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# Flora and vegetation of banded iron formations of the Yilgarn Craton: Mount Forrest – Mount Richardson Range

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## ABSTRACT

A study of the flora and plant communities of the banded ironstone range of Mount Forrest – Mount Richardson found 114 taxa, with a single introduced taxon. Four priority taxa and 5 taxa with significant range extensions (> 100km) were found. Fifty one quadrats were established to cover the major geographical, geomorphological and floristic variation across the range. Data from 51 of these quadrats were used to define seven community types. Differences in communities were strongly correlated with soil fertility, landform and underlying geology. The communities described were not similar to those found on nearby ironstone ranges. None of the plant communities found on the Mount Forrest – Mt Richardson are currently in secure conservation reserves.

## INTRODUCTION

Regional surveys of the eastern goldfields (Milewski & Dell, 1992; Keighery *et al.* 1995) and previous studies on the Archaean ironstone and greenstone ranges in the Goldfields area of the Yilgarn Craton have found patterns of high plant endemism and restricted plant communities (Gibson *et al.* 1997; Gibson & Lyons 1998a, 1998b; Gibson & Lyons 2001a, 2001b; Gibson 2004a, 2004b). More recent surveys of the banded iron formation ranges of the northern Yilgarn Craton have also shown these patterns (Markey & Dillon, 2008a, 2008b; Meissner & Caruso, 2008a, 2008b, 2008c). These ancient ranges are also of significant interest for base metals and recent growth in iron ore exports to China has resulted in an increase in exploration and mining activities on these ranges.

This study covers the Mount Forrest - Mt Richardson ironstone range, partly located in the proposed Ida Valley - Mt Forrest Conservation Park, and formerly a part of the Bulga Downs pastoral lease. The proposed Conservation Park is approximately 84 000 ha and located about 100 km southeast of Sandstone within the Murchison Bioregion (Interim Biogeographic Regionalisation of Australia - IBRA); Department of the Environment and Water Resources 2004). In addition, the proposed park currently includes active exploration leases.

The Mount Forrest - Mount Richardson ranges occur on the Youanmi Terrane and are part of the northern section of the Illaara Greenstone Belt, which extends southwest approximately 100 km. The ranges are characterized by strike ridges and subrounded hills, with prominent ridges of banded iron formations and chert (Chen 2004, Cassidy *et al.* 2006). Mt Forrest and Mt Richardson have the thickest unit of banded iron formation and are the highest points in the belt, at 596 and 554 m above sea level respectively (Stewart *et al.* 1983). In addition, the banded iron formation is often intercalated with tuffaceous mafic and ultramafic rocks (Stewart *et al.* 1983).

The climate of the region is semi-desert Mediterranean with mild wet winter and hot dry summers (Beard 1990). Mean annual rainfall at Cashmere Downs Station (ca. 30km west of the range) is 252.9 mm, with moderate seasonal variation over the 83 years of record (1919–2002: decile 1, 128.5 mm; decile 9, 426.9 mm). Mean rainfall is spread throughout the year, with little difference between winter and summer. The highest maximum temperatures occur during summer, with January as the hottest month (mean maximum temperature 36 °C and mean 6.2 days above 40°C). Winters are mild with lowest mean maximum temperatures recorded for July of 17.5°C. Temperatures occasionally fall below 0 °C in winter (a mean 0.9 days below 0°C), with a mean minimum of 5.9° C in July.

Floristic surveys in the eastern goldfield have described the vegetation of the ironstone ranges at a very coarse scale. Beard (1976) mapped the range, as well as several other ironstone ranges in the region, as shrublands of mulga and *Acacia quadrimarginea* scrub at a scale of 1:1 000 000. At a scale of 1:500 000, Payne *et al.* (1998) described the Mount Forrest - Mount Richardson range as part of the Brooking Land system. This system was composed mainly of ridges, hill slopes and stony plains of stony ironstone Mulga shrublands, composed of *Acacia aneura* occurring with other *Acacia* spp. (*Acacia burkittii*, *A. quadrimarginea*, *Acacia ramulosa* and *Acacia tetragonophylla*) over an understorey of *Eremophila* spp. (*Eremophila forrestii* and *Eremophila latrobei*), *Rhagodia eremaea*, *Scaevola spinescens* and *Sida calyxhymenia*.

Recent more detailed vegetation mapping (c. 1:35 000) in the Mt Forest – Mt Richardson area covering both the ranges and the surrounding sandplain identified a number of structural units on the three major landforms, sandplain (7 units), stony plains and low hills (6 units), band ironstone ridges (4 units) and two minor units associated with drainage lines (Outback Ecology Services 2007). A total of 118 taxa were recorded in this July survey. This study also includes an analysis of the composition of presence/absence data of 30 quadrats sampling all three major landforms and reported significant compositional difference between them. The resultant ordination shows the sandplain units to be distinct but the difference between the stony plains and hill and the banded ironstone ridges is less clear.

The aim of the current survey was to document further the flora and the plant communities that occur on the ironstone range of Mount Forrest and Mount Richardson area. This was done through compiling detailed flora lists and community descriptions based upon 51 permanently established quadrats on the range. This survey is part of a continuing series investigating the flora and vegetation of banded iron formation ranges across the Yilgarn.

