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# Flora and vegetation of the banded iron formations of the Yilgarn Craton: the central Tallering Land System

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## ABSTRACT

A quadrat-based survey was undertaken on the flora and floristic communities of several ironstone ranges and outcrops in the Yalgoo bioregion, covering the central extent of the Tallering Land System. One hundred and three 20 x 20 m quadrats were established over the extent of this region, and covered the topographic profile of these landforms. A total of 414 taxa (species, subspecies, varieties and forms) and four hybrids were identified from these quadrats. Fifteen taxa of conservation significance were found in this survey, five of which had not been previously recorded from the area. Significant range extensions for 21 species are reported in this study. At least nine new taxa were identified, of which several are of conservation significance. Nine regional endemic and near-endemic taxa were found over the study area, with half restricted to the south-west hills.

Eight floristic community types (five main types, two with subtypes) were resolved from classification analysis of floristic data (presence / absence). These community types were strongly associated with topography and soil chemistry. Geographical variation was found among the floristic communities within the region, and some communities were found to be restricted to the south-west of the survey area. These restricted communities were found to occur in the more mesic regions of the survey area, on rocky uplands of BIF, and had notable component of flora from the South West Floristic Region.

The central Tallering Land System is currently unreserved, although three pastoral leases have been purchased by the Western Australian Department of Conservation and Land Management (CALM) (now known as the Department of Environment and Conservation (DEC)) with the intention for future inclusion in the conservation estate. Mining and exploration tenements cover nearly all of the central Tallering Land System. This area has significant conservation values, and proposed mining activities must be assessed and managed to minimise impacts on significant flora and floristic communities.

## INTRODUCTION

Previous quadrat-based surveys have examined the flora and floristic communities on a number of ranges in the eastern goldfields. These have provided a regional overview of these ranges, improved current knowledge of their flora and found that individual ranges of both banded iron formation (BIF) and greenstones possess unique communities that differ floristically from other ranges (Gibson 2004a, b; Gibson and Lyons 1998, 2001a, 2001b). Ironstone and greenstone landforms within the northern Murchison geological region currently lack such detailed information, and are currently subject to considerable exploration and mining interests. This current survey aims to examine the flora and floristic communities of a series of small ironstone ranges in the northern Yilgarn region, and is one of a series of surveys being conducted by DEC on ranges of prospectable BIF and associated metasedimentary geologies. These surveys aim to ultimately redress deficiencies in data for these areas, provide a regional context for these communities, and contribute to the conservation and management of biodiversity on BIF ranges.

## STUDY SITE

This survey focuses on the vegetation communities associated with several narrow, elongate belts of metamorphic sedimentary rocks that occur within the central Tallering Land System of Payne et al. (1998). These form two main arches that span a distance of c. 52 km east – west and extend c. 55 km in a north-south direction between Perenjori, Paynes Find and Yalgoo (Figure 1). The study area extends over the Karara, Badja, Thundelarra and Warriedar Stations, within the Yalgoo and Perenjori shires. This survey specifically targeted hills and ridges of banded iron formation (BIF) within this area.

The Tallering Land System was first described and mapped by Payne et al. (1998), and refers to the hills and ranges of ironstone, volcanic and metasedimentary geologies which are located between Mt Gibson and Tallering Peak. As the central portion of this land system coincides with the banded iron formations targeted by this survey, and the name ‘central Tallering Land System’ is adopted by this study as the collective name of these landforms within the study region.

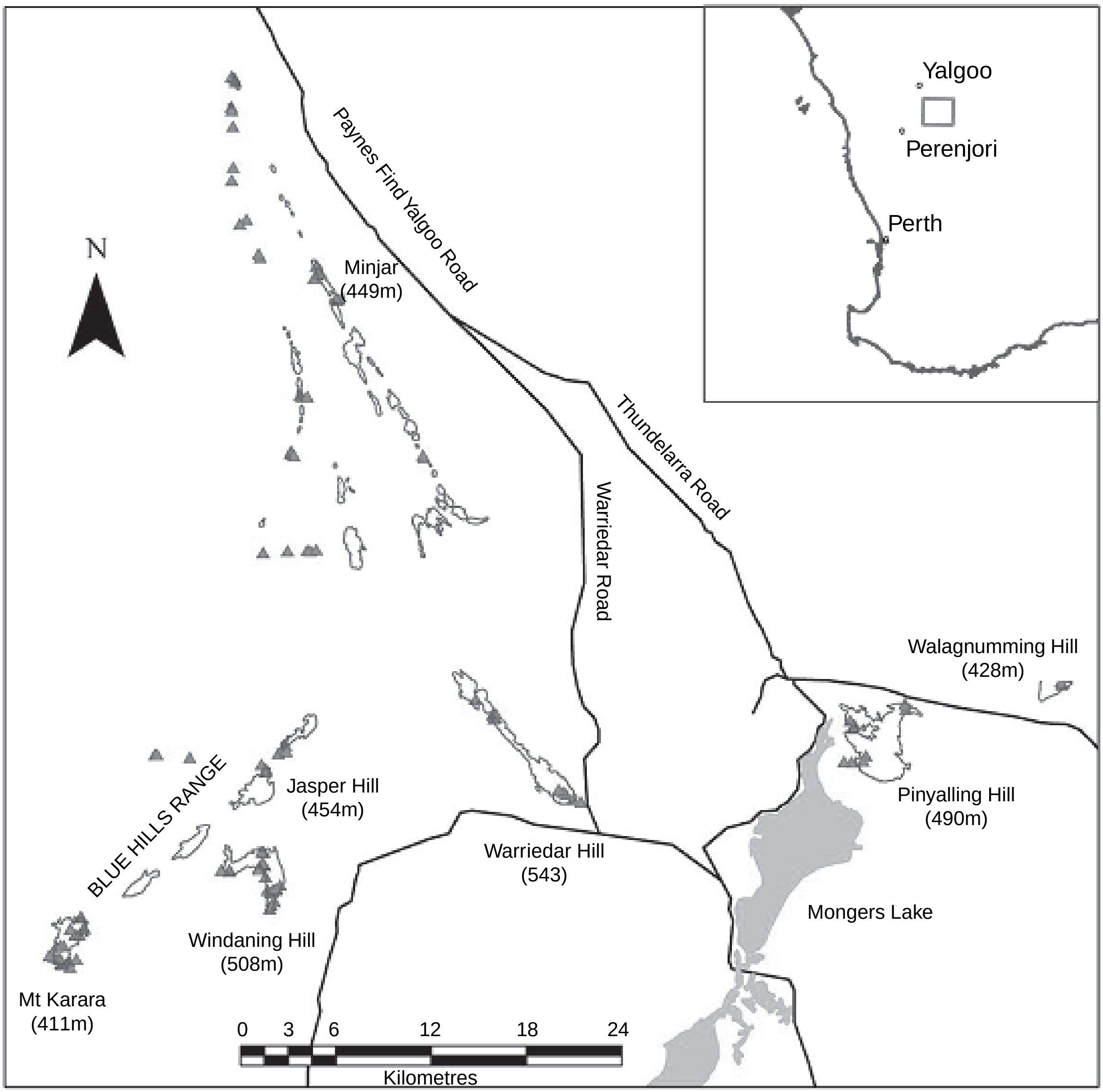


*Figure 1. Map showing the location of the survey region and location of the specific ranges, landforms and landmarks which constitute the central Tallering Land System. Locations of the 103 floristic quadrats are marked by triangles (▲).*

## Land Use History

The lands within the Yalgoo bioregion have been subject to pastoral and mining activity, although it has not been subject to extensive land clearing like the adjacent wheatbelt region. Pastoral leases were first established in the study area in the latter half of the 19th century, commencing with Thundelarra (Pinyalling Spring) and Badja stations in the early 1870's, and with most leases established by the early 1900's (Hennig 1998a). Thundelarra and Badja Stations are currently active. Between 2000 and 2004, the adjoining Karara, Lochada and Warriedar pastoral leases were purchased by the Department of Conservation and Land Management (CALM 2004). The current tenure status of this area is Unallocated Crown Land, and is in the process of tenure review with the intention of this area becoming conservation estate. These former leases have been subsequently de-stocked, wells closed and feral animal eradication programs implemented (CALM 2005).

Gold discoveries in the late 19th century led to the establishment of towns and gold mining activities in the region (Beard 1976a; Hennig 1998a). From the late 1960s until 1974, iron ore mining was conducted at the Blue Hills (Beard 1976b). Within the past decade, there has been dramatic upsurge in mineral exploration and mining activities following increased demand from China. Current mineral exploration activities in the region target rock ores as a source of iron, and both precious (Ag, Au) and industrial metals (Ni, Cr, Mn, Mo, Va, Tg) (Baxter & Lipple 1985; Baxter et al. 1983; Department of Industry and Resources 2007; Lipple et al. 1983; Muhling and Low 1977). There are currently two active mines in the study area at Gossan Hill and Golden Grove, whilst iron ore exploration is in progress on Mt Karara, Windaning Ridge and Blue Hills Range. Most of the central Tallering Land System is covered by mining tenements.

## Climate

The study area is bounded by the 300 and 250 mm isohyet and lies within the Semi-Desert Mediterranean bioclimatic region (Beard 1976a, 1990), where the annual evaporation range of 2800 – 3200 mm greatly exceeds the annual rainfall (Leighton 1998). The area has mild winters and hot, dry summers, and a low, moderately variable rainfall that falls mostly in winter, but irregular summer rainfall may occur (Beard 1976a, b; Leighton 1998). Winter rainfall is derived from rain-bearing cold fronts associated with the westerly wind system, and 62% of median annual rainfall is received during the winter season (Leighton 1998). Summer rainfall events are thunderstorms and heavy downpours derived from the depressions that are the remnants of tropical cyclones (Leighton 1998), such that over 120 mm can fall in a day (Australian Bureau of Meteorology 1908–). Rainfall is patchy and irregular in its distribution over the study area. Downpours may not be widespread but can be restricted to small areas, even within or between adjacent stations (Leighton 1998; A. Markey, pers. obs[1] ).

As Paynes Find and Yalgoo are the two closest meteorological centres to the study area, weather data from these centres provides some information on the climate of the survey area (Australian Bureau of Meteorology 1908–). There is a rainfall gradient over the region, such that rainfall decreases in a north-easterly direction. Therefore, the mean annual rainfall declines from Paynes Find (282 mm) northwards to 258 mm at Yalgoo (these records commencing from 1896 (Paynes Find) and 1919 (Yalgoo) until 2004). Rainfalls were good in the months preceding this current field survey (Spring 2005), and consequently there was an abundant growth of annuals and good flowering of perennial species within the study season.

For both centres, the average winter (June – August) maximum temperature is 19.1 °C, and the average summer (December – February) daily maximum is 36.3°C. January is the hottest month, with maximum temperatures of 37.1 °C and 37.2 °C in Paynes Find and Yalgoo, respectively. Conversely. the coldest month is July with mean minimum temperatures of 5.4 °C and 6.2 °C, respectively. Temperatures rarely fall below 0 °C, and occur on an average of 3.1 days and 0.6 days during July for Paynes Find and Yalgoo respectively. The predominant growing season is in winter, given that it is the coolest and wettest season (Leighton 1998).

## Geology

The geology of the study region has been described and mapped over four geological sheets; Perenjori 1: 250 000 (SH/50 – 6) (Baxter & Lipple 1985), Yalgoo 1: 250 000 (SH/50-2) (Muhling and Low 1977), Ninghan 1: 250 000 (SH/50-7) (Lipple et al. 1983), Kirkalocka 1: 250 000 (SH/50-3) (Baxter et al. 1983). The Murchison region is an undulating plateau of low relief, with large playa lake systems and erosional escarpments (breakways). Much of this region consists of Cainozoic deposits which overlie the granitoids, infolded belts of metamorphic sedimentary and igneous rocks of the Archaean Yilgarn Craton (Baxter et al. 1983; Johnson 1998; Lipple et al. 1983; Muhling & Low 1977). This subdued landscape is interrupted by hills, ridges and uplands of exposed Archaean granitoid and metamorphic sedimentary bedrock which rise above the surrounding plains.

Within the study area, the altitude ranges from low to high relief (360 – 543 m above sea level). Most hills range from 30 to 180 m in height above the surrounding plains, although a number of significant hills can exceed this (Figure 1). Whilst granitoids form monoliths and pavements, the metamorphic sedimentary and igneous rocks form elongate hills and rugged strike ridges that are linear-arcuate, and north to north-west trending (Johnson 1998; Lipple et al. 1983; Payne & Pringle 1998). These belts of Archean metamorphosed and deformed greenstones consist of mafic to ultramafic volcanics and felsic volcanics, and metasedimentary rocks of shale, siltstone, chert, jaspilite, and banded iron formation (BIF) (Baxter & Lipple 1985; Johnston 1998; Lipple et al. 1983; Muhling & Low 1977). Erosion of these Archean metasediments and volcanics forms a colluvium of sand, silt and angular ironstone, greenstone and quartz fragments, which deposit as talus and scree slopes and outwash fans on the margins of these landforms (Johnson 1998). Soils of these landforms consist of shallow or skeletal (< 50 cm) stony soils on the ridges, rises and hills, and associated with rocks, boulders and outcropping bedrock, which are replaced by shallow stony red earths and red clayey sands and ferruginous gravel on the lower slopes and outwashes (Hennig 1998b).

Three Land Systems have been identified by Payne and Pringle (1998) which refer to landforms of greenstone and banded iron formation in the Paynes Find – Sandstone area. These are the Tallering (prominent ridges and hills of banded iron formation, dolerite and metasedimentary rocks), Watson (metasedimentary rocks), and Gabanintha (volcanics and metasedimentary rocks) Land Systems. Of these Land Systems, the central extent of the Tallering Land System is the geomorphological unit which most specifically corresponds to the strike ridges and hills of banded iron formation examined in this survey. The banded iron formations and other metasedimentary rocks of the central Tallering Land System are associated with the Warriedar Fold Belt.

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## *Vegetation*

The study area is located in the Yalgoo subregion, which is nested within the Austin Botanical District of the Eremaean Botanical Province (Beard 1976b, 1990). This subregion of Beard (1976a) corresponds to the IBRA Yalgoo Bioregion (Environment Australia 2000; Thackway & Creswell 1995). Being in close proximity to the north-eastern boarders of the biologically diverse South West Botanical Province (Beard 1990; Hopper & Gioia 2004), the Yalgoo subregion is a transitional zone between the two botanical provinces (Beard 1976a; Environment Australia 2000; Thackway & Creswell 1995). However, there have been few detailed surveys on the vegetation communities within this region which spans this transition from the South West Botanical Province to the arid Eremaean Province. The vegetation maps of the Austin Botanical District were on a scale of 1:1000 000, and communities were defined primarily by physiognomy and dominant taxa (Beard 1976a). The Austin Botanical District is dominated by low mulga (*Acacia aneura*) woodland on the plains and reduced to *Acacia* scrub on hills (Beard 1976a, 1990). The hill vegetation was reported as shrublands dominated by *Acacia aneura*, *Acacia quadrimarginea, Acacia ramulosa* and *Acacia grasbyi* over a mid stratum of *Senna* and *Eremophila* shrubs, with little difference being noted between communities on granitoids and metamorphic sedimentary rocks at this scale (Beard 1976a, 1990).

On a more detailed scale, Beard (1976b) produced a 1:250 000 map of physiognomic vegetation formations of the Perenjori area, which only covers the lower half of this current survey area. On this scale, the extensive outcroppings of Archean metamorphic rocks (including banded iron formations) are associated with two vegetation systems; the Windaning System and Gnow's Nest System. The Windaning System consists of outcrops of Archaean metamorphic rocks which are covered in scrub (*Acacia ramulosa*, *Allocasuarina* sp., *Melaleuca* cf. *uncinata*, *Acacia quadrimarginea* and *Acacia acuminata* (=*A. burkittii*), and scattered eucalypts. The valleys are vegetated with acacia scrub and scattered emergent trees (Beard 1976b). Only the southern extent of the Gnows Nest System (coinciding with the Gnows Nest Range) was mapped, this southern extent being more subdued in topography than the Windaning system (Beard 1976b). Vegetation was described as *Acacia* scrub, dominated by A. *ramulosa* and *A. acuminata* (=*A. burkittii*), with *A. quadrimarginea* on steeper slopes.

Pringle (1998) described the vegetation of the Sandstone – Yalgoo - Paynes Find area on a scale of 1:250 000, defining structural vegetation systems based on perennial taxa. A total of eight upland vegetation communities ('habitats') were identified from across all the land systems, of which three were characteristic of ironstone substrates. These three upland ironstone communities occur within the Tallering Land System (Pringle 1998), as does a fourth, lowland community. These communities are: stony ironstone acacia (SIAS), ironstone ridge mixed shrubland (IRMS) and breakaway mixed shrubland (BRXS) on the hillslopes and crests (uplands), and lateritic sandplain acacia shrubland (LACS) and the lower slopes and outwashes. The SIAS community consists of a dominant stratum of trees of *Acacia* spp., *Casuarina* and / or *Eucalyptus*, over a tall shrub layer of *A. ramulosa*, *A. burkittii*, *A. quadrimarginea*, *A. tetragonophylla* and *Santalum spicatum*, over lower shrub strata of diverse and variables species, including *Eremophila forrestii*, *Scaevola spinescens*, *Ptilotus obovatus*, *Senna artemisioides* subsp. *filifolia*, *Eremophila latrobei*, *Philotheca brucei*, *Solanum lasiophyllum* and *Sida atrovirens* (= *Sida* sp. dark green fruits (S. van Leeuwen 2260), the grass, *Austrostipa elegantissima* and the pteridiophyte, *Cheilanthes austrotenuifolia*. The IRMS community includes *Philotheca sericea* and *Thryptomene decussata* as dominant taxa, is species-rich and has floristic affinities to the South West Botanical Province. This community is restricted to the southwest of the Sandstone-Paynes Find-Yalgoo area (Pringle 1998).

