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Flora and vegetation of banded iron formations on the Yilgarn Craton: south Illaara Greenstone Belt

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ABSTRACT

The Illaara Greenstone Belt is located within the Southern Cross Geological Province, extending discontinuously over 80km in a north-south direction. Previous surveys have been undertaken on the northern part of the greenstone belt. This paper describes the flora and vegetation of the southern ranges of the area. One hundred and forty five taxa, including 31 annuals and no introduced taxa were recorded from the range. One declared rare flora, *Ricinocarpos brevis*, and one priority taxon, *Banksia arborea*, were recorded. Hierarchical classification identified four floristic communities on the range. The main floristic differences occurred between communities found on laterite and banded ironstone (Communities 1 and 2) and communities occurring on a mixture of banded ironstone and mafic substrate. Significant differences were found in the soil chemistry between these substrates. Currently, the southern ranges of the Illaara Greenstone Belt occur on unallocated crown land and not within Western Australian conservation estate.

Keywords: BIF, banded ironstone, floristic communities, ranges, Yilgarn

INTRODUCTION

Banded iron formations (BIF) are iron-rich deposits composed of alternating layers of iron and silica-rich layers, formed 3.8 to 2.5 billion years ago, which are hypothesised to have formed through quiet, deep water deposition (Page 2001). In the Yilgarn Craton, BIF are associated with Archaean greenstone belts, such as the Illaara Greenstone Belt, and form distinct ranges and hills within the region.

Greenstone belts in the Yilgarn Craton have historically been mined for gold and other base metals. The discovery of gold at Coolgardie and Kalgoorlie in the 1890s led to an influx of prospectors to the region. Previous mining on the Illaara Greenstone Belt at Metzke Find and Lawrence Find (Wyche 2003) was primarily for gold. However current exploration is being undertaken for iron ore. The range is located on unallocated Crown land where the primary land use is the harvesting of native sandalwood (*Santalum spicatum*).

Previous floristic and vegetation surveys have been undertaken on other ironstone ranges within the Illaara Greenstone Belt to the north of this current survey area. Both earlier surveys found unique floristic communities associated with different substrates and positions in the landscape (Meissner *et al.* 2009, Meissner & Owen in press). The aim of this paper is to describe the flora and vegetation of the southern ranges of the Illaara Greenstone Belt, focussing on banded ironstone formations, as well as describing relationships with environmental variables. This paper forms part of a continuing series describing the flora and vegetation of BIF of the Yilgarn Craton.

Geology

The Illaara Greenstone Belt occurs within the Southern Cross Province (Griffin 1990) and is located 90km northwest of Menzies (Fig. 1). The greenstone belt extends for a strike length of 80km, in an approximately north-south direction (Wyche 2003), with varying degrees of exposure. Travelling southwards, the greenstone belt is first exposed as Mount Forrest - Mount Richardson, followed by Brooking Hills and then in an unnamed range at the southern extent, which is the subject of this survey. The greenstone belt is not expressed continuously and is separated by several breaks in the strike ridges, Lake Barlee separates Mount Forrest and Mount Richardson from Brooking Hills, and 15km of sandplain and low mulga woodland separate Brooking Hills from the southern ranges of the greenstone belt.

The greenstone belt is composed of a succession of quartzite and quartz-rich metasedimentary rocks, overlain with interval of mafic, ultramafic and meta-sedimentary rocks that includes BIF, chert and shale. Mafic refers to rocks or minerals with a high magnesium-iron content (Eggleton 2001), such as basalts, but they are also high in calcium and sodium (Gray & Murphy 2002). The Illaara Greenstone Belt differs from other greenstone belts in the region in that it contains greater amounts of quartzite and quartz-rich meta-sedimentary rocks.