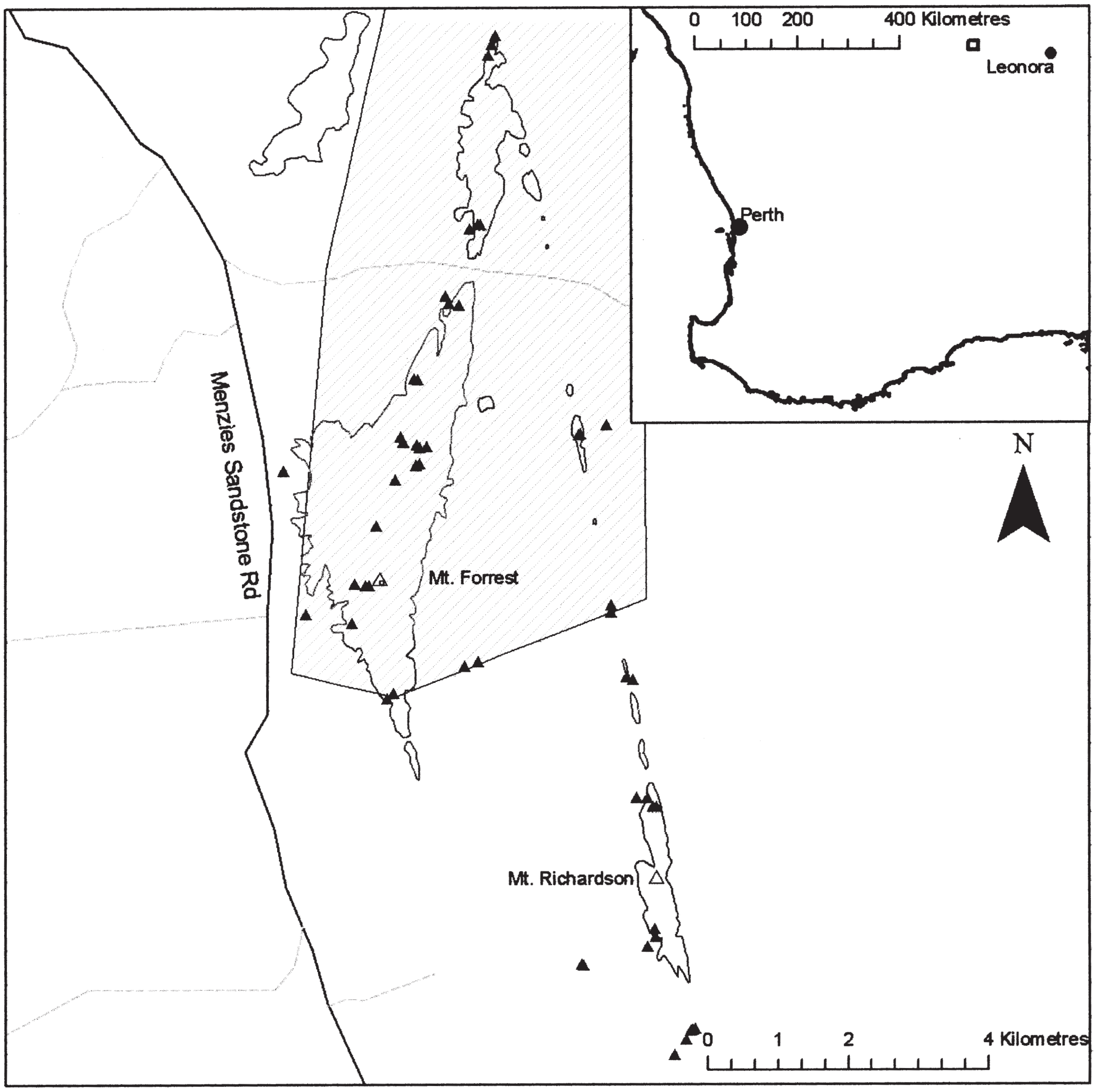



*Figure 1. Location of the study area and distribution of the 51 quadrats (▲) on the Mount Forrest – Mount Richardson range. Mount Forrest is the highest peak (Δ) on the range. Shaded area represents the proposed conservation park. The 500m contour is shown.*

## METHODS

The methodology employed in this survey follows the standard procedure used in previous vegetation surveys of other ironstone and greenstone ranges in Western Australia (Gibson and Lyons 1998a, 1998b, 2001a, 2001b; Gibson 2004a, 2004b; Markey and Dillon 2008 a, 2008b). Fifty one 20 x 20 m quadrats were established on the crests, slopes and foot slopes of Mount Forrest - Mount Richardson ranges in August 2006 (Figure 1). These quadrats were established strategically in the vegetation on the BIF and adjacent geologies to cover the major geographical, geomorphological and floristic variation found in the study area. Each quadrat was permanently marked with four steel fence droppers and their positions determined using a GPS unit. All vascular plants within the quadrat are recorded and collected for later identification at the Western Australian Herbarium (PERTH).

Data on topographical position, disturbance, abundance, size and shape of coarse fragments on surface, the amount of exposed bedrock, cover of leaf litter and bare ground were recorded following McDonald *et al.* (1990). Additionally, growth form, height and cover classes were recorded for dominant taxa in each stratum (tallest, mid- and lower). The quantitative data 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 soil was bulked and the 2 mm fraction extracted using the Mehlich No. 3 procedure (Mehlich 1984). The extracted samples were analysed for B, Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S and Zn using an Inductively Coupled Plasma - Atomic Emission Spectrometer (ICP-AES). This procedure is an effective and cost efficient alternative to traditional methods for evaluating soil fertility and has been calibrated for Western Australian soils (Walton and Allen 2004). pH was measured in 0.01M $CaCl_2$ at soil to solution ratio of 1:5. Organic carbon was measured on soil ground to less than 0.15 mm using Metson's colorimetric modification of the Walkley and Black method 6A1 (Metson 1956; Walkley 1947). It involved wet oxidation by a dichromate-sulfuric acid mixture, which produced enough heat to induce oxidation of the organic carbon (Rayment and Higgenson 1992). Total nitrogen was measured using the Kjeldahl method 7A2 (Rayment and Higgenson 1992). The nitrogen was measured as $NH_4^+$-N by automated colorimetry by the nitroprusside/ dichloro-S-triazine modification (Blakemore *et al.* 1987) of the Berthelot indophenol reaction reviewed by Searle (1984). Electrical conductivity (EC) was based on a 1:5 soil/deionised water extract and measured by a conductivity meter at 25° C (Rayment and Higgenson 1992).

Quadrats were classified on the basis of similarity in species composition on perennial species only. This was to facilitate comparison and to be consistent with other analyses of banded ironstone ranges (Gibson & Lyons 1998a, 1998b, 2001a, 2001b; Gibson 2004a, 2004b; Markey and Dillon 2008a, 2008b) as surveys in semi-arid regions can occur in years with below average rainfall resulting in a patchy distribution of annuals (e.g. Gibson & Lyons 1998a). The quadrat and species classifications were undertaken using the Bray - Curtis coefficient followed by Flexible UPGMA (Unweighted pair-group mean average; $\beta = -0.1$; Belbin 1989) clustering. The Bray – Curtis coefficient is commonly used in ecological studies especially in presence/ absence datasets (Belbin 1989; Clarke *et al.* 2006) while Flexible UPGMA is an effective method of recovering true group structure (Belbin & McDonald 1993). PATN uses a beta value of -0.1 in Flexible UPGMA to dilate and counteract the known underestimation of larger association values (Belbin 1989; Belbin *et al.* 1992). Indicator species and species assemblages characterising each community were determined following Dufréne and Legendre (1997) using INDVAL routine in PC-ORD (McCune and Mefford 1999). Quadrats were ordinated using SSH (semi-strong hybrid multidimensional scaling), a non parametric approach and does not presume any underlying model of species response gradients. Correlations of environmental variables were determined using PCC (Principal Component Correlation) routine and significance determined by MCAO (Monte Carlo Attributes in Ordination) routine in PATN (Belbin 1989). PCC uses multiple linear regressions of variables in the three dimensional ordination space (Belbin 1989). Statistical relationships between quadrat groups were tested using Kruskal-Wallis non parametric analysis of variance (Siegel 1956), followed by Dunn's Multiple comparison test (Zar 1999).

Nomenclature generally follows Paczkowska and Chapman (2000).