Since Pringle (1998), various small-scale, unpublished surveys have been undertaken on various landforms within the study area, these being undertaken by consultants and restricted to areas within immediate vicinity of proposed mining activities. The most comprehensive of these surveys at the time of this survey described 21 structural vegetation communities for the landforms in the south-western part of the survey area, of which 10 are associated with ironstone landforms (Woodman Environmental Consulting Pty Ltd 2003, 2004a, 2004b, 2004c). These can be generally partitioned into *Eucalyptus* woodlands on lower slopes and outwash plains, and thickets and scrubs on the hills, rises and uplands variously dominated by *Allocasuarina acutivalvis*, *Acacia ramulosa* subsp. *ramulosa*, *Acacia burkittii* (=*A. acuminata*) mixed dominant *Acacia* species over a heath or low scrub of mixed species.

Prior surveys on the central Tallering Land System are based on structural descriptions of vegetation communities, at scales either too broad or too refined for a regional overview within this land system. The aim of the current survey is to provide a regional overview of the flora and vegetation which is sufficient in detail to resolve floristic communities both within and among these landforms within the central Tallering Land System.

## METHODS

One hundred and three 20 x 20m permanent quadrats were established on Mt Karara, Jasper Hill, Windaning Hill and its associated ridge (henceforth referred to as Windaning Ridge), Warriedar Hill, Pinyalling Hill, Walagnumming Hill, Minjar Hill and the low strikes of ironstone west and north of Minjar Hill (Figure 1), between September and October 2005. Quadrats were placed on the crests, slopes and peneplains mainly within the middle third of Tallering Land System type of Payne et al. (1998), and were placed strategically to encompass the topographical profile of these landforms and their associated vegetation communities. This methodology has been used to survey other ranges in Western Australia (e.g. Gibson 2004a). Quadrats were established only in the least disturbed vegetation in the area, and burnt, heavily grazed and cleared areas were avoided.

Quadrats were marked with four steel fence droppers and their altitude and position recorded by GPS and photographed at a set distance (usually 5 m) from each corner. The presence and cover of all vascular plant species (angiosperms, gymnosperms and pteridiophytes) were recorded in each quadrat, with material collected for verification at the Western Australian Herbarium. Vegetation structure was described according to McDonald et al. (1998). All data on topographical position, aspect, slope, % litter, % bare ground, % rock cover class of both surface deposits and exposed bedrock, shape of surface rock fragments, soil colour and soil texture were noted according to the standard definitions outlined in McDonald et al. (1998). Percentage surface rock fragment cover class, maximum rock fragment size (MxR) and exposed bedrock outcrop cover were all coded on a semi-quantitative scale. Percentage surface rock fragment cover classes (Frag Rock) were scored on seven point scale; 0 % cover (0); < 2 % cover (1); 2 – 10% (2); 10 – 20% (3); 20 – 50% (4); 50 – 90% (5); > 90% (6). Maximum rock fragment size was classed on a six point scale; 2 – 6 mm (1); 6 – 20 mm (2); 20 – 60 mm (3); 60 – 200 mm (4); 200 – 600 mm (5); 600 mm – 2m (6). Leaf litter and bare ground were visual estimates of the percentage of ground cover. Topographic position (Tp) in the landscape was coded on a five point scale which was semi-quantitative: outwash (1); lower slope (2); mid slope (3), upper slope or low, isolated ridge (4), crest (5).

For each quadrat a bulked soil sample was collected from the top 10 cm, this being complied from 20 smaller samples collected regularly over the area of the quadrat. The ≤ 2mm fraction of these soils were analysed for a suite of 12 elements at the Chemistry Centre of Western Australia, using inductively coupled plasma atomic emission spectrometry (ICP AES). This involved the simultaneous determination of a suite of elements (P, K, S, Ca, Mg, Na, B, Co, Cu, Fe, Mg and Zn) using the Mehlich No. 3 soil test procedure (Mehlich 1984, Walton and Allen 2004). Effective cation exchange capacity (eCEC) was calculated from the summing of charge equivalents of Ca, Mg, Na and K after their conversion from their respective elemental concentrations (dividing by the constants 200.4, 121.6, 230, and 390 respectively) (D. Allan, pers. comm. [2]; Rayment & Higginson 1992, Soil & Plant Council, 1999). Estimates of climatic variables (mean annual temperature, mean annual rainfall, rainfall coefficient of variation) was obtained from BIOCLIM (Busby 1986).

Classification and ordination analyses were conducted on a data matrix of 164 perennial taxa, with the singleton and annual taxa having being omitted from the data matrix prior to analysis. Resemblance matrixes (Bray Curtis measure of distance) were compared using the '2 Stage' algorithm in Primer (Clark & Gorley 2006) to determine the degree of correlation between datasets following the exclusion of taxa. Preliminary analyses found that singletons (species known from a single quadrat) contained little information. The omission of annuals was justified on the basis that their distribution and abundance over the landscape is a function of rainfall in the preceding months (Mott 1972, 1973). It also allows for comparison of data collected between seasons and years, and is consistent with previous surveys on Western Australian ironstone and greenstone ranges (e.g. Gibson 2004a).

Pattern analysis was conducted using PATN (V3.03) (Belbin 1989). The Bray-Curtis coefficient was used to generate an association matrix for both the classification and ordination analyses. This association matrix consisted of pairwise coefficients of similarities between sites based on floristic data. Agglomerative, hierarchical clustering, using flexible UPGMA ($\hat{a}$ = -0.1), was used to generate a species and site classification (Sneath and Sokal 1973). A two-way table of the site by species matrix, sorted into groups generated from these site and species classifications. Indicator species analysis was calculated using PC-Ord (McCune & Mefford 1999), using the methods of Dufrêne and Legendre (1997). Indicator values (INDVAL) were used to determine the significant indicator species for each floristic community type, and this statistic were calculated from a combination of the fidelity and constancy of each species to a community type. The INDVAL statistic (%) is maximum (100 %) when all occurrences of a species are restricted to one community type, occurring in all sites that community. INDVAL values were calculated for each species at the eight group level, and a Monte Carlo permutation test (10000 simulations) was used to test for the significance of these indicator species.

Three dimensional semi-strong hybrid multidimensional scaling (SSH MDS) was implemented for the ordination of the sites from the floristic data, using 1000 random starts and 50 iterations (Belbin 1991). Principal Component Correlation (PCC) runs a multiple linear regression of variables on the site ordination (Belbin 1989), and PCC was run on the extrinsic environmental variables on the site ordination from floristic data. The Monte-Carlo procedure (MCAO) was employed in PATN as a bootstrap analysis to evaluate the significance of these correlation coefficients. This was done for each environmental attribute by implementing PCC on the same ordination using randomly assigned values for each environmental variable in the dataset (Belbin 1989). One thousand iterations of this procedure were run. The data was found to be non-normal, highly skewed and heteroscedastic. Therefore, the Kruskal-Wallis non-parametric, one-way analysis of variance and Dunns' posthoc multiple comparisons were used to detect differences among community types for climatic and edaphic variables (Zar 1984).

Nomenclature follows Packowska and Chapman (2000), with the exception of phrase (informal) names which are currently used at Western Australian Herbarium (1998–) to denote taxa that are not yet formerly named.

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Representative specimens of all taxa have been lodged at the Western Australian Herbarium. Geographical distributions of taxa were obtained from online records at the Western Australian Herbarium (1998–).

## RESULTS

### Flora

A total of 414 taxa (species, subspecies, varieties and forms) and 4 putative hybrids were recorded within or adjacent to quadrats placed on the ironstone hills, ridges and uplands within the region bounded by Mt Karara, Pinyalling Hill and the Minjar Hill area (Appendix 1). Of these 414 taxa, 26 were introduced weeds. Taxa were from 69 families, of which the most speciose were the Asteraceae (69 native taxa, 1 possible hybrid and 4 introduced taxa), Poaceae (23 native and 7 introduced taxa), Mimosaceae (25 taxa), Myrtaceae (24 taxa) Chenopodiaceae (23 taxa and 1 hybrid), Myoporaceae (17 taxa), Goodeniaceae (12), Amaranthaceae (11), Proteaceae (10) and Lamiaceae (8). The most speciose genera were *Acacia* (28), *Eremophila* (17 taxa), *Rhodanthe* (13 taxa), *Ptilotus* (11 taxa) and *Austrostipa* (9 taxa) (Appendix 1). This pattern is common among floras from other ironstone surveys, and among flora within the transition from the South West to the Eremaean Botanical Province (Beard 1976a, 1990; Gibson et al. 2000; Gibson 2004a, b).

### *Priority taxa*

Fifteen taxa of conservation significance were collected in this survey, of which five were new populations (Table 1). These taxa were listed as priority taxa according to the DEC conservation codes for Western Australia (Atkins 2006). As a direct consequence of this survey, three of these priority taxa (*A. karina, A. woodmaniorum* and *Drummondita fulva*) were recently described (Maslin & Buscomb 2007; Meissner & Markey 2007). Several of these priority taxa particularly the perennial shrubs, are largely restricted to outcrops of BIF and associated metasedimentary rocks. These taxa include *Polianthion collinum*, *Calytrix uncinata*, *Micromyrtus trudgenii* and *M. acuta* (Western Australian Herbarium 1998–, Woodman Environmental Consulting Pty Ltd 2007). Other species (*Cryptandra imbricata, Drummondita fulva*) are more catholic in their occurrence on particular substrates.

*Acacia woodmaniorum* is a recently described species formerly known as *Acacia* sp. Blue Hills Range (R.J. Cranfield 8582), which has taxonomic affinities to *Acacia alata*. It was first collected from the Blue Hills Range in 1992, but was only described by Maslin and Buscomb (2007) after recent collections from both this study and surveys by Woodman Environmental Consulting Pty Ltd (2007). This species appears to be restricted to steep, massive outcrops of BIF on Windaning Hill proper, Windaning Ridge and part of the adjacent Blue Hills Range. However, it does not occur on Mt Karara (Woodman Environmental Consulting Pty Ltd 2007; this study). The most northerly extent of this distribution occurs at Jasper Hill. It is absent from the western (Mt Karara) and the northern half of the study area (north of Jasper Hill and ironstone hills on Badja Station), although apparently suitable habitat has been investigated (C. Godden, pers. comm. [3]; Woodman Environmental Consulting Pty Ltd 2007; this study).

*Acacia karina* (previously known as *Acacia* sp. Karara (C. Godden 14)) is a member of *Acacia* sect. Juliflorae and bears some resemblance to *Acacia jibberdingensis*, but differs from the latter by lacking a pulvinus. Instead, it appears to be most closely aligned to *A. stanleyi* (Maslin & Buscumb 2007). *Acacia karina* was only recorded on Mt Karara by this current survey, where it is most common (Maslin & Buscumb 2007). Further surveys have located this taxon on the Blue Hills Range and, less frequently, on Windaning Ridge and some nearby, low hills of BIF and granite (Maslin & Buscumb 2007; Woodman Environmental Consulting Pty Ltd 2007). Beyond this area, there is a single collection from Mt Gibson Station (c. 120 km south east of Morowa). However, this taxon was not found during a recent survey of ironstone landforms on Mt Gibson Station (Meissner & Caruso 2008). Recent surveys of BIF in the wider Yalgoo IBRA have failed to find this species beyond its current known range (Markey & Dillon in review, unpublished data).

A variant of *Drummondita microphylla* was collected which had been previously noted by Wilson (1998) to differ from *Drummondita microphylla s.s* in that it possesses minute, red-brown apicula on the leaves and flattened, coriaceous, suborbicular sepals. Populations of this variant are greatly disjunct from *Drummondita microphylla s.s.,* occurring c. 300 km west of the latter species. This variant was not described by Wilson (1998) owing to a lack of flowering material in the Western Australian Herbarium at that time. However, subsequent collections from this and other recent surveys in the Yalgoo IBRA region (Markey & Dillon in review; unpublished data) enabled the formal description of this entity as a new species, *Drummondita fulva* (Meissner & Markey 2007). *Drummondita fulva* appears to be restricted to the survey area, over which it was found to be common on upland sites (particularly within Community type 3, see 'Floristic Communities').

The ranges of four priority species were extended by this survey. The two succulent herbs, *Gunniopsis divisa* and *G. rubra* were located c. 200 km and 100 km away from their respective previously known locations. Both species of *Gunniopsis* were located on colluvial outwash sites within the western half of the study area. At the time of this survey, this was the third record at the Western Australian Herbarium (1998–) for the former taxon (excluding entities that have been recently identified as *Gunniopsis* aff. *divisa* (R. Meissner, pers. comm. [4]).

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Another collection of *Gunniopsis divisa* was made following this survey, located some five km south of the collection from this survey (D. Coultas s.n.), which brings the total to three known locations for this species.

Two of the other priority species found in this survey also occur on BIF hills c. 70 km west of Mt Karara, these being *Austrostipa blackii* and *Millotia dimorpha*. The former taxon is now known from several locations across southwest Western Australia, its range having been extended by previous surveys (Gibson & Lyons 2001a). The latter, *Millotia dimorpha* is a small annual previously only known from hills of Koolanooka (C.A. Gardner 2680B) and adjacent Kadji Kadji station (W.E. Blackall & C.A. Gardner WEB 744). Several decades after these initial collections, it was relocated on the Koolanooka and Perenjori hills in 2005 (Meissner & Caruso 2008). This survey located a new population of this species on the slopes of Mt Karara.

This current survey did not locate eleven priority taxa (*Calandrinia kalanniensis* (P2), *Chamelaucium* sp. Yalgoo (Y. Chadwick 1916) (P1), *Eurymyrtus patrickiae*, *Grevillea globosa* (P3), *Grevillea scabrida* (P3), *Grevillea subtiliflora* (P1), *Melaleuca barlowii (P1), Micromyrtus racemosa var. mucronata*, *Spartothamnella* sp. Helena & Aurora Range (P.G. Armstrong 155–109) (P3), *Stenathemum poicilum* (P2) and *Hydrocotyle* sp. Warriedar (P.G. Wilson 12267) (P1), which known from the area from previous flora surveys of mining tenements in the study area (Gindalbie Pty Ltd 2004; Woodman Environmental Consulting Pty Ltd 2004a, 2007). Most of these taxa have been located by these surveys on the lowlands surrounding the BIF ranges.

## Undescribed taxa

Several taxa were identified in this survey which had affinities to known taxa, but were sufficiently morphologically distinct to consider as new entities. Most of these have been subsequently formally described (see above), but five entities require further taxonomic work to resolve their status. Some of these taxa may warrant further consideration for conservation listing as they appear to be restricted to the study area.

- The discovery of an entity with affinities to *Calotis cuneifolia* was surprising in that the latter taxon is common in the Northern Territory, Queensland and New South Wales (Jessop 1981), yet is known from only two locations in Western Australia. These two locations are Perrin Vale station (c. 323 km east from Windaning Ridge) and one 1903 collection in the general vicinity of 'Cue' (c. 235 km north east of Windaning Ridge). This represents a significant disjunction from the eastern Australian populations. Further examination of these two Western Australia accessions and material collected during this survey found this Western Australian entity to be different from the eastern Australian *Calotis cuneifolia s.s.*, in that the former is a diminutive annual which possess a habit more akin to that of *Calotis hispidula* than that of the taller, robust, perennial, herbaceous habit of the latter taxon (Jessop 1981). Therefore, the Western Australian material may represent a closely related taxon (i.e. *Calotis* aff. *cuneifolia* (A. Markey & S. Dillon 3447). In this survey, *Calotis* aff. *cuneifolia* was located on ironstone hill slopes growing in dense patches of leaf litter under mulga shrubland.
- *Lepidosperma* sp. (A. Markey & S. Dillon 3468) is distributed primarily on ironstone substrates on Karara Station, and appears to be endemic to the south west of the study area[5] (Woodman Environmental Consulting Pty Ltd 2007). It has taxonomic affinities to the *L. costale* species complex and the most closely related taxon to it is *Lepidosperma* sp. Koolanooka (K.R. Newbey 9336) (R. Barrett, pers. comm.[4]). This latter taxon is also an ironstone endemic, and appears to be restricted to the banded iron formations of Perenjori and Koolanooka Hills (Meissner & Caruso 2008; R. Barrett, unpublished data[4]). Further taxonomic work is required to both formally describe and clarify relationships among these taxa of *Lepidosperma*.
- Two unusual variants of *Eremophila* were collected from the eastern-most outwash communities on rocky plains, both of which require further work to resolve their taxonomic relationships and distribution. One was an unusual variant of *Eremophila playcalyx* (*E.* cf. *platycalyx* A. Markey & S. Dillon 3337) with greatly enlarged calyces. However, *Eremophila playcalyx* is a highly variable species, and this extreme form may be still within this range of variation**.**
- The second entity, *Eremophila* sp. (A. Markey & S. Dillon 3338), could not be matched to any known species within the collections of the Western Australian Herbarium. It has affinities to *E. georgei* and *E. clarkei* because of sigmoidally shaped and flattened pedicel and serrated leaf margins, however, this entity differs from the former two taxa by having a deeper purple flower colour and narrower, shorter leaves with highly recurved leaf margins that gave the leaves a terete appearance. Furthermore, *E. clarkei* has simple, sometimes dendritic hairs on sepals, whilst this variant has glandular hairs.