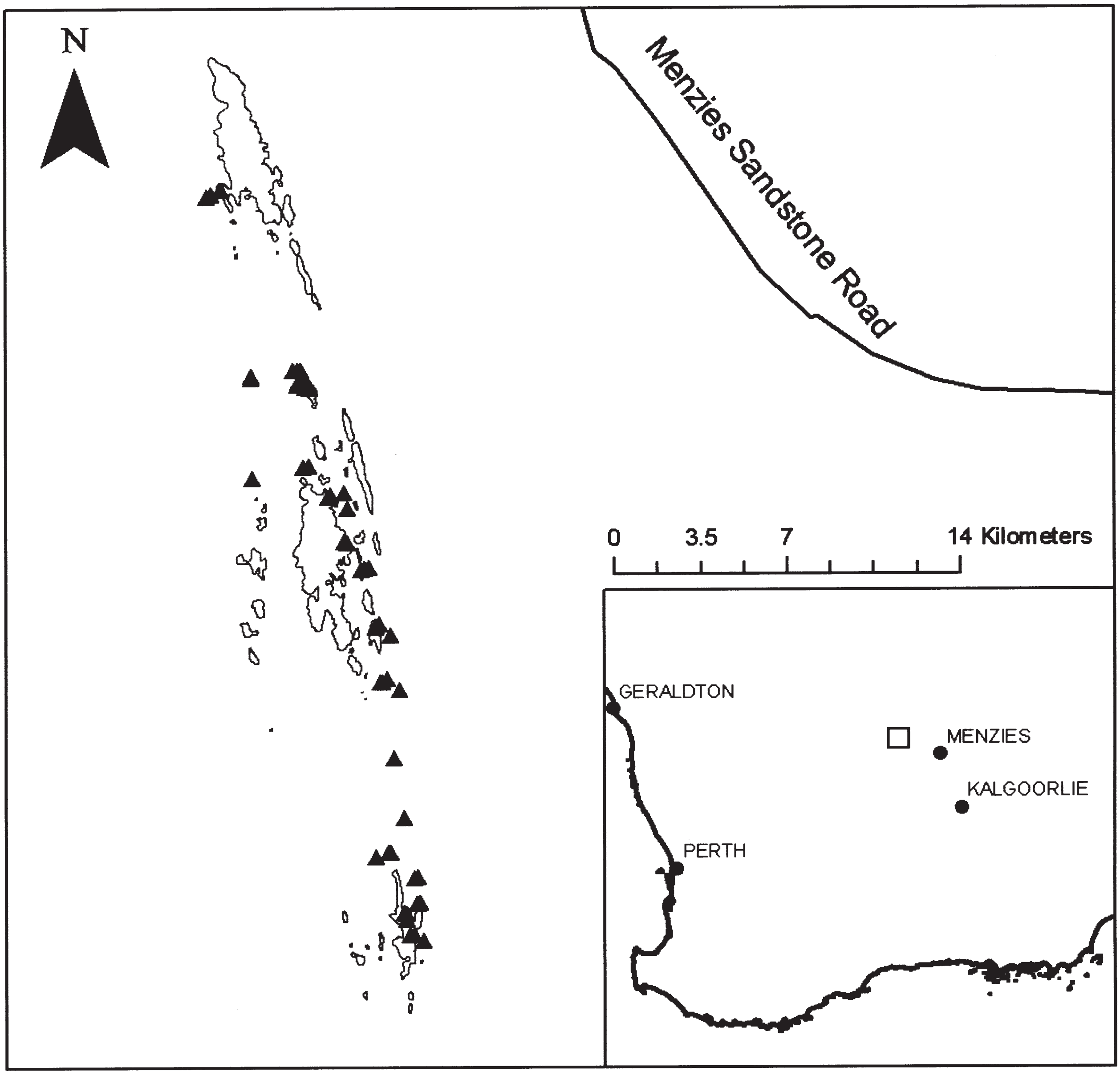

Figure 1. Location of the study area, approximately 90km north west of Menzies. Fifty quadrats (▲) were established on the southern ranges on the Illaara Greenstone Belt. The 480m contour is shown.

Climate

The climate of the region is semi-desert Mediterranean with mild wet winters and hot, dry summers (Beard 1990). Mean annual rainfall at Cashmere Downs Station (c. 75km northwest of the range) is 252.9mm, with moderate seasonal variation over the 83 years of record (1919–2002: decile 1, 128.5mm; decile 9, 426.9mm). Mean rainfall is spread throughout the year, with little winter-summer difference. 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 a lowest mean maximum temperatures recorded for July 17.5°C. Temperatures rarely fall below 0°C in winter (a mean of 0.9 days below 0°C), with a mean minimum of 5.9°C in July.

Vegetation

Initial vegetation surveys of the Illaara Greenstone Belt by Beard (1976) mapped the southern range as shrublands of *Acacia aneura* and *Acacia quadrimarginea* flanked by low woodlands and *A. aneura* on the plains. A rangeland condition survey of the eastern goldfields mapped the area as landsystems, which incorporate information on the vegetation in association with geomorphology and soils (Pringle *et al.* 1994). The ranges in this survey were mapped as the Brooking Landsystem, which is described as prominent ridges of banded ironstone formation supporting mulga shrublands with occasional halophytic communities in the south-east. This landsystem was characterised by Stony Ironstone Mulga Shrublands (SIMS), a vegetation type described as shrublands of *A.*

aneura, *Acacia ramulosa* and *Acacia tetragonophylla* and *Eremophila* spp. (*E. fraseri*, *E. forrestii*), *Senna* spp. (*S. artemisioides* subsp. *helmsii*, *S. artemisioides* subsp. *x coriacea*, *S. artemisioides* subsp. *x sturtii*) over shrublands of *Sida calyxhymenia*, *Solanum lasiophyllum* and *Spartothamnella teucriiflora* (Pringle *et al.* 1994).

Previous surveys of the Illaara Greenstone Belt have been undertaken on the northern and central sections of the Illaara Greenstone Belt. Meissner *et al.* (2009) and Meissner & Owen (in press) surveyed Mount Forrest and Mount Richardson in 2006 and Brooking Hills in 2007. The main community recorded on Mount Forrest and Mount Richardson was described as open woodlands and shrublands of *A. aneura*, *A. quadrimarginea*, *A. 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* (Meissner *et al.* 2009). In contrast, the common community on the Brooking Hills is described as open to sparse shrubland of *A. aneura* over open shrubland of *Eremophila georgei*, *Philotheca brucei* subsp. *brucei* and *Ptilotus obovatus* (Meissner & Owen, in press).

METHODS

The methodology employed in this survey followed the standard procedure used in previous vegetation surveys of other ironstone and greenstone ranges in Western Australia (Meissner & Caruso 2008 a,b,c). Fifty 20 x 20 m quadrats were established on the crests, slopes and foot slopes of south Illaara Greenstone Belt in September 2008 (Fig. 1). The quadrats were established using an environmentally stratified approach to cover the major geographical, geomorphologic and floristic variation but biased (non random) as there were restrictions in access to the range. Each quadrat was permanently marked with four steel fence droppers and its positions were determined using a Global Positioning System (GPS) unit. All vascular plants within the quadrat were recorded and collected for later identification at the Western Australian Herbarium.

