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Flora and vegetation of banded iron formations of the Yilgarn Craton: Mt Ida Greenstone Belt and Mt Hope

RACHEL MEISSNER AND GAYNOR OWEN

Science Division, Department of Environment and Conservation,
PO Box 51, Wanneroo, Western Australia, 6946.
Email: Rachel.Meissner@dec.wa.gov.au

ABSTRACT

The Mount Ida greenstone belt is located within the Southern Cross Granite-Greenstone terrane (Wyche 2003) and is expressed as low ranges of banded ironstone formation. Recent increases in the value of iron ore have made the mining of banded iron formations more attractive. This paper describes the flora and vegetation on these ranges. A total eighty seven taxa, including one annual, were recorded from the ranges. One priority species, *Calytrix erosipetala*, and two range extensions were recorded. Hierarchical classification identified four plant communities on the ranges. The dominant floristic communities occurred on the slopes and crests (Community 2) and on the lower and colluvial slopes (Community 3). Upland communities were less fertile and there was a lower concentration of soil mobile elements than in the lowland communities. Currently, the Mt Ida Greenstone Belt is not within a conservation estate.

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

INTRODUCTION

Banded iron formations (BIF) are ancient sedimentary rocks formed in the Archaean period approximately 3.8 to 2.5 billion years ago. On the Yilgarn Craton, BIFs occur as relatively thin deposits associated with Archaean greenstone belts (Page 2001). As they are more resistant to erosion, BIFs form distinct ranges and hills within the Yilgarn region and include the ranges of the Mount Ida Greenstone Belt (Fig. 1). Mining in the area has occurred to the east of the ranges at Copperfield and Bottle Creek mines, focusing upon gold (Wyche & Duggon 2003) but with the current increase in iron ore values, mining low grade iron ore has become economical once again.

Previous vegetation surveys of ironstone ranges on the Yilgarn Craton have shown that each range supports distinct plant communities and an often unique and rare flora (Markey & Dillon 2008a,b; Meissner & Caruso 2008 a,b,c). The aim of this paper is to describe the flora and vegetation of the Mt Hope and the Mt Ida Greenstone Belt and their relationships with environmental variables to provide baseline information for future management.

Geology

The Mt Ida Greenstone Belt is located on the Southern Cross Granite-Greenstone Terrane (Wyche 2003) approximately 200km northeast of Kalgoorlie (Fig. 1). Mt Hope occurs approximately 50km south of Mt Ida and is part of a small unnamed greenstone belt.

The main range of the Mt Ida Greenstone Belt can be divided into two areas; the Mount Mason range in the north extending 13km, and the Mt Ida Range, south of Mt Mason and extending c. 7km. The Mt Mason range is composed of ridges of metamorphosed BIF intercalated with medium to coarse-grained mafic rock flanked by iron-enriched lateritic duricrust and ferruginous colluvium. Minor outcropping of BIF occurs parallel to the main ridge, to the east and at lower elevations (Wyche & Duggan 2003). The Mt Ida range has undergone greater deformation and consists of major ridges of banded ironstone intercalated with minor mafic rock and flanked by regolith of lateritic duricrust and ferruginous colluvium (Wyche & Duggan 2003).

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 west 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 the January as the hottest month (mean maximum 36°C and mean 6.2 days above 40°C). Winters are mild with the lowest mean maximum temperature of 17.5°C recorded for July. Temperatures occasionally 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.