## RESULTS

### Flora

A total of 114 taxa were recorded from Mount Forrest - Mount Richardson range, from quadrats and opportunistic collections. The flora were represented by 29 families in 60 genera (Appendix 1) covering both the banded iron formation and associated mafic substrates but largely excluding sandplain. The dominant families were Myrtaceae (21 taxa), Poaceae (15), Myoporaceae (13), Mimosaceae (9) and Amaranthaceae (5), while the representative genera were *Eremophila* (13 taxa), *Acacia* (9), and *Eucalyptus* (7). A single introduced taxon to the State, *Pentaschistis airoides* subsp. *airoides*, was recorded.

### Rare and Priority Flora

Four priority flora were recorded within the survey area.

- *Aluta teres* is a Priority 1 taxon in the Myrtaceae and was first collected in 1992 on Bulga Downs pastoral lease. Prior to this survey, this species was known only from the holotype. It is closely related to *Aluta* *aspera* but is easily distinguished by prominent recurved apicula on the leaves and bracteoles (Rye & Trudgen 2000). It was restricted to the northern end of the range.

- *Beyeria lapidicola* belongs in the Euphorbiaceae and is Priority 2 taxon. It was first collected in the 2005 survey of the Mt Forrest - Mt Richardson range (Outback Ecology Services 2007). It appears to be an ironstone endemic with other recent collections of the taxon on Weld Range and the banded ironstone range west of Wiluna.
- *Baeckea* sp. Melita Station (H. Pringle 2738) is a Priority 3 myrtaceous shrub to 2.5 m with distinctive pointed and hooked golden green leaves. The nearest population located 100 km to the east, and represents a significant range extension.
- *Euryomyrtus patrickiae* is a Priority 3 taxa in the Myrtaceae. A shrub to 1 m with light pink flowers. A single specimen was collected from the northern part of the range growing in red sand.

## Range Extensions

In addition to new records of priority flora, the survey extended the range of four taxa, including one Priority taxon, *Baeckea* sp. Melita Station (H. Pringle 2738).

- *Cheilanthes adiantoides* is a small rhizomatous, perennial fern often associated with rocky sites. Recent collections in previous ironstone surveys extended it's range to the Yalgoo IBRA region. The collections from this survey extend the taxon's eastern extent, with the nearest population approximately 300 km to the west.
- *Cheilanthes brownii* is another distinctive perennial fern found growing in cracks within the rocky outcrops on the range. It is a small fern with densely woolly fronds and can be confused for *Cheilanthes sieberi* subsp. *pseudovellea*, the latter having twisted hairs on the pinnules. An additional collection was made at the nearby Cashmere Downs Range, 30 km to the west Both collections extend the eastern range by 300 km.
- *Leptospermum fastigiatum* is a myrtaceous shrub to 3m with white flowers. It was an opportunistic collection from the sandplains north of the range which increased the taxon's northwest extent. The nearest population is approximately 200 km south east.

## Plant Communities

A total of 103 taxa (including 80 perennials) were recorded in the 51 quadrats. Sixty eight taxa occurred in more than one quadrat. Final analysis was conducted using perennial species occurring in two or more quadrats. Preliminary analysis showed high correlations between the dissimilarity matrix derived from the full data set and that with the annual species and singletons were removed (r = 0.981). This indicates that with the removal of annuals and singletons, there is little difference between the two dissimilarity matrices and therefore the outcome would be similar. In the final analysis, 57 perennial species from 51 quadrats were analysed.

Six communities were elucidated from the classification, based upon groupings that were ecologically sound (Figure 2). Communities 2 and 3 (upland sites) were distinguished from Communities 4 and 5 (communities on colluvial or mafic sites), as well as two species poor sites. These sites were then separated from the species poor mulga sites on lower slopes (Community 1). From the dendrogram, Community 6, a spinifex community found in northern part of the range, was clearly separated from the other communities. The two species poor quadrats were found on a lower slope and crest of banded ironstone, the latter heavily grazed by feral goats. The two quadrats can not be confidently described as a community type, with only two shared perennial species.

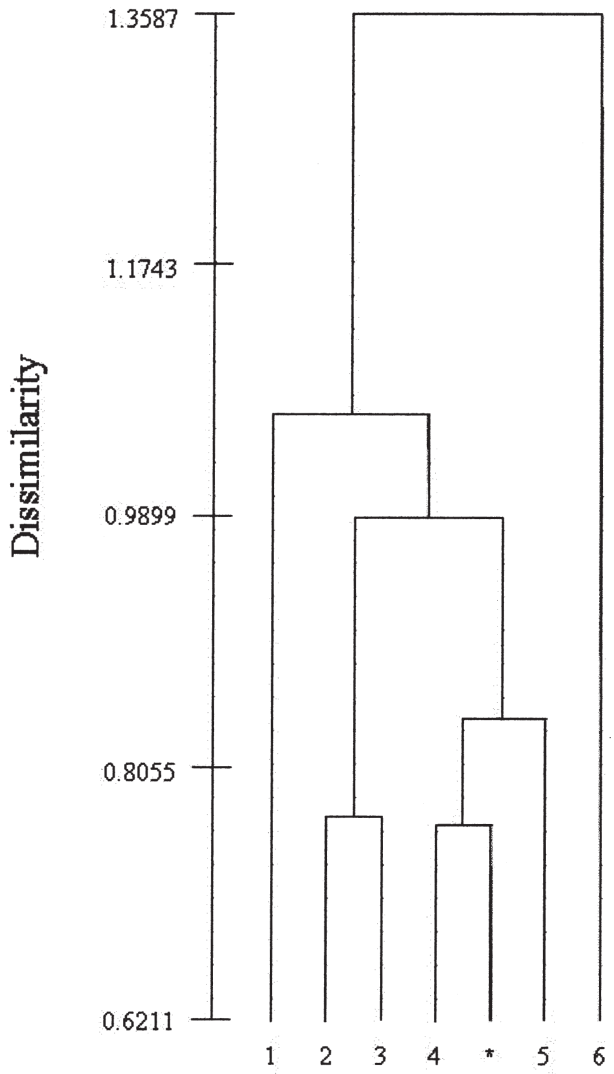



*Figure 2. Dendrogram of 7 group level classification of the 51 quadrats established on Mount Forrest - Mount Richardson range. * represents the species poor quadrats (BULG39 and BULG48). Dissimilarity is based upon the Bray-Curtis dissimilarity measure (dilated using $\beta = -0.1$).*

Community 1 – The community is found on lower slopes of banded iron formation ridges and hills. It can be described as open shrublands and mallee shrublands of *Acacia aneura* and *Eucalyptus kingsmillii* subsp. *kingsmillii* over sparse shrublands of *Eremophila forrestii* subsp. *forrestii* over isolated grassland and shrublands of *Monachather paradoxus* and *Sida calyxhymenia*. It is characterised by Species Group A and D. Indicator species are *E. forrestii subsp. forrestii*, *M. paradoxus*, *Sida chrysocalyx*, *Acacia aneura* var. *microcarpa*, *Acacia ramulosa* var. *ramulosa* and *E. kingsmillii subsp. kingsmillii* (Table 1). This community had low mean species richness with 8.3 (± 2.3 SE) taxa per quadrat.