## Putative Hybrids

Several putative hybrids were identified, their surmised from morphological characters. A putative hybrid of *Cheilanthes* cf. *lasiophyllum x sieberi* (A. Markey & S. Dillon 3048) was collected, and this is the first collection of a putative hybrid within this genus in Western Australia. Hybridisation and polyploidy has been documented among species in North America (Wagner & Gilbert 1957) and Europe (Knobloch et al. 1975), however recent publications only document polyploidy among Australian species (Tindale & Roy 2002). The hybrid, *Senna glutinosa*

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ssp. *chatelainiana* x *charlesiana* (A. Markey & S. Dillon 3413) is another new putative hybrid, although hybrids within *Senna* complex are well documented (Randall & Barlow 1998).

A number of intergrades between taxa were identified in this survey. Intergrades among the subspecies of both *Allocasuarina acutivalvis* and *Eucalpytus leptopoda* are known for the study region, as this coincides with an area where the two subspecies co-occur (M. French, pers. comm.[6]; Wilson & Johnson 1989). Similarly, integrades of *Maireana planifolia* x *villosa* are known from areas where the parental species co-occur (Wilson 1984). Some of these intermediate forms may represent distinct taxa (P. Wilson, pers. comm.[7]).

In the case of *Prostanthera althoferi* ssp. *althoferi* x *serica* (intergrade), this intergrade has the greatest affinity to *P. campbellii*, *P. sericea* and *P. althoferi* ssp. *althoferi*, although the terete, villous and relatively wide (2 mm) leaves place this as distinct from these three taxa (*c.f.* Conn 1988). One putative parental taxon (*Prostanthera sericea*) is not known from the Yalgoo subregion, although a similar species (*Prostanthera campbellii*) is more widespread and possibly involved. A range of intermediate forms between these three species have been collected from over a wide area over the northern and eastern goldfields.

## *Endemic Taxa*

Nine endemic and near endemic taxa were identified within the study area, (a regional endemic being defined as restricted to an area within a 100 km radius, and near endemics being defined having most populations located within a 100 km radius with one – two outlying, disjunct populations) these being; *Millotia dimorpha*, *Lepidosperma* sp. (Markey & Dillon 3468), *Acacia karina*, *Acacia woodmaniorum*, *Micromyrtus trudgenii*, *Micromyrtus acuta*, *Wurmbea* sp. Paynes Find, *Caladenia petrensis, Polianthion collinum* and *Drummondita fulva*. Seven of these nine taxa are listed as priority taxa (Table 1), and three taxa appear to be mostly or wholey restricted to the south-western corner of the survey area (*Acacia karina*, *Acacia woodmaniorum*, *Lepidosperma* sp. (Markey & Dillon 3468). Information to date would suggest that *Acacia woodmaniorum* and *Lepidosperma* sp. (A. Markey & S. Dillon 3468) are endemic to Jasper Hill, Mt Karara and Windaning Ridge (Woodman Environmental Consulting Pty Ltd 2007).

## *Range extensions*

Range extensions of over 100 km were found for a total of 21 species, 17 of which are not listed as threatened. There were eleven species collected which represent a range extension of c. 100 – 200 km from closest, previously known collection at the Western Australian Herbarium (1998–). A number of these were notable in that these were new records for these species in the Yalgoo subregion, including: *Austrodanthonia* sp. Goomalling (A.G. Gunness et al. OAKP 10/63), *Davesia hakeoides* subsp. *subnuda, Hydrocotyle callicarpa, Trachymene pilosa, Podolepis gardneri, Einadia nutans* subsp. *eremaea, Maireana marginata*, *Centrolepis aristata, Crassula closiana* and *Pleurosorus rutifolius.* The nearest known location of *Cheilanthes brownii* was 200 km north of the survey area, with the majority of collections from the far northern regions of Western Australia. Both *Cheilanthes brownii* and *Cheilanthes adiantoides* have been poorly collected from the Murchison Region, which may reflect poor collection and confusion with *Cheilanthes austrotenuifolia* and *C. sieberi* subsp. *sieberi* rather than actual scarcity. Greater range extensions of c. 250 – 400 km beyond the currently known range were recorded for *Calotis* aff *cuneifolia*, *Crassula tetramera, Sclerolaena microcarpa, Senecio gregorii, Stylidium perpusillum* and *Sida ectogama*.

## Floristic Communities

Prior to analysis, fifteen taxa had to be amalgamated into seven species complexes for floristic analyses as there was some difficulty in differentiating between closely related taxa owing to quality of flowering material (e.g. the *Velleia cycnopotamica / rosea* complex), the presence of intergrades (e.g. *Eucalyptus leptopoda* subsp. *arctata* and *Eucalyptus leptopoda* subsp. *elevata*) or when varieties were closely related and were more informative when combined at a higher taxonomic level (e.g. the three forms of *Haloragis odontocarpa*). The *Acacia aneura* species complex was resolved to morphotypes which approximate the varieties described by Pedley (2001), as the mulga complex (*Acacia aneura* and allied species) is currently being reviewed by Miller et al. (2002).

Three hundred and ninety taxa were recorded from 103 quadrats within the survey area, of which 180 were annual taxa while 46 perennial taxa were recorded from only one quadrat. Preliminary analyses found that singletons and annuals had little overall effect on community classification, apart from enhancing the separation of outwash sites from hillslopes. These taxa were omitted, leaving 164 taxa in the dataset (42 % of total taxa). '2-Stage' comparison (Clark & Gorley 2006) of resemblance matrices found 89% correlation between the data matrix with all taxa (singletons and annuals) and the perennial dataset used in final analyses. For the 103 quadrats, the average species richness per quadrat was 48.8 ± 10.5 taxa per quadrat, and ranged from 26 to 79 taxa per quadrat. For the final dataset, there was an average of 23.3 ± 4.9 shared perennial taxa per quadrats (range 9 – 37 taxa per quadrat).

The floristic classification of the 103 quadrats resulted in their ordering into eight community types and subtypes, which is illustrated by a summary dendrogram in Figure 2. Five main community types were recognised, with three of these communities (1, 4 and 5) further divided into

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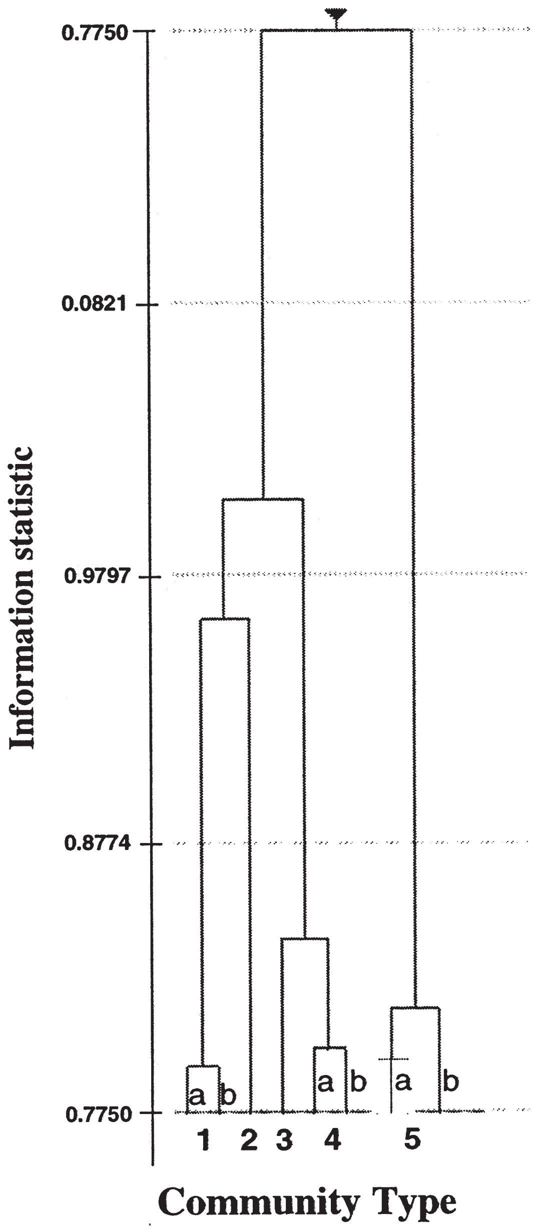


*Figure 2. Summary dendrogram of floristic community types of the Central Tallering Land System, resolved from classification analysis of a presence / absence data matrix of 164 perennial taxa from 103 quadrats. The dendrogram is resolved to the five group level, with subtypes resolved in Community types 1, 4 and 5.*

distinctive subtypes (Figure 2). Therefore, the floristic communities have been resolved at two levels, these being the five and eight group levels. The classification also resolved the 164 species into twelve Species Groups (Appendix 2). These decisions on selecting levels within the site and species dendrograms were based on dendrogram topographies, the two way table (Appendix 2) and field observations. INDVAL statistics are presented in Table 2, and statistically significant indicator taxa (as determined from the Monte Carlo routine at the eight group level) are also marked in Appendix 2.

The primary division separates floristic communities on lower slopes, footslopes, colluvial outwashes and plains (type 5) from those on hillslopes, crests and upland plateaux (types 1, 2, 3 and 4). Hence, the first major distinction was between the lowland tall open *Acacia* shrublands and *Eucalyptus* woodlands from the shrublands and thickets on the hillslopes and uplands. This division is also discernable on the sorted two-way table ordered by the site and species classification (Appendix 2), and is particularly evident in Species groups G, J and L.

Below this primary level of divergence, four floristic communities were identified for the crests, slopes and foothills on the ironstones of the Tallering Land System. The second major division separated Community types 1 and 2 from Community types 3 and 4, which coincides with the segregation of the southern and western sites with richer loamy soils from the eastern and northern sites in drier situations (outcrops) and on more skeletal soils. This division is associated with Species Group H, and, to a lesser extent, group G (Appendix 2).

**Community type 1** was a relatively wide-ranging community found from Mt Karara to the northern and eastern limits of the study area. It consists of both the lower slope *Acacia* shrublands with emergent *Eucalyptus* woodlands and upper hillslope and crest shrublands. This community is subdivided according to floristic differences associated with topographical position.

**Community type 1a** occurs on ironstone substrates that were low in the landscape (at an average altitude of 361 m), either on the lower slopes of hills, small massive outcrops of banded ironstone formation or low rises in the upland peneplains. It is distributed from Mt Karara to the strikes of BIF north of Minjar Hill and east to the footslopes of Warriedar Hill, but was absent from the extreme south-east extent of the study area. Community type 1a is differentiated from Community type 1b by being relatively species poor (Appendix 2), and lacking good representation of the ubiquitous Species Group G. The majority of species from Species Groups H and I are well represented. There is an average of 38.9 ± 2.6 total taxa per quadrat, of which there is a correspondingly poor number of annuals (19.5 ± 5.3 taxa / quadrat). Common and significant indicator species (Table 2) include *Acacia coolgardiensis* subsp. *latior* and *Acacia sibiana* in the dominant stratum, over the shorter shrubs, *Aluta aspera* subsp. *hesperia*, *Eremophila forrestii* subsp. *forrestii, Philotheca desertii* subsp. *desertii* and *Hemigenia* sp. Cue (K.F. Kenneally 47A). *Eremophila latrobei* subsp. *latrobei* and the rockfern, *Cheilanthes adiantoides* are characteristic understorey species for both this community, and Community types 1b and 2. Being a lowland community, this community included emergent trees such as *Callitris columellaris*, *Eucalyptus ewartiana*, *E. leptopoda*, and open tall shrublands of *Acacia* (*A. aneura*, *A. ramulosa* var. *ramulosa* and *A. coolgardiensis* subsp. *latior*).

**Community type 1b** is the most common and widespread community type, and consists of the typical, speciose shrublands which occur on the shallow, loamy soils of hillslopes and isolated ridges throughout the survey area. This community type typically consists of *Acacia* (*A.

*sibiana*, *A. ramulosa* var. *ramulosa*) and *Allocasuarina* dominated shrublands and thickets over a rich shrub understorey, and often with emergent trees of *Eucalyptus* and *Melaleuca leiocarpa*. Community type 1b was found to usually occur on gently sloping hillslopes that were moderately high in landscape (average altitude 399 ± 5 m. However, it was found at all levels along the topographical profile as this vegetation unit was repeated on foothills of outcropping BIF. There is good representation from Species Groups G, H and, in particular, group I, which distinguish this group from Community Type 1a. Characteristic and common species include *Eremophila latrobei* subsp. *latrobei*, *Mirbelia bursarioides*, *Philotheca sericea*, *Eremophila clarkei*, *Prostanthera magnifica* and *Cheilanthes adiantoides* (Table 2, Appendix 1).

**Community type 2** is found relatively high in the landscape, on moderate – very steep, rocky inclines and facing a range of aspects. This community is restricted in its distribution, being located only on the slopes of Mt Karara and the far western slopes on Windaning Ridge (near the old Mungada minesite). Whilst most typical of upper slopes, this community type is also repeated low in the landscape on low ridges of exposed ironstone on lower slopes and foothills. It consists of a range of shrublands and thickets over an understorey rich in shrubs, and as such was moderately species rich (average total 50.9 ± 7.3 taxa / quadrat). Annuals were particularly abundant in this community type in the, averaging 27.6 ± 5.3 annual taxa per quadrat (Table 3). Significant indicator species include the tall shrubs *Allocasuarina acutivalvis*, *Melaleuca nematophylla, Grevillea paradoxa and Gastrolobium laytonii* and the low shrubs *Aluta aspera* subsp. *hesperia*, and *Xanthosia bungei* (Table 2). Of particular note is the presence of the sedge, *Lepidosperma* sp. (A. Markey and S. Dillon 3468), which was restricted to this community type on Mt Karara. Taxa in species Group F and a subset of Species Groups D both are characteristic of Community type 2, with many of the taxa in the former group being largely restricted to this community on the slopes of Mt Karara and Windaning Ridge (e.g. *Mirbelia microphylla*, *Eucalyptus petraea* and *Calothamnus gilesii*, *Grevillea paradoxa* and *Persoonia hexagona* and *Acacia karina*.

**Community type 3** consists of sparse shrublands on the crests and moderately steep slopes of low escarpments, ridges and outcrops of BIF. Sites are typically rocky and situated moderately high in the landscape (at an average altitude of 406 m). This community is located predominantly in the northern and eastern parts of the survey area, particularly on the low ridges on Badja Station in addition to the top plateau of Windaning Ridge. The underlying geology consists of both banded iron formation and paler, weathered sedimentary siltstones and cherts. It is a moderately species rich community, with an average of 48.3 ± 10.3 taxa per quadrat, albeit relatively low in annuals (21.2 + 5.4 taxa per quadrat, Table 3). Characteristic species include those which grow in fissures of exposed pavements of BIF such as *Stylidium longibracteatum*, *Micromyrtus trudgenii* and *Calytrix uncinata* (Table 2). Also of note is *Acacia aulacophylla*, which replaces *Acacia assimilis* subsp. *assimilis* as a dominant shrub in the northern extent of the study site. Other notable and significant indicator species include *Eremophila glutinosa*, *Melaleuca hamata* (rarely encountered, with both occurrences in this community type), *Austrodanthonia caespitosa*, *Mirbelia bursarioides*, *Cheiranthera filifolia* var. *simplicifolia*, *Drummondita fulva*, *Prostanthera patens* and *Thryptomene costata* (Table 2, Appendix 2). Many of these taxa are in either Species Groups G or E which, together with Group I, constitute the main species groups associated with this community type. An absence of taxa from Group D distinguishes Community type 3 from type 4.

**Community type 4** occurs on rocky ridges and tors usually in the east and north of the study area. As with Community type 1, the division of this community into subtypes also corresponds with topography.

**Community type 4a** consists of open stands of *Callitris collumelaris* and sparse shrublands located at the highest points in the landscape on steep, rocky or boulder-strewn ridges, cliffs and tors with shallow, loamy soils (Table 3). This community was found on the east-facing steep cliffs of Windaning Ridge, rocky upper slopes of Pinyalling Hill, two foothill sites on Mt Karara and on the metasedimentary rocks (psammitic and peltic – semi peltic) of Warriedar Hill (*cf.* Lipple et al. 1983). It is a very species rich community (54.8 ± 9.4 taxa per quadrat), with much of this richness being contributed by annuals (Table 3). Typical and consistent species in this community type are in Species Groups G and I, whilst taxa from Species Group H are conspicuously absent. Species group C is particular to sites on Warriedar Hill, which may possibly reflect the underlying geology. Notable and significant indicator species include those characteristic of rocky terrain, namely the shrubs *Calycopeplus pauciflorus, Dodonaea petiolaris* and *Dodonaea viscosa*, the rockferns, *Cheilanthes sieberi* subsp. *sieberi, Cheilanthes lasiophyllum and Pleurosorus rutifolius* and the herbaceous *Isotoma petraea* (Table 2, Appendix 2). The latter three species were infrequent but faithful to this community type.

**Community type 4b** appears to be restricted to the eastern regions of the survey area, on the slopes of Pinyalling, Walagnumming, Warriedar and Chulaar Hills. Although still rocky, this community occurs on gentle – moderate slopes with less exposed bedrock and more collvium than Community type 4a. Structurally, the vegetation consists of tall shrublands of *Acacia ramulosa* var. *ramulosa* or *Acacia aneura* with a sparse shrub understorey. This community type was located over the topographical profile of hills, from lower slopes to crests. It is relatively more species depauperate than type 4a and lacks representation from across Groups A to F (Table 3, Appendix 2). However, there is still good representation in groups G and I. Characteristic indicator species include *Acacia aneura* var. cf. *major* and *Acacia umbraculiformis* in the dominant stratum over the low shrubs and herbaceous perennials, *Phyllanthus erwinii*, *Ptilotus drummondii* var. *drummondii*, *Sida* sp. Golden calyces glabrous fruit (H.N. Foote 32), and *Solanum ellipticum* (Table 2).

