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Flora and vegetation of the greenstone ranges of the Yilgarn Craton: Kangaroo Hills and surrounding area

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ABSTRACT

A series of timber reserves in the Coolgardie Bioregion were gazetted in the early 20th century to protect the woodlands and to ensure sufficient local supply of firewood close to towns. This paper describes the flora and vegetation on the greenstone hills within these timber reserves and their relationships with environmental variables. A total of 160 taxa were recorded from the survey, including a single taxon of conservation significance. The reserves are characterised by four different *Eucalyptus* woodland communities, with the most widespread community (community 3) occurring on the slopes and crests of the greenstone ranges. This community is dominated by *Eucalyptus lesouefii*, *E. torquata*, *E. griffithsii* and *E. celastroides* subsp. *celastroides*, and is consistently associated with soils that are more alkaline and higher in Mg and Ca compared with soils of other communities. Floristically, this woodland community is different to other eucalypt communities occurring on the crests of the greenstone ranges in the region.

Keywords: greenstone, floristics, ranges, vegetation communities, Yilgarn

INTRODUCTION

Previous surveys of greenstone ranges in south-west Western Australia have highlighted the significance of the greenstone ranges within the South Western Interzone as areas of high plant endemism (Gibson et al. 2012). The greenstone ranges contain the rich deposits of nickel and gold found in the Western Australian goldfields. The recent boom in exploration and mining has led to a potential conflict between resource development and conservation values within the region. This paper is part of a continuing series investigating the flora and vegetation occurring on greenstone ranges within the Yilgarn Craton of Western Australia.

Several timber reserves, state forests and nature reserves are located within the Great Western Woodlands within the Coolgardie IBRA Bioregion. Many of these occur in the area south of Coolgardie and there are also significant areas of forest within the Norseman–Wiluna Greenstone Belt. This greenstone belt is expressed in the landscape as north-north-west trending ranges that lie between the towns of Coolgardie and Widgiemooltha (Fig. 1). The highest peak within the range, Comet Hill (508 m), occurs within Kangaroo Hills Timber Reserve. Surrounding the ranges are Quaternary-aged colluvial deposits derived from the greenstone range.

The objective of this paper is to describe the flora and vegetation of the greenstone ranges within the Kangaroo Hills Timber Reserve and the surrounding Coolgardie area and to examine whether the patterns in community composition can be explained by any of the environmental variables. This information will provide baseline information for future management of the greenstone ranges in the area.

Land use

Kangaroo Hills Timber Reserve is located in the woodlands surrounding Kalgoorlie and Coolgardie. These woodlands are part of the Great Western Woodlands, the largest extant area of Mediterranean-climate woodland in the world (Department of Environment and Conservation 2011). There has been a long association of the area with timber and mining since gold was first discovered in 1892 (Blatchford 1899). Timber was felled and used domestically for firewood, as timber supports in underground mining, and as a source of fuel in the steam boilers (Keally 1991). After clearfelling, the woodlands were then left to regenerate naturally from seed and coppicing (Beard 1990). The reserves were established to control the extent of cutting, to protect the woodlands and to ensure sufficient local supply of firewood (Keally 1991). Current land tenure surrounding the reserves is a combination of unallocated crown land and pastoral leases, with much of the area covered by mining tenements.

Climate

The climate of the region is classified as semi-arid and characterised by hot, dry summers and mild winters.