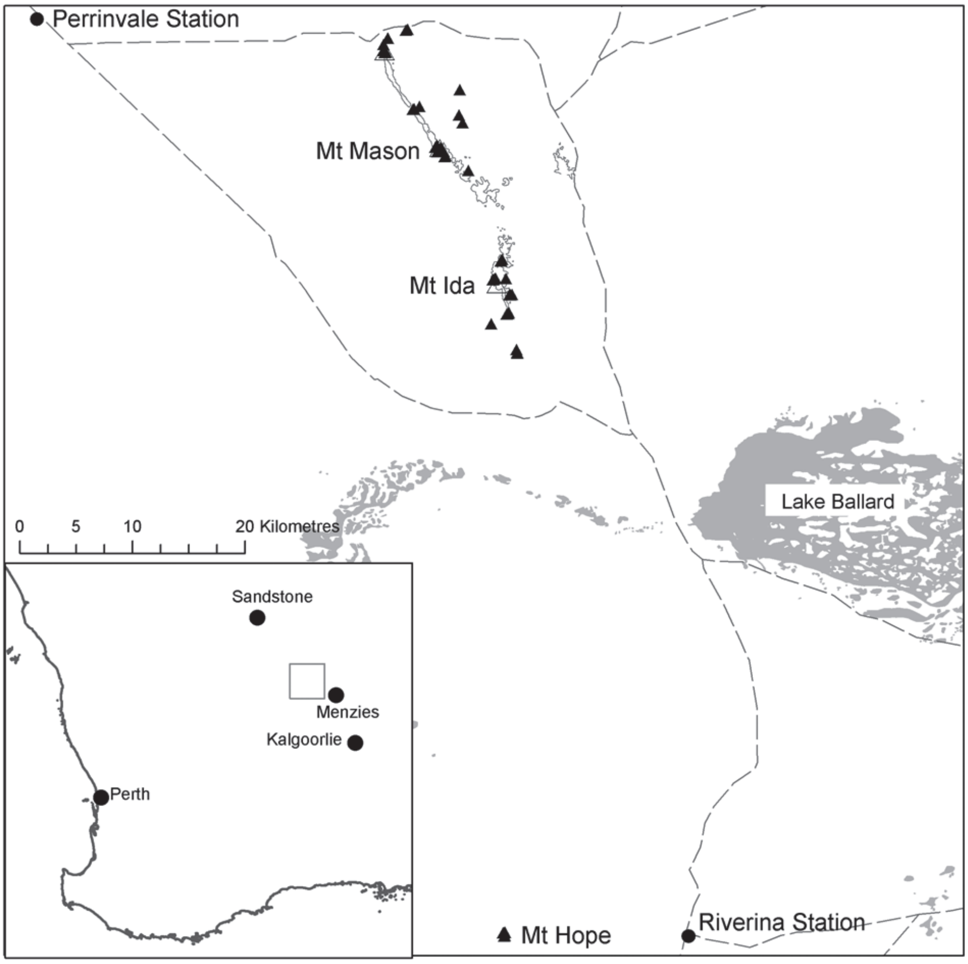

Figure 1. Location of the Ida Greenstone Belt showing the location of the 51 sites (▲). The 520 m contour is shown with the highest peaks of Mt Mason (566m) and Mt Isa (594m).

Vegetation

The ironstone ranges on the Mt Ida Greenstone Belt covers two main land systems: the Bevon and the Brooking (Pringle *et al.* 1994). A land system describes a catena of landforms, their geological features and vegetation types. The Bevon land system encompasses the lower colluvial slopes of the Mt Ida Greenstone Belt and is defined as irregular low ironstone hills and stony lower slopes supporting *Acacia aneura* shrublands. The Brooking Landsystem, named after the Brooking Hills, 35km to the west, describes the main ironstone ranges of the greenstone belt. The land system is defined as prominent ridges of banded iron formation supporting *A. aneura* shrublands; occasional halophytic communities in the southeast.

METHODS

Fifty 20 x 20m quadrats were established on the crests, slopes and foot slopes of banded ironstone ranges of the Mt Ida Greenstone Belt and Mt Hope in September 2007 (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 position was 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.

For each quadrat, the abundance, size and shape of coarse fragments on the surface were recorded, in addition to the amount of exposed bedrock, amount of disturbance, topographical position, cover of leaf litter and bare ground following McDonald *et al.* (1990). Additionally, growth form, height and cover were recorded for dominant taxa in each stratum (tall, mid and lower).

Twenty soil samples were collected from the upper 10cm of the soil profile within each quadrat. The soil was bulked and the 2mm fraction analysed for B, Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S and Zn using the Mehlich No. 3 procedure (Mehlich 1984). The extracted samples were then analysed using 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 pH was measured in 0.01M CaCl2 at a 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). Total Nitrogen was measured using the Kjeldahl method 7A2 (Rayment & Higginson 1992). 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 on perennial species only, to be consistent with the other analyses of banded ironstone ranges (Gibson 2004 a,b). The quadrat classification was followed by similarity profile (SIMPROF) testing to determine the significance of internal group structures using permutation testing (Clarke & Gorley 2006).

Similarity percentages (SIMPER), based upon Bray and Curtis similarities, was used to determine typifying species for each community. SIMPER analyses the contribution of individual species to the average similarity within groups and average dissimilarity between groups (Clarke & Warwick 2001).