As previously mentioned, **Community type 5** was the group of sites found to have the highest dissimilarity to other sites in the dataset. This community was further resolved into two subtypes, as is shown in the sorted two-way table (Appendix 2). Community type 5a typically consists of shrublands on rocky terrain and exposed low tors of bedrock on footslopes and peneplains, whilst Community type 5b is associated with flatter terrain, a sparser covering of surface gravels and no exposed bedrock.

**Community type 5a** consists of open *Eucalyptus* woodlands and sparse *Eremophila* or *Acacia* shrublands over sparse, low chenopod shrubs. Being located in the depositional part of the landscape, this community receives colluvium from the adjacent uplands. The substrate consists of readily eroding siltstone, cherts, and other sedimentary rocks which have been exposed from under layers of more resistant BIF. This is a species rich community (53.1 ± 17.2 taxa per quadrat), and is relatively richer in annual taxa (29.0 ± 14.8 taxa per quadrat) than Community type 5b (Table 3). There is consistent representation from species group L, and the significant indicator species include *Acacia erinacea*, *Enchylaena lanata / tomentosa*, *Eremophila oldfieldii* subsp. *oldfieldii*, *E. oppositifolia* subsp. *angustifolia*, *Senna* sp. Austin, *Maireana carnosa*, and a number of species of *Sclerolaena* (Table 2). This community was encountered on two distinctive footslope sites from Mt Karara and at various locations over Badja station.

**Community type 5b** is comprised of lowland open *Eucalyptus* woodlands and *Acacia ramulosa* var. *ramulosa* shrublands over sparse shrubs of *Senna*, *Ptilotus obovatus* var. *obovatus*, *Scaevola spinescens* and chenopods. These occur on gently sloping – flat lower slopes and outwash plains, on deeper red earths. Whilst occurring in the north and west of the study area, the community is absent from eastern sites, possibly being replaced by the eastern stony shrublands within Community type 5a (see above). The significant indicator species include *Eucalyptus kochii* subsp. *amaryssia*, *Maireana planifolia* x *villosa*, *Olearia humilis*, and the two characteristic species of *Senna*, *S. charlesiana* and *S. artemisioides* subsp. *filifolia* (Table 2). This community differs from type 5a by the more consist presence of taxa from Species group I, distinctive taxa from Species Groups H and J fewer taxa from Species Group L (Appendix 2).

### Other communities not in classification

A distinctive structural vegetation community was observed in this survey that has been described previously in flora surveys in the area around Windaning Ridge (Bennett Environmental Consulting Pty Ltd 2003, Woodman Environmental Consulting 2004a). These low dense shrublands and heaths occur on the lower slopes and upland plateaux, and appear to occur on shallow gravels over a sheet of bedrock which prevents the establishment of taller shrubs. Only one or two species of myrtaceous shrub were dominant; such as *Micromyrtus acuta*, *Thryptomene costata* and *Aluta aspera* subsp. *hesperia*. Otherwise, these patches of vegetation were relatively depauperate (c. 12 perennial species per quadrat), and are considered to be a subset of the surrounding vegetation within a structural mosaic of vegetation on the lower slopes and undulating uplands. These patches of vegetation were not fully sampled in this survey because of this low species richness. However, such low heaths and dense shrublands around ironstone belts harbour species of conservation significance (e.g. *Micromyrtus acuta*).

## Environmental Correlates

### Univariate Analyses

The elements cadmium, molybdenum and boron were omitted from analysis owing to levels being below the limit of instrument detection in over half of the soil samples. The remaining soil elemental concentrations, soil pH and effective cation exchange capacity (eCEC) were compared for intercorrelation, and correlation with site physical and climatic variables, using the non-parametric Spearman rank correlation coefficient (Table 3). Soil pH, eCEC and elemental concentrations (except lead) were intercorrelated, the highest correlation being among eCEC, calcium and magnesium. Most soil elements were not correlated with physical parameters, although iron and phosphorus were positively correlated with topography. As expected, climate variables were all highly intercorrelated, and there was a significant correlation between these and both latitude and altitude. With the exception of surface fragment abundance, there was also a high degree of intercorrelation among the physical parameters (eg: slope, topographic position, rock size and cover) (Table 4).

The soils for the survey area were found to be acidic (pH ≤ 5.1), which has been reported for shallow, stony soils within the larger Sandstone – Paynes Find area (Hennig 1998b). Differences in soil parameters were expected to correlate with floristic community and topographical position. Non-parametric analysis of variance found significant differences in values for all soil variables among the eight floristic community types (Table 3). Soil parameter values were the lowest for Community type 1a and, to a lesser extent, Community types 1b and 4b. Conversely, high values were found in various soil parameters for Community types 3, 4a, 5a and 5b. Therefore, the soils from sites classified as Community type 1a were the most acidic, had the lowest eCEC and low concentrations of exchangeable cations and minerals. These values correspond to leached, skeletal red earths over weathered, exposed bedrock high in the landscape. Low pH may be associated with both products of ironstone weathering and low levels of basic cations (*cf.* Gray & Murphy 2002). Soils from Community types 5a and 2 were trending to being relatively less acidic, and soils within Community type 5a and 5b were high in minerals such Na, Ca, Mg, Ni and S. These high-mineral, less acidic soils can be largely attributed to topographic position, where these sites are enriched by colluvium, leachates and clay (Gray & Murphy 2002). Soils from

Community types 2 and 4a had high eCEC levels and relatively high levels of various elements, notably Ca, K, Mg, P, Fe and Zn (Table 3). Such high levels in these rocky, upland sites may related to *in situ* soil development from weathering of the parental rock (*cf.* Gray & Murphy 2002). It was observed that upland rocky sites did accumulate rich loams in rock crevices that trapped organic material and moisture, and high numbers of annuals were associated with such microsites for Community types 2 and 4a (Table 3).

From a comparison of physical site parameters among the community types, there were significant differences among groups for altitude, slope, topographical position and various estimates of exposed bedrock, loose rock and leaf litter cover (Table 3). On average, Community type 4a occurs on sites with the steepest gradient, highest altitudes, large surface rocks and high cover of exposed bedrock. Community types 2 and 3 also are associated with rocky, high topographical positions and altitudes, but occur on less steep slopes, at lower topographical positions and with reduced amounts of exposed bedrock (Table 3). Community types 1b and 4b occur at lower altitudes and are associated with moderate gradients and less exposed bedrock. Community types 5a and 1a occur at the lowest altitudes, and 1a, 5a and 5b occupy the lowest topographical positions with a reduced gradient. Sites within these latter community types (particularly 1a and 5b) have significantly smaller surface rocks and a lower percentage cover of exposed bedrock (Table 3).

There were differences in climatic variables among the community types, although the differences in average annual temperatures were low (< 1° C) and may not be biologically meaningful (Table 3). There were significant differences in latitude and longitude among the community types (Table 3), and this may partially relate to climate, as geographical location and climate are intercorrelated (Table 4). Community Type 2 is the most geographically restricted community, being associated with the south-western part of the region where the climate is significantly cooler and wetter (Table 3). Community Type 1a and 3 are located predominantly in northern sites associated with higher temperatures but average rainfall, whilst Community Type 4b is occurs in the north-east of the study area with the lowest average rainfall. The remaining communities (1b, 4a, 5a and 5b) are located over the extent of the study area where temperatures and rainfall are within the middle range of estimates, except for Community Type 4a which has the lowest average rainfall estimates among the communities (Table 3). Within Community Type 5a, two distinctive sites on the eastern stony plains are associated with a relatively more arid climate.

### SSH MDS Ordination

Semi strong hybrid multidimensional scaling (SSH MDS) of the site floristic data was used to illustrate graphically compositional differences among the sites that had been classified into their respective floristic community types (Figure 3). The stress level (0.22) indicates that there was some difficulty in reducing the data to three dimensions. Sites from Community types 5a and 5b have the greatest separation from the other community types in the ordination, and five sites within Community type 5a are particularly distinct from the main spread of the ordination. It is noted that two sites from the eastern stony plains around Pinyalling Hill are relatively dissimilar in floristic composition to other, more western sites within Community type 5a (Figure 3b), which was also observed in the entire site classification dendrogram (results not shown). Further sampling of these eastern stony plains may determine if these eastern areas support a distinct floristic community.

Principal component correlation (PCC) found significant correlations between the majority of environmental variables and the ordination (Figure 3). There are two major trends across the ordination which are generally orthogonal to one another; one that is associated with a gradient of soil chemistry, and a second general trend associated with site physical parameters (especially topographical position, slope and substrate). Among these site physical parameters, topography is the least correlated with the other variables. The association of the trends across the ordination and with community types reiterates most of the findings from the univariate comparisons. As indicated by their co-linearity, groups of soil variables are highly correlated (Figure 3, Table 4). One suite of correlated soil parameters (Co, Cu, eCEC, Ca, Mg, Na, Ni, S and K) aligns with Community Types 5a and 5b, which are sites of high overall soil mineral content. Sites from these communities, particularly Community Type 5b, also coincide with a region associated with low topographic position. Sites trending to the lower end of the nutrient gradient and also higher leaf litter levels belong to Community types 1a, 1b and 2. Only Community Type 4a aligns closely with the high end of the gradient for slope and rockiness, whilst Community type 3 is associated with this region to a lesser degree. Another trio of nutrients (Fe, Zn and P) are co-linear with both slope and maximum rock fragment size. Together, these environmental parameters are positively correlated with sites from Community types 3, 4a and 4b. Community Type 2 aligns with the high extremes of the rainfall gradient, whilst Community types 4a and 4b are at the drier extreme. This stronger association of Community type 2 with a rainfall and latitudinal gradient could explain why Community Type 2 was not closely associated the gradient of physical parameters, as would have been expected from the univariate analyses.

## DISCUSSION

### Flora

Recent surveys of BIF and greenstone ranges of the Yilgarn Craton are finding these arid landforms to be floristically richer than previously considered (Gibson et al. 2007). This survey of several ranges within the Central Tallering land System recorded 414 taxa in a season which was

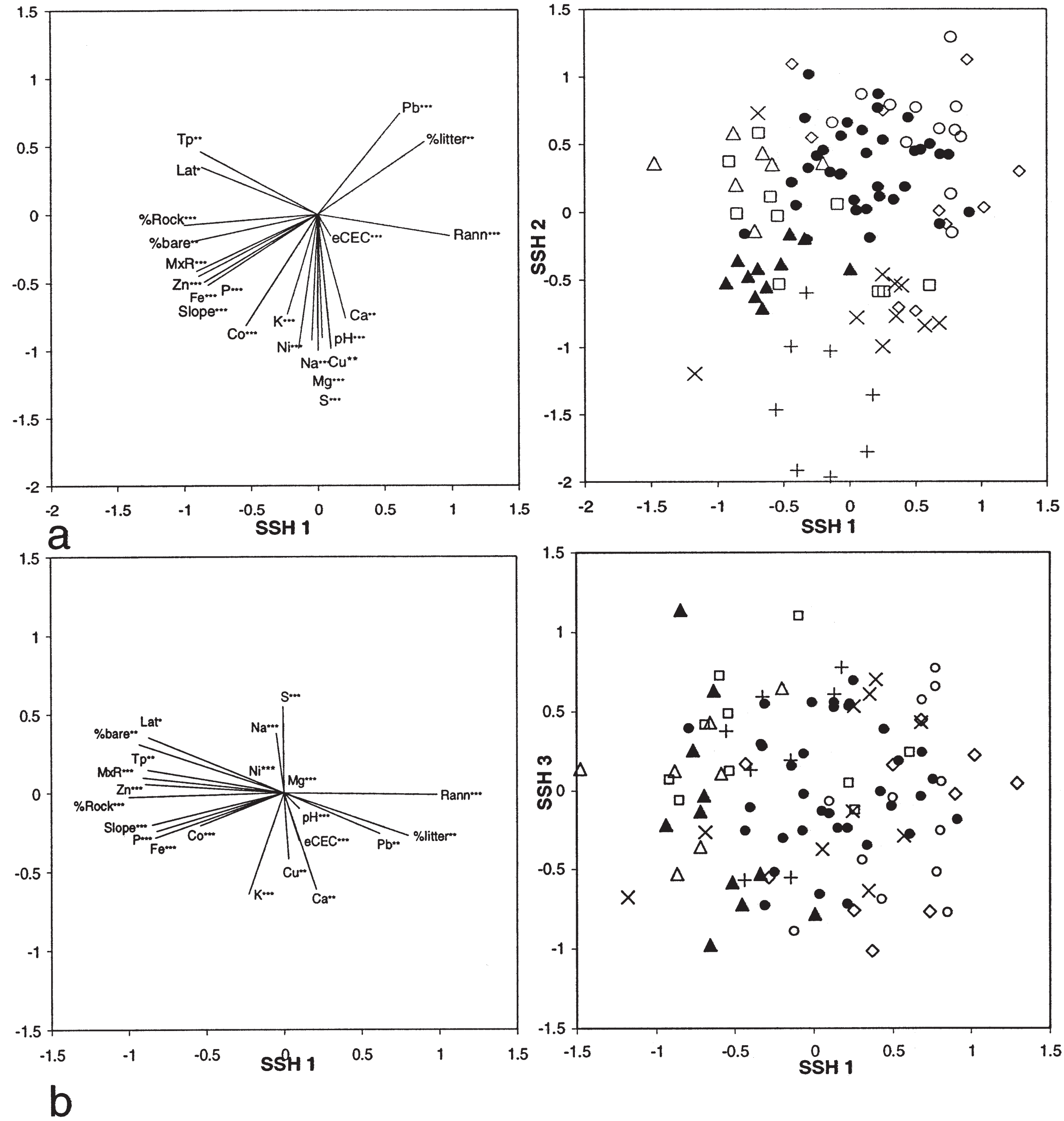


*Figure 3. Ordination and vector diagrams of the three dimensional solution from SSH MDS of the central Tallering Land System floristic dataset. Quadrats (sites) are labelled by community type (1a ○, 1b ●, 2 ◇, 3 □, 4a ▲, 4b Δ, 5a +, 5b ×). Vectors indicating best linear fit of the variables are drawn in positive direction. Only vectors with a significant correlation (from MCAO) are illustrated, with the level of significance for each parameter indicated by asterisks (* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$). See methods for explanation of codes for environmental parameters. a: Ordination axes 1 versus 2, b: Ordination axes 1 versus 3.*

notable for its abundance of annuals following good rainfall in the preceding months. Within Mt Karara, Windaning Ridge and Jasper Hill alone, 335 taxa are documented. A similar survey in the nearby Koolanooka and Perenjori hills (70 km west of Mt Karara) recorded 238 taxa (Meissner & Caruso 2008) and 235 taxa were recorded from BIF ranges in the Gullewa region (55 km northwest of Mt Karara). (Markey & Dillon in review). Quadrat based surveys in the eastern goldfields report numbers of taxa ranging from 238 taxa in the Mt Manning Range (Gibson 2004b) to 345 taxa in the southern Forrestiana greenstone belt (Gibson 2004a). Moving from the interzones to the interior of the Eremaean province, species counts from similar, quadrat-based surveys are lower for BIF ranges in the northern goldfields. In the Murchison IBRA, this number ranges from 173 to 244 taxa (Markey & Dillon 2008, Meissner et al. in review). These relatively high species counts for the Central Tallering Land System are elevated, in part, by high counts of winter annuals, but they also suggest that these BIF landforms within the Central Tallering Land System are particularly speciose, especially around Mt Karara, Windaning Hill and the Blue Hills Range.

As would be expected for the interzonal nature of the Yalgoo bioregion (Beard 1976a; Environment Australia 2000; Thackway & Cresswell 1995), the total flora of the study region has affinities to both the speciose and mesic South West and arid Eremaean Botanical Provinces / Floristic Regions described by Beard (1976a, 1990) and Hopper and Gioia (2004). A high proportion of the taxa recorded within the study area are at the southern or western limits of their distribution (e.g. *Ptilotus aervoides*, *Gnephosis arachnoidea* and *Senna glaucifolia*), others are at their northern limits (e.g. *Ptilotus drummondii* var. *drummondii*, *Alyxia buxifolia* and *Centrolepis aristata*) and another subset of the flora are characteristic of this interzonal region bordering the two provinces (e.g. *Erymophyllum glossanthus*, *Bellida graminea* and *Chamaexeros macrantha*). These range extensions and new records for the Yalgoo bioregion are a consequence of increased collecting efforts. These findings also continue a trend for the discovery of species in the transitional regions of the Eremaean that were previously considered to be endemic to the South West Botanical Province / Floristic Region (Hopper & Gioia 2004).

The flora and floristic communities of the central Tallering Land System are dominated by wide-ranging taxa, with relatively few endemic or disjunctly distributed taxa. Of the nine endemic and near endemic taxa identified, five of these are restricted to the southwest corner. Other surveys have found from none to five endemic taxa on greenstone and BIF ranges in the northern and eastern goldfields (Gibson et al. 2007). Within the wider region of the northern Yilgarn, the central Tallering Land System, especially the Mt Karara – Windaning area, is comparatively rich in endemic and near endemic taxa.