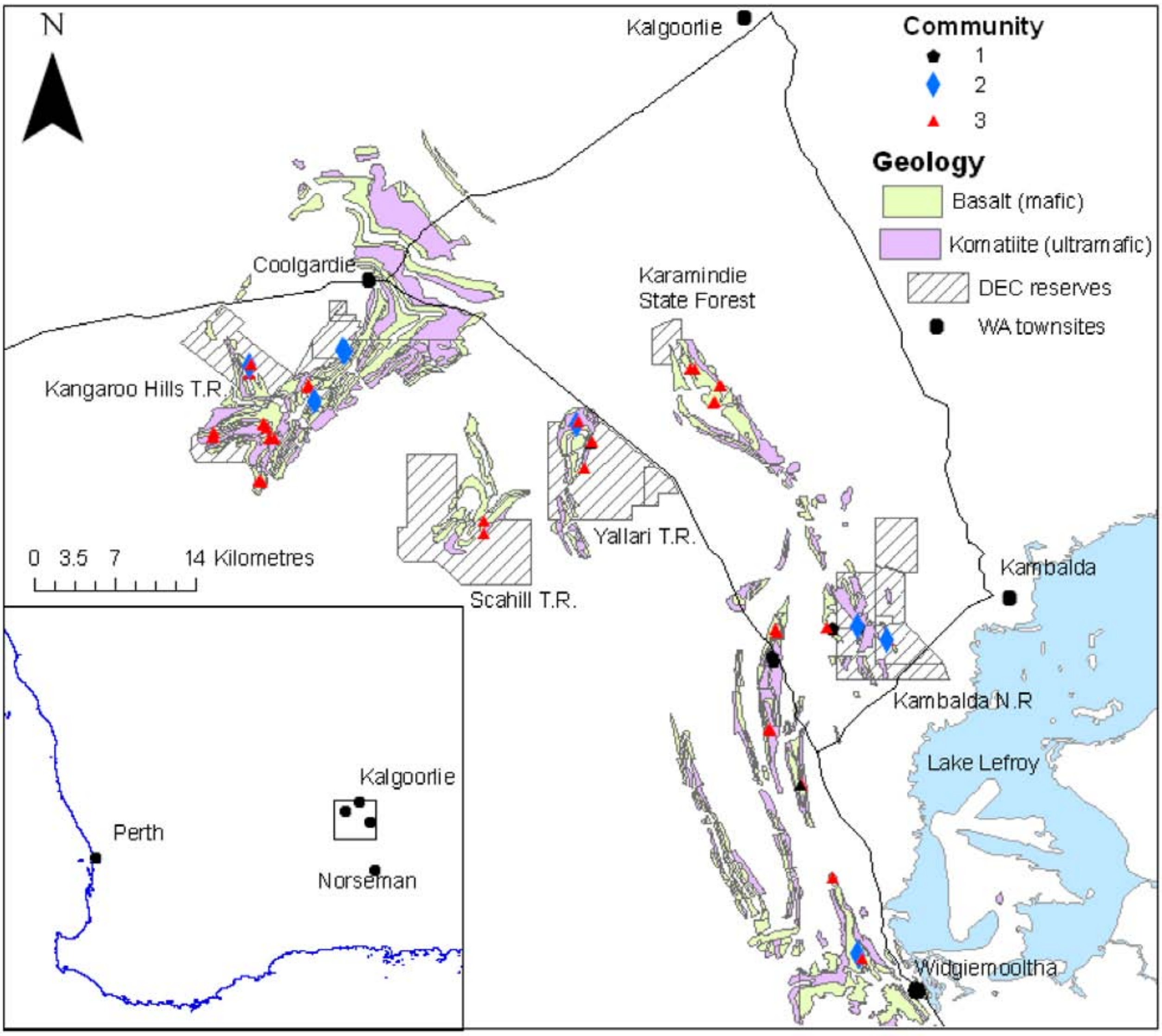


Figure 1. Location of the 52 quadrats (▲) established on the greenstone ranges on the Kangaroo Hills timber reserves (T.R.) and other reserves (hatched areas) within the Coolgardie Bioregion. The Archaean mafic and ultramafic geology are shown in green and purple respectively.

Rainfall is bimodal, with peaks occurring in summer (January to March) and winter (May to August). The highest mean monthly rainfall at Coolgardie occurs in June (29.6 mm) with the highest daily rainfall of 181.4 mm occurring in January 1967. Mean annual rainfall at Coolgardie is 270.7 mm, with a large variation (169.3 mm, 1st decile; 373.8 mm, 9th decile; recorded 1893–2012). The highest maximum temperatures occur during summer, with January the hottest month (mean maximum temperature 33.3 °C; 1897–1953). Winters are mild, with lowest mean maximum temperatures recorded for July of 5.2 °C.

Geology

The greenstone ranges occur within the Kalgoorlie Terrane and form the western boundary of the Norseman–Wiluna Greenstone Belt. The Norseman–Wiluna Greenstone Belt is composed of a series of mafic to ultramafic volcanic flows, which were formed approximately 2.8 to 2.5 billion years ago during the Proterzoic eon (Griffin 1989) and then underwent metamorphism, including folding, fracturing and intrusion. Sedimentary rock, such as banded ironstones and cherts, are often associated with other greenstone belts and are interlayed with the volcanic flows. The name greenstone is derived from the greenish colour that some of the metamorphic minerals give to the volcanic rocks. The Norseman–Wiluna Greenstone Belt is high in komatiite, a type of ultramafic volcanic rock low in Si, K and Al, and high to extremely high in Mg content, and the site of the rich nickel deposits in the area (Anand & Butt 2010). Basalts are also present, interlayed with the komatiite, and are generally classified as mafic rocks (high in Mg and Fe). Both komatiite and basalt are referred to as greenstone rocks.

Vegetation

Despite the amount of mining and pastoral activity in the region and the number of collections in the Western Australian Herbarium, there have been few detailed botanical surveys of the vegetation within the reserves and surrounding areas south of Coolgardie. The area was first broadly mapped by Beard (1976), with the greenstone ranges part of his Coolgardie system, which is characterised by mainly sclerophyll woodlands with some mallee and broombush thicket. Beard (1990) later described the vegetation of greenstone ranges as woodlands predominantly of *Eucalyptus torquata* – *Eucalyptus lesouefii*, with associated *Casuarina cristata*, *Eucalyptus campaspe* and *Eucalyptus clelandii*, with an open shrub understorey of common species such as *Eremophila scoparia*, *E. glabra*, *E. oldfieldii*, *Dodonaea lobulata*, *Senna cardiosperma* and *Acacia* spp.

The vegetation on the greenstone ranges around Kambalda and Widgiemooltha, in the southern part of our study area (Fig. 1), was described in more detailed geobotanical studies by Cole (1973, 1992). The communities on the basalt around Kambalda were characterised as open woodlands dominated by *Eucalyptus lesouefii* associated with *E. salmonophloia*, *Santalum acuminatum* and *S. spicatum* on deeper soils. On skeletal soils on the hill crests, the woodland is replaced by tall shrubland of *Acacia quadrimarginea*, *A. tetragonophylla*, *Dodonaea lobulata*, *Eremophila duttonii* and *Scaevola spinescens* over *Ptilotus obovatus*. *Eucalyptus foecunda* and *E. torquata* were also common eucalypts on the deeper soils. Around Widgiemooltha, Cole (1973) described the communities as woodlands of relatively tall *Eucalyptus griffithsii*, *E. oleosa* and *E. salmonophloia* associated with the tall shrubs *Alyxia buxifolia*, *Acacia hemiteles*, *Eremophila glabra*, *E. interstans*, *E. ionantha*, *E. scoparia* and *Scaevola spinescens* over low shrubs of *Acacia colletioides*, *Maireana georgei* and *Olearia muelleri*. Of note, she highlighted *Hybanthus floribundus* and *Trymalium myrtillus* as shrubs that are confined to skeletal soils with high concentrations of Cr and Ni, with *H. floribundus* a hyper-accumulator of Ni (see also Severne & Brooks 1972).

