system of the Queensland Department of Natural Resources and Mines (Jeffrey *et al.* 2001). The Data Drill produces synthetic climate data for any location by modelling and interpolation of point Bureau of Meteorology station records. Site 1 experiences a similar climate to Mareeba, which has a highly seasonal rainfall pattern of wet summers and very dry winters, typical of the tropical savannas of northern Australia. Site 4, because of its altitude and landscape position, experiences a higher annual rainfall and significant rainfall during the winter months. Site 4 experiences a climate typical of the western part of the Wet Tropics bioregion, whereas the other three sites all contain regional ecosystems typical of the Einasleigh Uplands bioregion (see Fig. 1).

Site 1 was located 16.5 km north of Mareeba at 16º51'19", 145º23'15" at an altitude of 380 m. *Eucalyptus platyphylla* (Basal Area (BA) is 3 m^2/ha) 15-18 m tall and *E. leptophleba* (BA 2) 18-20 m open-woodland with ground layer dominated by *Themeda triandra*. A single subcanopy tree *Dolichondrone heterophylla* 9 m tall was present, with *Melaleuca minutifolia* nearby. This site occured on a virtually level depositional plain on duplex soils in an ungrazed road reserve. It is typical of regional ecosystem 9.5.9, which covered 59,301 ha in the Einasleigh Uplands bioregion in 2001 (Accad *et al.* 2003, Queensland Herbarium 2003).

Site 2 was located 15.9 km east of Mareeba at 16º58'11", 145º34'00" at an altitude of 440 m. *Corymbia clarksoniana* (BA 10) dominated a 14-20 m tall woodland with *Eucalyptus leptophleba* (BA 1), *E. platyphylla* (BA 1), and *C. dallachiana* subdominant canopy trees. A very sparse (<1%) subcanopy layer of *Melaleuca viridiflora* and *Petalostigma banksii* trees 2-9 m tall was present, as well as a very sparse (<1%) shrub layer <1.5 m tall. The ground layer was dominated by *Themeda triandra* and in stony patches, *Schizachyrium* species. It was located on a lower slope of ranges on shallow soil overlying metamorphic schist. It occurs in a State Forest and was subject to light grazing by domestic stock as evidenced by cattle dung and limited numbers of grazed plants. This site occurs in an outlying occurrence of regional ecosystem 9.11.7, which covered 30,387 ha in the Einasleigh Uplands bioregion in 2001 (Accad *et al.* 2003, Queensland Herbarium 2003).

Site 3 was located 15.5 km east of Mareeba at 17º00'41", 145º33'55" at an altitude of 600 m. *Eucalyptus granitica* (BA 5) dominated a 18-22 m tall woodland with *Corymbia citriodora* (BA 2), *C. clarksoniana* (BA 1) and *Erythrophleum chlorostachyus* (BA 1) subdominant canopy trees. A very sparse (<1%) subcanopy layer of *Melaleuca viridiflora* and *Petalostigma banksii* trees 2-6 m tall was present, as well as a sparse (<5%) shrub layer 0.5-1.5 m tall, mainly composed of *M. viridiflora*. The ground layer was dominated by *Themeda triandra* and in stony patches, *Schizachyrium* species. It occurred in Davies Creek National Park near the crest of a ridge on shallow soil overlying metamorphic schist. This site was typical of regional ecosystem 9.11.2, which covered 353,362 ha in the Einasleigh Uplands bioregion in 2001 (Accad *et al.* 2003, Queensland Herbarium 2003). The ground layer of this site was burnt after the sampling in November 1992. Some low (1-2 m tall) shrubs were killed although the majority resprouted soon after the fire.

Site 4 was located 15.9 km south-east of Mareeba at 17º04'58", 145º32'32" at an altitude of 840 m. *Eucalyptus reducta* (BA 13) and *Corymbia intermedia* (BA 6) dominated a 22-25 m tall open-forest with *C. citriodora* (BA 1) and *E. granitica* (BA 1) subdominant canopy trees. *Allocasuarina torulosa* (BA 5) dominated a 6-8 m (up to 15 m) tall subcanopy tree layer. A very sparse (<1%) shrub layer <1.0 m tall was present. The ground layer was dominated by *Themeda triandra*, with *Mnesithea rottboellioides* and *Arundinella setosa* being subdominant grasses. It occurred near the crest of a steep granite range in the State Forest and was lightly grazed by domestic stock. Ground layer plants generally retained a green appearance throughout the year. This site was typical of regional ecosystem 7.12.27, which covered 3295 ha in the Wet Tropics bioregion in 2001 (Goosem *et al.* 1999, Accad *et al.* 2003, Queensland Herbarium 2003).

Data analysis

Field data were collated and entered into a Microsoft Access database. Data were analysed using S-PLUS (Venables and Ripley 2000). The effects of season, site and year on the number of observed ground taxa, total ground PFC, *Themeda* PFC, non-*Themeda*/*Heteropogon* PFC and tree PFC were investigated using a three-factor mixed model ANOVA. The factors, season and site, were treated as fixed and the year factor treated as random. The type I error rate of the analyses was fixed at 0.05. To ensure the assumptions of ANOVA were met, data on the number of observed taxa were transformed using square-root transformation and PFC data were

transformed using arcsine transformation. Bartlett's test was used to confirm that the variances of the data were homogeneous.