Trends in endemism and species diversity on BIF ranges across the Central Tallering land system are on a small scale relative to the wider region, but mirror those documented for other BIF ranges and granite outcrops in the Yilgarn Craton, and in the overall southern Western Australian flora (Beard 1976a, 1990; Gibson et al. 2007; Hopper et al. 1997; Hopper & Gioia 2004). A combination of fluctuations in climate and a trend for increasing aridity during the Tertiary, stochastic events (dispersal, survival and extinctions) and evolutionary processes have been postulated to account for the high species diversity and endemism in the South West Floristic Region, in which ancient rock outcrops and ranges act as isolated refugia and sites of speciation (Hopper et al. 1997, Hopper & Gioia 2004). This hypothesis has been applied to account for patterns of species distribution and endemism observed in the interzonal regions of the Eremaean (Gibson & Lyons 1998; Gibson et al. 2007).

## Floristic Communities:

Beard (1976b) mapped the Mt Karara, Windaning Ridge and the southern portion of the Gnows Nest Range at a scale of 1:250 000, resolving these into two vegetation systems (the Windaning and Gnows Nest Systems). This study supports the distinctiveness of the Windaning System, but further resolves eight distinct floristic communities within and among these two systems, and within the larger context of the central Tallering Land System. While some communities were found to be relatively widespread over the study area, there was evidence to suggest a regional differentiation of communities across the study area which is aligned along an east-west and north-south gradient. This coincides with a serial replacement of species over the extent of the area (e.g. *Persoonia hexagona* is replaced by *Persoonia manotricha* in the north east of the area). Most notably, Community type 1 (a & b) are replaced by Community type 4 (a & b) over a north-eastern gradient. There is also a transition within Community type 5, where the lowland *Eucalpytus* woodlands of Community type 5b are replaced in the far eastern extent of the study area by a variant of Community type 5a, which may be an under-sampled and possibly different community type. These *Acacia* shrublands on the eastern stony plains were sampled around Pinyalling and Walagnumming Hills, and may occur from the base of Walagnumming Hill to further north around the vicinity of Fields Find and the Bullajungadean Hills.

Although only c. 55 km apart, the slopes and crests of Mt Karara, Pinyalling and Warriedar Hills habour relatively dissimilar communities. Of note is Community type 2, which was located only on the slopes of Mt Karara and western face of Windaning Ridge and, with more sampling, may be located on ironstone ridges between Mt Karara and Windaning Ridge. Even within this community there were differences in particular species and species groups between Mt Karara and Windaning Hill (e.g. *Persoonia hexagona* was only located on Mt Karara, whilst *Acacia woodmaniorum* was not located on Mt Karara). Such geographical variation (east – west) within this community type has been confirmed by subsequent surveys (Woodman Environmental Consulting Pty Ltd 2007).

The findings of this study reiterate those from other studies (e.g. Gibson 2004 a, b; Gibson & Lyons 1998, Markey & Dillon 2008), that there are differences in floristic composition of the communities among the greenstone and BIF ranges of the Yilgarn Craton. Therefore, BIF ranges tend to harbour unique or geographically restricted communities (Gibson et al. 2007). The nearest ironstone ranges west of the study area are the Koolanooka Hills, some 70 km west of Mt Karara, which share with the latter range some restricted taxa such as *Millotia dimorpha*. However, when the perennial flora of both ranges is combined and compared, there is nearly 30 % difference in species (30 of 98 taxa) (data from Meissner and Caruso (2008)). Furthermore, the communities described for the Koolanooka Hills, from classification analysis of floristic data, were unlike any described in this study for the central Tallering Land System (Meissner & Caruso 2008). Of particular note is the more widespread occurrence of *Eucalyptus* in the communities and over the entire topographic profile of the Koolanooka Hills. This genus is gradually restricted to the lower slopes and, eventually, only to outwash sites over a north-east gradient within the central Tallering Land System. *Acacia* and, in particular, *Acacia aneura*, dominates the vegetation communities of the central Tallering Land System while it is notably absent from Koolanooka. This concurs with Beard's (1976a, b) documentation of the transition from *Eucalyptus* to *Acacia* dominated communities across the Yalgoo region and description of the Murchison region as 'mulga country'.

## Environmental correlates

The primary division in the classification segregates the communities of *Eucalyptus* woodlands and open *Acacia* shrublands on lowland – outwash sites from those on the rocky, steeper terrain higher on the landform. This major distinction between upland and lowland communities has been noted in other studies within the greater Yalgoo – Murchison region (Beard 1976a, b; Markey & Dillon in review; Pringle 1998). Topographic position is strongly associated with other environmental attributes, such as slope, rock outcrop cover, fragment abundance, bedrock exposure and soil chemical composition, water retention and soil development (Cole 1973; Gibson 2004a, b; Gibson & Lyons 2001b; Hennig 1998b; this study). Therefore, the greatest floristic differences coincide with extremes in topographic and environmental gradients. The Central Tallering lowland communities are situated on a deeper soil profile of stony red earths, red clayey sands and ironstone gravels deposited at the base of the landforms, which has been enriched by leachates and receives colluvium from the hillsides (Hennig 1998b). This compares with communities that have developed on the steeper slopes on exposed, weathered bedrock covered in shallow – skeletal stony soils that have formed *in situ*. These soils are derived from the parent rock (Cole 1973; Gray & Murphy 2002), and the relatively higher levels of iron and phosphorus in upland soils reflects this process of soil development from massive BIF.

Although there was a small gradient of increasing soil pH with decreasing topographic position in the landscape, soils were generally acidic throughout the survey area. The tendency for lower slope outwash sites to have relatively less acidic soils probably relates to the higher concentrations of cations and higher eCEC, which buffers against acidity (Gray & Murphy 2002), whilst skeletal soils are being derived directly from heavily weathered rocks. Other studies have reported more basic soils (pH > 8.0) in outwash locations which have been derived from the weathering of mafic rocks and calcretes. In turn, these sites support quite distinct vegetation communities (e.g. Gibson & Lyons 1998, 2001b). Such sites are not reported for this survey because areas of mafic and ultramafic rocks of the Warriedar Fold Belt were not sampled, these areas being excluded from the Tallering Land System of Payne et al. (1998). Such geologies do occur in the eastern part of the area (Lipple et al. 1983), and the vegetation communities of these would be interesting to compare with the ironstone communities.

The rapid changes in topography over the BIF ranges produce a variety of diverse habitats and microhabitats over a relatively short distance within the landform, which support a number of different floristic community types. These communities are composed of generalist taxa that are both widely dispersed over the landform and surrounds (e.g. *Acacia aneura*, *Solanum lasiophyllum*), and characteristic taxa with a more limited distribution and greater specificity for particular microhabitats. This sequence of communities over the topographic catena (the 'catenary sequence' *sensu* Beard (1976a, 1990)), has been found in similar surveys on ironstone and greenstone ranges in the northern and eastern goldfields (Gibson 2004a, b; Gibson & Lyons 1998, 2001a, b; Meissner & Caruso 2008, Markey & Dillon 2008) and BIF landforms in the arid Pilbara (van Etten & Fox 2004) and in Brazil (Jacobi et al. 2007).

The turnover of communities among BIF ranges is a trend also noted for granite communities (Hopper et al. 1997), and has been attributed to a number of possible, interrelated causes. Geographical position and its associated climate may have also some bearing on some of these communities, and account for their restriction to particular parts of the region. The latitudinal and longitudinal transition in floristic communities across the central Tallering Land System and within the wider Yalgoo – Murchison region coincides with a climatic gradient of increasing aridity (Beard 1976a, b). Differences in floristic composition among ranges may also be associated with differences in the physical characteristics of each landform, such as soil chemistry, geological substrate or topography. Furthermore, these ranges are isolated by expanses of low plains, and opportunities for an exchange of species among them may be limited. In addition to these possible factors, differences in floristic composition may be a consequence of climatic and evolutionary history over the Tertiary and Quaternary. Increasing aridity and climatic instability over these periods has been hypothesised to account for patterns in speciation, endemism and biogeography in the South West Floristic Region (Hopper & Goia 2004) and among granite outcrops in this region (Hopper et al. 1997). This fluctuating aridity could have worked in combination with limited dispersal between ranges, stochastic events of immigration or local extinction, *in situ* speciation events, and range-specific habitats and substrates to account for biogeographic patterns currently observed in BIF ranges of southern Western Australia (Hopper et al. 1997, Hopper & Goia 2004). Like granite outcrops (Hopper et al. 1997), BIF ranges in the northern Yilgarn are biodiversity hotspots, and refugia for endemic or uncommon taxa and floristic communities (Gibson et al. 2007).

## Conservation

A number of taxa endemic and near-endemic to the ironstones ranges of the Central Tallering Land System are recommended to have their conservation status reviewed, given their restricted distribution and a potential threat from mineral exploration and mining. In particular, it is recommended that the conservation status of *Millotia* *dimorpha* is revised from P1 to declared rare flora (DRF) given that all known populations are under threat from mining proposals. Both *Acacia woodmaniorum* and *Acacia karina* were recently listed at priority 2 conservation status (Maslin & Buscomb 2007), and should be considerd for a higher priority or declared rare flora (DRF) listing (B. Maslin, pers. comm.[8]). Although not restricted to the study region, *Calotis* aff. *cuneifolia* is recommend for priority listing (P3) as it is only known from three highly disjunct locations, one of which occurs over several exploration or mining tenements. *Lepidosperma* sp. (A. Markey & S. Dillon 3468) requires further taxonomic work before it can be considered for priority listing, but it is likely that it will be awarded high conservation status (R. Barrett, pers. comm.[9]).

The study area has been subject to over a century of pastoralism, and this would be expected to have had some impact on vegetation condition. However, the study region was found to be relatively weed free and in reasonably good condition, as was found previously by Payne et al. (1998). This is to be expected for hilly terrain, which is not under the same sheep grazing pressure as the lowland plains and paddocks supplied with bores. Annual grasses and weedy herbaceous annuals were common in most quadrats, the most common annual being *Pentaschistis airoides*, which was present in 58% of quadrats. Goats were recognised as a serious problem in the Sandstone – Yalgoo region (Payne et al. 1998). This situation has not changed. Goat browsing is evident in all areas visited, and was noted to be so intense in some area that sampling was abandoned (i.e. Walagnumming Hill). Large flocks (≥ 20 animals) were observed in areas within weeks following ground-based culls, which suggest a requirement for regional control programs.

BIF landforms are highly prospectable for minerals, and mining would present greatest immediate threat to their unique and endemic floristic communities and flora. Although BIF ranges constitute a relatively small area of the Yilgarn Craton, they are specifically targeted by mining and very few of these ranges are reserved or have been proposed for protection within the conservation estate. The high turnover of species and communities both within and among these ranges makes the adequate reservation of such floristic diversity particularly challenging. To date, none of the central Tallering Land System occurs on conservation reserve, although the pastoral leases of three stations within the study area (Karara, Lochada and Warriedar) were purchased by CALM (now DEC) for the purposes of inclusion in the reserves system. These stations are currently Unallocated Crown Land undergoing tenure review. Most of these ex-pastoral stations are covered by exploration or mining tenements, and mineral exploration has already commenced on the hematite and magnetite deposits (i.e.: Mt Karara, Jasper Hill and Windaning Ridge). Tenements for various minerals also exist on all of the ironstone and greenstone ranges on adjoining pastoral leases on Thundelarra and Badja Stations, and indeed cover most of the central Tallering Land System. Proposed exploration and mining activities need to be carefully assessed and managed to minimise their impacts on geographically restricted floristic community types and on endemic, priority and poorly known taxa which have been identified for this region.

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[9] Russell Barrett: PhD Candidate, Botanic Gardens and Parks Authority, Perth

**Note**: Following the acceptance of this manuscript for publication/during the preparation of this manuscript for publication, Calotis aff cuneifolia has been given the phrase name Calotis sp. Perrinvale Station (R.J. Cranfield 7096), and listed as having Priority 3 conservation status.

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Table 1

Taxa of conservation significance collected within the Central Tallering Land System. Priority conservation status is according to Atkins (2006), and population status refers to whether the population was unknown or known prior to this study. Endemic taxa are defined as those restricted to hills within 100 km radius. IBRA Regions are denoted as: Yal = Yalgoo, Mur = Murchison, AW = Avon Wheatbelt, GS = Geraldton Sandplain (Thackway & Cresswell 1995, Environment Australia 2000). Asterisks indicate that the distribution is centred on Yalgoo IBRA.

| Family | Taxon | Priority status | Population status | Distribution |
|---|---|---|---|---|
| Aizoaceae | *Gunniopsis divisa* | P1 | new population | Yal, Mur |
| Aizoaceae | *Gunniopsis rubra* | P3 | new population | Coo, Mur, Yal, AW |
| Asteraceae | *Millotia dimorpha* | P1 | new population | Endemic |
| Asteraceae | *Rhodanthe collina* | P1 | previously known | Yal, AW* |
| Celastraceae | *Psammomoya implexa* | P3 | previously known | YA, AW |
| Mimosaceae | *Acacia karina* | P2 | new population | Endemic |
| Mimosaceae | *Acacia woodmaniorum* | P2 | previously known | Endemic |
| Myrtaceae | *Calytrix uncinata* | P3 | previously known | Yal, Mur |
| Myrtaceae | *Micromyrtus trudgenii* | P1 | previously known | Endemic |
| Myrtaceae | *Micromyrtus acuta* | P1 | previously known | Endemic |
| Poaceae | *Austrostipa blackii* | P3 | new population | Widespread |
| Proteaceae | *Persoonia pentasticha* | P2 | previously known | Yal, GS, AW |
| Rhamnaceae | *Cryptandra imbricata* | P3 | previously known | Mur, Yal, AW* |
| Rhamnaceae | *Polianthion collinum* | P3 | previously known | Endemic |
| Rutaceae | *Drummondita fulva* | P3 | previously known | Endemic |

Table 2

Significant indicator taxa of the eight group classification of BIF landforms within the central Tallering Land System. Indicator values (%) are shown only for taxa which were found to be significant at $p \leq 0.05$ from a Monte Carlo permutation test (* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$). The highest INDVAL statistics per taxon are highlighted.

| | Floristic Community Type | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Species** | **1a** | **1b** | **2** | **3** | **4a** | **4b** | **5a** | **5b** |
| *Acacia coolgardiensis* subsp *latior* * | 22 | 1 | 14 | 0 | 0 | 0 | 0 | 1 |
| *Acacia sibina* ** | 30 | 4 | 6 | 0 | 1 | 0 | 0 | 3 |
| *Aluta aspera* subsp. *hesperia* ** | 30 | 17 | 2 | 0 | 0 | 4 | 0 | 0 |
| *Cheilanthes adiantoides* ** | 18 | 18 | 18 | 11 | 4 | 3 | 2 | 6 |
| *Dianella revoluta* var. *divaricata* ** | 28 | 3 | 0 | 0 | 0 | 2 | 0 | 7 |
| *Eremophila forrestii* subsp. *forrestii* * | 24 | 1 | 0 | 0 | 0 | 6 | 4 | 3 |
| *Hemigenia* sp. Cue * | 20 | 3 | 10 | 0 | 0 | 0 | 0 | 0 |
| *Philotheca deserti* subsp. *deserti* ** | 26 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| *Thysanotus pyramidalis* * | 21 | 5 | 0 | 0 | 0 | 0 | 2 | 1 |
| *Eremophila latrobei* subsp. *latrobei* ** | 19 | 21 | 1 | 14 | 9 | 11 | 0 | 2 |
| *Philotheca sericea* ** | 1 | 20 | 6 | 18 | 12 | 17 | 0 | 0 |
| *Prostanthera magnifica* ** | 1 | 40 | 4 | 0 | 0 | 2 | 0 | 0 |
| *Acacia karina* * | 1 | 2 | 19 | 0 | 0 | 0 | 0 | 0 |
| *Acacia assimilis* subsp. *assimilis* * | 12 | 7 | 23 | 0 | 0 | 1 | 2 | 6 |
| *Allocasuarina acutivalvis* ** | 5 | 5 | 46 | 4 | 0 | 0 | 0 | 0 |
| *Calothamnus gilesii* * | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 0 |
| *Cyanicula amplexans* ** | 0 | 2 | 33 | 0 | 0 | 0 | 0 | 0 |
| *Eucalyptus petraea* * | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 0 |
| *Gastrolobium laytonii* ** | 0 | 0 | 31 | 0 | 2 | 0 | 0 | 0 |
| *Grevillea paradoxa* ** | 0 | 0 | 47 | 0 | 0 | 0 | 0 | 0 |
| *Hypoxis glabella* var. *glabella* * | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 0 |
| *Lepidosperma* sp. (Markey & Dillon 3468) ** | 0 | 0 | 40 | 0 | 0 | 0 | 0 | 0 |
| *Leucopogon* sp. Clyde Hill * | 7 | 3 | 17 | 1 | 0 | 0 | 0 | 0 |
| *Melaleuca nematophylla* ** | 1 | 6 | 47 | 3 | 0 | 0 | 0 | 0 |
| *Melaleuca radula* * | 0 | 0 | 23 | 3 | 0 | 0 | 0 | 0 |
| *Mirbelia microphylla* * | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 0 |
| *Persoonia hexagona* ** | 0 | 0 | 31 | 0 | 2 | 0 | 0 | 0 |
| *Thysanotus manglesianus* ** | 13 | 12 | 25 | 0 | 2 | 0 | 0 | 1 |
| *Xanthosia bungei* ** | 0 | 4 | 58 | 2 | 2 | 0 | 0 | 0 |
| *Acacia aulacophylla* ** | 0 | 1 | 0 | 38 | 10 | 4 | 3 | 0 |
| *Arthropodium dyeri* * | 3 | 10 | 15 | 20 | 3 | 2 | 6 | 2 |
| *Astroloma serratifolium* * | 0 | 1 | 10 | 18 | 1 | 0 | 0 | 0 |
| *Austrodanthonia caespitosa* ** | 0 | 1 | 0 | 24 | 6 | 1 | 19 | 0 |
| *Calytrix uncinata* ** | 0 | 0 | 0 | 30 | 0 | 0 | 3 | 0 |
| *Cheiranthera filifolia* var. *simplicifolia* ** | 2 | 4 | 0 | 44 | 0 | 1 | 3 | 1 |
| *Drummondita fulva* ** | 1 | 8 | 0 | 37 | 0 | 0 | 0 | 0 |
| *Eremophila glutinosa* ** | 0 | 1 | 0 | 24 | 3 | 2 | 2 | 0 |
| *Melaleuca hamata* * | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 0 |
| *Micromyrtus trudgenii* * | 0 | 6 | 0 | 22 | 19 | 1 | 0 | 0 |
| *Mirbelia bursarioides* ** | 0 | 27 | 0 | 32 | 5 | 7 | 0 | 0 |
| *Philotheca brucei* subsp. *brucei* ** | 3 | 8 | 8 | 23 | 5 | 8 | 0 | 8 |
| *Prostanthera patens* ** | 0 | 5 | 0 | 37 | 10 | 0 | 0 | 0 |
| *Stylidium longibracteatum* ** | 0 | 0 | 0 | 50 | 1 | 0 | 2 | 0 |
| *Thryptomene costata* ** | 1 | 3 | 0 | 24 | 0 | 8 | 0 | 0 |
| *Austrostipa trichophylla* * | 0 | 1 | 0 | 0 | 22 | 14 | 6 | 7 |
| *Calycopeplus paucifolius* ** | 1 | 8 | 17 | 0 | 25 | 0 | 0 | 0 |
| *Cheilanthes lasiophylla* * | 0 | 0 | 0 | 0 | 18 | 0 | 0 | 0 |
| *Cheilanthes sieberi* subsp. *sieberi* ** | 0 | 1 | 0 | 0 | 40 | 16 | 3 | 0 |
| *Dodonaea petiolaris* * | 0 | 0 | 0 | 17 | 20 | 6 | 0 | 1 |