METHODS

The methods used in this survey follow the standard procedure used in previous vegetation surveys of other ironstone and greenstone ranges in Western Australia (Markey & Dillon 2008; Meissner & Caruso 2008). Fifty-two 20 × 20 m quadrats were established on the stony crests, slopes and footslopes of the greenstone ranges within the reserves and on unallocated crown land (UCL) during October 2011 (Fig. 1). The reserves were Kangaroo Hills, Scahill, Kambalda and Yallari timber reserves, Karamindie State Forest and Kamabalda Nature Reserve, all managed by the Department of Parks and Wildlife. The placement of quadrats was stratified based on the broad variation in geology and topography, with quadrats located across the hills in a toposequence from crests to footslopes and plains, in the least disturbed vegetation available in the area sampled, avoiding areas heavily grazed or cleared. Each quadrat was permanently marked with four steel fence droppers and their positions determined using a Garmin GPS MAP 60CSx. All vascular plants within the quadrat were recorded and collected, in addition to opportunistic collections outside the quadrats, for later identification at the Western Australian Herbarium. Nomenclature follows the Western Australian Herbarium (1998–).

Data were recorded on the following: aspect, slope, morphology type (1 – crest, 2 – mid slope, 3 – lower slope, 4 – simple slope); landform (1 – hill crest, 2 – hill slope); disturbance (0 – no effective disturbance, 1 – no effective disturbance except grazing by hoofed animals); maximum size of coarse fragments (CF size; 1 – fine gravely to 6 – boulders); coarse fragment (CF) abundance (0 – no coarse fragments to 6 – very abundant coarse fragments); rock outcrop (RO) abundance (0 – no bedrock exposed to 4 – very rocky); runoff (0 – no runoff to 4 – rapid); soil depth (1 – skeletal, 2 – shallow, 3 – deep); cover of leaf litter and proportion of bare ground (McDonald et al. 1990). Additionally, growth form, height and cover were recorded for the dominant taxa in each strata (upper, mid and lower). Cover was estimated as one of six cover classes: dense (> 70%), mid-dense (30–70%), sparse (10–30%), very sparse (<10%), isolated plants (< 1%) and isolated clumps (<1%) (McDonald et al. 1990). Growth form of the plant was classified as either a tree, tree mallee (>8 m), shrub mallee (<8 m), shrub, chenopod shrub, sedge, forb or fern. Cover and growth form for each strata were used to describe the plant communities following McDonald et al. (1990).

Twenty soil samples were collected from the upper 10 cm of the soil profile within each quadrat. The samples were bulked and the 2 mm fraction analysed for Al, B, Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, S and Zn using an Inductively Coupled Plasma – Atomic Emission Spectrometer (ICP–AES). Electrical conductivity (EC), organic C, N and pH were determined using alternative methods, which are fully described in Meissner and Wright (2010).

Quadrats were classified on the basis of similarity in species composition using perennial species only and excluding single occurrences. This removed any temporal variation associated with the presence of annual species that may confound comparisons with other greenstone and banded ironstone ranges (Markey & Dillon 2008; Meissner & Caruso 2008 and references therein). The quadrat and species classifications were undertaken using the Bray–Curtis coefficient on presence/absence data followed by hierarchical clustering (using group-average linking) in PRIMER (Clarke & Gorley 2006). Quadrat classification was followed by similarity profile (SIMPROF) testing to determine the significance of internal group structures using permutation testing (Clarke & Gorley 2006). Vegetation communities were assigned based upon the SIMPROF results. Indicator species for vegetation communities were determined following De

Cáceres et al. (2010) using 'indicspecies' in the R language (De Cáceres & Legendre 2009). Indicator species are taxa that, due to niche preferences, can be used as ecological indicators of community types (De Cáceres & Legendre 2009) and can be used to identify community types during further surveys. Following the classification, the quadrat data was ordinated using non-metric multidimensional scaling (nMDS), a nonparametric approach not based upon the assumptions of linearity or presumption of any underlying model of species response gradients (Clarke & Gorley 2006).

To determine the environmental variables that best explained the community pattern, the BEST analysis using BIOENV algorithm in PRIMER v6 (Clarke & Gorley 2006) was undertaken on a Euclidean distance resemblance matrix based on normalised environmental data. The BEST routine selects environmental variables that best explain the community pattern, by maximising a rank correlation between their respective resemblance matrices (Clarke & Warwick 2001). In the BIOENV algorithm, all permutations of the environmental variables were tried and the five best variables selected. The environmental variables were then fitted to the nMDS ordination and Pearson rank correlation values ($r > 0.6$) were calculated to determine linear relationships between the variables and the vegetation communities.

RESULTS

Flora

A total of 160 taxa (species, subspecies, varieties and forms) were recorded from all the quadrats and opportunistic collections. The most common families were Chenopodiaceae (18 taxa), Asteraceae (17), Scrophulariaceae (17) and Myrtaceae (16), and the most common genera were *Eremophila* (17 taxa), *Eucalyptus* (12), *Acacia* (10) and *Austrostipa* (7). Forty-five annuals were recorded, including all five introduced taxa (Table 1). None of the introduced taxa were declared weeds and no endemic taxa were recorded for the range.

Priority flora

A single priority taxon (Smith 2012) was collected from five quadrats spread across the survey area. *Austrostipa blackii* (P3) is a perennial tufted grass found mainly in the eastern states of Australia. It has a distinctive lemma with a long coma at the base of the awn. It is found in disjunct locations from Paynes Find to Widgiemooltha.

Flora of taxonomic interest

Two taxa collected require either taxonomic study to determine their taxonomic status or were determined to be new species:

Acacia coatesii was found at a single site within the Kangaroo Hills Timber Reserve, and is known from only two other localities within the Kangaroo Hills. This taxon has a distinctive small, compact, low-domed habit to 20 to 40 cm tall and has short, pungent phyllodes (Maslin 2014).

Lepidosperma aff. *diurnum* was collected at several sites, mostly opportunistically, and growing on laterised greenstone. It appears to have close affinities to *L. diurnum*, found on Mount Day on the Bremer Range, and possesses similar red ciliate leaf margins. In this survey, it was collected from Saddle Hills, the same location as the only other known specimen in the Western Australian Herbarium.

Vegetation

Three vegetation communities were determined from the classification (Fig. 2). The dendrogram shows a stepwise division of the four communities. The first division consisted of two sites only, a sample too small to describe

Table 1

Summary of the number of families, genera and taxa, including numbers of introduced taxa, recorded from the survey.