Quadrats were ordinated using Semi-Strong Hybrid (SSH) multidimensional scaling, correlations of environmental variables were determined using Prinicipal Component Correlation (PCC) routine and significance determined by Monte-Carlo Attributes in Ordination (MCAO) routine in PATN (Belbin 1989).

Statistical relationships between quadrat groups were tested using Kruskal-Wallis non parametric analysis of variance (Siegel 1956), followed by non-parametric comparison (Zar 1999).

Nomenclature generally follows Paczkowska and Chapman (2000).

RESULTS

Flora

A total of 87 taxa from 26 families were recorded from the Mt Ida Greenstone Belt and Mt Hope. Dominant families were Mimosaceae (15 species), Myrtaceae (10), Myoporaceae (9) and Poaceae (8). No exotic species and a single annual, *Eriachne pulchella*, were recorded in the survey.

Priority Species

A single priority species was recorded in the survey. Priority taxa are considered to be poorly known, potentially rare or threatened (Atkins 2008). *C. erosipetala* is a Priority 3 (poorly known) shrub that grows to 70 cm with white to pink flowers. It is closely related to *Calytrix warburtonensis* but is distinguished by it's erose to sub-erose petal margin and longer hypanthium (Craven 1987). It was collected on the slopes of laterised ironstone near Mt Mason growing with *A. aneura*, *A. cockertoniana*, *Philotheca brucei* and *Prostanthera althoferi*.

Range Extensions

Range extensions were defined as any new record more than 100km from the nearest population to be consistent with previous surveys (Meissner & Caruso 2008a). This survey recorded range extensions for two species.

Callitris canescens, a tree that grows to 5m, differs from the more common arid species, being distinguished by dorsal surface of the cone being rounded and the dorsal point of cone being inconspicuous. This species is commonly found on breakaways, rock outcrops and slopes around salt lakes. In this study, it was found growing near Mount Hope, in an open woodland of *Casuarina pauper* and *A. aneura* shrubland on a crest of banded ironstone and mafic rock.

Hemigenia sp. Yalgoo (A.M. Ashby 2624) is a spinescent, low shrub to 90 cm with white, blue or purple flowers commonly found on lateritic soil. This is a range extension of approximately 250km north of the nearest population. It was found growing at two sites on a rocky crest and lower slope of banded ironstone.

Plant Communities

Fifty three perennial taxa, occurring in two or more plots (singlestons were removed), were used in the final analyses. A preliminary comparison between the full and final dataset showed high correlation between the two matrices (correlation of 0.99), indicating that the removal of singletons would have little effect on the classification and ordination analyses.

Four community groups and an outlier were determined following the hierarchical classification using SIMPROF ($p < 0.05$). The outlier, MTMN14, was located in the northern part of the survey near Mt Bevon, on a small crest of laterised ironstone. Only a few species recorded from the site occurred in the major communities, making it difficult to determine if the site was a species-poor representation of one of the four communities or a different community.

The outlier, MTMN14, was the first division in the dendrogram. Community 1, found on lower slopes and flats of the range, separated first on the dendrogram from the other communities. Community 2, the most prevalent community on the range and found mainly on the crests and midslopes of the ranges, was the next division in the dendrogram, separating from Communities 3 and 4, the communities that were most similar to each other. Community 3 was found on mid to lower slopes while Community 4 was found mainly on colluvial and lower slopes. Both communities had species in common with Community 2 but also had additional species that are found mainly in Communities 3 and 4 (Table 1).

Community 1 occurred on the lower slopes and flats associated with the ironstone ranges of Mt Ida and Mt Mason. It was characterised as open shrublands and mallee shrublands of *A. quadrimarginea*, *A. aneura*, *A. ramulosa* var. *ramulosa*, *Allocasuarina dielsiana* and *Eucalyptus rigidula* over open to sparse shrublands of *Eremophila forrestii* subsp. *forrestii* and *P. althoferi* over shrubland of *Ptilotus obovatus*. The mean species richness was the lowest of all communities, with 8.0 (±0.9) taxa per plot. The community was typified by *A. aneura* var. cf. *aneura*, *A. quadrimarginea* and *E. forrestii*.