Results

A total of 181 vascular plant species, representing 44 families, were recorded in the sites during the three years of sampling. Poaceae (39 species) and Fabaceae (22 species) were the dominant families. Appendix 1 lists all of the species recorded in the ground layer by the sites they occurred in and their frequency of occurrence and average cover (PFC averaged from 10 quadrats) at a site over the three years of sampling.

The overall plant species richness in the ground layer during the sampling period averaged 15.6 taxa (standard deviation, SD 9.5) for Site 1, 27.5 (SD 12.3) for Site 2, 30.0 (SD 13.6) for Site 3, and 20.2 (SD 6.5) for Site 4. The results of the ANOVA analysis showed a significant effect for site for the number of ground taxa ($P<0.005$), ground layer PFC ($P<0.025$), *Themeda triandra* and *Heteropogon triticeus* PFC ($P<0.005$), ground layer PFC – *T. triandra* and *H. triticeus* ($P<0.025$) and tree layer PFC ($P<0.025$). Therefore conclusions based on comparisons among sites can only be limited.

The ANOVA analysis showed a significant effect for month of sampling for the number of ground taxa ($P<0.005$). The highest number of ground taxa was recorded in the May sampling at all four sites in all years except for Sites 1 and 2 in 1993, with the November sampling consistently recording the lowest number of taxa (Fig. 3). By May all the ground layer plants were in a fertile state and readily identifiable, although some had already started to shed seed sometimes making identification more difficult. At Site 1, *Camptacra gracilis* germinated in the early November storms and reached its fertile peak in February. This species was missed in two of the May samplings, but the vast majority of ground taxa were present and identifiable in early May.

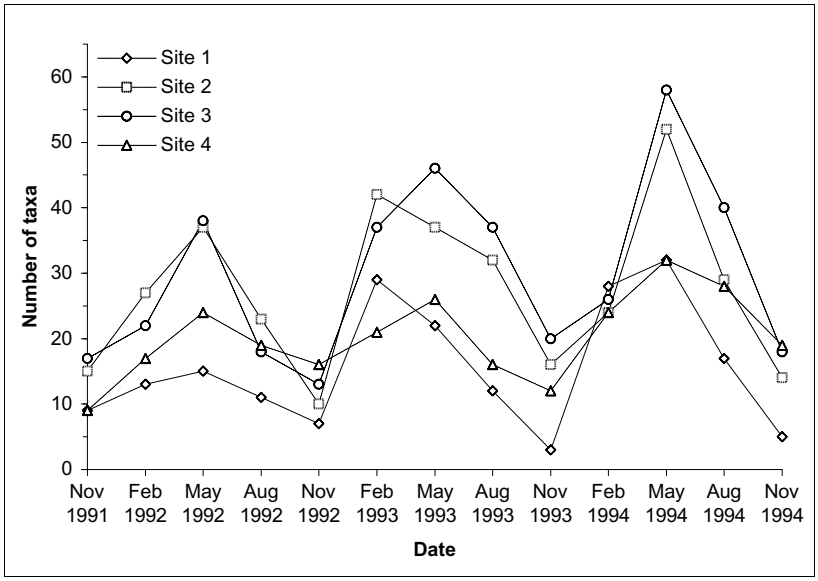

Figure 3. The number of ground taxa collected at each site, displayed by sampling occasion.

The percentage of the ground taxa recorded in the May sampling at each site varied from 84% to 86% of the accumulated taxa recorded across the whole three years (Fig. 4), whereas the

November sampling's accounted for between 21 and 56% of the site total. The disparity between end of wet and dry season sampling was highest in Site 1 and lowest in Site 4 (Fig. 4).