	Total	Dicotyledons	Monocotyledons	Pteridophytes
Families	38	33	4	1
Genera	78	68	7	1
Taxa	160	143	14	3
Native	155	139	13	3
Introduced	5	4	1	-

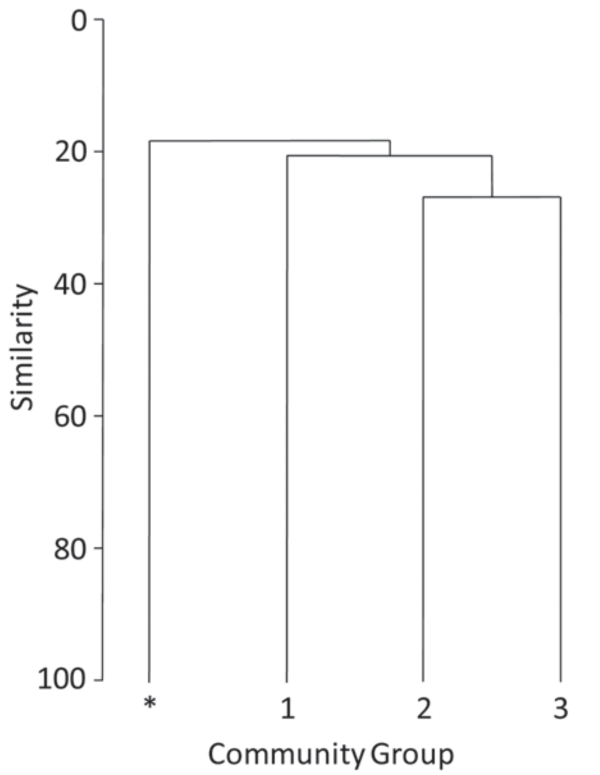
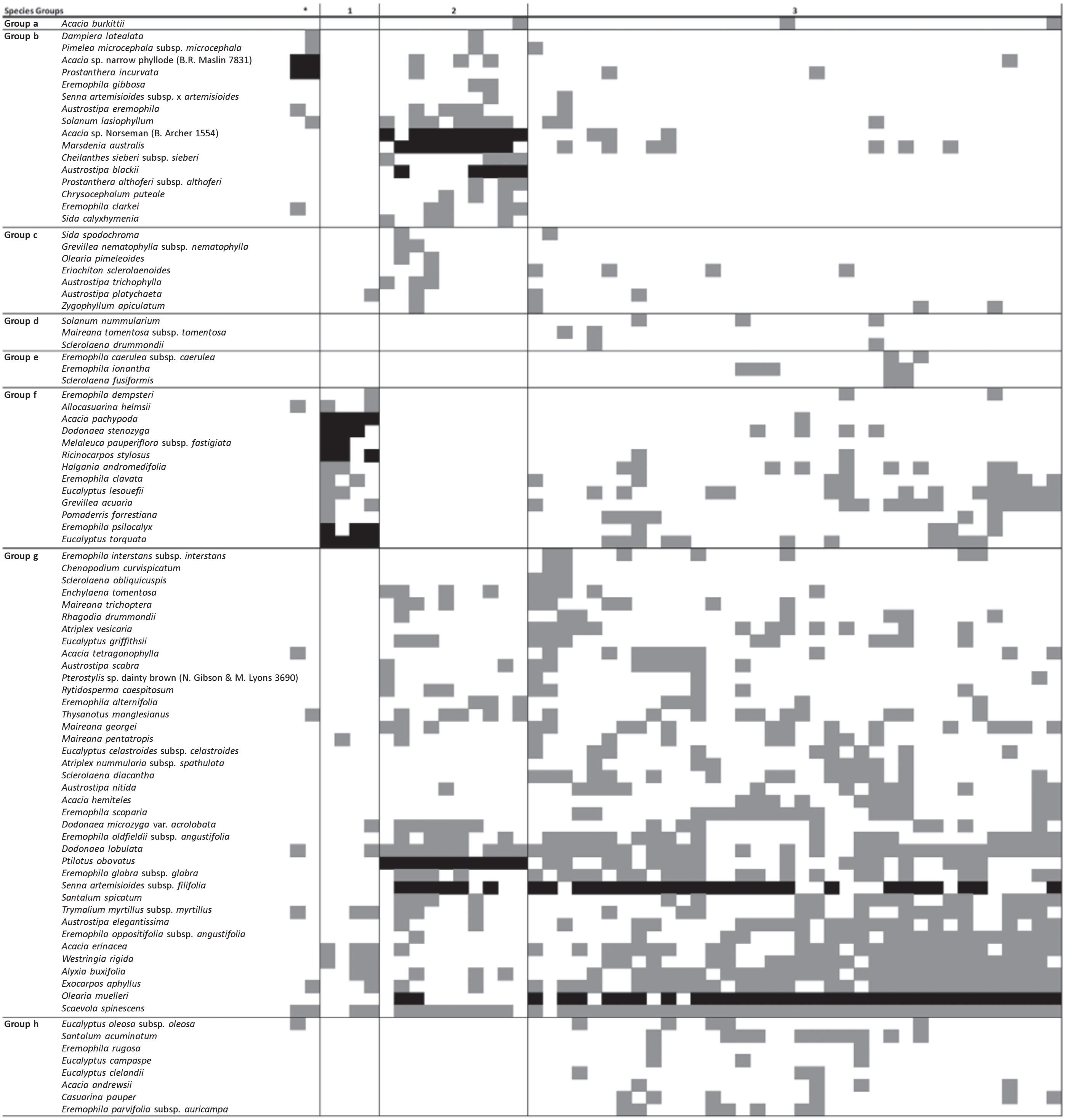


Figure 2. Dendrogram of the vegetation communites derived from the 52 quadrats established on the Kangaroo Hills and surrounding area. (represents two species-poor quadrats.)*

Table 2

Two-way table of quadrat and species classification of the three communities found on the Kangaroo Hills timber reserve and surrounding areas. Taxa shaded black within a community are indicator species determined by 'indicspecies' (p< 0.05; De Cáceres & Legendre 2009). (* represents 2 species poor quadrats.)



as a community, followed by community 1, found on the crests of hills in an area around Kambalda Nature Reserve. Communities 2 and 3 were widespread across the study area and were most similar to each other.