Community 2 was a common community found on the crests and slopes of the ranges. It can be described as open to sparse shrublands dominated by *A. aneura* and other *Acacia* spp. (*A. cockertoniana*, *A. quadrimarginea* and *A. minyura*) over open to sparse shrublands of *Eremophila* spp. (*E. forrestii* subsp. *forrestii*, *E. latrobei* subsp. *latrobei*, *E. georgei*, *E. glutinosa*), *P. althoferi* subsp. *althoferi*, *Olearia humilis*, *P. brucei* subsp. *brucei*, *Allocasuarina acutivalvis* subsp. *acutivalvis* and *Dodonaea lobulata*. The mean species richness was 11.0 (±0.5) taxa per plot and the typical species were *A. quadrimarginea*, *E. georgei*, *E. latrobei* subsp. *latrobei*, *O. humilis*, *P. brucei* subsp. *brucei* and *P. althoferi* subsp. *althoferi*.

Community 3 was found on the mid- to lower slopes of the banded ironstone ranges. It was characterised by open to sparse shrubland of *A. aneura*, *Casuarina pauper*, *A. quadrimarginea*, *A. ramulosa* var. *ramulosa* and *Allocasuarina dielsiana* over sparse to open shrubland of *Acacia tetragonophylla*, *A. ramulosa* var. *ramulosa*, *Scaevola spinescens*, *E. latrobei* subsp. *latrobei*, *P. brucei* subsp. *brucei*, *Sida ectogama*, *Dodonaea rigida*, *Dodonaea lobulata*, *Scaevola spinescens* and *E. forrestii* subsp. *forrestii* over shrublands of *Ptilotus obovatus*. The typifying species were *A. aneura* var. cf. *microcarpa*, *A. tetragonophylla*, *E. forrestii*, *E. latrobei* subsp. *latrobei*, *Ptilotus obovatus* and *Scaevola spinescens*. This community had the highest mean species richness of 13.8 (±0.9) taxa per plot.

Community 4 was found on low terrain, on mid, lower and colluvial slopes and crests of banded ironstone of the ranges. The community was described as open to sparse shrublands of *A. aneura*, *A. quadrimarginea* and *A. cockertoniana* over open shrubland of *E. forrestii* subsp, *forrestii* and *E. georgei* over sparse shrubland of *Ptilotus obovatus*, *Solanum lasiophyllum* and *Sida* sp. Golden calyces glabrous H.N. Foote 32. The mean species richness of the community was 11.0 (±0.3) taxa per plot with only two typifying species, *E. forrestii* and *Sida* sp. Golden calyces glabrous H.N. Foote 32.

Physical Parameters

Non-parametric analysis of variance found significant differences in 13 of the 17 soil parameters and six of the nine site parameters (Table 2 and 3). Communities 2 and 3 differed the most, representing opposite ends of a continuum between lowland and upland communities, with Communities 1 and 4 possessing intermediate values between the two.

Community 2 was a common plant community, occurring on sites at higher elevations on the crests and slopes of the range. The sites had greater cover of exposed bedrock, shallower to skeletal soils and a greater surficial coarse fragment size than Community 3 sites (Table 3). In comparison, Community 3 occurred on sites at lower elevations on the mid-slopes and lower slopes of the ranges. The soils were less acidic, higher in potassium and magnesium but lower in organic carbon than Community 2 soils. The remaining trace elements (B, Ca, Co, Cu, Mn and Ni) were all significantly lower in concentration in Community 2 soils, but were significantly higher for iron and sulphur (Table 2).

The soils of Communities 1 and 4 showed intermediate concentrations of nutrients between the two main communities. Community 1 was less fertile, with the lowest concentrations of phosphorus, organic carbon and total nitrogen, but these were not significantly different from the other communities (Table 2). It was significantly lower in cobalt and iron, possibly reflecting the lower coarse fragment size and presence of rock outcrops, both of which represent potential sources of these elements (Gray & Murphy 2002). Community 4 occurred on sites at lower elevations on deeper soils with significantly higher potassium than Community 1 soils (Table 3).

The three dimensional ordination (Fig. 2; stress = 0.1919) using SSH multidimensional scaling showed results similar to that found in the univariate analysis. Communities 2 and 3 are clearly separated from each other with Community 2 occurring in the lower half and Community 3 in the upper half of the ordination. Communities 1 and 4 are intermediate between these two communities.