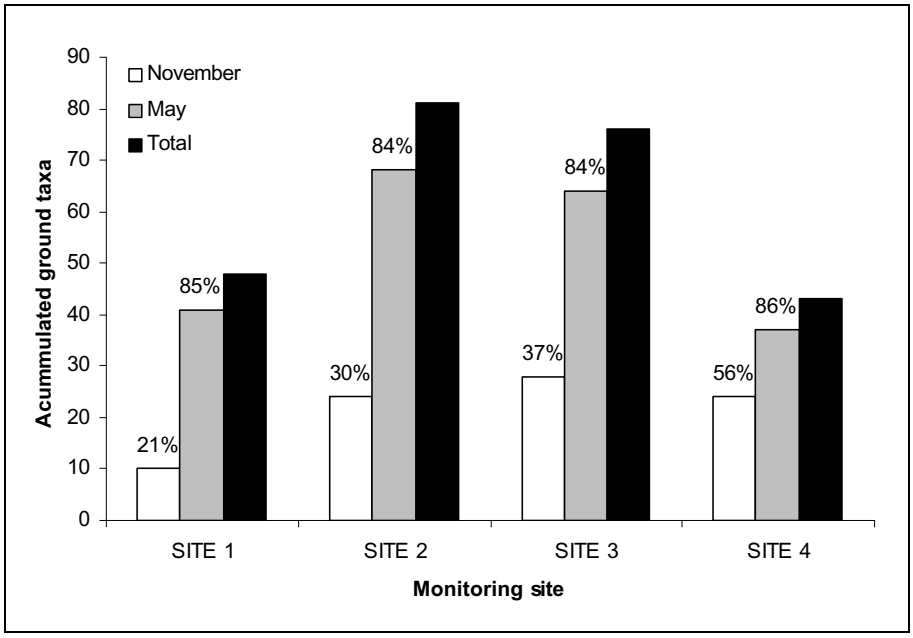

Figure 4. The total number of accumulated ground taxa over the entire sampling period (1992-94) displayed by site. The percentage of total taxa recorded for a site for the months of May and November are presented in comparison to the total for all months.

The cover of the ground layer species was also affected by season (Fig. 5) with the ANOVA analysis showing a significant effect of month of sampling on ground layer PFC ($P<0.05$). Within any year the highest cover was recorded in the May sampling except for Site 1 in 1992 and 1993, while November generally recorded the lowest ground cover. There was significant variation among sites in the total cover averaged over all times of sampling, with both Site 4 (mean 55% and SD of 12) and Site 1 (mean 48% and SD of 17) generally recording the highest cover.

Themeda triandra was the only species that was recorded at each site on every sampling occasion (Appendix 1). It also had the highest cover at all sites, with average PFC of 46.1% at Site 1, 11.3% at Site 2, 14.1% at Site 3 and 31.8% at Site 4. Figure 6 shows the variation in *T. triandra* PFC across the sites and sampling times. Although variable, the overall PFC recorded for this dominant perennial species was relatively consistent throughout. *Heteropogon triticeus* was recorded at all sites, and all but one November sampling. It was the subdominant grass at Site 1 with an overall PFC of 4.7%. *Heteropogon contortus* was only recorded at Sites 2 and 3, but was only consistently present with moderate cover at Site 3. *Alloteropsis semialata* and *Arundinella setosa* are other perennial grasses which were widely recorded in time and space. *Mnesithea rottboellioides* and *A. setosa* were subdominant grasses at Site 4. The PFC of the ground layer excluding the dominant grasses is shown in Fig. 7. It displays a strong seasonal pattern, with May generally recording the highest PFC and November the lowest. Frequent forbs included *Cyanthillium cinereum, Pterocaulon sphacelatum, Chamaecrista nomame, Phyllanthus virgatus, Crotalaria medicaginea* and *Zornia muriculata*.

The ANOVA analysis showed that the seasonal effect on PFC of the tree layer depended on site

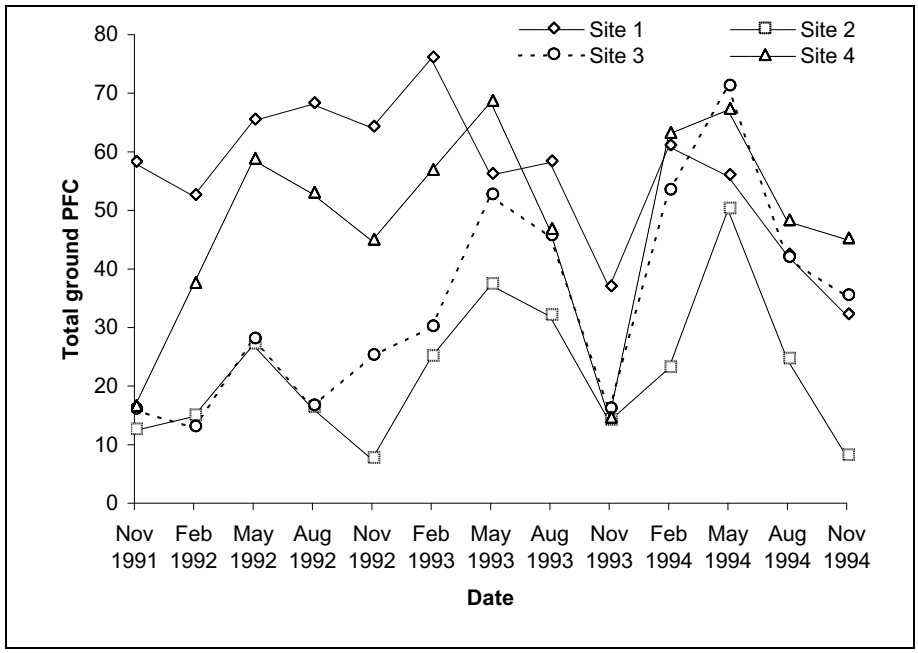

Figure 5. The projective foliage cover for the ground layer at each site, displayed by sampling occasion.