Community 1 was characterised by woodlands (10–30% cover) or open forest (30–70% cover) of *Eucalyptus torquata* (coral gum) over sparse shrubland (<10% cover) of *Ricinocarpos stylosus*, *Dodonaea stenozyga*, *Eremophila* spp. (*E. dempsteri*, *E. psilocalyx*), over low shrubland (30–70% cover) of *Westringia rigida*, *Halgania andromedifolia* and *Acacia pachypoda*. Quadrats contained in this group (n = 4) were located on the basalt crests occurring in the Kambalda Nature Reserve and the basalt hills to the west. Indicator species were *Acacia pachypoda*, *Dodonaea stenozyga*, *Melaleuca pauperiflora* subsp. *fastigiata*, *Ricinocarpos stylosus*, *Eremophila psilocalyx* and *Eucalyptus torquata* (Table 1). Mean species richness was 17.8 (±1.9 SE) perennial taxa per plot.

Community 2 was characterised by mallee woodlands and shrublands (10–30% cover) to open mallee woodlands and shrublands (<10% cover) of *Eucalyptus griffithsii* and *Acacia* sp. Norseman (B Archer 1554) over shrublands (30–70% cover) of *Dodonaea lobulata*, *Eremophila* spp. (*Eremophila oldfieldii* subsp. *angustifolia*, *Eremophila glabra* subsp. *glabra*, *Eremophila clarkei* and *Eremophila alternifolia*), *Scaevola spinescens* over low shrubland (30–70% cover) of *Ptilotus obovatus*. The quadrats in this community (n = 10) were located mainly on the crests of the greenstone hills throughout the study area. Indicator species were *Acacia* sp. Norseman (B Archer 1554), *Ptilotus obovatus*, *Marsdenia australis* and *Austrostipa blackii* (Table 1). The mean species richness was 19.0 (±1.1 SE) perennial taxa per plot.

Community 3 was characterised as an open forest to open woodland complex of *Eucalyptus* spp. (*E. lesouefii*, *E. torquata*, *E. griffithsii*, or *E. celastroides* subsp. *celastroides*) over open shrublands of *Scaevola spinescens*, *Eremophila oldfieldii* subsp. *angustifolia*, *Senna artemisioides* subsp. *filifolia* and *Halgania andromedifolia*. The quadrats characterising this community (n = 36) occurred across all positions within the landscape across the study area. There were no unique indicator species for this community, but *Olearia muelleri* and *Senna artemisioides* subsp. *filifolia* were indicator species for both communities 2 and 3 (Table 1). Mean species richness was 17.4 (±0.8 SE) perennial taxa per plot.

Table 3

Mean values for site attributes by plant community type: aspect (degrees); slope (degrees); morphology type (1 – crest, 2 – mid slope, 3 – lower slope, 4 – simple slope); landform (1 – hill crest, 2 – hill slope); disturbance (0 – no effective disturbance, 1 – no effective disturbance except grazing by hoofed animals); maximum size of coarse fragments (CF size; 1 – fine gravely to 6 – boulders); coarse fragment (CF) abundance (0 – no coarse fragments to 6 – very abundant coarse fragments); rock outcrop (RO) abundance (0 – no bedrock exposed to 4 – very rocky); runoff (0 – no runoff to 4 – rapid); soil depth (1 – skeletal, 2 – shallow, 3 – deep). Differences between ranks were tested using Kruskal–Wallis nonparametric analysis of variance. Standard error in parentheses (n = number of quadrats, p = probability).

Community	1	2	3	p value
n	4	10	36	
Aspect	4.8 (1.3)	5.4 (0.6)	5.4 (0.4)	0.8495
Slope	2.8 (0.5)	5.3 (1.2)	3.4 (0.4)	0.2965
MorphType	1.8 (0.8)	2.5 (0.3)	2.4 (0.2)	0.6318
Landform	1.3 (0.3)	1.7 (0.2)	1.5 (0.1)	0.3075
Disturbance	0 (0)	0.3 (0.2)	0.9 (0.2)	0.0634
CFAbund	4.3 (0.3)	4 (0.3)	4.1 (0.2)	0.8473
CFMaxSize	3.5 (0.5)	3.6 (0.2)	3.8 (0.1)	0.6207
ROAbund	0.5 (0.5)	0.7 (0.3)	0.3 (0.1)	0.5385
Soil Depth	2.5 (0.3)	2.2 (0.1)	2.3 (0.1)	0.5762
Bare Ground	3 (0)	3 (0)	3.1 (0.1)	0.4542
Leaf Litter	2.5 (0.3)	1.7 (0.2)	2.0 (0.1)	0.0725

Environmental correlates

The topography of the greenstone ranges is characterised by gentle hills with moderate to gentle slopes, with the elevations of sampled sites ranging from 348 to 510m. Soils at these quadrats were predominantly shallow to skeletal soils of red-brown sandy clay loam.

The nonparametric analysis of variance on communities 1, 2 and 3 found that while 12 of the 20 soil parameters were significantly different (Table 4), none of the 13 site attributes were significantly different between the three communities (Table 3). Soils associated with community 2, confined to the crests of the range, had significantly lower concentrations of B, Ca, Cd and Mg and had lower soil pH than communities 1 and 3, but significantly greater concentrations of Al, Co, Cu and Mn (Table 4). EC and Na were only significantly greater in the soils of community 3 than those of community 2. Sites that were more alkaline also had higher Ca and Mg concentrations.