The principal components correlation (PCC) showed many environmental variables correlated with the ordination. High levels of Cu, pH, Mg, Ni, K, Mn, N and Co were associated with Community 3 in the upper left quadrant while higher values of organic C and S were associated with Community 2 in the lower half of the ordination (Fig. 2). Community 2 was also correlated with positions higher in the landscape (land type) and higher elevations, results also shown by the univariate analysis. Copper, magnesium, pH and elevation were the highest correlated variables ($r^2 > 0.5$).

DISCUSSION

Flora

A very low number of taxa were recorded on the Mt Ida Greenstone Belt primarily due to the low number of ephemerals represented in the taxa, with only one recorded. Brooking Hills area had a similar low number of perennial taxa, with a total of 82 perennial taxa and 22 ephemerals (Meissner & Owen 2010). The low number of annuals was attributed to the fact that in the four months preceding the survey, only 54 mm of rainfall was recorded at Bulga Downs, 90km to the north-east, with the average for that period approximately twice that value.

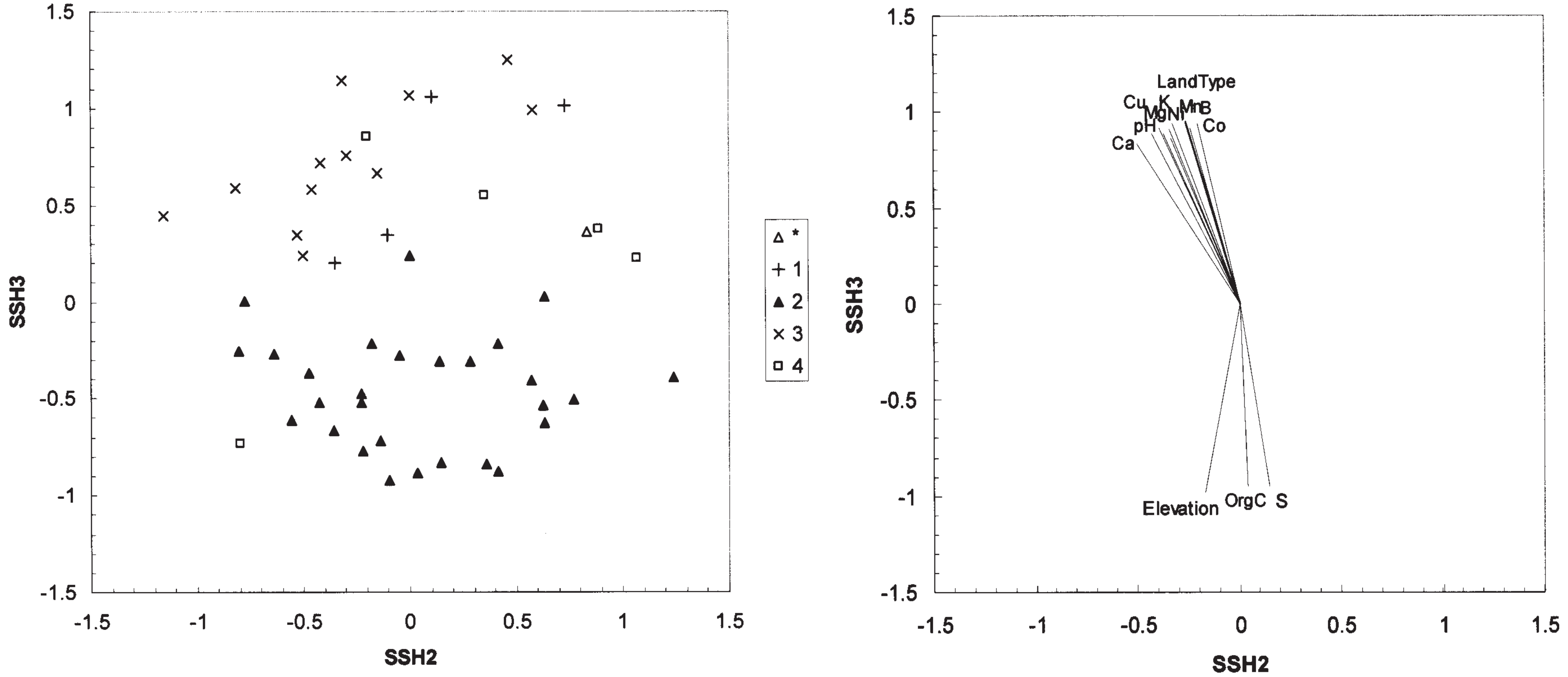

Figure 2. Three dimensional SSH ordination showing Axis 1, 2 and 3 of the 50 quadrats established on the Mount Ida Greenstone Belt. The four communities are shown and lines represent the strength and direction of the best fit linear correlated variables (P<0.05).