Community 2 – This was the most common community found on the range, occurring mainly on the upper slopes and crests of banded ironstone. It can be described as open woodlands and shrublands of *A. aneura*, *A. quadrimarginea*, *Acacia cockertoniana*, *Callitris columellaris* and *Grevillea berryana* over sparse to open shrubland of *Eremophila glutinosa*, *Drummondita microphylla*, *Thryptomene decussata*, *Baeckea* sp. Melita Station (H. Pringle 2738), *Dodonaea petiolaris*, *Aluta aspera* subsp. *hesperia* over sparse fernland of *Cheilanthes sieberi* subsp. *sieberi*. It is characterised by Species Groups A and B, and characterised by indicator species *C. sieberi subsp. sieberi*, *E. glutinosa*, *D. petiolaris* and *T. decussata* (Table 1). It had a mean species richness of 12.9 (± 2.8 SE) taxa per quadrat.

Community 3 – This community occurred on the crests and slopes of the banded ironstone range. It is described as shrublands to open shrublands of *A. quadrimarginea*, *A. cockertoniana*, *C. columellaris* over shrubland to open shrublands of *Eremophila* spp. (*E. glutinosa*, *Eremophila georgei*, *Eremophila conglomerata* and *E. forrestii subsp. forrestii*), *D. microphylla*, *Olearia humilis* and *A. aspera subsp. hesperia* over sparse to open shrubland and fernland of *C. sieberi subsp. sieberi* and *Prostanthera althoferi* subsp. *althoferi*. It is characterised by taxa from Species Groups A, B and F. Indicator species were *S. chrysocalyx*, *E. glutinosa*, *A. cockertoniana* and *P. althoferi subsp. althoferi* (Table 1). It had a mean species richness of 10.4 (± 2.5 SE) taxa per quadrat.

Community 4 – Communities of lower slopes of banded ironstone found mainly in the valley between the two strike ridges (Figure 1) and found on colluvial soils. Shrublands of *A. aneura*, *Acacia ramulosa* var. *ramulosa* and *A. quadrimarginea* over shrublands of *Eremophila* spp. (*Eremophila oldfieldii* subsp. *angustifolia*, *E. conglomerata* and *E. georgei*), *Dodonaea adenophora*, *D. microphylla* and *Ptilotus obovatus* var. *obovatus* over grassland and fernland of *Eriachne pulchella* and *C. sieberi subsp. sieberi*. Characterised by taxa from Species Groups A, B and D (Table 1). Indicator species were *Acacia exocarpoides* and *D. adenophora* with a mean species richness of 13.6 (± 2.9 SE) taxa per quadrat.

Community 5 – This community was located on the midslopes of Mount Forrest growing on metabasalt bedrock. It is described as open mallee shrublands of *Eucalyptus* spp. (*Eucalyptus carnei* and *Eucalyptus gypsophila*) and *A. aneura* over of *Eremophila pantonii*, *D. adenophora*, *Dodonaea lobulata* and *Philotheca brucei* subsp. *brucei* over sparse shrubland of *P. obovatus var. obovatus*, *D. microphylla* and *D. petiolaris* over fernland of *C. sieberi subsp. sieberi*. It is characterised by taxa from Species Group A, B and H. Indicator species were *P. obovatus var. obovatus*, *D. lobulata*, *E. pantonii*, *E. carnei* and *P. brucei* subsp. *brucei* (Table 1), with a mean species richness of 13.6 (± 5.2 SE) taxa per quadrat.

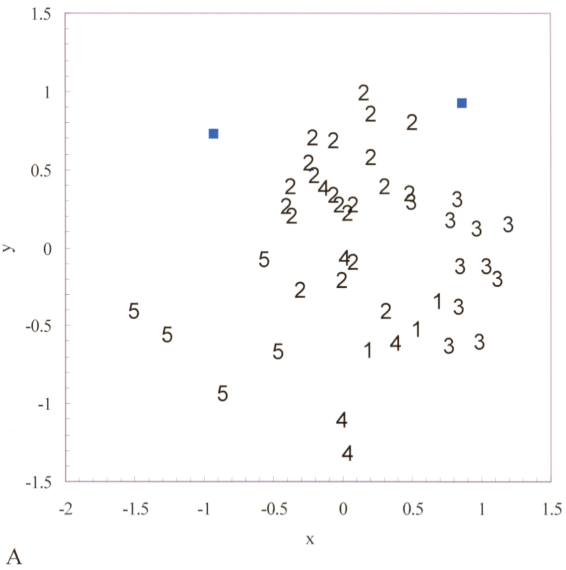
Community 6 – This community occurred in the northern area of the range where the sandplain was accumulating against the side of the range. It is described as sparse to open mallee shrublands and shrublands of *Eucalyptus oldfieldii*, *A. quadrimarginea* and *A. aneura* over sparse to open shrubland of *Calothamnus gilesii* and characterised by Species Group I. Indicators species were *Aluta teres*, *Verticordia helmsii*, *Triodia lanigera*, *Hibbertia arcuata*, *E. oldfieldii* and *C. gilesii* over shrubland and hummock grassland of *H. arcuata*, *A. teres* and *T. lanigera* (Table 1). It had a mean species richness of 11.7 (± 4.2 SE) taxa per quadrat.

## Environmental Parameters

Given the large floristic differences between Community 6 and the other communities, the ordination excluded these quadrats in order to better elucidate the relationships between the remaining quadrats. The patterns in soil chemistry found in the univariate analyses were also correlated with the location of sites in the three dimensional ordination (stress = 0.18, Figure 3A). Calcium, magnesium, nickel, manganese, cobalt, pH and ECEC all increased toward Community 5, in the lower left quadrant (Figure 3B). Organic carbon, iron and maximum surficial rock size higher in the upper left quadrant, corresponding to sites of Community 2, while conversely, these were all lower in Communities 1, 3 and 4 (Figure 3B).

All soil chemical parameters, except cadmium, showed significant differences between communities in the non-parametric univariate analysis. Community 6, the spinifex community, occurred on sandy soil with the poorest soil nutrition, with the lowest phosphorus, potassium, nitrogen and organic carbon (Table 2). It is also has the lowest values of calcium, cobalt, copper, manganese, molybdenum, sodium, nickel, sulphur, zinc, eCEC and EC.