Table 2 (cont.)

| **Species** | **1a** | **1b** | **2** | **3** | **4a** | **4b** | **5a** | **5b** |
|---|---|---|---|---|---|---|---|---|
| | **Floristic Community Type** | | | | | | | |
| *Dodonaea viscosa* ** | 0 | 0 | 5 | 0 | 40 | 0 | 0 | 0 |
| *Isotoma petraea* * | 0 | 0 | 0 | 0 | 18 | 0 | 0 | 0 |
| *Acacia aneura* var. cf. *major* ** | 7 | 9 | 4 | 2 | 1 | 29 | 1 | 0 |
| *Acacia umbraculiformis* ** | 1 | 2 | 0 | 5 | 7 | 39 | 0 | 0 |
| *Acacia ramulosa* var. *ramulosa* ** | 10 | 11 | 0 | 6 | 3 | 23 | 3 | 15 |
| *Monachather paradoxus* * | 18 | 10 | 1 | 2 | 2 | 19 | 0 | 10 |
| *Phyllanthus erwinii* ** | 0 | 0 | 0 | 0 | 0 | 26 | 0 | 0 |
| *Ptilotus drummondii* var. *drummondii* ** | 1 | 3 | 2 | 14 | 0 | 29 | 1 | 4 |
| *Sida* sp. Golden calyces glabrous fruit** | 0 | 1 | 2 | 0 | 8 | 60 | 0 | 0 |
| *Solanum ellipticum* ** | 0 | 0 | 0 | 2 | 13 | 31 | 1 | 1 |
| *Solanum lasiophyllum* * | 0 | 2 | 4 | 2 | 8 | 21 | 3 | 4 |
| *Thryptomene decussata* * | 0 | 3 | 0 | 6 | 9 | 22 | 0 | 0 |
| *Acacia erinacea* ** | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 0 |
| *Austrostipa elegantissima* * | 1 | 2 | 0 | 5 | 19 | 1 | 22 | 14 |
| *Austrostipa nitida* ** | 0 | 0 | 0 | 0 | 1 | 0 | 42 | 0 |
| *Enchylaena lanata* ** | 0 | 0 | 0 | 1 | 5 | 5 | 47 | 1 |
| *Eremophila oldfieldii* subsp. *oldfieldii* ** | 0 | 0 | 0 | 2 | 0 | 0 | 42 | 0 |
| *Eremophila oppositifolia* subsp. *angustifolia* ** | 0 | 0 | 0 | 1 | 0 | 0 | 36 | 1 |
| *Exocarpos aphyllus* ** | 0 | 0 | 0 | 0 | 1 | 0 | 25 | 2 |
| *Frankenia setosa* ** | 0 | 0 | 0 | 0 | 0 | 0 | 25 | 0 |
| *Maireana carnosa* ** | 0 | 0 | 0 | 0 | 0 | 0 | 64 | 1 |
| *Maireana thesioides* ** | 0 | 0 | 0 | 1 | 0 | 0 | 37 | 9 |
| *Rhagodia drummondii* ** | 0 | 0 | 0 | 0 | 0 | 0 | 32 | 29 |
| *Scaevola spinescens* ** | 0 | 0 | 0 | 8 | 0 | 0 | 47 | 23 |
| *Sclerolaena densiflora* * | 0 | 0 | 0 | 2 | 1 | 0 | 25 | 0 |
| *Sclerolaena diacantha* ** | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 2 |
| *Sclerolaena fusiformis* ** | 0 | 0 | 0 | 0 | 0 | 0 | 42 | 2 |
| *Sclerolaena gardneri* ** | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 2 |
| *Senna* sp. Austin ** | 1 | 0 | 1 | 0 | 0 | 0 | 48 | 3 |
| *Cryptandra imbricata* * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 |
| *Eucalyptus kochii* subsp. *amaryssia* ** | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 32 |
| *Maireana villosa* x *planifolia* ** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40 |
| *Maireana georgei* * | 1 | 0 | 0 | 0 | 0 | 0 | 16 | 19 |
| *Olearia humilis* ** | 2 | 6 | 0 | 3 | 0 | 0 | 1 | 33 |
| *Ptilotus obovatus* var. *obovatus* ** | 0 | 0 | 1 | 6 | 25 | 5 | 10 | 25 |
| *Senna artemisioides* subsp. *filifolia* ** | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 32 |
| *Senna charlesiana* ** | 0 | 1 | 1 | 7 | 1 | 0 | 1 | 27 |
| Number of quadrats | 12 | 35 | 10 | 10 | 11 | 7 | 8 | 10 |

Table 3

Summary statistics (average ± s.e.) of environmental variables for floristic community types of the Central Tallering Land System. Differences were determined using Kruskal – Wallis non-parametric analysis of variance. (* indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$), with Dunn's posthoc test (LSD $p < 0.05$). Despite significant results for AOV, posthoc tests were insignificant for S. Parameter codes are explained in the methods section. Units for parameters; eCEC = cmol(+)/kg, minerals = mg/kg, annual temperature (Tann) = °C and annual rainfall (Rann) = mm. Abbreviations: Rock Frag = surface rock fragment cover, Rock Max Size = maximum surface rock size category.

| | Community type | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Variable** | **1a** | **1b** | **2** | **3** | **4a** | **4b** | **5a** | **5b** |
| **Soil Parameters** | | | | | | | | |
| eCEC *** | 0.91 ± 0.14 [a] | 1.91 ± 0.12 [ab] | 5.67 ± 1.35 [c] | 2.41 ± 0.27 [bc] | 3.26 ± 0.36 [c] | 1.95 ± 0.19 [ab] | 5.20 ± 1.11 [cb] | 3.45 ± 0.94 [bc] |
| pH *** | 4.26 ± 0.03 [a] | 4.57 ± 0.05 [bc] | 4.93 ± 0.12 [c] | 4.36 ± 0.09 [ab] | 4.63 ± 0.15 [abc] | 4.56 ± 0.13 [abc] | 5.10 ± 0.23 [c] | 4.98 ± 0.21 [bc] |
| Ca *** | 98.2 ± 17.4 [a] | 223.0 ± 16.8 [ab] | 807.0 ± 217 [c] | 246.0 ± 35.3 [abc] | 389.1 ± 60.3 [bc] | 237.1 ± 28.4 [abc] | 376.0 ± 106 [bc] | 464.0 ± 166 [bc] |
| K *** | 71.2 ± 8.4 [a] | 114.4 ± 6.0 [abc] | 145 ± 17.8 [bc] | 102.3 ± 9.4 [ab] | 164.5 ± 13.3 [c] | 118.0 ± 9.2 [abc] | 127.8 ± 11.5 [bc] | 137.5 ± 13.8 [bc] |
| Mg *** | 23.2 ± 3.3 [a] | 52.8 ± 3.0 [ab] | 138.4 ± 26.7 [c] | 76.3 ± 9.4 [bc] | 94.0 ± 8.7 [bc] | 50.0 ± 7.1 [ab] | 235.9 ± 57.3 [c] | 78.4 ± 12.8 [bc] |
| P *** | 4.8 ± 0.4 [a] | 6.6 ± 0.5 [a] | 19.3 ± 9.5 [ab] | 12.0 ± 4.3 [ab] | 68.3 ± 15.3 [b] | 13.9 ± 3.8 [ab] | 6.9 ± 0.8 [a] | 6.9 ± 0.7 [a] |
| Co *** | 0.05 ± 0.01 [a] | 0.19 ± 0.07 [ab] | 0.12 ± 0.02 [bc] | 0.12 ± 0.04 [a] | 0.14 ± 0.03 [abc] | 0.40 ± 0.33 [ab] | 0.95 ± 0.40 [bc] | 0.32 ± 0.05 [c] |
| Cu ** | 0.83 ± 0.0 [a] | 1.11 ± 0.07 [ab] | 1.03 ± 0.11 [ab] | 0.74 ± 0.06 [a] | 1.13 ± 0.12 [ab] | 0.96 ± 0.10 [ab] | 1.16 ± 0.21 [ab] | 1.33 ± 0.16 [b] |
| Fe *** | 35.2 ± 4.0 [ab] | 42.8 ± 3.0 [ab] | 80.6 ± 20.5 [bc] | 87.5 ± 14.7 [c] | 162.8 ± 28.9 [c] | 59.4 ± 9.2 [bc] | 53.0 ± 9.1[bc] | 31.6 ± 2.0 [a] |
| Mn ** | 24.1 ± 5.4 [ab] | 47.2 ± 4.4 [ab] | 48.1 ± 6.4 [ab] | 21.2 ± 6.0 [a] | 46.1 ± 12.3 [ab] | 43.4 ± 15.8 [ab] | 58.1 ± 22.2 [ab] | 64.0 ± 10.3 [b] |
| Na *** | 10.6 ± 3.3 [a] | 16.7 ± 1.7 [ab] | 30.7 ± 5.6 [bc] | 67.4 ± 31.4 [bc] | 27.3 ± 3.5 [bc] | 11.4 ± 1.5 [ab] | 243.5 ± 64.8 [c] | 30.7 ± 8.4 [abc] |
| Ni *** | 0.12 ± 0.02 [a] | 0.22 ± 0.03 [a] | 0.18 ± 0.0 [a] | 0.24 ± 0.03 [ab] | 0.25 ± 0.03 [ab] | 0.20 ± 0.05 [a] | 0.88 ± 0.15 [b] | 0.24 ± 0.04 [ab] |
| Pb ** | 0.69 ± 0.04 [ab] | 0.75 ± 0.03 [b] | 0.81 ± 0.06 [b] | 0.60 ± 0.06[ab] | 0.45 ± 0.07 [a] | 0.66 ± 0.06 [ab] | 0.68 ± 0.10[ab] | 0.68 ± 0.06 [ab] |
| S * | 17.6 ± 1.6 | 14.1 ± 0.7 | 13.3 ± 1.9 | 22.4 ± 6.9 | 14.6 ± 1.3 | 13.0 ± 1.5 | 41.3 ± 11.7 | 11.7 ± 1.4 |
| Zn ** | 1.95 ± 0.20 [a] | 2.79 ± 0.23 [ab] | 2.21 ± 0.32 [a] | 3.28 ± 0.56 [ab] | 4.68 ± 0.55 [b] | 3.30 ± 0.56 [ab] | 4.96 ± 1.21 [ab] | 2.39 ± 0.22 [ab] |
| **Climate estimates** | | | | | | | | |
| Tann *** | 20.1 ± 0.0 [c] | 19.9 ± 0.0 [abc] | 19.6 ± 0.0 [a] | 20.0 ± 0.1 [bc] | 19.6 ± 0.1 [a] | 20.1 ± 0.0 [c] | 20.1 ± 0.1 [bc] | 20.0 ± 0.1 [abc] |
| Rann *** | 284 ± 3 [ab] | 290 ± 2 [ab] | 305 ± 1 [c] | 284 ± 4 [ab] | 293 ± 4 [bc] | 267 ± 5 [a] | 280 ± 6 [ab] | 292 ± 4 [abc] |
| Rcv*** | 55.5 ± 0.5 [a] | 56.3 ± 0.3 [ab] | 57.9 ± 0.2 [b] | 54.9 ± 0.4 [a] | 57.4 ± 0.2 [ab] | 55.9 ± 0.6 [ab] | 55.9 ± 0.6[ab] | 56.2 ± 0.5 [ab] |
| **Site Parameters** | | | | | | | | |
| Latitude *** | -28.957 ±0.053 [b] | -29.051 ±0.021 [ab] | -29.168 ±0.007 [a] | -28.900 ±0.054 [b] | -29.126 ±0.012 [ab] | -28.971 ± 0.059 [b] | -28.986 ± 0.059 [ab] | -29.039 ± 0.052 [ab] |
| Longitude*** | 116.907 ±0.023 [ab] | 116.948 ±0.023 [ab] | 116.815 ±0.019 [a] | 116.934 ± 0.014 [ab] | 116.993 ± 0.054 [b] | 117.198 ±0.084 [b] | 116.983 ± 0.074 [ab] | 116.886 ± 0.020 [ab] |
| Altitude *** | 360 ± 4 [a] | 399 ± 5 [ab] | 428 ± 12 [b] | 406 ± 11 [ab] | 443 ± 18 [b] | 374 ± 18 [ab] | 363 ± 13 [a] | 379 ± 9 [ab] |
| Slope *** | 3.5 ± 0.6 [ab] | 7.5 ± 0.9 [ab] | 12.5 ± 2.7 [b] | 10.8 ± 2.2 [ab] | 23.0 ± 2.6 [b] | 10.6 ± 2.6 [ab] | 9.4 ± 3.3 [ab] | 3.1 ± 1.0 [a] |
| Topography *** | 2.2 ± 0.3 [ab] | 3.4 ± 0.2 [abc] | 3.8 ± 0.4 [bc] | 4.6 ± 0.2 [c] | 4.0 ± 0.3 [bc] | 3.5 ± 0.5 [abc] | 2.5 ± 0.6 [ab] | 1.3 ± 0.1 [a] |
| MxR size *** | 3.2 ± 0.2 [a] | 4.2 ± 0.2 [abc] | 5.1 ± 0.2 [cd] | 5.0 ± 0.2 [cd] | 5.6 ± 0.2 [d] | 4.9 ± 0.4 [bcd] | 4.5 ± 0.5 [abcd] | 3.3 ± 0.2 [ab] |
| Fragment *** | 4.3 ± 0.3 [ab] | 4.8 ± 0.1 [bc] | 4.4 ± 0.2 [ab] | 5.4 ± 0.2 [c] | 4.8 ± 0.2 [bc] | 5.0 ± 0.0 [bc] | 5.4 ± 0.2 [bc] | 3.7 ± 0.2 [a] |
| Outcrop *** | 0.2 ± 02 [a] | 1.5 ± 0.3 [ab] | 3.1 ± 0.4 [bc] | 3.3 ± 0.4 [bc] | 4.1 ± 0.3 [c] | 2.6 ± 0.6 [abc] | 1.2 ± 0.6 [ab] | 0.1 ± 0.1 [a] |
| % Litter *** | 21.6 ± 3.7 [bc] | 20.5 ± 2.4 [bc] | 43.0 ± 7.6 [c] | 9.1 ± 3.7 [ab] | 3.9 ± 0.8 [a] | 17.4 ± 5.6 [abc] | 3.4 ± 1.1 [a] | 32.0 ± 5.6 [c] |
| %Bare *** | 71.8 ± 4.1 [ab] | 70.6 ± 2.1 [a] | 68.0 ± 4.1 [a] | 80.0 ± 2.1 [ab] | 80.4 ± 2.1 [ab] | 80.7 ± 4.7 [ab] | 85.0 ± 2.8 [ab] | 79.0 ± 5.8 [b] |
| **Species Richness** | | | | | | | | |
| All Taxa[1] | 38.9 ± 2.6 | 49.4 ± 1.7 | 50.9 ± 2.3 | 48.3 ± 3.3 | 54.8 ± 2.8 | 47.4 ± 3.3 | 53.1 ± 6.1 | 47.9 ± 2.2 |
| Annuals [1] | 19.5 ± 1.5 | 25.1 ± 1.3 | 27.6 ± 1.7 | 21.2 ± 1.7 | 30.1 ± 2.0 | 26.1 ± 3.6 | 29.0 ± 5.2 | 23.9 ± 2.8 |
| Perennials [1] | 19.4 ± 1.4 | 24.3 ± 0.7 | 23.3 ± 1.3 | 27.1 ± 2.3 | 24.7 ± 1.3 | 21.3 ± 1.5 | 24.1 ± 1.3 | 24.0 ± 1.5 |
| N. quadrats | 12 | 35 | 10 | 10 | 11 | 7 | 8 | 10 |