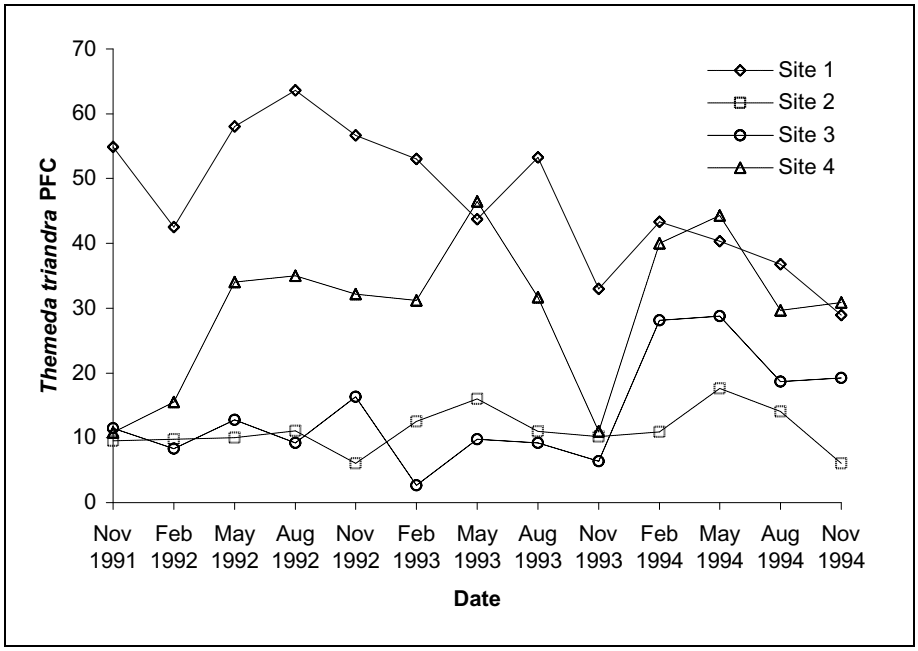

Figure 6. The projective foliage cover for *Themeda triandra* at each site, displayed by sampling occasion.

with Sites 3 and 4 being less affected than 1 and 2 (Fig. 8). In contrast, the ground layer PFC was significantly affected by month of sampling averaged over all sites (Fig. 5).

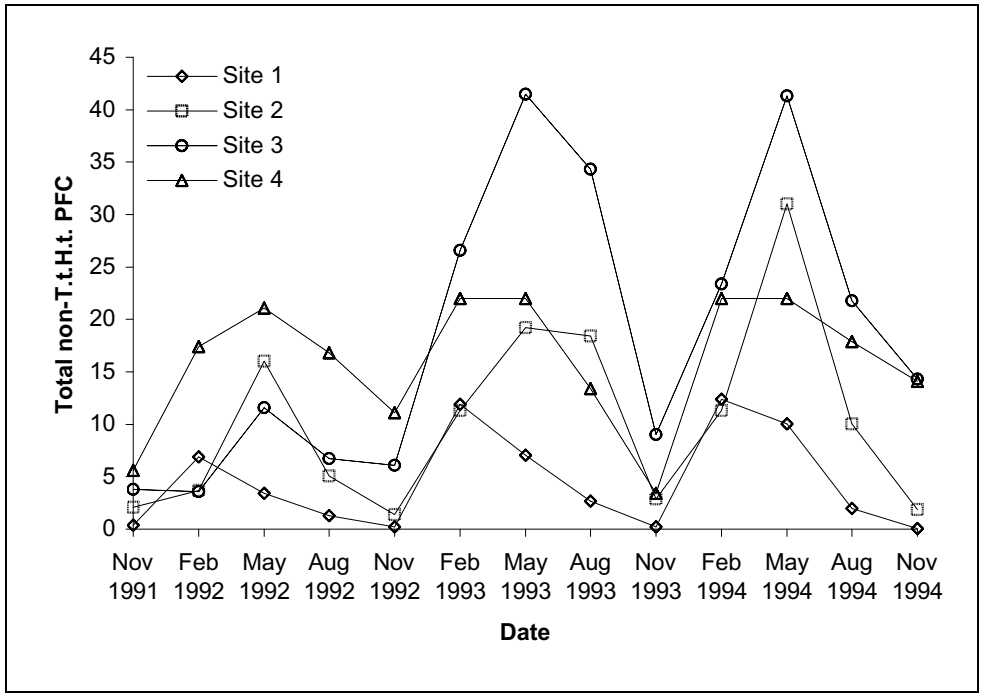

Figure 7. The projective foliage cover for the ground layer at each site, excluding *Themeda triandra* and *Heteropogon triticeus*, displayed by sampling occasion.