Data on topographical position, disturbance, abundance, size and shape of coarse fragments on the surface, the abundance of rock outcrops (defined as the cover of exposed bedrock), cover of leaf litter and bare ground were recorded following McDonald *et al.* (1990). Additionally, growth form, height and cover were recorded for dominant taxa in each stratum (tall, 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 10cm of the soil profile within each quadrat. The samples were bulked and the 2mm 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 & Allen 2004). The soil pH was measured in 0.01M $CaCl_2$ at soil to solution ratio of 1:5. Effective cation exchange capacity (eCEC) was calculated from the sum of exchangeable Ca, Mg, Na and K (Rengasamy & Churchman 1999). Exchangeable Ca, Mg, Na and K were obtained by multiplying the values of Ca, Mg, Na and K obtained from ICP-AES by a standard constant. Organic carbon was measured on soil that was ground to less than 0.15mm 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 & Higgenson 1992). Total Nitrogen was measured using the Kjeldahl method 7A2 (Rayment & Higgenson 1992). The nitrogen was measured 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 & Higgenson 1992).

Quadrats were classified on the basis of similarity in species composition using perennial species only and excluding singletons. This was to facilitate comparison with other analyses of banded ironstone ranges and remove any temporal variations in ephemeral numbers that might confound comparisons (Meissner & Caruso 2008 a,b,c). The quadrat and species classifications were undertaken using the Bray - Curtis coefficient followed by Flexible Unweighted Pair-Group Mean Average (UPGMA) clustering (Clarke & Gorley 2006). 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). Quadrat classification was followed by similarity profile (SIMPROF) testing to determine the significance of internal group structures using permutation testing (Clarke & Gorley 2006). Indicator species and species assemblages characterising each community were determined following Dufréne and Legendre (1997) using INDVAL routine in PC-ORD (McCune & Mefford 1999). Quadrats were ordinated using semi-strong hybrid (SSH) multidimensional scaling, a non parametric approach, which is not based upon the assumptions of linearity, or any presumed underlying model of species response gradients. Correlations of environmental variables were determined using Principal Component Correlation (PCC) routine and significance determined by Monte Carlo Attributes in Ordination (MCAO) 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 145 taxa (species, subspecies, varieties, forms and hybrid taxa) from 79 genera and 39 families were recorded from collections within and adjacent to survey plots on the southern ranges of the Illaara Greenstone Belt. Dominant families were Mimosaceae (20), Chenopodiaceae (12), Poaceae (12), Asteraceae (11) and Myrtaceae (11). Thirty one of the taxa were ephemerals and no introduced taxa were recorded.

Rare and Priority Flora

One declared rare flora (DRF) and one priority taxon, as defined by Atkins (2008), were recorded from the southern ranges of the Illaara Greenstone Belt. Priority taxa are considered to be poorly known, potentially rare or threatened (Atkins 2008). Declared rare flora are taxa that are deemed to be rare or in danger of extinction in accordance with the Western Australian Wildlife Conservation Act 1950.

- *Ricinocarpos brevis* (DRF) was collected from a single specimen during the survey growing on the crest of BIF. *Ricinocarpos brevis* is a monoecious intricately twiggy shrub to 1.8 m, with small white flowers (Halford & Henderson 2007). A targeted survey in the following months found a population close to 3000 individuals on the range (Western Botanical 2008). The nearest population occurs on the Johnston Range, ca. 95km west of the range (Markey & Dillon, in press), but the species is known mainly from the Windarling Range, 105km to the south-west (Halford & Henderson 2007). At each of these locations, it is restricted to outcrops of banded ironstone at higher elevations (Halford & Henderson 2007).
- *Banksia arborea*, commonly known as the Yilgarn Dryandra, is a priority 4 shrub or tree growing to 6m and is endemic to banded ironstone hills in the eastern goldfields area of Western Australia. It was found growing on the crests of banded ironstone in shallow soils. This is the most northerly extent for this species, with the nearest known population occurring on the Yerilgee Hills, 35km to the south west (Markey & Dillon, in review).

Plant Communities

Sixty-one perennial taxa, excluding singletons, were used in the classification. Similarity profile (SIMPROF) analysis identified four significant groups or communities on the southern ranges of the Illaara Greenstone Belt ($p < 0.05$; Clarke & Warwick 2001). The main division in the dendrogram separates Communities 1 and 2, found on ferruginous duricrust and crests and slopes of banded ironstone respectively, from Community 3 and 4, occurring on sites of banded ironstone and mafic geology (Fig. 2).

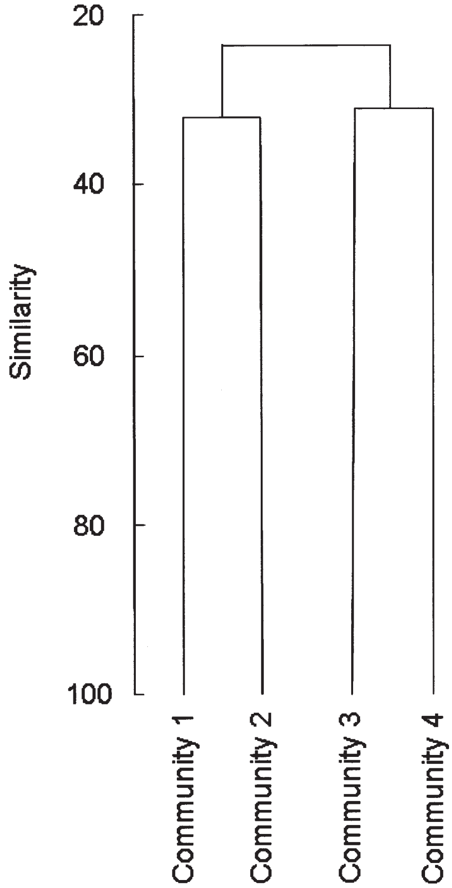

Figure 2. Dendrogram of the four group level classification of 50 quadrats established on southern range of the Illaara greenstone belt.