[1]: including singleton taxa

**Table 4:** Spearman Rank Correlation coefficients for environmental variables from 103 quadrats on the Central Tallering Land System. Only correlations significant at $p < 0.01$ are shown. Full details on parameter codes are given in the methods section.

| | Tann | Rann | Rcv | ECEC | pH | Ca | Co | Cu | Fe | K | Mg | Mn | Na | Ni | P | Pb | S | Zn | Slope | Tp | %Leaf | %Bare | MxR | Fragment a | Outcrop ab | Altitude | Latitude |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Climate Estimates** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Tann** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Rann** | -0.854 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Rcv** | -0.724 | 0.618 | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Soil Parameters** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **ECEC** | -0.497 | 0.406 | 0.393 | | | | | | | | | | | | | | | | | | | | | | | | |
| **pH** | -0.419 | 0.347 | 0.454 | 0.661 | | | | | | | | | | | | | | | | | | | | | | | |
| **Ca** | -0.610 | 0.501 | 0.454 | 0.910 | 0.696 | | | | | | | | | | | | | | | | | | | | | | |
| **Co** | -0.271 | . | 0.439 | 0.632 | 0.792 | 0.555 | | | | | | | | | | | | | | | | | | | | | |
| **Cu** | -0.349 | 0.255 | 0.273 | 0.442 | 0.588 | 0.488 | 0.632 | | | | | | | | | | | | | | | | | | | | |
| **Fe** | . | . | . | 0.449 | . | 0.399 | . | . | | | | | | | | | | | | | | | | | | | |
| **K** | -0.511 | 0.324 | 0.493 | 0.712 | 0.554 | 0.681 | 0.641 | 0.615 | 0.344 | | | | | | | | | | | | | | | | | | |
| **Mg** | -0.431 | 0.347 | 0.388 | 0.930 | 0.615 | 0.753 | 0.618 | 0.373 | 0.440 | 0.669 | | | | | | | | | | | | | | | | | |
| **Mn** | -0.457 | 0.363 | 0.539 | 0.426 | 0.782 | 0.560 | 0.711 | 0.692 | . | 0.563 | 0.362 | | | | | | | | | | | | | | | | |
| **Na** | . | . | . | 0.604 | . | 0.368 | 0.304 | . | 0.364 | 0.434 | 0.703 | . | | | | | | | | | | | | | | | |
| **Ni** | . | . | . | 0.613 | 0.352 | 0.448 | 0.548 | 0.418 | 0.372 | 0.574 | 0.696 | 0.352 | 0.520 | | | | | | | | | | | | | | |
| **P** | -0.250 | . | . | 0.469 | . | 0.451 | . | . | 0.728 | 0.432 | 0.420 | . | 0.278 | 0.287 | | | | | | | | | | | | | |
| **Pb** | . | 0.282 | 0.264 | . | . | . | . | . | -0.325 | . | . | . | . | . | -0.272 | | | | | | | | | | | | |
| **S** | . | . | -0.252 | . | -0.603 | -0.319 | -0.474 | -0.424 | . | -0.278 | . | -0.619 | 0.389 | . | . | . | | | | | | | | | | | |
| **Zn** | . | . | . | 0.318 | . | 0.251 | 0.217 | . | 0.413 | 0.370 | 0.340 | . | 0.291 | 0.306 | 0.476 | . | . | | | | | | | | | | |
| **Physical Site Parameters** | | | | | | | | | | | | | | | | . | | | | | | | | | | | |
| **Slope** | -0.313 | . | . | 0.424 | . | 0.369 | . | . | 0.622 | 0.429 | 0.397 | . | 0.241 | 0.231 | 0.599 | . | . | 0.330 | | | | | | | | | |
| **Tp** | . | . | . | . | . | . | -0.363 | -0.315 | 0.599 | . | . | -0.293 | . | . | 0.415 | -0.230 | 0.245 | . | 0.341 | | | | | | | | |
| **%Leaf** | . | . | . | . | . | . | . | . | -0.265 | . | -0.254 | . | -0.321 | -0.256 | -0.258 | 0.241 | -0.259 | -0.340 | -0.290 | . | | | | | | | |
| **%Bare** | 0.335 | -0.348 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | | | | | | |
| **MxR** | . | . | . | 0.407 | . | 0.371 | . | . | 0.776 | 0.285 | 0.365 | . | 0.266 | . | 0.611 | -0.296 | . | 0.460 | 0.697 | 0.601 | -0.259 | . | | | | | |
| **Frag Rock** | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 0.276 | . | . | -0.378 | . | . | | | | |
| **Outcrop** | . | . | . | 0.331 | . | 0.329 | . | . | 0.783 | . | 0.287 | . | . | . | 0.624 | -0.259 | . | 0.370 | 0.524 | 0.732 | . | . | 0.763 | . | | | |
| **Altitude** | -0.743 | 0.492 | 0.239 | 0.363 | . | 0.457 | . | . | 0.319 | 0.320 | 0.282 | . | . | . | 0.364 | . | . | . | 0.422 | 0.468 | . | -0.315 | 0.433 | . | 0.396 | | |
| **Latitude** | 0.804 | -0.831 | -0.902 | -0.401 | -0.454 | -0.490 | -0.405 | -0.352 | . | -0.465 | -0.382 | -0.563 | . | -0.235 | . | -0.341 | 0.284 | . | . | . | . | 0.237 | . | . | . | -0.268 | |
| **Longitude** | 0.361 | -0.694 | -0.374 | . | . | . | . | . | . | . | . | . | . | . | . | -0.41 | . | . | . | . | . | 235 | . | . | . | 0.518 | . |

# APPENDIX 1

Flora List for BIF ranges of the central Tallering Land System (Pinyalling Hill, Walagnumming Hill, Mt Karara, Windaning Hill and associated Windaning ridge, Minjar Hill and unnamed BIF on Badja Station). Nomenclature follows Packowska and Chapman (2000), introduced weeds by "*" and both phrase (informal) names and taxa of uncertain taxonomic status (i.e.: *confer* or *affinis*) are followed by a collection number.

## Adiantaceae

*Cheilanthes* cf. *lasiophylla* x *sieberi* (A. Markey & S. Dillon 3048)
*Cheilanthes adiantoides*
*Cheilanthes brownii*
*Cheilanthes lasiophylla*
*Cheilanthes sieberi* subsp. *sieberi*

## Aizoaceae

* *Cleretum papulosum* subsp. *papulosum*
*Gunniopsis divisa*
*Gunniopsis rubra*
* *Mesembryanthemum nodiflorum*
*Tetragonia diptera*
*Tetragonia eremaea*
*Tetragonia moorei*

## Amaranthaceae

*Ptilotus aervoides*
*Ptilotus divaricatus* var. *divaricatus*
*Ptilotus drummondii* var. *drummondii*
*Ptilotus exaltatus*
*Ptilotus gaudichaudii* var. *gaudichaudii*
*Ptilotus gaudichaudii* var. *parviflorus*
*Ptilotus helipteroides*
*Ptilotus macrocephalus*
*Ptilotus obovatus* var. *obovatus*
*Ptilotus polystachyus* var. *polystachyus*
*Ptilotus sp.* Northampton (R. Davis 10952)

## Anthericaceae

*Arthropodium curvipes*
*Arthropodium dyeri*
*Caesia* sp. Wongan (K.F. Keneally 8820)
*Thysanotus manglesianus*
*Thysanotus pyramidalis*
*Thysanotus rectantherus*

## Apiaceae

*Daucus glochidiatus*
*Hydrocotyle callicarpa*
*Hydrocotyle pilifera* var. *glabrata*
*Hydrocotyle rugulosa*
*Trachymene cyanopetala*
*Trachymene ornata*
*Trachymene pilosa*
*Xanthosia bungei*

## Apocynaceae

*Alyxia buxifolia*

## Asclepiadaceae

*Marsdenia australis*
*Rhyncharrhena linearis*
*Asphodelaceae*
*Bulbine semibarbata*

## Aspleniaceae

*Pleurosorus rutifolius*

## Asteraceae

*Actinobole uliginosum*
*Angianthus tomentosus*
* *Arctotheca calendula*
*Bellida graminea*
*Blennospora drummondii*
*Brachyscome cheilocarpa*
*Brachyscome ciliaris*
*Brachyscome ciliocarpa*
*Brachyscome perpusilla*
*Calocephalus* aff. *multiflorus* (A. Markey & S. Dillon 3464)
*Calocephalus multiflorus*
*Calotis* aff. *cuneifolia* (A. Markey & S. Dillon 3447)
*Calotis hispidula*
*Calotis multicaulis*
*Cephalipterum drummondii*
*Ceratogyne obionoides*
*Chthonocephalus pseudevax*
*Dielitzia tysonii*
*Erymophyllum glossanthus*
*Erymophyllum tenellum*
*Feldstonia nitens*
*Gilberta tenuifolia*
*Gilruthia osbornei*
*Gnephosis arachnoidea*
*Gnephosis brevifolia*
*Gnephosis tenuissima*
*Helipterum craspedioides*
*Hyalosperma demissum*
*Hyalosperma glutinosum* subsp. *glutinosum*
*Hyalosperma glutinosum* subsp. *venustum*
*Hyalosperma zacchaeus*
* *Hypochaeris glabra*
*Isoetopsis graminifolia*
*Lawrencella davenportii*
*Lawrencella rosea*
*Lemooria burkittii*
*Millotia dimorpha*
*Millotia myosotidifolia*
*Myriocephalus guerinae*
*Myriocephalus oldfieldii*
*Myriocephalus pygmaeus*

*Myriocephalus rudallii*
*Olearia humilis*
*Olearia muelleri*
*Olearia pimeleoides*
*Podolepis canescens*
*Podolepis capillaris*
*Podolepis gardneri*
*Podolepis lessonii*
*Podotheca gnaphalioides*
*Pogonolepis stricta*
*Rhodanthe battii*
*Rhodanthe chlorocephala* subsp. *rosea*
*Rhodanthe chlorocephala* subsp. *splendida*
*Rhodanthe citrina*
*Rhodanthe collina*
*Rhodanthe humboldtiana*
*Rhodanthe laevis*
*Rhodanthe manglesii*
*Rhodanthe maryonii*
*Rhodanthe polycephala*
*Rhodanthe propinqua*
*Rhodanthe pygmaea*
*Rhodanthe spicata*
*Schoenia cassiniana*
*Senecio glossanthus*
*Senecio gregorii*
*Senecio pinnatifolius*
* *Sonchus oleraceus*
*Trichanthodium skirrophorum*
* *Urospermum picroides*
* *Ursinia anthemoides*
*Waitzia acuminata* var. *acuminata*
*Waitzia nitida*

## Boraginaceae

*Cynoglossum* sp Inland Ranges (C.A Gardner 12684)
*Omphalolappula concava*

## Boryaceae

*Borya sphaerocephala*

## Brassicaceae

* *Brassica tournefortii*
*Lepidium oxytrichum*
* *Sisymbrium erysimoides*
*Stenopetalum* aff. *sphaerocarpum* (A. Markey & S. Dillon 3414)
*Stenopetalum anfractum*
*Stenopetalum filifolium*
*Stenopetalum pedicellare*
*Stenopetalum sphaerocarpum*

## Caesalpiniaceae

*Senna artemisioides* subsp. *filifolia*
*Senna charlesiana*
*Senna glaucifolia*
*Senna glutinosa* subsp. *chatelainiana* x *charlesiana* (A. Markey & S. Dillon 3413)
*Senna glutinosa* subsp. *chatelainiana*
*Senna* sp. Austin (A. Strid 20210)

## Campanulaceae

*Wahlenbergia gracilenta*
*Wahlenbergia preissii*
*Wahlenbergia tumidifructa*
*Caryophyllaceae*
* *Silene nocturna*
* *Spergula pentandra*

## Casuarinaceae

*Allocasuarina acutivalvis* subsp. *prinsepiana*
*Allocasuarina acutivalvis* subsp. *acutivalvis* intergrade subsp. *prinsepiana*
*Allocasuarina dielsiana*

## Celastraceae

*Psammomoya implexa*

## Centrolepidaceae

*Centrolepis aristata*

## Chenopodiaceae

*Atriplex bunburyana*
*Atriplex semilunaris*
*Chenopodium curvispicatum*
*Chenopodium melanocarpum* forma *melanocarpum*
*Chenopodium saxatile*
*Dysphania glomulifera* subsp. *eremaea*
*Einadia nutans* subsp. *eremaea*
*Enchylaena lanata*
*Enchylaena tomentosa* var. *tomentosa*
*Maireana carnosa*
*Maireana convexa*
*Maireana georgei*
*Maireana marginata*
*Maireana planifolia*
*Maireana planifolia* x *villosa* (intergrade) (A. Markey & S. Dillon 3482)
*Maireana planifolia* x *villosa* (intergrade) (A. Markey & S. Dillon 3479)
*Maireana thesioides*
*Maireana trichoptera*
*Rhagodia drummondii*
*Rhagodia eremaea*
*Sclerolaena densiflora*
*Sclerolaena diacantha*
*Sclerolaena fusiformis*
*Sclerolaena gardneri*
*Sclerolaena microcarpa*

## Colchicaceae

*Wurmbea* sp. Paynes Find (C.J. French 1237)

## Convolvulaceae

*Porana sericea*

## Crassulaceae

*Crassula closiana*
*Crassula colorata* var. *acuminata*
*Crassula colorata* var. *colorata*
*Crassula extrorsa*
*Crassula tetramera*

## Cupressaceae

*Callitris columellaris*

## Cuscutaceae

* *Cuscuta epithymum*

## Cyperaceae

*Isolepis congrua*
*Lepidosperma* sp. (A. Markey & S. Dillon 3468)
*Schoenus nanus*

## Dasypogonaceae

*Chamaexeros macranthera*
*Xerolirion divaricata*

## Dilleniaceae

*Hibbertia arcuata*
*Hibbertia glomerosa* var. *glomerosa*
*Hibbertia stenophylla*

## Droseraceae

*Drosera macrantha* subsp. *macrantha*

## Epacridaceae

*Astroloma serratifolium*
*Leucopogon* sp. Clyde Hill (M.A. Burgman 1207)

## Euphorbiaceae

*Calycopeplus paucifolius*
*Euphorbia boophthona*
*Euphorbia drummondii* subsp. *drummondii*
*Euphorbia tannensis* subsp. *eremophila*
*Phyllanthus erwinii*
*Poranthera microphylla*
*Stachystemon intricatus*

## Frankeniaceae

*Frankenia setosa*

## Geraniaceae

* *Erodium aureum*
* *Erodium cicutarium*
*Erodium cygnorum*

## Goodeniaceae

*Brunonia australis*
*Goodenia berardiana*
*Goodenia havilandii*
*Goodenia occidentalis*
*Goodenia pinnatifida*
*Goodenia pusilliflora*
*Goodenia tenuiloba*
*Scaevola spinescens*
*Velleia cycnopotamica*
*Velleia hispida*
*Velleia rosea*
*Velleia* sp. (A. Markey & S. Dillon 3463)

## Haloragaceae

*Gonocarpus nodulosus*
*Haloragis odontocarpa* f. *octoforma*
*Haloragis odontocarpa* f. *pterocarpa*
*Haloragis odontocarpa* f. *rugosa*
*Haloragis trigonocarpa*
*Myriophyllum decussatum*

## Hypoxidaceae

*Hypoxis glabella* var. *glabella*

## Juncaginaceae

*Triglochin* sp. B Flora of Australia (P.G. Wilson 4294)

## Lamiaceae

*Hemigenia* sp. Cue (K.F. Kenneally 47A)
*Hemigenia* sp. Yalgoo (A.M. Ashby 2624)
*Hemigenia* sp. Yuna (A.C. Burns 95)
*Prostanthera althoferi* subsp. *althoferi*
*Prostanthera althoferi* ssp. *althoferi* x *serica* (intergrade)
*Prostanthera magnifica*
*Prostanthera patens*
*Spartothamnella teucriiflora*

## Lobeliaceae

*Isotoma petraea*
*Lobelia heterophylla*
*Lobelia rhytidosperma*
*Lobelia cleistogamoides*
*Lobelia winfridae*

## Loganiaceae

*Phyllangium sulcatum*

## Loranthaceae

*Amyema gibberula* var. *tatei*
*Amyema preissii*
*Lysiana casuarinae*

## Malvaceae

*Abutilon cryptopetalum*
*Abutilon oxycarpum*
*Sida* sp. Excedentifolia (J.L. Egan 1925)
*Sida* sp. Golden calyces glabrous fruit (H.N. Foote 32)
*Sida* sp. dark green fruits (S. van Leeuwen 2260)
*Sida ectogama*

## Mimosaceae

*Acacia acuaria*

*Acacia* aff. *coolgardiensis* subsp. *latior* (A. Markey & S. Dillon 3477)
*Acacia andrewsii*
*Acacia aneura* var cf. *aneura*
*Acacia aneura* var. cf. *argentia*
*Acacia aneura* var. cf. *tenuis*
*Acacia anthochaera*
*Acacia assimilis* subsp. *assimilis*
*Acacia aulacophylla*
*Acacia burkittii*
*Acacia* cf. *kalgoorliensis* (A. Markey & S. Dillon 3478)
*Acacia colletioides*
*Acacia coolgardiensis* subsp. *effusa*
*Acacia coolgardiensis* subsp. *latior*
*Acacia craspedocarpa*
*Acacia erinacea*
*Acacia exocarpoides*
*Acacia grasbyi*
*Acacia karina*
*Acacia longispinea*
*Acacia minyura*
*Acacia ramulosa* var. *linophylla*
*Acacia ramulosa* var. *ramulosa*
*Acacia rigens*
*Acacia sibina*
*Acacia woodmaniorum*
*Acacia umbraculiformis*
*Acacia tetragonophylla*