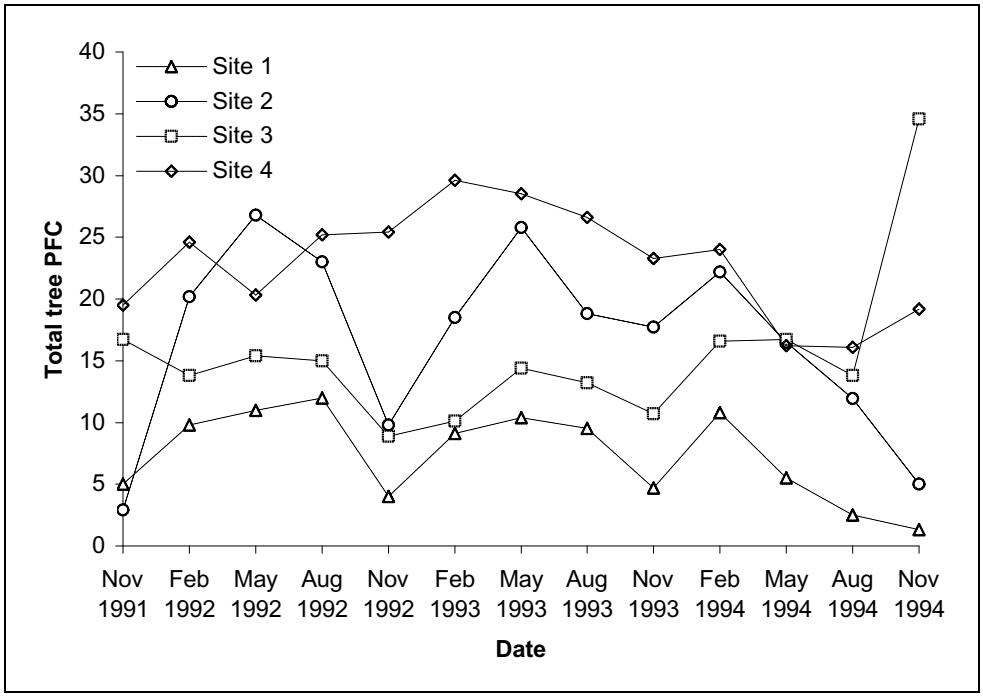

Figure 8. The projective foliage cover for the tree layer at each site, displayed by sampling occasion.

Discussion

The families and genera represented in this study are typical of the flora of the Australian tropical savannas (Clarkson and Kenneally 1988).

Variation among sites

There was significant variation among sites both in terms of the environmental conditions (landscape position, geology, climate) and the vegetation, and each site was assigned to a different regional ecosystem (Queensland Herbarium 2003). The higher vascular plant biodiversity recorded for Sites 2 and 3 is interesting, but this study does not present any evidence on why this is so. Site 2 and Site 3 showed evidence of light grazing and Site 3 was burnt in a ground fire in November 1992.

Seasonal effects on the ground layer

The sites were deliberately selected to cover a gradient in the amount of mean annual rainfall (992 to 1317 mm) and amount of seasonality experienced at each site (50% (Site 4) to 58% (Site 1) of annual rainfall experienced in summer months). The three years of sampling (1992-1994) were relatively dry years compared to the long-term average rainfall for the area (Mareeba recorded 64, 74 and 54% of the long-term mean annual rainfall of 911 mm in 1992, 1993 and 1994 respectively, and Atherton received 67, 48 and 51% respectively of 1413 mm) (Bureau of Meteorology 2003). However, the summer rainfall dominance of 65, 74, and 58% of annual rainfall received in 1992, 1993 and 1994 at Mareeba, and 67, 48 and 51% at Atherton was similar to the long-term summer rainfall percentage for these towns of 61 and 54% respectively. Hence while the actual amount of rainfall received varied during the sampling period, the seasonal distribution of rainfall was typical of the long-term rainfall pattern.

The results of this study support the experiences of other authors that a May sampling is near optimum for sampling the ground layer floristic diversity (Rice and Westoby 1983, Taylor and Dunlop 1985). Sampling in February returned the second highest overall number of ground taxa, but generally there are serious vehicle access problems at this time of year. November is the least effective time to sample for ground layer diversity.

Themeda triandra dominated the ground cover of all four sites, and was easily identified at all times of the year, as it holds some of its distinctive inflorescences even in the dry season. The seasonal variation in cover is mainly explained by the lack of cover of other ground layer species in the dry season (Figs 6 and 7). The month of sampling did not have a significant effect on *T. triandra* and *H. triticeus* PFC, but showed a significant effect for ground layer PFC other than these two species ($P<0.005$). At Site 1 where *T. triandra* exerted the highest dominance, the cover of non-*Themeda* species was virtually negligible in the dry season months, but was most conspicuous in February and May. A similar effect was also observed in the other three sites but was not as pronounced.

Seasonal effects on the woody plants

Deciduous eucalypt trees are a conspicuous feature of some northern tropical savannas. In the sample sites there were a number of canopy tree species, *Eucalyptus platyphylla, Corymbia dallachiana,* and *Erythrophleum chlorostachyus;* and subcanopy species, *Planchonia careya, Petalostigma banksii* and *Dolichondrone heterophylla,* which were mostly or completely deciduous from August to November. Projective foliage cover is a component in the widely used Specht (1970, 1981) vegetation classification. Because of the seasonal sensitivity with deciduous

woody plants in the tropics, Walker and Hopkins (1990) used canopy cover in their classification system. Canopy cover treats tree crowns as solid to the outer extent of the branches.