The BIOENV analysis indicated that the best correlation between the quadrat and environmental similarity matrices was obtained with five soil variables: pH, Al, B, Fe and Mn ($r = 0.406$). The two dimensional MDS (stress = 0.17; Fig. 3) clearly showed that all four communities were separated on the MDS. Four soil variables correlated with the MDS ($r > 0.6$; Fig. 3). B, pH and Mg were positively correlated with communities 1 and 3 while Al was positively correlated with community 2.

DISCUSSION

Flora

The flora of the greenstone ranges of the Kangaroo Hills and surrounding areas is not as rich as floras found on other greenstone ranges closer to the boundary of the South-West Interzone, a transitional region between the South-West and Eremaean flora (Beard 1990). For example, the Helena and Aurora ranges, 180 km north-west of the current survey area, supports a flora of 324 taxa (of which 45% are annuals) with a high degree of endemism (Gibson et al. 1997, 2007). Similarly, the Parker Range (150 km south-west) supports a flora of 253 taxa (Gibson & Lyons 1998). Both these ranges include mafic as well as banded ironstone geologies and are in areas of higher annual rainfall. More comparable to this survey is the greenstone range north-west of Bullfinch,

Table 4

Mean values for soil attributes (measured in mg kg^{-1} except pH and EC [mS m^{-1}]) by plant community type. Differences between ranked values were tested using Kruskal–Wallis nonparametric analysis of variance, and differences between communities determined using Dunn's post-hoc comparison. Standard error of the mean in parentheses. Superscript a and b represent significant differences between community types at $p < 0.05$ (n = number of quadrats; p = probability). Significant results are in bold font.

Comm.	**1**	**2**	**3**	p value
n	4	10	36	
EC	15.3 (1.7) ^{ab}	8.5 (1.9) ^{a}	16.2 (2.0) ^{b}	**0.009**
pH	8.0 (0.1) ^{b}	6.4 (0.2) ^{a}	7.5 (0.1) ^{b}	**<0.0001**
Org C	2.3 (0.5)	1.7 (0.2)	2.0 (0.1)	0.2653
N	0.1375 (0.0224)	0.1173 (0.0101)	0.1327 (0.0062)	0.4053
P	7.0 (0.9)	5.8 (0.5)	8.7 (0.7)	0.0667
K	203 (9) ^{a}	257 (22) ^{ab}	306 (17) ^{b}	**0.0245**
Mg	1500 (0) ^{b}	428 (47) ^{a}	873 (68) ^{b}	**0.0001**
Al	301 (102) ^{b}	720 (32) ^{a}	484 (35) ^{b}	**0.0004**
B	3.0 (0.7) ^{b}	0.7 (0.2) ^{a}	2.3 (0.2) ^{b}	**0.0001**
Ca	6700 (800) ^{b}	2890 (565) ^{a}	5596 (384) ^{b}	**0.0018**
Cd	0.03 (0.0108) ^{ab}	0.011 (0.0016) ^{a}	0.027 (0.004) ^{b}	**0.0255**
Co	1.22 (0.47) ^{b}	3.5 (0.43) ^{a}	1.94 (0.13) ^{b}	**0.0005**
Cu	2.25 (0.23) ^{a}	6.91 (0.98) ^{b}	4.77 (0.32) ^{b}	**0.0031**
Fe	100.8 (17.4)	75.3 (4.4)	67.1 (3.0)	0.1044
Mn	49 (8) ^{b}	110 (9) ^{a}	81 (4) ^{b}	**0.0016**
Mo	0.0063 (0.0013)	0.007 (0.0008)	0.0111 (0.0012)	0.1322
Na	30.8 (2.9) ^{ab}	21.9 (2.6) ^{a}	68.9 (24.2) ^{b}	**0.0182**
Ni	6.55 (1.73)	4.46 (1.92)	4.59 (0.70)	0.1763
S	14.8 (3.0)	9.3 (2.3)	16.4 (3.0)	0.0813
Zn	1.03 (0.09)	1.87 (0.23)	1.83 (0.20)	0.0715