Community One – This community occurred on sites with a ferruginous duricrust. It is described as open to mid-dense shrubland of *Acacia* spp. (*A. cockertoniana*, *A. effusifolia*, *A. stowardii* and *A. aneura*) over open to mid-dense shrubland of *Eremophila forrestii* and *Baeckea elderiana* over sparse to open shrubland of *Prostanthera althoferi* and *Mirbelia microphylla*. The community had the second highest species richness at 15 taxa (±1.1) per plot. Indicator species were *Acacia aneura* var. *microcarpa*, *Sida* sp. Golden calyces glabrous (H.N. Foote 32), *A. effusifolia*, *Baeckea elderiana*, *Mirbelia microphylla*, *Eragrostis eriopoda*, *Euryomyrtus maidenii*, *Monachather paradoxus* and *Prostanthera althoferi* (Table 1).

Community Two – This community occurred on crests and slopes of banded ironstone on the entire length of the range. It is described as open to mid-dense shrublands of *A. aneura* and other *Acacia* spp. (*A. cockertoniana* or *A. quadrimarginea*) over open to mid-dense shrubland of *Philotheca brucei* subsp. *brucei*, *Olearia humilis* and *Eremophila* spp. (*E. latrobei*, *E. glutinosa* and *E. forrestii*) over isolate to sparse shrubland of *Sida* sp. Golden calyces glabrous (H.N. Foote 32) and *Cheilanthes sieberi* subsp. *sieberi*. This community had the lowest species richness with 12.5 taxa (±0.4) per plot. Indicator species were *A. aneura* var. *microcarpa*, *Acacia cockertoniana*, *Sida* sp.

Golden calyces glabrous (H.N. Foote 32), *O. humilis*, *A. quadrimarginea* and *E. glutinosa* (Table 1).

Community Three – This was the most prevalent community on the range, composed of over half of the sites surveyed. It was found on the crest and slopes across the range primarily on banded ironstone, but also on a mixture of ironstone and mafic lithologies. It is described as open to sparse shrubland of *A. aneura* and *Acacia* spp. (*A. quadrimarginea* and/or *A. tetragonophylla*) over sparse to open shrublands of *Sida ectogama*, *Dodonaea rigida*, *Eremophila* spp. (*E. latrobei* and *E. forrestii*), *Scaevola spinescens* and *P. brucei* subsp. *brucei* over isolate to sparse shrublands and fernland of *Ptilotus obovatus* and *Cheilanthes sieberi* subsp. *sieberi*. This community had the highest species richness with 17.3 taxa (±0.8) per plot. Indicator species were *D. rigida*, *A. tetragonophylla*, *P. obovatus*, *S. spinescens* and *S. ectogama* (Table 1).

Community Four – This community occurred on the slopes and crests of banded ironstone and mafic geology. It is described as open to mid-dense mallee woodland and shrubland of *Eucalyptus* spp. (*Eucalyptus salubris* or *Eucalyptus* aff. *griffithsii*) and *Acacia duriuscula* over open to mid-dense shrubland of *Eremophila* spp. (*E. oldfieldii* and *E. pantonii*) and *A. tetragonophylla* over open to sparse shrubland of *P. obovatus* and *Lepidium platypetalum*. Species richness was the lowest of all communities, with 14.2 taxa (±0.8) per plot. Indicator species were *A. tetragonophylla*, *P. obovatus*, *S. spinescens*, *S. ectogama*, *A. duriuscula*, *Enchylaena tomentosa*, *Eucalyptus salubris*, *L. platypetalum*, *Eremophila pantonii*, *Olearia muelleri* and *S. spicatum* (Table 1).

Environmental correlates

Prior to analysis, soil cadmium and molybdenum were removed, as both were below detectable limits. Non-parametric analysis of variance found that 14 of the 17 soil elements were significantly different (Table 2), while only one of 12 site attributes were significantly different between the four communities (Table 3). Slope was significant but post-hoc comparison did not show any differences, although Communities 1 and 3 tended to occur on gentler slopes. The main differences occurred between Community 1, on the ferricrete community, and Community 4, the *Eucalyptus* woodland community. Communities 2 and 3, the main communities on the range, were intermediate between Communities 1 and 4.

Community 1 occurred on the most acidic (mean pH 4.2) and the least fertile sites on gentle slopes, generally on the footslopes of the range. This community had lower amounts of phosphorous, potassium and magnesium than Community 4 (Eucalypt woodland) while having the lowest amount of trace elements (Table 2). Community 4 had the highest fertility of all communities and was less acidic with more abundant trace elements.

Community 2, found only on ironstone, and Community 3 , occurring on a mixture of ironstone and mafic substrates, showed intermediate soil chemistry between Communities 1 and 4. Community 2 was similar to Community 1, with similar acidic soils, and low fertility, but showed no significant differences in soil chemistry to Community 3, apart from higher amounts of sulphur and more acidic soils. Community 3 had similar soil chemistry to Community 4. It was less acidic, but more fertile, with significantly higher amounts of phosphorous, and potassium than Community 1.

The three-dimensional SSH ordination (Fig. 3; stress = 0.1653) shows a gradual species turnover from Community 1 through to Community 4 and a similar pattern to the univariate analysis. The ordination also confirms the results of the univariate analysis and is best seen in Fig. 3a and b. The floristic communities grade from Community 1 in the upper right quadrant, through to Communities 2 and 3, which also overlap with Community 4 the lower left quadrant (Fig.3b). Similar patterns of soil chemistry are also shown in the ordination, where Community 4 is correlated with higher levels of Na, Mn, Zn, Cu, Ni, Mg, K and Ca but is lower in S, while Community 1 shows the opposite trend (Fig. 3 c & d).