For vegetation mapping purposes, the tallest layer (Specht 1970, 1981, Walker and Hopkins 1990) or the predominant layer (Neldner *et al.* 2004) (the layer that contributes most to the above-ground biomass of the site) defines the vegetation units (Sun *et al.* 1997). In most communities, apart from grasslands and herblands, it is the perennial trees or shrubs that determine the mapped vegetation community. Hence survey data collected at any time of the year generally can capture the necessary data for mapping woody communities. Species identification in deciduous vine thickets can, however, be problematic. Neldner and Howitt (1991) found that numerical classification of the woody component of floristic site data generally provided a high correlation with mapped communities, particularly when an abundance measure was analysed. Hence survey data collected in the dry season is certainly valuable for vegetation mapping purposes, but it has limited use for providing full floristic inventories or modelling non-woody species.

Conclusions

In Eucalypt communities experiencing highly seasonal rainfall in north Queensland, vegetation sampling in the late wet season (May) maximises the diversity of flora recorded. Most vegetation survey and mapping data are of necessity collected in less ideal times of the year due to access issues. Care must be exercised in using data collected in the dry season, as only a limited proportion of the total ground flora is likely to be recorded. This has implications for the types of data analysis and modelling that can be used on these data. For example, a floristic classification based on all species recorded should be constrained to the data collected in the peak sampling months of April to June. It also means that studies designed to capture the full florisitic inventory of species present in these highly seasonal environments need to budget resources and plan to access these environments in the late wet season.

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Appendix 1. Vascular plants recorded in the ground layers of the four sites.
A "+" indicates the taxon was present but recorded<0.1% mean PFC

Species Name	Sampling Frequency (Maximum 12 overall, 3 for any month)												Mean Projective Foliage Cover (PFC) (%)											
	Site 1			Site 2			Site 3			Site 4			Site 1			Site 2			Site 3			Site 4		
	Overall	May	Nov	Overall	May	Nov	Overall	May	Nov	Overall	May	Nov	Overall	May	Nov	Overall	May	Nov	Overall	May	Nov	Overall	May	Nov
Acanthaceae																								
Brunoniella acaulis subsp. *acaulis*	6	2	1	1	1								0.8	1.0	+	+	+							
Rostellularia adscendens var. *latifolia*	7	2					1	1		12	3	3	0.3	0.4					+	+		0.6	1.1	0.2
Adiantaceae																								
Cheilanthes brownii				5	2		9	2	1							0.1	0.1		0.1	0.1	+			
Cheilanthes nitida				9	2	1	9	3	1							0.2	0.2	+	0.1	0.3	+			
Anthericaceae																								
Tricoryne anceps subsp. *anceps*							6	3		3	1								0.1	0.1		+	+	
Aristolochiaceae																								
Aristolochia holtzei	2	1		1			1						+	+		+			+					
Asclepiadaceae																								
**Cryptostegia grandiflora*	2	1											+	+										
Asteraceae																								
Blumea sp.				4	2		3	1								0.1	0.2		0.1	+				
Camptacra gracilis	3	1											+	+										
Cyanthillium cinereum	4	1		12	3	3	2	2		11	3	2	+	+		0.4	0.3	0.1	+	0.1		0.2	0.2	0.1