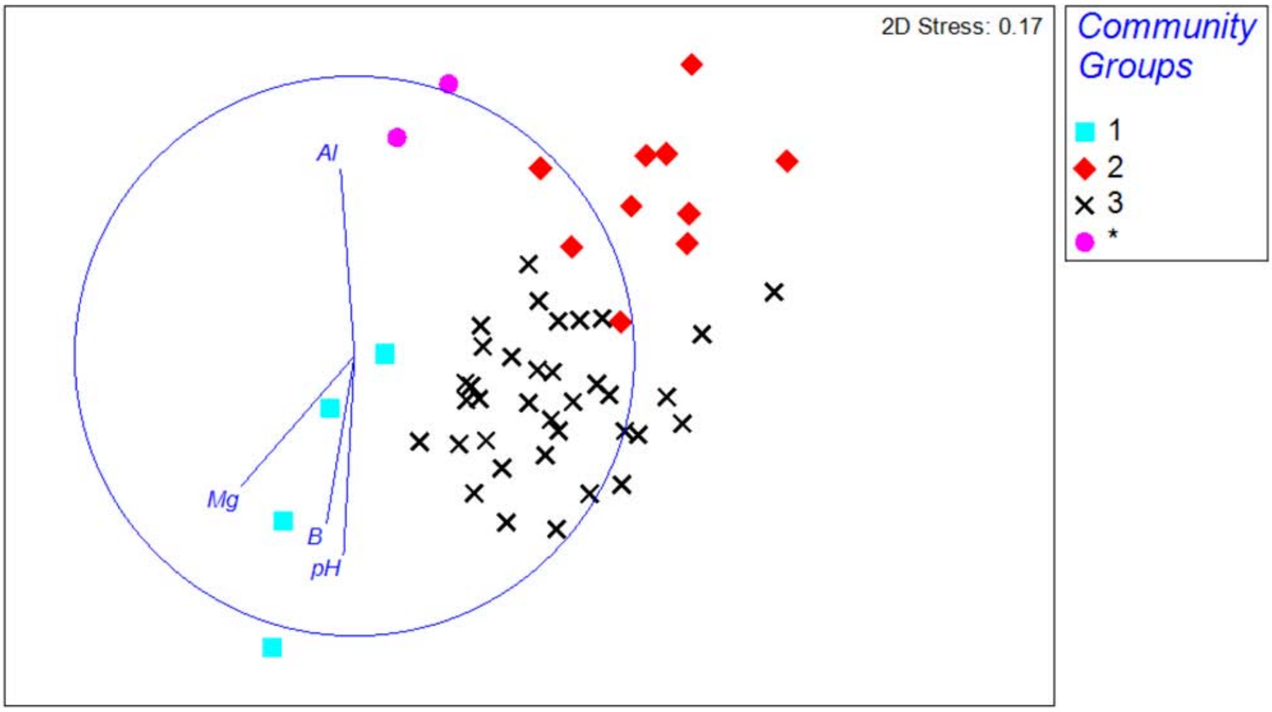


Figure 3. *Two dimensional MDS ordination of the 52 quadrats established on Kangaroo Hills and surrounding areas. The three communities and two quadrats not assigned to a community (*) are shown. The lines represent the strength and direction of the four soil variables correlated with the MDS using Pearson rank correlation (r > 0.6).*

approximately 200 km west of the Kangaroo Hills area, with a flora of 218 taxa (Thompson & Allen 2013) and on Credo station, 70 km north of Coolgardie, with a flora of 186 taxa recorded (Meissner & Coppen 2013).

The overall species richness within this survey is consistent with values recorded in a previous survey by Bamford et al. (1991), who similarly recorded 17 ± 2 perennial taxa per 20 x 20 m quadrat within the communities found on the basalt hill. The presence of dominant genera such as *Eucalyptus*, *Acacia* and *Eremophila* is also consistent with Bamford et al. (1991) and with those found elsewhere in the South-West Interzone (Gibson et al. 1997). The only difference between this study and others was the greater presence of taxa from Chenopodiaceae. However, this finding is unsurprising, given that chenopods are commonly found on more alkaline sites within the South-West Interzone (Beard 1990).

In addition, the floristic patterns found during this survey were largely consistent with the geobotanical work undertaken by Cole (1973) on the greenstone ranges at Widgiemooltha, also surveyed in our study. Cole (1973) examined the relative relationship between vegetation communities and ultramafic bedrock and found that the replacement of *Eucalyptus* woodland by a shrub community dominated by *Hybanthus floribundus* coincided with high Ni and Cu in the soil. In our study, we recorded *H. floribundus* subsp. *curvifolius* in a few quadrats on ultramafic geology, but too few to confirm Cole's (1973) observations. In addition, herbarium records show that *H. floribundus* subsp. *curvifolius* has a wide geographic distribution, largely associated with greenstone ranges but also occurring in other habitats, so it is unlikely to be an ultramafic endemic. As well as these observations, Cole (1973) also found that *Trymalium myrtillus* was restricted to skeletal soils associated with strong outcrops of ultramafic rocks. Again, our findings disagree with Cole (1973), as *T. myrtillus* was widespread on mafic and ultramafic geology and not restricted to any community type.

Vegetation communities

The communities described in this study are consistent with a similar survey within the Kangaroo Hills. Bamford et al. (1991) described several communities dominated by *Eucalyptus griffithsii* occurring in the Kangaroo Hills timber reserve. Community 2, the *Acacia* sp. Norseman shrubland found on the crests of the greenstones, is similar to the community described by Bamford et al. (1991), and occupies a band near the top of the greenstone ridges in Kangaroo Hills. Soils associated with this community tended to be higher in Al but lower in Ca, Mg and Na. It was highly suggestive that the soils that this community occupies are highly weathered, since weathering results in the more mobile elements being leached down to the colluvial soils on the lower slopes (Britt et al. 2001).

The differences in mafic and ultramafic geologies were not as sharply reflected by differences in the vegetation communities as suggested by Cole (1992). The chemical composition of the soil analysed from the ranges was consistent with the chemistry of mafic and ultramafic rocks. Mafic rocks are high in Mg, Ca and iron oxides (generally 20–30%) and ultramafic rocks are even higher (generally >30%; Gray & Murphy 2002). While Cole (1992) concluded that there were distinctive plant assemblages on particular substrates around Widgiemooltha, there was no distinctive flora associated with serpentinite (or ultramafic) geology across the Goldfields region. Our data supports this interpretation and we agree with Cole's (1992) suggestion that the plant communities in the eastern Goldfields are complex and involve the interaction of many environmental factors and not just geology. The regional differences in vegetation highlights the high species turnover characteristic of the South-West Interzone, as shown for the vegetation communities on the banded ironstone ranges (Gibson et al. 2012).

Conservation

The Kangaroo Hills and the surrounding areas have a long history of mining and timber clearfelling, and the impact of these activities is still evident today within the reserves. The results of this survey found no endemic taxa associated with the greenstone ranges of Kangaroo Hills and the surrounding areas. The main vegetation community (community 3) is well represented in state forest, nature reserves or timber reserves throughout the survey area; however, all three communities are not represented on the nearest greenstone ranges at Credo Station to the north (Meissner & Coppen 2013). The greenstone ranges show the same pattern as the banded ironstone ranges, where each range has unique vegetation communities, with a decrease in endemics as aridity increases (Gibson et al. 2012). Although the communities are well represented within the gazetted conservation estate, all the reserves either have exploration permits or mining lease tenements overlying them.

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APPENDIX

Flora list for the greenstone ranges on the Kangaroo Hills and other timber reserves, including all taxa from the sampling quadrats and adjacent areas. Nomenclature follows Western Australian Herbarium (1998–).