DISCUSSION

Flora

This survey completes the floristic survey of the Illaara Greenstone Belt, adding to floristic surveys of Mount Forrest-Mt Richardson (Meissner *et al.* 2009) and Brooking Hills (Meissner & Owen, in press). The flora of the southern ranges of the Illaara Greenstone Belt are comparable in terms of the number of taxa recorded within the nearby Yerilgee Hills (183 taxa; Markey & Dillon, in review) but more than in Brooking Hills to north (104 taxa; Meissner & Owen, in press) and Mount Forrest-Mount Richardson (114 taxa; Meissner *et al.* 2009).

While the southern ranges had a higher number of taxa compared to the rest of the greenstone belt, they had similar dominant families, namely Mimosaceae, Myoporaceae, Myrtaceae and Poaceae (Table 4). These families are typical of communities found in the Murchison Interim Biogeographic Regionalisation for Australia (IBRA) (Beard 1976). In total, 242 taxa have been recorded for the entire Illaara greenstone from the three surveys, with only 37 taxa common to all three ranges. Furthermore, nearly half of the flora in this survey (71 taxa) are unique to the southern ranges. This shift in species composition has been noted on other extensive BIF ranges (Markey & Dillon 2008) and on granite outcrops (Hopper *et al.* 1997) within Western Australia.

Endemic, rare and priority taxa are commonly found on the ironstone ranges within the Yilgarn Craton (Gibson *et al.* 2007). Several species in this survey are defined as endemic to the ironstone ranges, found only in BIF or ironstone. However, there were no taxa endemic to the southern ranges of the Illaara Greenstone Belt. *Banksia arborea* and *Ricinocarpos brevis* are both endemic to banded ironstone but are also classed as regional endemics, found only in a small area within the Eastern Goldfields. Such localised and restricted distributions associated with

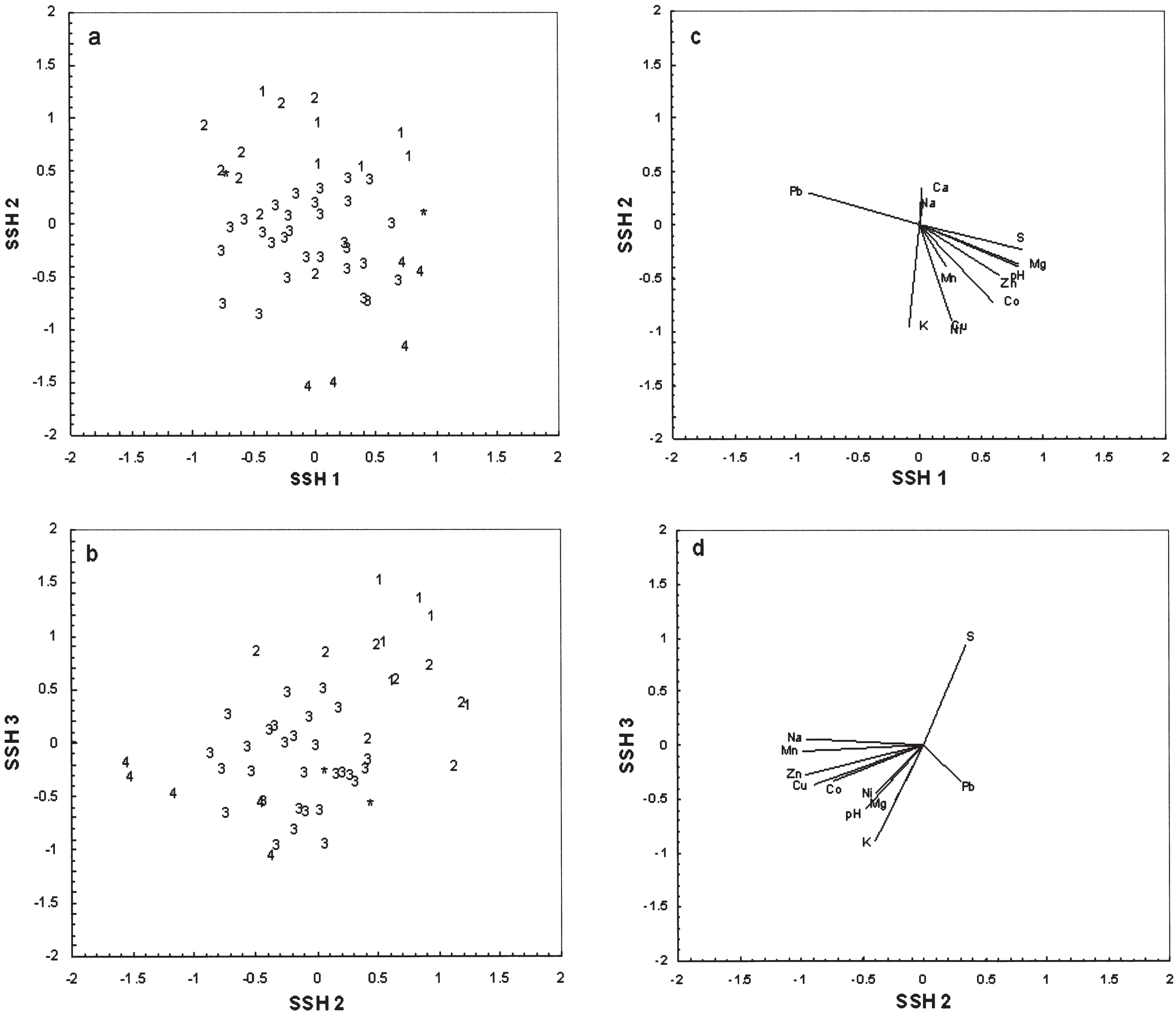

Figure 3. Three dimensional ordination showing Axes 1, 2 and 3 of the 50 quadrats established on southern ranges of the Illaara Greenstone Belt. The four communities are shown and lines represent the strength and direction of the best fit linear correlated variables (P<0.05).

ironstone ranges are hypothesised to be the result of the ranges acting as refugia during periods of cooler and drier climates at glacial maxima (Byrne 2008).