Aside from Community 6, the main differences in soil chemistry occurred between the *Eucalyptus* community on meta basalt (or mafic) bedrock (Community 5) and the communities 1, 2 and 3. Soils at Community 5 were the most fertile and had a significantly higher pH and greater concentration of molybdenum than Communities 1, 2 and 3. Community 1 tended to occur on less fertile soils and lower concentrations of micro nutrients than Community 5. Community 3 showed a similar pattern to Community 1 except for significantly lower concentrations of potassium, copper and nickel than Community 5. Community 2, occurring on the crests and slopes of the ranges, was lower in cobalt, copper, manganese and nickel than Community 5, but was significantly higher in



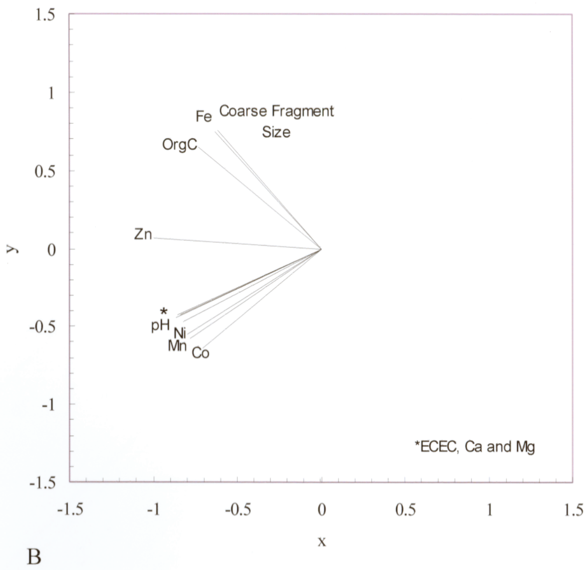




*Figure 3.* ***A***. *Three dimensional ordination showing Axis 1 and 2 of 47 quadrats, excluding community 7, established on Mount Forrest – Mount Richardson range showing community type. " represent species poor sites (BULG39 and BULG48).* ***B***. *Best fit linear correlated variables (P<0.05) shown as lines representing the strength and direction of the correlation.*

phosphorus to Community 4, significantly higher in iron than Communities 1, 3 and 4 and total nitrogen to Community 1.

In general, Community 4 was intermediate in soil nutrients between Community 5 and Communities 1, 2 and 3, except for lower concentrations of phosphorus and iron when compared to Community 2 and lower organic carbon than Community 5. Community 4 differed from 7 in percentage organic carbon, otherwise the remaining soil chemicals were not significantly different in the post-hoc tests (Table 2).

Only four of the eight site parameters were significantly different between community types (Table 3). Community 5 occurred at significantly higher elevation than Community 1. Community 5 was only located on the midslopes around Mount Forrest while Community 1 primarily occurred on the lower slopes of the range. Community 1 and 4 had smaller surficial rock size than Community 2. Community 2 also had lower amount of leaf litter than Community 5 and occurred on much steeper slopes than Communities 1 and 3.

## DISCUSSION

In this survey, a total of 114 taxa were recorded, this included 65 taxa not recorded in an earlier survey of this range (Outback Ecology Services 2007). However the present survey was restricted to the range and did not include the sandplain that formed a large area of the previous survey.

The banded ironstone range on Cashmere Downs pastoral lease some 30 km to the west were also surveyed in 2006 (Meissner *et al.* 2009), where 139 taxa were recorded. These figures contrast with 287 taxa that were previously recorded from the Hunt Range, Yendelberrin and Watt Hills, approximately 160 km south (Gibson & Lyons 2001b) and 238 taxa on the Mount Manning Range, 140 km south east (Gibson 2004a). Both the Mount Manning and Hunt Range floras had higher numbers of annuals represented due to good winter and spring rains. In contrast, the Mount Forrest – Mt Richardson and Cashmere Downs Ranges had below average rainfall, with less than 20 mm in the two months preceding the survey. Twenty percent of the flora were annuals, compared with nearly 30% and 40% of flora as annuals recorded on Mount Manning and Hunt Range respectively (Gibson & Lyons 2001b, Gibson 2004a).

The Mount Forrest – Mount Richardson Range also had a lower number of perennial taxa (93 taxa *cf.* 142 and 148 on Mount Manning and Hunt Range respectively). These latter ranges are at the northern extent of the South West Interzone, where floral elements of the Southwest and Eremaean Botanical Provinces intermingle (Beard *et al.* 2000). This boundary also marks the transition from low shrublands of *Acacia* (mainly mulga) in the drier north to euclaypt woodlands in the more mesic south. The differences between Mount Forrest and the ranges further south highlights this transition and may possibly explain the difference in the number of perennials and total number of taxa.

Several priority species were recorded in the survey. However no new taxa were discovered. Prior to the survey, *Aluta teres* was known only from the type specimen. In this survey, it was only found growing in Community 7, the spinifex community in the northern section of the range.

Previous surveys of ironstone have shown high plant endemicity (Markey & Dillon, 2008 a, 2008b; Meissner & Caruso, 2008 a, 2008b, 2008c) on individual ranges.

In this survey, *Beyeria lapidicola* was found only in the Mount Forrest area on the crests of the ironstone range. Additional surveys by consultants have confirmed that it is restricted to a 700 m area of the banded ironstone ridgeline (Outback Ecology Services 2007). This species appears to be an ironstone endemic. However it is not restricted to the Mount Forrest - Mount Richardson Range, as other specimens were collected from other ironstone ranges on the Yilgarn Craton, namely the Weld Range, northwest of Cue, and an ironstone range west of Wiluna. This survey also increased collections of *A. cockertoniana*, a species largely restricted to other ironstone ranges in the region.

The soil substrate and chemistry was the major factor separating the floristic communities on the range, the spinifex community (Community 7) growing on sandy soils located in the northern end of the range on the poorest soils, while the *Eucalyptus* community (Community 5) found on soil derived from mafic bedrock in at higher elevations around Mount Forrest occurs on the richest. Both these communities are restricted on the range. The spinifex community appears to be a transitional community, growing where sandplains to the north meet and overlays the banded ironstone. The community contains floral elements from the sandplain community (ie. the *T. lanigera*, *C. gilesii* and *E. oldfieldii*) and those from ironstone communities (e.g. *A. aneura*, *A. quadrimarginea*, *A. cockertoniana*, *Eremophila latrobei*).

The soil chemistry of the *Eucalyptus* community (Community 5) is characteristic of soils derived from mafic bedrock. Mafic rocks are generally higher in phosphorus, manganese, potassium, calcium, zinc, and magnesium (Gray & Murphy 2002). The difference in soil chemistry clearly limits the species that can grow there, as shown by the high constancy of several species such as *D. lobulata* and *E. pantonii* (Table 1).