Plant Communities

This survey described four plant communities on the Mount Ida greenstone belt and Mt Hope. Pringle *et al.* (1994) characterised this range within two land systems, Brooking and Bevon, which broadly correlate with the occurrence of Communities 2 and 3, respectively. In this survey, Communities 2 and 3 represented the lowland and upland communities and were characterised by different suites of species. Pringle *et al.* (1994) did not differentiate between vegetation communities on the upper and lower slopes of the range and classified the vegetation as Stony Ironstone Mulga Shrublands. This study shows that these upland and lowland communities are distinct with different composition and associated with different environmental characteristics.

Community 3 was typified by species characteristic of colluvial and lower slopes of ironstone ranges, such as *E. forrestii*, *Scaevola spinescens* and *A. tetragonophylla*, while Community 2 was typified by species found on outcrops and ridges of ironstone ranges, such as *P. brucei* subsp. *brucei*, *O. humilis* and *E. georgei*. The distribution of nutrients was also typical of erosional environments and similar to patterns found on other ironstone ranges (Meissner *et al.* 2009a ,b). The more mobile elements, Na, Ca, Mg, Co, Ni, Cu and Zn, were all lower in Community 2 due to leaching and weathering (Britt *et al.* 2001).

Communities 1 and 4 differed slightly in community composition but were intermediate in physical characteristics between Community 2 and 3. Community 1 occurred at similar elevations, intermediate soil fertility between Community 2 and 3 and occurred on the lower slopes and flats. This community had the lowest species richness and was the first division in the dendrogram. It is likely that this community is a species-poor representation of the lowland community (Community 3). Similarly, Community 4 was found on lower terrains on midslopes and crests and is closely related to Community 3. It represents another variation of a lowland community, and is intermediate between Communities 2 and 3, sharing many of the physical characters and typifying species.

There were no communities recorded during the survey that were restricted within the range, with the communities spread across the greenstone belt however the communities found on the Mount Ida greenstone belt were unique to that range. An initial comparison of taxa between the Brooking Hills and this range found only 43 taxa in common. In addition, a preliminary comparison of the communities on the Mount Ida greenstone belt to the nearest ironstone range at Brooking Hills, found that the plant communities were significantly different (ANOSIM Global $R = 0.154$, $P < 0.01$, Clarke & Warwick 2001).

Conservation

At the time of the survey, the Mt Ida Greenstone Belt and Mt Hope were not within a conservation estate. This survey has shown that this range had a unique suite of communities that differ from other ironstone ranges in the region, however, there were no restricted communities and only one priority taxon. Additional surveys during years of higher rainfall may add further annual species. The banded iron formations of the Mt Hope and Mt Ida Greenstone Belt are currently under prospective mining interest.

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APPENDIX

Floristic list for the Mount Ida Greenstone Belt and Mt Hope including all taxa from the sampling quadrats and adjacent areas. Nomenclature follows Paczkowska and Chapman (2000).

Adiantaceae
Cheilanthes brownii
Cheilanthes sieberi subsp. *sieberi*

Amaranthaceae
Ptilotus helipteroides
Ptilotus obovatus

Apocynaceae
Alyxia buxifolia

Asclepiadaceae
Marsdenia australis
Rhyncharrhena linearis

Asteraceae
Olearia humilis
Olearia muelleri

Caesalpiniaceae
Senna artemisioides subsp. *helmsii* x *Senna glaucifolia*
Senna artemisioides subsp. *filifolia*
Senna cardiosperma
Senna glaucifolia

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

Chenopodiaceae
Maireana planifolia
Maireana triptera
Rhagodia drummondii
Sclerolaena fusiformis

Cupressaceae
Callitris canescens

Dilleniaceae
Hibbertia arcuata

Goodeniaceae
Scaevola spinescens

Lamiaceae
Hemigenia sp. Yalgoo (A.M. Ashby 2624)
Prostanthera althoferi subsp. *althoferi*
Spartothamnella teucriiflora

Loranthaceae
Amyema fitzgeraldii

Malvaceae
Hibiscus cf. *krichauffianus*
Sida sp. Golden calyces glabrous (H.N. Foote 32)
Sida ectogama