Plant communities

Unlike previous surveys, topography and other site attributes, such as surficial rock, were not significantly correlated with the different communities. These relationships have been found on other ironstone ranges, including nearby Yerilgee Hills (Markey & Dillon, in review b). The greatest distinction occurred between communities on ironstone substrates and those on a mixture of ironstone and mafic substrate. This is reflected in the chemical composition of the soils, with mafic and ironstone communities high in calcium, magnesium, potassium and manganese, that are characteristic of soils derived from mafic substrates (Gray & Murphy 2002).

The two common communities found on the range, Communities 2 and 3, both correspond to the stony ironstone mulga shrublands (SIMS) described by Pringle *et al.* (1994). However, at a finer scale, these communities are quite distinct from each other, with differences in their understorey with *O. humilis* and *E. glutinosa* in Community 2 and *D. rigida* and *S. ectogama* in Community 3.

Communities 2 and 3 were similar in terms of soil chemistry, with the exceptions of soil pH and sulphur. Differences between the two communities seemed to be based upon substrate lithology, with Community 2 occurring mainly on BIF, while Community 3 was found on a mixture of BIF and mafic bedrock. A gradual shift in species composition between the communities can be seen in the ordination and soil chemistry was intermediate between the extremes of mafic and laterite lithologies.

The most distinct community recorded was that restricted to small areas flanking the range on ferrginous duricrust, or ferricrete (Community 1). This community was distinctive in terms of several taxa, notably *A. effusifolia*, *Baeckea elderiana*, *Mirbelia microphylla* and *Euryomyrtus maidenii*. This community occurred on the least fertile sites, which is not surprising given that ferricrete is a product of deep weathering of the greenstone in the Tertiary, which would lead to the leaching of mobile elements (Britt *et al.* 2001). In contrast, the eucalypt woodland (Community 4) occurred on the most fertile sites. This pattern has been observed on other ranges such as Koolanooka Hills (Meissner & Caruso 2008a), where the eucalypt woodlands occurred on richer and deeper soils.

The southern ranges of the Illaara Greenstone Belt share communities similar to those recorded on the Brooking Hills and Mount Forrest-Mount Richardson, as discussed previously. Meissner and Owen (in press) hypothesised that the survey of southern part of the Illaara Greenstone Belt would find different set of communities indicating further species turnover. A preliminary analysis combining all the survey data collected for the entire greenstone belt found that each section had significantly different communities from each other (ANOSIM Global $R = 0.321$, $P < 0.01$, Clarke and Warwick 2001). This species turnover from north to south along the range is probably due to the primary environmental gradients of increasing rainfall and decreasing aridity (Beard 1976).

Conservation

Currently, the southern ranges of the Illaara Greenstone Belt occur on unallocated Crown Land and are not located within Western Australian conservation estate. Mining exploration is being undertaken in the region but currently the major land use within the range is sandalwood extraction, which requires an extensive system of tracks through the vegetation.

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APPENDIX

Flora list for the southern ranges of the Illaara Greenstone Belt, including all taxa from the sampling quadrats and adjacent areas. Nomenclature follows Paczkowska and Chapman (2000). R = declared rare flora

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

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

Anthericaceae
- *Thysanotus manglesianus*

Apocynaceae
- *Alyxia buxifolia*

Asclepiadaceae
- *Marsdenia australis*

Asteraceae
- *Brachyscome ciliocarpa*
- *Calotis hispidula*
- *Helipterum craspedioides*
- *Lawrencella rosea*
- *Myriocephalus guerinae*
- *Olearia humilis*
- *Olearia muelleri*
- *Podolepis gardneri*
- *Rhodanthe battii*
- *Vittadinia humerata*
- *Waitzia acuminata* var. *acuminata*

Brassicaceae
- *Lepidium platypetalum*

Caesalpiniaceae
- *Senna artemisioides* subsp. *filifolia*
- *Senna artemisioides* subsp. x *artemisioides*
- *Senna artemisioides* subsp. x *artemisioides* x *filifolia*
- *Senna charlesiana*
- *Senna glutinosa* subsp. *chatelainiana* x *charlesiana*

Casuarinaceae
- *Allocasuarina acutivalvis* subsp. *acutivalvis*
- *Casuarina pauper*

Chenopodiaceae
- *Enchylaena lanata*
- *Enchylaena tomentosa*
- *Maireana convexa*
- *Maireana georgei*
- *Maireana planifolia*
- *Maireana triptera*
- *Rhagodia eremaea*
- *Sclerolaena eriacantha*
- *Sclerolaena eurotioides*
- *Sclerolaena fusiformis*
- *Sclerolaena gardneri*

Convolvulaceae
- *Duperreya sericea*

Crassulaceae
- *Crassula tetramera*

Cupressaceae
- *Callitris columellaris*

Epacridaceae
- *Leucopogon* sp. Clyde Hill (M.A. Burgman 1207)

Euphorbiaceae
- *Euphorbia tannensis* subsp. *eremophila*
- *Ricinocarpos brevis* R

Geraniaceae
- *Erodium cygnorum*

Goodeniaceae
- *Brunonia australis*
- *Dampiera roycei*
- *Goodenia havilandii*
- *Goodenia macroplectra*
- *Goodenia mimuloides*
- *Scaevola spinescens*
- *Velleia hispida*
- *Velleia rosea*

Haloragaceae
- *Gonocarpus nodulosus*
- *Haloragis odontocarpa* forma *octoforma*
- *Haloragis trigonocarpa*