Amaranthaceae
Ptilotus exaltatus var. *villosus*
Ptilotus gaudichaudii var. *parviflorus*
Ptilotus holosericeus
Ptilotus obovatus

Apiaceae
Daucus glochidiatus

Apocynaceae
Alyxia buxifolia
Marsdenia australis

Araliaceae
Hydrocotyle pilifera var. *glabrata*
Trachymene ornata

Asparagaceae
Thysanotus manglesianus
Thysanotus speckii

Asteraceae
Asteridea athrixioides
Brachyscome ciliaris
Calotis hispidula
Cephalipterum drummondii
Chrysocephalum puteale
Cratystylis conocephala
Isoetopsis graminifolia
Leucochrysum fitzgibbonii
Millotia myosotidifolia
Olearia muelleri
Olearia pimeleoides
Podolepis canescens
Podolepis capillaris
Podolepis lessonii
Rhodanthe oppositifolia subsp. *oppositifolia*
**Sonchus oleraceus*
Waitzia acuminata var. *acuminata*

Boraginaceae
Halgania andromedifolia

Brassicaceae
**Carrichtera annua*
Stenopetalum filifolium
Stenopetalum lineare

Campanulaceae
Wahlenbergia gracilenta

Casuarinaceae
Allocasuarina campestris
Allocasuarina helmsii
Casuarina pauper

Celastraceae
Stackhousia sp. Mt Keith (G Cockerton & G O'Keefe 11017)

Chenopodiaceae
Atriplex nummularia subsp. *spathulata*
Atriplex vesicaria
Chenopodium curvispicatum
Enchylaena tomentosa
Eriochiton sclerolaenoides
Maireana aff. *planifolia*
Maireana georgei
Maireana pentatropis
Maireana radiata
Maireana tomentosa subsp. *tomentosa*
Maireana trichoptera
Rhagodia drummondii
Rhagodia sp. (R Meissner & R Coppen 3958)
Sclerolaena cuneata
Sclerolaena diacantha
Sclerolaena drummondii
Sclerolaena fusiformis
Sclerolaena obliquicuspis

Crassulaceae
Crassula colorata var. *acuminata*
Crassula colorata var. *colorata*
Crassula tetramera

Cyperaceae
Lepidosperma aff. *diurnum* (R Meissner & R Coppen 3792)

Euphorbiaceae
Ricinocarpos stylosus

Fabaceae
Acacia acuminata
Acacia andrewsii
Acacia burkittii
Acacia erinacea
Acacia hemiteles
Acacia pachypoda
Acacia pritzeliana
Acacia sp. (R Meissner & R Coppen 3720)
Acacia sp. Norseman (B Archer 1554)
Acacia tetragonophylla
Daviesia pachyloma
**Medicago minima*
Senna artemisioides subsp. *filifolia*
Senna artemisioides subsp. ×*artemisioides*

Geraniaceae
Erodium cygnorum

Goodeniaceae
Dampiera latealata
Goodenia havilandii
Scaevola spinescens
Velleia rosea

Haloragaceae
Haloragis trigonocarpa

Lamiaceae
Prostanthera althoferi subsp. *althoferi*
Prostanthera incurvata
Westringia rigida

Loganiaceae
Phyllangium sulcatum

Malvaceae
Brachychiton gregorii
Sida calyxhymenia
Sida spodochroma
Calothamnus gilesii

Myrtaceae
Eucalyptus campaspe
Eucalyptus celastroides subsp. *celastroides*
Eucalyptus cf. *ravida*
Eucalyptus clelandii
Eucalyptus gracilis
Eucalyptus griffithsii
Eucalyptus lesouefii
Eucalyptus oleosa subsp. *oleosa*
Eucalyptus salmonophloia
Eucalyptus stricklandii
Eucalyptus torquata
Eucalyptus websteriana subsp. *websteriana*
Melaleuca hamata
Melaleuca pauperiflora subsp. *fastigiata*
Melaleuca sheathiana

Orchidaceae
Pterostylis sp. dainty brown (N Gibson & M Lyons 3690)

Pittosporaceae
Pittosporum angustifolium

Poaceae
Aristida contorta
Austrostipa blackii P3
Austrostipa elegantissima
Austrostipa eremophila
Austrostipa nitida
Austrostipa platychaeta
Austrostipa scabra
Austrostipa trichophylla
**Pentameris airoides* subsp. *airoides*
Rytidosperma caespitosum

Portulacaceae
Calandrinia calyptrata
Calandrinia eremaea
Calandrinia sp. Blackberry

Primulaceae
**Lysimachia arvensis*

Proteaceae
Grevillea acuaria
Grevillea nematophylla subsp. *nematophylla*

Pteridaceae
Cheilanthes adiantoides
Cheilanthes lasiophylla
Cheilanthes sieberi subsp. *sieberi*

Rhamnaceae
Cryptandra sp. (R Meissner & R Coppen 3900)
Pomaderris forrestiana
Trymalium myrtillus subsp. *myrtillus*

Santalaceae
Exocarpos aphyllus
Santalum acuminatum
Santalum spicatum

Sapindaceae
Dodonaea lobulata
Dodonaea microzyga var. *acrolobata*
Dodonaea stenozyga

Scrophulariaceae
Eremophila alternifolia
Eremophila caerulea subsp. *caerulea*
Eremophila cf. *deserti*
Eremophila clarkei
Eremophila clavata
Eremophila dempsteri
Eremophila gibbosa
Eremophila glabra subsp. *glabra*
Eremophila interstans subsp. *interstans*
Eremophila ionantha
Eremophila oldfieldii subsp. *angustifolia*
Eremophila oppositifolia subsp. *angustifolia*
Eremophila parvifolia subsp. *auricampa*
Eremophila psilocalyx
Eremophila rugosa
Eremophila saligna
Eremophila scoparia

Solanaceae
Solanum ellipticum
Solanum lasiophyllum
Solanum nummularium

Thymelaeaceae
Pimelea microcephala subsp. *microcephala*

Violaceae
Hybanthus floribundus subsp. *curvifolius*

Zygophyllaceae
Zygophyllum apiculatum
Zygophyllum compressum
Zygophyllum eremaeum
Zygophyllum ovatum
Zygophyllum reticulatum