**Emilia sonchifolia*				4	3		2	2								+	0.1		+	0.1				
Phacellothrix cladochaeta				7	3	1	7	3	1							0.3	0.8	+	0.5	1.3	+			
Pterocaulon sphacelatum	8	3	1	1	1		6	2	1	1	1		0.1	0.1	+	+	+		0.1	0.1	+	+	+	
Wedelia biflora										9	3	1										0.1	0.1	+
Bignoniaceae																								
Dolichandrone heterophylla	5	1											0.2	0.3										
Boraginaceae																								
Heliotropium peninsularis				1	1		3	1								+	+		0.1	0.1				
Byblidaceae																								
Byblis liniflora				2	1		4	2								+	+		+	0.1				
Caesalpiniaceae																								
Chamaecrista absus var. *absus*				2	2		6	3								+	0.1		0.1	0.2				
Chamaecrista nomame var. *nomame*	3	1		6	3	1	6	2	1	7	3	1	++	+		0.1	0.3	+	0.2	0.4	+	0.1	0.2	+
Erythrophleum chlorostachys							4	2											0.1	0.1				
Campanulaceae																								
Wahlenbergia caryophylloides				6	2	3				1						0.1	0.1	0.1				+		
Capparaceae																								
Capparis canescens	1	1								5	2	1	+	+								+	0.1	+
Clusiaceae																								
Hypericum gramineum				1	1											+	+							
Colchicaceae																								
Iphigenia indica	1			2	1					2			+			+	+					+		
Commelinaceae																								
Cartonema spicatum							1												+					
Commelina ensifolia							2	1											+	+				
Murdannia graminea				4												+								
Convolvulaceae																								
Evolvulus alsinoides	3	1		2	1		8	3	1				+	+		+	+		0.1	0.2	+			
Ipomoea eriocarpa							5	2											0.1	0.2				
Ipomoea graminea	3	1											+	+										
Cyperaceae																								
Abildgaardia ovata				10	3	1										0.4	0.3	+						
Bulbostylis barbata				2	1											+	0.1							
Cyperus castaneus var. *castaneus*				1	1											+	+							
Cyperus pulchellus				1												+								
Fimbristylis bisumbellata							12	3	3										1.2	1.7	0.2			
Fimbristylis recta				3			2	1								+			+	+				
Fimbristylis sp.	8	3		2	1					2	1		0.3	0.4		0.2	0.6					+	0.1	
Rhynchospora heterochaeta				4	2		3	3								0.1	0.3		+	0.1				
Scleria brownii	2	1					1			1			+	0.1					+			+		
Scleria mackaviensis										4		1										0.1		0.2
Dilleniaceae																								
Hibbertia longifolia										5	2	1										+	0.1	+
Euphorbiaceae																								
Breynia cernua										7	2	1										0.4	0.6	0.3
Chamaesyce mitchelliana var. *mitchelliana*	2			1	1		8	3					+			+	+		0.1	0.1				
Petalostigma banksii							4	2											0.1	0.3				
Phyllanthus virgatus	4	1		8	3		9	3	2	9	3	2	+	0.1		0.1	0.2		0.1	0.1	0.1	0.1	0.2	0.1
Poranthera microphylla				3	2		2	1		1						0.1	0.2		0.1	0.1		+		
Fabaceae																								
Crotalaria brevis										11	3	3										0.1	0.1	0.1
Crotalaria calycina				2	1		1									+	+		+					
**Crotalaria goreensis*	6	2	1	1	1		6	2	1				0.4	0.7	+	+	+		0.1	0.2	+			
Crotalaria medicaginea var. *medicaginea*	1			7	3	1	8	3	1	8	3		+			0.2	0.5	+	0.3	0.8	+	0.2	0.2	
Crotalaria montana	1			6	2	1	9	3	1				+			0.1	0.1	+	0.1	0.3	+			
Desmodium filiforme				7	2	2										0.4	1.0	0.1						
Desmodium heterocarpon							2	1		7	2	2							0.1	+		0.1	0.1	0.1
Desmodium rhytidophyllum				6	3											0.1	0.5							
Desmodium sp.	1						4	1					+						0.1	0.3				
**Desmodium strigillosum*	7	2											0.1	0.1										
Desmodium trichostachyum				1	1											+	+							
Eriosema chinense	2	1											+	+										