In contrast, the main Communities 2 and 3 on the range possess intermediate soil nutrition between the communities on poor, sandy soils and the rich, mafic sites. These two communities are characterised as shrublands of *A. aneura*, *A. quadrimarginea* over shrublands *E. glutinosa* and *E. latrobei* subsp. *latrobei*, and occurred from the midslopes to crests across the entire range. The relationship between these two communities is close, as shown in the dendrogram and ordination, and differed only in several indicator species i.e *A. cockertoniana* and *P. althoferi subsp. althoferi* (Community 3) and *D. petiolaris* and *T. decussata* (Community 2). As well as differences in floristic composition, Community 2 occurs on slightly richer soils than Community 3, with higher organic carbon, phosphorus, iron and potassium.

The present survey shows that the communities on the Mount Forrest – Mount Richardson Range show the same soil - landscape patterns as described for other banded ironstone ranges with characteristic communities occurring on the crest and slopes of ironstone (Markey & Dillon 2008 a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c). The communities described also fall within the broad category of the stony Acacia shrublands (Payne *et al.* 1998), except for the Eucalypt Community 5 and the sandplain Community 7. The latter falls within the sandplain spinifex hummock grassland habitat group, found within the Marmion Landsystem (Payne *et al.* 1998). In comparison to recent survey work, all communities except Community 5 occur within the broad categories as described by Outback Ecology Services (2007). The lower slope and colluvial communities 1 and 4 are consistent with Acacia woodlands on stony plains/ low hills, Communities 2 and 3, found on the crests and slopes of the range correspond to the Acacia Woodland on Banded Ironstone Ridge, while the sandplain community (Community 7) corresponded to Eucalypt Tree Mallee on sandplain (Outback Ecology Services, 2007).

Currently, none of this range is in secure conservation reserve. However, part of the Mount Forrest – Mount Richardson Range is within a proposed conservation park, the Ida Valley – Mt Forrest Conservation Park.

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**Table 1**

Sorted two-way table of quadrats established on Mount Forrest - Mount Richardson range showing species analysed by community type (+ represent the species poor quadrats). Taxa shaded grey within a community are indicator species identified by INDVAL >17 (Dufrene and Legendre 1997) at the 7 group level (* indicates p< 0.05; ** indicates p<0.01; statistical significance tested by randomisation procedures).

| | Species Community | 1 | 2 | 3 | 4 | + | 5 | 6 |
|---|---|---|---|---|---|---|---|---|
| A | *Acacia aneura var. aneura/intermedia* | * | * * * * *   * *   *   * * | * | | | * * | * |
| | **Eremophila forrestii subsp. forrestii* | * * * | * * * * *   * | * * * | * | * | | |
| | ***Monachather paradoxus* | * * * | * *   * * *   * * *   * | *   *   * * | | | | |
| | ***Sida chrysocalyx* | * * * | * * *   * * * * * * * *   *   * | * * * * * * *   * | | | * | |
| | *Acacia aneura var. microcarpa* | * * * | * * * *   * * * *   * * * * * * * * * * * | * * * * * * * * * * * | * * * * * | * * | *   * * | * |
| | ***Cheilanthes sieberi subsp. sieberi* | | * * * * * * * * * * * * * * * * * * * * * | * * * *   * * | * * * | * * | *   * | |
| | ***Eremophila glutinosa* | | * * * * * * * * * * * * * * * * * * * * * | * * * * * * * * * * * | | | | |
| | ***Dodonaea petiolaris* | | *   * * * * * * * * * * * * * * * * * * | *   * | *   * | * | *   *   * | |
| | ***Thryptomene decussata* | | *   * * * * *   * *   * * * * * * * * * * | * | | | * * | |
| | ***Ptilotus obovatus var. obovatus* | | * * * * * * * * * * * *   * * * | * | * *   * * | * | * * * * * | |
| B | **Acacia cockertoniana* | | * * * *   * | * * * * * * * * * * | * | | * * * | * |
| | *Eremophila latrobei subsp. latrobei* | | * * *   *   *   * *   *   * * * * | * *   * * * * * * * | * * * * | | * * * | * |
| | *Drummondita microphylla* | | * * * *   * * * * * * | *   * * * | *   * | | * | |
| | *Acacia quadrimarginea* | | * *   * * * * * *   *   *   * | * | * * * | | | * * |
| | *Callitris columellaris* | | * * * * *   * * | * | | * | | |
| | *Austrostipa scabra* | | *   *   * * | | | | * | |
| | *Baeckea sp. Melita Station (H. Pringle 1738)* | | * * | * | | | * | |
| C | *Acacia aneura var. argentea x A. minyura* | | * | | * | | | |
| | *Senna cardiosperma* | | | | * | | * | |
| | *Eremophila conglomerata* | | * | * | * * | | | |
| | *Acacia tetragonophylla* | | *   * | | | | | |
| | *Eragrostis lacunaria* | | *   *   * | | | | | |
| | *Dodonaea rigida* | | *   *   * | | | | | * |
| D | **Acacia exocarpoides* | | | | *   * * | | | * |
| | *Eremophila oldfieldii subsp. angustifolia* | | | | * * | | * | |
| | ***Dodonaea adenophora* | | * | | * * * * * | | * | |
| | ***Acacia ramulosa var. ramulosa* | * * * | * | | *   * | | | |
| | *Eragrostis eriopoda* | *   * | * | | * | | | * |
| | *Psydrax suaveolens* | * | *   * | | | | | |
| E | ***Eucalyptus kingsmillii subsp. kingsmillii* | * | | * | | | | |
| | *Olearia humilis* | | * | *   *   * | | | | |
| F | *Acacia minyura* | * | *   * | *   * | | | | |
| | ***Prostanthera althoferi subsp. althoferi* | | * *   * | *   * * * * * * * * | * | | | |
| | *Aluta aspera subsp. hesperia* | | * | *   * | | | | |
| | *Dianella revoluta var. divaricata* | * | | * | | | | |
| | *Eremophila gilesii subsp. variabilis* | | | *   * | | | | |
| | *Eremophila georgei* | | | *   * | * | | | |
| | *Marsdenia australis* | | * | * | | | * | |
| | *Solanum ashbyae* | | | * * | * | | | |
| G | *Cheilanthes brownii* | | *   * | | | | | |
| | *Grevillea berryana* | | * | * | | | | |
| | *Eriachne helmsii* | * | * | | | | | * |
| H | ***Dodonaea lobulata* | | | | | | * * * * | |
| | ***Eremophila pantonii* | | | | | | * * * * * | |
| | ***Eucalyptus carnei* | | | | | | * *   * * | |
| | **Philotheca brucei subsp. brucei* | | * | | | | * *   * | |
| | *Eremophila oppositifolia subsp. angustifolia* | | | | | | * * | |
| | *Olearia muelleri* | | | | | | * * | |
| | *Eremophila platycalyx subsp. platycalyx* | | | | | * | *   * | |
| | *Scaevola spinescens* | | *   * | | * * * | | * * * * * | * * |
| | *Senna artemisioides subsp. filifolia* | | | | * | | * * | |
| I | ***Aluta teres* | | | | | | | * * * |
| | ***Verticordia helmsii* | | | | | | | * * * |
| | ***Triodia lanigera* | | | | | | | * * * |
| | ***Hibbertia arcuata* | | | | | | | * * * |
| | *Eucalyptus oldfieldii* | | | | | | | * * * |
| | ***Calothamnus gilesii* | | | | | | | * * * |