Lamiaceae
- *Prostanthera althoferi*
- *Prostanthera althoferi* subsp. *althoferi* x *campbellii*
- *Spartothamnella teucriiflora*
- *Wrixonia prostantheroides*

Lobeliaceae
- *Isotoma petraea*

Loranthaceae
- *Amyema miquelii*
- *Amyema nestor*
- *Lysiana casuarinae*

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

Mimosaceae
- *Acacia aneura* green (Meissner & Wright 2555)
- *Acacia aneura* hybrid
- *Acacia aneura* var. *alata/microcarpa* (BRM 9083)
- *Acacia aneura* var. *argentea* (BRM 9713.)
- *Acacia aneura* var. *argentea* (narrow phyllode variant) (BRM 9745)
- *Acacia aneura* var. *argentea* (short phyllode variant) (BRM 9300)
- *Acacia aneura* var. *microcarpa* (BRM 9794)

Acacia aneura var. *microcarpa* (broad, incurved phyllode variant) (BRM 9929)
Acacia aneura var. *microcarpa* hybrid
Acacia aneura var. *tenuis* (BRM 9296)
Acacia burkittii
Acacia cf. *oswaldii*
Acacia cockertoniana
Acacia duriuscula
Acacia effusifolia
Acacia exocarpoides
Acacia quadrimarginea
Acacia ramulosa var. *linophylla*
Acacia ramulosa var. *ramulosa*
Acacia tetragonophylla

Myoporaceae
Eremophila alternifolia
Eremophila forrestii subsp. *forrestii*
Eremophila georgei
Eremophila glutinosa
Eremophila latrobei subsp. *latrobei*
Eremophila oldfieldii subsp. *angustifolia*
Eremophila pantonii

Myrtaceae
Baeckea elderiana
Eucalyptus aff. *griffithsii* (Meissner & Wright 2590)
Eucalyptus ebbanoensis subsp. *ebbanoensis*
Eucalyptus leptopoda subsp. *subluta*
Eucalyptus oleosa subsp. *oleosa*
Eucalyptus orbifolia
Eucalyptus salubris
Euryomyrtus maidenii
Melaleuca leiocarpa
Micromyrtus flaviflora
Verticordia interioris

Papilionaceae
Mirbelia microphylla
Swainsona kingii

Phormiaceae
Dianella revoluta var. *divaricata*

Pittosporaceae
Bursaria occidentalis
Pittosporum angustifolium

Poaceae
Aristida contorta
Austrostipa elegantissima
Austrostipa scabra
Austrostipa sp.
Austrostipa trichophylla
Enneapogon caerulescens
Eragrostis eriopoda
Eragrostis lacunaria
Eriachne mucronata
Eriachne pulchella subsp. *pulchella*
Monachather paradoxus
Paspalidium basicladum

Proteaceae
Banksia arborea
Grevillea haplantha subsp*. haplantha*
Grevillea nematophylla subsp*. supraplana*
Hakea recurva subsp*. recurva*

Rhamnaceae
Cryptandra connata

Rubiaceae
Psydrax latifolia
Psydrax suaveolens

Rutaceae
Philotheca brucei subsp*. brucei*

Santalaceae
Santalum spicatum

Sapindaceae
Dodonaea lobulata
Dodonaea petiolaris
Dodonaea rigida

Solanaceae
Solanum ellipticum
Solanum ferocissimum
Solanum lasiophyllum
Solanum nummularium

Sterculiaceae
Brachychiton gregorii

Violaceae
Hybanthus floribundus subsp. *curvifolius*

Zygophyllaceae
Zygophyllum eichleri

Table 1

Sorted two-way table of quadrats established on southern ranges of the Illaara Greenstone Belt showing species by community type. Taxa shaded grey within a community are indicator species determined by INDVAL (Dufréne & Legendre 1997) at the four group level ($p < 0.05$).

	One	Two	Three	Four
Abutilon cryptopetalum				
Solanum ellipticum				
Rhagodia eremaea				
Acacia burkittii				
Amyema nestor				
Abutilon oxycarpum				
Psydrax suaveolens				
Spartothamnella teucriiflora				
Acacia aneura var. *argentea*				
Cheilanthes sieberi subsp. *sieberi*				
Dodonaea rigida				
Eremophila latrobei subsp. *latrobei*				
Eremophila forrestii				
Acacia ramulosa				
Marsdenia australis				
Solanum lasiophyllum				
Sida sp. dark green fruits (S. van Leeuwen 2260)				
Acacia tetragonophylla				
Ptilotus obovatus				
Scaevola spinescens				
Sida ectogama				
Eremophila oldfieldii subsp. *angustifolia*				
Senna artemisioides subsp. *filifolia*				
Dodonaea lobulata				
Dianella revoluta var. *divaricata*				
Hakea recurva subsp. *recurva*				
Lysiana casuarinae				
Maireana planifolia				
Solanum ferocissimum				
Acacia aneura var. *microcarpa*				
Brachychiton gregorii				
Eremophila georgei				
Acacia cockertoniana				
Sida sp. Golden calyces glabrous (H.N. Foote 32)				
Olearia humilis				
Acacia exocarpoides				
Acacia quadrimarginea				
Philotheca brucei subsp. *brucei*				
Dodonaea petiolaris				
Dryandra arborea				
Eremophila glutinosa				
Austrostipa trichophylla				
Melaleuca leiocarpa				
Acacia duriuscula				
Casuarina pauper				
Enchylaena tomentosa				
Eucalyptus salubris				
Lepidium platypetalum				
Allocasuarina acutivalvis subsp. *acutivalvis*				
Eremophila pantonii				
Olearia muelleri				
Santalum spicatum				
Austrostipa scabra				
Eucalyptus aff. *griffithsii*				
Acacia effusifolia				
Baeckea elderiana				
Mirbelia microphylla				
Eragrostis eriopoda				
Euryomyrtus maidenii				
Monachather paradoxus				
Prostanthera althoferi				

Table 2

Mean values for soil attributes (measured in mg/kg except EC and pH) by plant community type. Differences between ranked values tested using Kruskal-Wallis non-parametric analysis of variance. Standard errors in parentheses. a, b and c represent significant differences between community types at P < 0.05 determined by Dunns *post-hoc* test (n = number of quadrats, P = probability). * *post-hoc* test showed no significance.