## Myoporaceae

*Eremophila clarkei*
*Eremophila decipiens* subsp. *decipiens*
*Eremophila eriocalyx*
*Eremophila forrestii* subsp. *forrestii*
*Eremophila galeata*
*Eremophila georgei*
*Eremophila glutinosa*
*Eremophila granitica*
*Eremophila latrobei* subsp. *latrobei*
*Eremophila oldfieldii* subsp. *oldfieldii*
*Eremophila oppositifolia* subsp. *angustifolia*
*Eremophila pantonii*
*Eremophila* cf. *platycalyx* (A. Markey & S. Dillon 3337)
*Eremophila platycalyx* subsp. *platycalyx*
*Eremophila serrulata*
*Eremophila* sp. (A. Markey & S. Dillon 3338)

## Myrtaceae

*Aluta aspera* subsp. *hesperia*
*Calothamnus gilesii*
*Calytrix uncinata*
*Eucalyptus ewartiana*
*Eucalyptus gypsophila*
*Eucalyptus kochii* subsp. *amaryssia*
*Eucalyptus leptopoda* subsp. *arctata*
*Eucalyptus leptopoda* subsp. *elevata*
*Eucalyptus loxophleba* subsp. *supralaevis*
*Eucalyptus petraea*
*Homalocalyx thryptomenoides*
*Malleostemon tuberculatus*
*Melaleuca cordata*
*Melaleuca hamata*
*Melaleuca leiocarpa*
*Melaleuca nematophylla*
*Melaleuca radula*
*Micromyrtus acuta*
*Micromyrtus clavata*
*Micromyrtus sulphurea*
*Micromyrtus trudgenii*
*Thryptomene costata*
*Thryptomene decussata*
*Verticordia interioris*

## Orchidaceae

*Cyanicula amplexans*
*Caladenia petrenis*
*Pterostylis* sp. inland (A.C. Beauglehole 11880)
*Pterostylis* sp. scooped sepals (G. Brockman GBB386)
*Pterostylis spathulata*

## Oxalidaceae

*Oxalis perennans*

## Papilionaceae

*Daviesia hakeoides* subsp. *subnuda*
*Gastrolobium laytonii*
* *Medicago minima*
*Mirbelia bursarioides*
*Mirbelia microphylla*

## Phormiaceae

*Dianella revoluta* var. *divaricata*

## Pittosporaceae

*Bursaria occidentalis*
*Cheiranthera filifolia* var. *simplicifolia*
*Pittosporum angustifolium*

## Plantaginaceae

*Plantago* aff. *hispida* (A. Markey & S. Dillon 3440)

## Poaceae

*Amphipogon caricinus* var. *caricinus*
*Aristida contorta*
*Austrodanthonia caespitosa*
*Austrodanthonia* sp. Goomalling (A.G. Gunness et al. OAKP 10/63)
*Austrostipa blackii*
*Austrostipa elegantissima*
*Austrostipa eremophila*
*Austrostipa hemipogon*
*Austrostipa nitida*
*Austrostipa scabra*
*Austrostipa trichophylla*
*Bromus arenarius*
*Cymbopogon ambiguus*
* *Ehrharta longiflora*

* *Elymus scaber*
*Enneapogon caerulescens*
*Eragrostis dielsii*
*Eragrostis pergracilis*
*Eriachne pulchella* subsp. *pulchella*
*Lachnagrostis plebeia*
* *Lamarckia aurea*
*Monachather paradoxus*
*Paspalidium basicladum*
* *Pentaschistis airoides*
* *Rostraria pumila*
*Thyridolepis mitchelliana*
*Thyridolepis multiculmis*
*Tripogon loliiformis*
* *Vulpia muralis*
* *Vulpia myuros* var. *myuros*

## Polygalaceae

*Comesperma integerrimum*
*Comesperma volubile*

## Polygonaceae

* *Emex australis*

## Portulacaceae

*Calandrinia sp. Truncate capsules* (A. Markey & S. Dillon 3474)
*Calandrinia* aff. *eremaea* (A. Markey & S. Dillon 3472)
*Calandrinia calyptrata*
*Calandrinia creethae*
*Calandrinia eremaea*
*Calandrinia* sp. The Pink Hills (F. Obbens FO 19/06)
*Calandrinia* sp. Blackberry (D.M. Porter 171)

## Primulaceae

* *Anagallis arvensis*

## Proteaceae

*Grevillea extorris*
*Grevillea obliquistigma* subsp. *obliquistigma*
*Grevillea paradoxa*
*Hakea invaginata*
*Hakea preissii*
*Hakea recurva* subsp. *arida*
*Hakea recurva* subsp. cf. *recurva*
*Persoonia hexagona*
*Persoonia pentasticha*
*Persoonia manotricha*

## Ranunculaceae

*Ranunculus sessiliflorus* var. *sessiliflorus*

## Rhamnaceae

*Cryptandra imbricata*
*Polianthion collinum*

## Rubiaceae

* *Galium aparine*
*Psydrax latifolia*
*Psydrax suaveolens*
*Synaptantha tillaeacea* var. *tillaeacea*\

## Rutaceae

*Drummondita fulva*
*Philotheca brucei* subsp. *brucei*
*Philotheca deserti* subsp. *deserti*
*Philotheca sericea*

## Santalaceae

*Exocarpos aphyllus*
*Santalum acuminatum*
*Santalum spicatum*

## Sapindaceae

*Dodonaea adenophora*
*Dodonaea inaequifolia*
*Dodonaea lobulata*
*Dodonaea petiolaris*
*Dodonaea rigida*
*Dodonaea viscosa* subsp. *mucronata*
*Dodonaea viscosa* subsp. *spatulata*

## Solanaceae

*Nicotiana rosulata* subsp. *rosulata*
*Solanum ellipticum*
*Solanum lasiophyllum*
*Solanum nummularium*

## Stackhousiaceae

*Stackhousia muricata*

## Sterculiaceae

*Brachychiton gregorii*
*Keraudrenia velutina* subsp. *velutina*

## Stylidiaceae

*Levenhookia leptantha*
*Stylidium longibracteatum*
*Stylidium perpusillum*
*Stylidium warriedarense*

## Thymelaeaceae

*Pimelea avonensis*
*Pimelea microcephala* subsp. *microcephala*

## Urticaceae

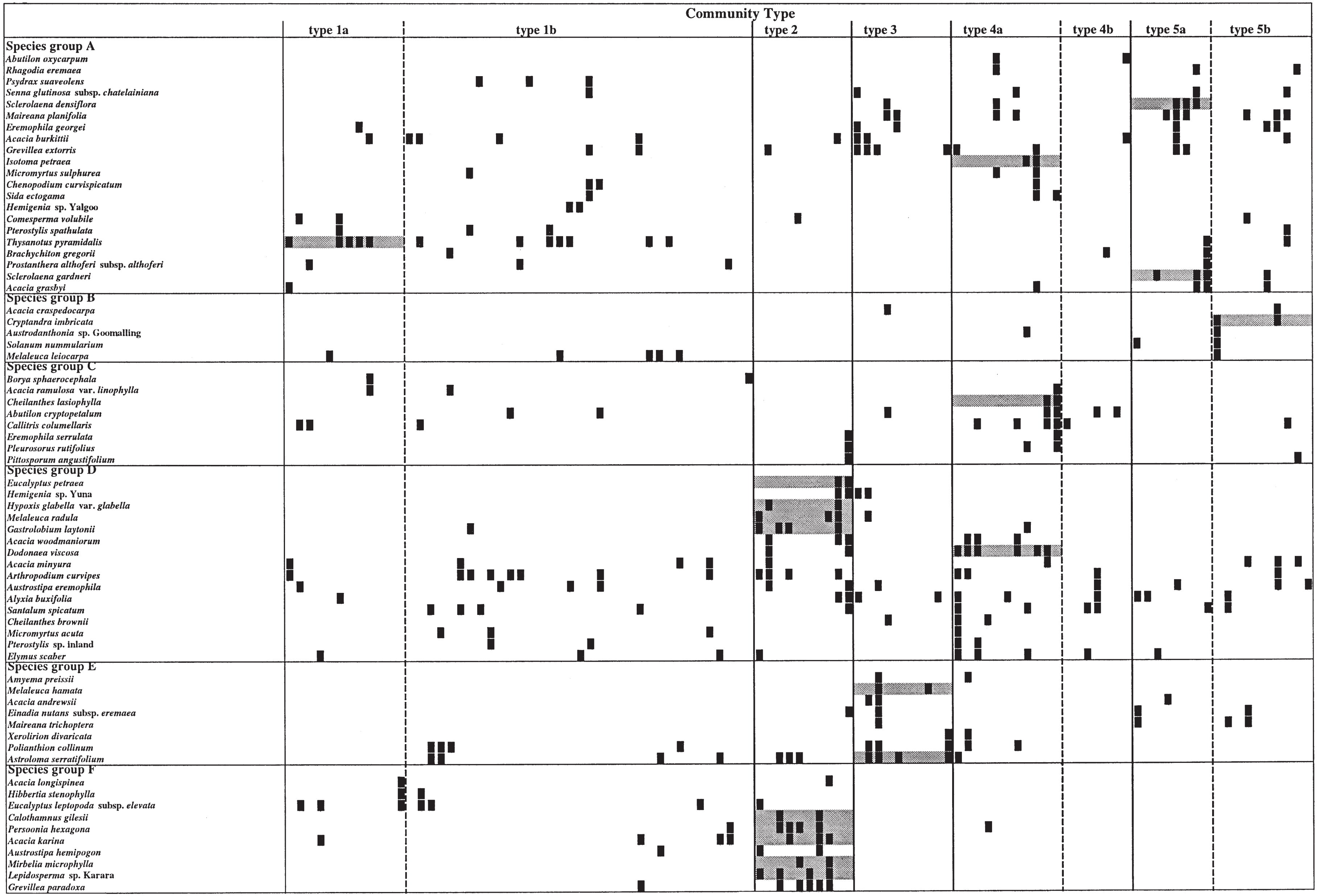
*Parietaria cardiostegia*

## Zygophyllaceae

*Zygophyllum eremaeum*
*Zygophyllum ovatum*

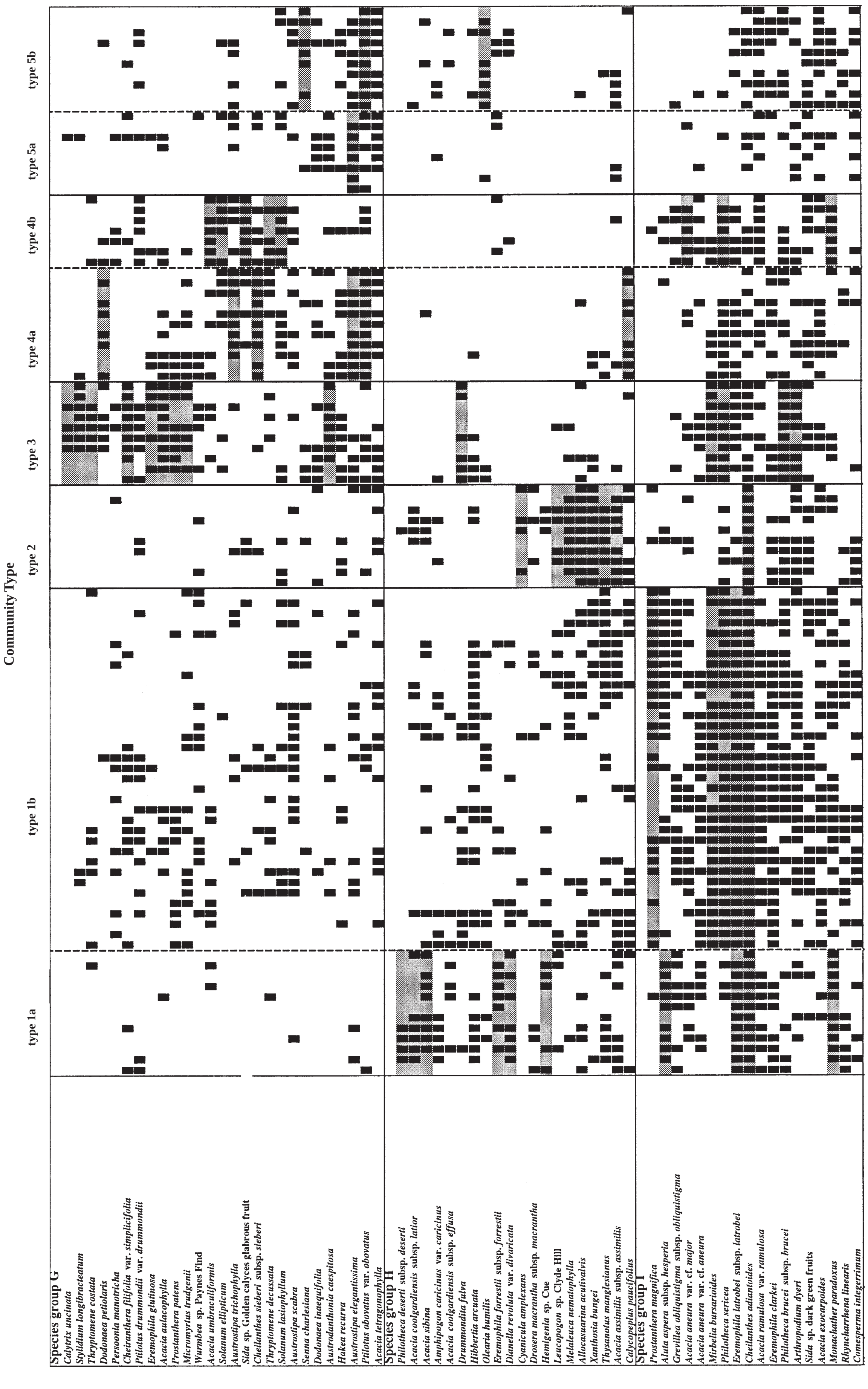
# APPENDIX 2

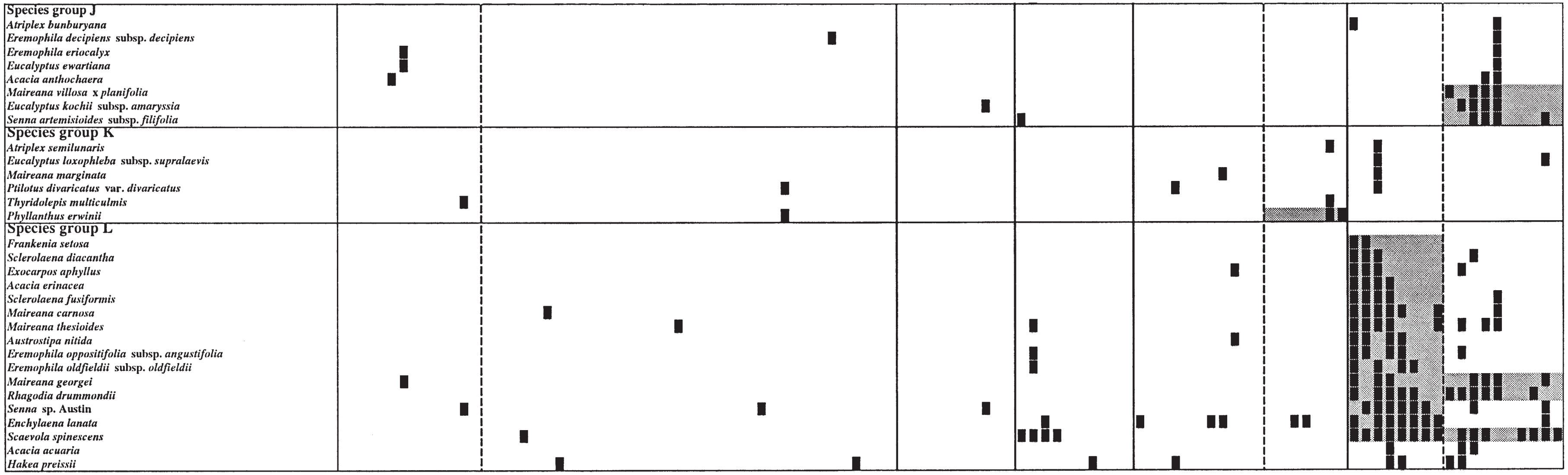
Two way table of site and perennial taxa used in classification and ordination analysis, sorted by quadrat and taxon classification. Species occurences per quadrat are indicated by a square. Species with significant INDVAL statistics are indicated by shading in the respective community type where these values were highest (see Table 2).



# APPENDIX 2

(cont.)




Species group J
Atriplex bunburyana
Eremophila decipiens subsp. decipiens
Eremophila eriocalyx
Eucalyptus ewartiana
Acacia anthochaera
Maireana villosa x planifolia
Eucalyptus kochii subsp. amaryssia
Senna artemisioides subsp. filifolia
Species group K
Atriplex semilunaris
Eucalyptus loxophleba subsp. supralaevis
Maireana marginata
Ptilotus divaricatus var. divaricatus
Thyridolepis multiculmis
Phyllanthus erwinii
Species group L
Frankenia setosa
Sclerolaena diacantha
Exocarpos aphyllus
Acacia erinacea
Sclerolaena fusiformis
Maireana carnosa
Maireana thesioides
Austrostipa nitida
Eremophila oppositifolia subsp. angustifolia
Eremophila oldfieldii subsp. oldfieldii
Maireana georgei
Rhagodia drummondii
Senna sp. Austin
Enchylaena lanata
Scaevola spinescens
Acacia acuaria
Hakea preissii