**Table 2**

Plant community mean values for soil chemistry parameters (measured mg/kg except eCEC, pH, Total N, Org C and EC). Differences between ranked values tested using Kruskal - Wallis non-parametric analysis of variance. Standard error in parentheses. a,b,c denote significant difference between groups by post hoc test (P < 0.05). (P = probability, n = number of quadrats, ns = not significant). Post-hoc tests undertaken on all communities except Community 5 due to low sample size.

| | Community Type | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | P |
| pH | 4.3 (0.0)b | 4.4 (0.0)b | 4.3 (0.0)b | 4.8 (0.2)ab | 4.8 (0.5) | 6.3 (0.4)a | 4.7 (0.1)ab | 0.000 |
| EC | 2.0 (0.0)b | 3.1 (0.2)ab | 2.6 (0.2)b | 6.4 (2.5)a | 3.5 (1.5) | 18.8 (9.4)a | 1.0 (0.0)b | 0.001 |
| Total N | 0.04 (0.00)b | 0.07 (0.00)a | 0.07 (0.01)ab | 0.05 (0.01)ab | 0.1 (0.0) | 0.08 (0.01)a | 0.01 (0.01)b | 0.001 |
| P | 5.5 (0.9)ab | 14.7 (1.9)a | 6.3 (0.6)b | 4.8 (0.9)b | 57.5 (52.5) | 9.8 (1.5)ab | 2 (0.6)b | 0.000 |
| K | 93.3 (8.0)abc | 135.8 (10.4)ab | 91.3 (8.2)bc | 154 (11.7)ab | 185 (75) | 172 (17.7)a | 36 (2.1)c | 0.002 |
| Org C | 0.5 (0.0)c | 1.2 (0.1)ab | 1.0 (0.1)abc | 0.7 (0.1)bc | 1.1 (0.5) | 1.5 (0.2)a | 0.4 (0.1)bc | 0.000 |
| Mg | 20.3 (3.4)bc | 42.3 (3.9)ab | 22.2 (2.6)c | 77.8 (22.2)a | 53 (32) | 261.8 (68.4)a | 17.3 (2.2)bc | 0.000 |
| eCEC | 0.85 (0.12)bc | 1.74 (0.13)abc | 1.01 (0.12)c | 2.58 (0.49)ab | 2.60(1.70) | 9.02 (2.40)a | 0.70 (0.06)c | 0.000 |
| Ca | 89.0 (14.9)b | 205.0 (17.5)ab | 119.8 (16.8)b | 298 (51.7)ab | 343.5 (246.5) | 1256 (393.6)a | 95.7 (8.7)b | 0.000 |
| Cd | 0.01 (0.0) | 0.01 (0.0) | 0.01 (0.0) | 0.01 (0.0) | 0.01 (0.0) | 0.02 (0.0) | 0.01 (0.0) | 0.173 |
| Co | 0.1 (0.0)ab | 0.1 (0.0)b | 0.1 (0.0)ab | 0.6 (0.3)a | 0.0 (0.0) | 1.7 (0.4)a | 0.0 (0.0)b | 0.000 |
| Cu | 0.8 (0.1)ab | 0.8 (0.0)b | 0.8 (0.0)ab | 0.9 (0.1)ab | 0.9 (0.1) | 3.2 (0.6)a | 0.2 (0.0)b | 0.002 |
| Fe | 26.5 (1.8)b | 60.6 (4.1)a | 40.5 (2.9)b | 35.2 (4.6)b | 72.5 (47.5) | 45.8 (3.1)ab | 27 (3.2)b | 0.000 |
| Mn | 28.3 (14.0)b | 25.4 (2.6)b | 27.3 (3.6)ab | 38.6 (10.7)ab | 18.5 (5.5) | 116 (30.5)a | 5.3 (0.7)b | 0.001 |
| Mo | 0.005 (0.000)b | 0.007 (0.010)b | 0.007 (0.001)b | 0.008 (0.003)ab | 0.005 (0.000) | 0.018 (0.002)a | 0.005 (0.000)b | 0.006 |
| Na | 2.5 (0.0)b | 4.1 (0.5)b | 2.7 (0.2)b | 16 (10.2)ab | 2.5 (0.0) | 30.2 (11.2)a | 2.5 (0.0)b | 0.000 |
| Ni | 0.1 (0.0)abc | 0.2 (0.0)bc | 0.1 (0.0)c | 0.3 (0.1)ab | 0.2 (0.1) | 1.3 (0.2)a | 0.1 (0.0)c | 0.000 |
| S | 15.5 (0.6)a | 11.8 (0.4)ab | 14.4 (0.8)a | 12.2 (1.7)ab | 11.5 (1.5) | 13.2 (3.8)ab | 5.7 (0.9)b | 0.007 |
| Zn | 0.7 (0.2)bc | 1.0 (0.1)ab | 0.8 (0.1)bc | 1.0 (0.1)abc | 3.2 (2.4) | 2.2 (0.6)a | 0.2 (0.0)c | 0.000 |
| n= | 4 | 21 | 11 | 5 | 2 | 5 | 3 | |

**Table 3**

Plant community mean values for physical site parameters; aspect (16 cardinal directions), slope (degrees), coarse fragment (CF) abundance (0 – no coarse fragments to 6 very abundant coarse fragments), maximum size of coarse fragments (1 – fine gravely to 7 large boulders), rock outcrop (RO) abundance (0 – no bedrock exposed to 5 – rockland), runoff (0 – no runoff to 5 – very rapid), % leaf litter (1 - >70% to 4 - <10%). Differences between ranks tested using Kruskal –Wallis non-parametric analysis of variance. Standard error is given in parentheses. a, b and c represent significant differences between community types at P < 0.05 (n = number of quadrats, P = probability, ns = not significant).