	Community				
Attribute	**One n = 6**	**Two n = 8**	**Three n = 29**	**Four n = 5**	**P-value**
pH	4.2 (0.03)^{a}	4.3 (0.1)^{a}	4.9 (0.1)^{b}	6.1 (0.2)^{b}	**< 0.0001**
P	4.8 (1.5)^{a}	6.9 (0.8)^{ab}	10.4 (1.3)^{b}	8.6 (1.0)^{b}	**0.002**
K	64 (8)^{a}	130 (9)^{ab}	170 (10)^{b}	210 (20)^{b}	**< 0.0001**
Mg	18 (1)^{a}	49 (7)^{ab}	105 (18)^{bc}	250 (43)^{c}	**< 0.0001**
OrgC	0.79 (0.06)	1.4 (0.1)	1.2 (0.1)	1.3 (0.1)	0.064
Total N*	0.062 (0.003)	0.098 (0.007)	0.086 (0.01)	0.10 (0.01)	**0.0236**
B	0.075 (0.025)^{a}	0.15 (0.02)^{ab}	0.16 (0.01)^{b}	0.32 (0.07)^{b}	**0.0019**
Ca	104 (11)^{a}	255 (40)^{ab}	533 (69)^{bc}	1300 (368)^{c}	**< 0.0001**
Co	0.065 (0.001)^{a}	0.36 (0.15)^{ab}	1.34 (0.24)^{bc}	3.7 (0.62)^{c}	**< 0.0001**
Cu	0.8 (0.1)^{a}	1.3 (0.2)^{ab}	2.0 (0.2)^{bc}	5.0 (1.4)^{c}	**< 0.0001**
Fe	40 (2)	56 (7)	53 (6)	60 (4)	0.149
Mn	13 (2)^{a}	48 (16)^{ab}	93 (17)^{bc}	248 (59)^{c}	**< 0.0001**
Na	0.58 (0.08)^{a}	2.8 (1.8)^{ab}	2.9 (0.4)^{bc}	14.0 (3.8)^{c}	**0.0004**
Ni	0.15 (0.02)^{a}	0.35 (0.08)^{ab}	0.71 (0.13)^{bc}	1.5 (0.2)^{c}	**< 0.0001**
Pb	0.57 (0.03)	0.74 (0.11)	0.65 (0.05)	0.5 (0.1)	0.251
S	14.8 (0.9)^{a}	14.5 (1.4)^{a}	8.1 (0.7)^{b}	9.8 (1.0)^{ab}	**0.0001**
Zn	0.76 (0.09)^{a}	1.34 (0.14)^{ab}	2.02 (0.12)^{b}	2.9 (0.7)^{b}	**< 0.0001**

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, 5 – hillock); Land type (1 – hillcrest, 2 – hill slope, 3 – foot slope, 4 – mound); 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 tested using Kruskal –Wallis non–parametric analysis of variance. Standard errors in parentheses. **post-hoc* test showed no significance.

Attribute	**Community 1 n = 6**	**Community 2 n = 8**	**Community 3 n = 29**	**Community 4 n = 5**	**P-value**
Aspect	217.5 (53.8)	196.9 (45.8)	184.7 (21.1)	207.0 (58.0)	0.925
Slope*	2.0 (0.4)	7.5 (1.2)	3.9 (0.8)	8.0 (1.5)	**0.0084**
Morph Type	2.7 (0.6)	2.5 (0.5)	2.7 (0.2)	2.8 (0.7)	0.9665
Landtype	0.3 (0.2)	0.3 (0.2)	0.3 (0.1)	0.2 (0.2)	0.9008
Disturbance	1.2 (0.2)	1.1 (0.1)	1.2 (0.1)	1.4 (0.4)	0.9695
CF_Abundance	4 (0.3)	4.5 (0.3)	3.8 (0.1)	4.4 (0.2)	0.0757
CF_Size	3.5 (0.5)	4.0 (0.3)	4.0 (0.2)	5.0 (0.3)	0.1913
RO_Abundance	0.3 (0.2)	1.3 (0.5)	0.9 (0.3)	0.6 (0.2)	0.75
Runoff	1.5 (0.2)	2.3 (0.3)	1.8 (0.2)	2.2 (0.5)	0.3837
Soil Depth	1.8 (0.2)	1.8 (0.3)	2.0 (0.1)	2.2 (0.2)	0.6057
%Leaf_Litter	1.8 (0.2)	2.0 (0.3)	1.9 (0.1)	2.4 (0.2)	0.4318
%Bare_Ground	4.0 (0)	3.8 (0.2)	3.7 (0.1)	3.8 (0.2)	0.4619

Table 4

A comparison of the floristic data on the Illaara Greenstone Belt.

	This survey	Brooking Hills	Mount Forrest - Mount Richardson
Flora	145	104	114
DRF	1	-	-
Priority	1	-	4
Ephemerals	31	22	34
Eucalyptus	6	0	7
Acacia	20	13	9
Eremophila	7	8	13
Senna	5	9	2