Appendix 1. (continued)

Species Name	Sampling Frequency (Maximum 12 overall, 3 for any month)												Mean Projective Foliage Cover (PFC) (%)											
	Site 1			Site 2			Site 3			Site 4			Site 1			Site 2			Site 3			Site 4		
	Overall	May	Nov	Overall	May	Nov	Overall	May	Nov	Overall	May	Nov	Overall	May	Nov	Overall	May	Nov	Overall	May	Nov	Overall	May	Nov
Flemingia parviflora										10	3	1										1.1	1.9	0.1
Galactia tenuiflora forma *sericea*	4	2								11	3	2	+	0.1								1.6	1.7	0.4
Glycine curvata				5	2					4	1	1				0.1	0.1					0.4	0.8	0.5
Indigofera pratensis	6	3		1			1			1	1		0.1	0.1		+			+			+	+	
Pycnospora lutescens				2	2											+	0.1							
Tephrosia filipes							1	1											+	+				
Tephrosia juncea				9	3	1	11	3	2							0.2	0.2	+	0.2	0.2	0.1			
Tephrosia purpurea var. *sericea*										1	1											+	+	
Vigna sp.							1	1											+	+				
Zornia muriculata subsp. *muriculata*	2	1		12	3	3	8	3		7	2		+	+		1.3	2.1	0.3	0.3	0.7		0.1	0.1	
Goodeniaceae																								
Goodenia pilosa				2	1											+	0.1							
Loganiaceae																								
Mitrasacme connata							6	3	1										0.2	0.3	0.1			
Mitrasacme pygmaea				4	2		2	1								0.1	0.2		+	+				
Lythraceae																								
Rotala diandra				1	1											+	+							
Mimosaceae																								
Neptunia gracilis forma *glandulosa*	1	1											+	+										
Myoporaceae																								
Eremophila debilis	5	2								2	1		+	0.1								+	+	
Phormiaceae																								
Dianella nervosa										7	2	2										0.2	0.4	0.3
Poaceae																								
Alloteropsis semialata	7	2	1	8	2	3	12	3	3	7	3	1	0.2	0.2	0.1	0.2	0.1	0.2	1.5	1.0	0.6	1.4	2.6	0.3
Ancistrachne uncinulata										5	1	2										0.1	0.2	0.2
Aristida utilis	1	1		7	2	1	6	3					+	+		0.1	0.1	+	0.1	0.1				
Arundinella setosa				10	3	3	7	1	3	12	3	3				0.6	1.2	0.3	0.1	+	0.1	5.0	4.6	4.2
Bothriochloa bladhii subsp. *bladhii*	1	1											+	+										
Brachiaria polyphylla							3	3											0.1	0.3				
Capillipedium parviflorum	6	3											0.1	0.2										
Chrysopogon fallax				5	2											0.1	0.2							
Cymbopogon obtectus							4	1	2										+	+	0.1			
**Dichanthium annulatum*	1	1											+	+										
Digitaria gibbosa				1			5	3	1	1						+			0.2	0.6	+	+		
Dimeria sp.				1	1											+	0.1							
Eragrostis brownii	9	3	1	1									0.2	0.2	+	+								
Eragrostis cumingii				8	2	1										0.1	0.1	+						
Eragrostis spartinoides				2	1		5	3								+	0.1		0.1	0.1				
Eremochloa bimaculata	1			9	3		4	2		9	3	1	+			0.1	0.1		+	0.1		1.1	2.0	0.7
Eriachne sp.							1	1		2	2								+	+		+	0.1	
Heteropogon contortus				4	1	1	11	3	3							0.2	0.3	0.2	3.6	5.3	3.8			
Heteropogon triticeus	12	3	3	11	3	2	12	3	3	12	3	3	4.7	4.9	4.6	1.0	1.5	0.3	1.5	1.9	1.7	1.5	1.5	0.6
**Melinis repens*							1	1		1	1								+	+		+	+	
Mnesithea formosa				3	3		5	3	1							0.2	0.8		0.4	1.3	+			
Mnesithea granularis				1												+								
Mnesithea rottboellioides				4						12	3	3				+						3.8	4.0	1.9
Panicum decompositum var. *tenuius*	5	2	1										0.1	0.2	+									
Panicum effusum var. *effusum*	6	1		3	1	1							0.5	0.4		+	+	+						
Panicum sp.										1	1											+	+	
Paspalidium distans	2	1											+	+										
Paspalidium retiglume	3												+											
Pseudopogonatherum contortum				2	2		2	2								+	0.1		+	0.1				
Schizachyrium occultum				11	3	3										3.0	6.0	0.8						
Schizachyrium pachyarthron							11	3	3										7.8	11.8	4.3			
Schizachyrium pseudeulalia				1	1											+	+							
Schizachyrium sp.				1	1											+	+							
Setaria surgens							2												+					
Sarga plumosum	6	2	1							2	1		0.1	0.2	+							+	+	
**Sporobolus jacqemontii*	3	2		1									0.1	0.2		+								
Sporobolus sp.				1												+								
Thaumastochloa major				7	3		7	3								1.5	3.1		1.2	1.7				
Themeda triandra	12	3	3	12	3	3	12	3	3	12	3	3	46.1	47.3	39.5	11.3	14.5	7.5	14.1	17.1	14.0	31.8	41.6	24.7
Polygalaceae																								
Polygala linariifolia				4	2		2	1								+	0.1		+	+				
Polygala longifolia	4	2		2	1								0.1	0.1		+	+							
Rhamnaceae																								
Alphitonia obtusifolia							2												+					
Rubiaceae																								
**Mitracarpus hirtus*				5	3		5	2								0.4	0.7		0.1	0.1				
Oldenlandia laceyi				3	1		2		1							+	+		+		+			
Spermacoce sp.				10	3	3	8	3	2							0.2	0.1	0.2	0.3	0.6	0.2			
Scrophulariaceae																								
Buchnera gracilis				6	3	1										0.1	0.2	+						
Buchnera linearis							5	2											0.1	0.1				
Lindernia sp.							1												+					
Stackhousiaceae										13														
Stackhousia intermedia				1			4	2								+			0.1	0.2				
Taccaceae																								
Tacca leontopetaloides							3	1											+	+				
Thymelaeaceae																								
Pimelea sericostachya subsp. *sericostachya*							10	3	3										0.2	0.2	0.3			
Thecanthes cornucopiae				6	3		5	3								0.2	0.7		0.1	0.2				
Tiliaceae																								
Grewia retusifolia	10	3	1	6	2		6	2					2.2	3.2	0.1	0.1	0.1		0.1	0.1				
Violaceae																								
Hybanthus enneaspermus				5	1	1	10	3	2							0.1	+	+	0.1	0.1	0.1			
Hybanthus stellarioides										3	1											+	+	
Vitaceae																								
Cayratia trifolia	7	3	1										0.2	0.1	+									
Xanthorrhoeaceae																								
Lomandra filiformis subsp. *filiformis*							4		2										+		0.1			
Lomandra multiflora subsp. *multiflora*				4	1											+	+							
Lomandra sp.	1	1					7	2	2	8	2	3	+	+					0.1	0.1	0.1	0.2	0.2	0.1