| | Community Type | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | P |
| Aspect | 12.3 (1.3) | 8.9 (0.9) | 8.5 (1.3) | 10.4 (2.8) | 5.0 (0.0) | 7.8 (2.8) | 15.0 (0.6) | 0.1219 |
| Slope | 3.8 (1.4)b | 14.4 (1.7)a | 5.8 (0.9)b | 5.8 (2.7)ab | 8.5 (6.5) | 13.4 (2.5)ab | 6.3 (0.9)ab | 0.001 |
| Elevation (m) | 453.5 (15.6)b | 510.1 (7.8)ab | 510.6 (13.8)ab | 491.8 (8.7)ab | 496.5 (43.5) | 538.6 (6.5)a | 496.3 (2.2)ab | 0.032 |
| Runoff | 1.5 (0.3) | 2.7 (0.3) | 1.8 (0.2) | 1.8 (0.5) | 1.5 (0.5) | 2.8 (0.2) | 2.3 (0.3) | 0.139 |
| Rock Outcrop* | 0.3 (0.3) | 2.4 (0.3) | 1.3 (0.6) | 0.4 (0.2) | 2.0 (2.0) | 1.2 (0.4) | 1.7 (0.3) | 0.032 |
| CF Max Size | 4.0 (0.4)b | 5.6 (0.1)a | 4.5 (0.3)ab | 3.8 (0.2)b | 4.5 (0.5) | 5.4 (0.2)ab | 4.0 (0.0)ab | 0.000 |
| CF Abundance | 3.5 (1.0) | 4.9 (0.2) | 5.0 (0.2) | 4.6 (0.5) | 4.5 (0.5) | 5.4 (0.2) | 3.3 (0.3) | 0.491 |
| % Leaf Litter | 1.7 (0.3)ab | 1.2 (0.1)b | 1.8 (0.2)ab | 1.6 (0.4) ab | 1.5 (0.5) | 2.2 (0.2)a | 1.3 (0.3)ab | 0.004 |
| n= | 4 | 21 | 11 | 5 | 2 | 5 | 3 | |

* post hoc pairwise comparison not significant

## APPENDIX 1

Floristic list for Mount Forrest - Mount Richardson, including all taxa from the sampling quadrats and from adjacent areas. * indicates introduced taxon to the State. Vouchers for each taxon were lodged at Western Australian Herbarium (PERTH).

**Adiantaceae**
- *Cheilanthes adiantoides*
- *Cheilanthes brownii*
- *Cheilanthes sieberi* subsp. *sieberi*

**Amaranthaceae**
- *Ptilotus aervoides*
- *Ptilotus exaltatus*
- *Ptilotus helipteroides*
- *Ptilotus obovatus* var. *obovatus*
- *Ptilotus polystachyus*

**Asclepiadaceae**
- *Marsdenia australis*

**Asteraceae**
- *Olearia humilis*
- *Olearia muelleri*
- *Olearia subspicata*

**Caesalpiniaceae**
- *Senna artemisioides* subsp. *filifolia*
- *Senna cardiosperma*

**Chenopodiaceae**
- *Chenopodium melanocarpum*
- *Rhagodia* sp.
- *Sclerolaena fusiformis*

**Cupressaceae**
- *Callitris columellaris*

**Dilleniaceae**
- *Hibbertia arcuata*

**Euphorbiaceae**
- *Beyeria lapidicola*
- *Euphorbia boophthona*
- *Euphorbia drummondii* subsp. *drummondii*
- *Euphorbia tannensis* cf. subsp. *eremophila*
- *Phyllanthus erwinii*

**Goodeniaceae**
- *Goodenia havilandii*
- *Scaevola spinescens*

**Haloragaceae**
- *Haloragis trigonocarpa*

**Lamiaceae**
- *Newcastelia hexarrhena*
- *Prostanthera althoferi* subsp. *althoferi*
- *Wrixonia prostantheroides*

**Malvaceae**
- *Sida* sp. tiny green fruits (S. van Leeuwen 2260)
- *Sida* sp. Golden calyces glabrous (H.N. Foote 32)
- *Sida ectogama*

**Mimosaceae**
- *Acacia aneura*
- *Acacia cockertoniana*
- *Acacia erinacea*
- *Acacia exocarpoides*
- *Acacia ligulata*
- *Acacia minyura*
- *Acacia quadrimarginea*
- *Acacia ramulosa* var. *ramulosa*
- *Acacia tetragonophylla*

**Myoporaceae**
- *Eremophila conglomerata*
- *Eremophila forrestii* subsp. *forrestii*
- *Eremophila georgei*
- *Eremophila gilesii* subsp. *variabilis*
- *Eremophila glutinosa*
- *Eremophila granitica*
- *Eremophila cf. jucunda*
- *Eremophila latrobei* subsp. *latrobei*
- *Eremophila oldfieldii* subsp. *angustifolia*
- *Eremophila oppositifolia* subsp. *angustifolia*
- *Eremophila pantonii*
- *Eremophila platycalyx* subsp. *platycalyx*
- *Eremophila simulans* subsp. *simulans*

**Myrtaceae**
- *Aluta aspera* subsp. *hesperia*
- *Aluta teres*
- *Baeckea* sp. Melita Station (H. Pringle 2738)
- *Calothamnus gilesii*
- *Calytrix strigosa*
- *Eucalyptus carnei*
- *Eucalyptus* cf. *oldfieldii*
- *Eucalyptus gypsophila*
- *Eucalyptus kingsmillii* subsp. *kingsmillii*
- *Eucalyptus leptopoda* subsp. *elevata*
- *Eucalyptus lucasii*
- *Eucalyptus oldfieldii*
- *Euryomyrtus patrickiae*
- *Leptospermum fastigiatum*
- *Melaleuca leiocarpa*
- *Melaleuca xerophila*
- *Micromyrtus flaviflora*
- *Micromyrtus sulphurea*
- *Thryptomene decussata*
- *Verticordia helmsii*
- *Verticordia interioris*

**Papilionaceae**
- *Daviesia* sp.
- *Swainsona* sp.

**Phormiaceae**
- *Dianella revoluta* var. *divaricata*

**Pittosporaceae**
- *Bursaria occidentalis*

**Poaceae**
- *Aristida contorta*
- *Austrostipa scabra*
- *Digitaria brownii*
- *Enneapogon caerulescens*
- *Eragrostis dielsii*
- *Eragrostis eriopoda*
- *Eragrostis lacunaria*
- *Eragrostis pergracilis*
- *Eriachne* cf. *mucronata*
- *Eriachne helmsii*
- *Eriachne pulchella*
- *Monachather paradoxus*

*Paspalidium basicladum*
**Pentaschistis airoides* subsp. *airoides*
*Triodia lanigera*

**Proteaceae**
*Grevillea berryana*
*Grevillea didymobotrya* subsp. *didymobotrya*

**Rubiaceae**
*Psydrax* cf. *rigidula*
*Psydrax suaveolens*
*Synaptantha tillaeacea* var. *tillaeacea*

**Rutaceae**
*Drummondita microphylla*
*Philotheca brucei* subsp. *brucei*

**Santalaceae**
*Exocarpos sparteus*
*Santalum spicatum*

**Sapindaceae**
*Dodonaea adenophora*
*Dodonaea lobulata*
*Dodonaea petiolaris*
*Dodonaea rigida*

**Solanaceae**
*Nicotiana cavicola*
*Solanum ashbyae*
*Solanum ellipticum*

**Sterculiaceae**
*Brachychiton gregorii*

**Stylidiaceae**
*Stylidium induratum*

**Zygophyllaceae**
*Zygophyllum iodocarpum*