Mimosaceae
Acacia aneura var. cf. *aneura*
Acacia aneura var. cf. *argentea*
Acacia aneura var. cf. *microcarpa*
Acacia burkittii
Acacia cockertoniana
Acacia duriuscula
Acacia erinacea
Acacia minyura
Acacia murrayana
Acacia quadrimarginea
Acacia ramulosa var. *ramulosa*
Acacia sibirica
Acacia tetragonophylla
Acacia victoriae

Myoporaceae
Eremophila forrestii subsp. *forrestii*
Eremophila georgei
Eremophila glutinosa
Eremophila latrobei subsp. *latrobei*
Eremophila oldfieldii subsp. *angustifolia*
Eremophila platycalyx subsp. *platycalyx*
Eremophila scoparia

Myrtaceae
Aluta aspera subsp. *aspera*
Calytrix erosipetala
Eucalyptus ewartiana
Eucalyptus leptopoda subsp. *elevata*
Eucalyptus lesouefii
Eucalyptus lucasii
Eucalyptus rigidula
Micromyrtus clavata
Thryptomene costata
Thryptomene decussata

Phormiaceae
Dianella revoluta var. *divaricata*

Pittosporaceae
Bursaria occidentalis

Poaceae
Austrostipa sp. indet. BIF
Austrostipa aff. *trichophylla* (R. Meissner & G.Owen 2010)
Austrostipa elegantissima
Austrostipa scabra
Austrostipa trichophylla
Eragrostis eriopoda
Eriachne helmsii
Eriachne pulchella

Proteaceae
Hakea recurva subsp. *recurva*

Rubiaceae
Psydrax rigidula
Psydrax suaveolens

Rutaceae
Philotheca brucei subsp. *brucei*

Sapindaceae
Dodonaea lobulata
Dodonaea petiolaris
Dodonaea rigida
Dodonaea viscosa subsp. *mucronata*

Solanaceae
Solanum ashbyae
Solanum ellipticum
Solanum lasiophyllum

Sterculiaceae
Brachychiton gregorii

Table 1

Sorted two-way table of quadrats established on the Mount Ida Greenstone Belt showing species by community type. Taxa shaded grey within a community are typifying species identified by SIMPER (Clarke & Warwick 2001) at the 4group level (P< 0.05).

Acacia aneura broad
Casuarina pauper
Olearia muelleri
Allocasuarina dielsiana
Dianella revoluta var. *divaricata*
Spartothamnella teucriiflora
Acacia aneura falcate
Acacia ramulosa var. *ramulosa*
Maireana planifolia
Senna artemisioides subsp. *filifolia*
Rhagodia drummondii
Acacia tetragonophylla
Solanum lasiophyllum
Dodonaea rigida
Sida ectogama
Cheilanthes sieberi subsp. *sieberi*
Eremophila oldfieldii subsp. *angustifolia*
Dodonaea lobulata
Scaevola spinescens
Acacia victoriae
Hakea recurva subsp. *recurva*
Acacia aneura var. cf. *aneura*
Eremophila georgei
Olearia humilis
Prostanthera althoferi subsp. *althoferi*
Acacia aneura var. cf. *microcarpa*
Eremophila latrobei subsp. *latrobei*
Acacia quadrimarginea
Eremophila forrestii
Philotheca brucei subsp. *brucei*
Ptilotus obovatus
Eremophila glutinosa
Hibbertia arcuata
Acacia minyura
Thryptomene decussata
Marsdenia australis
Sida sp. Golden calyces (H. N. Foote 32)
Acacia aneura var. *argentia*
Acacia cockertoniana
Psydrax suaveolens
Solanum ellipticum
Eucalyptus leptopoda subsp. *elevata*
Hemigenia sp. Yalgoo (A.M. Ashby 2624)
Allocasuarina acutivalvis subsp. *acutivalvis*
Austrostipa scabra
Senna cardiosperma
Bursaria occidentalis
Dodonaea petiolaris
Dodonaea viscosa subsp. *mucronata*
Brachychiton gregorii
Eucalyptus ewartiana
Eremophila platycalyx
Hibiscus cf. *krichauffianus*

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 error in parentheses. a and b represent significant differences between community types at p < 0.05 (n = number of quadrats, P = probability).

	Community Type				
	1	2	3	4	P
EC	2.5 (0.5)	3.7 (0.2)	4.8 (1.1)	4.0 (1.1)	0.2522
pH	4.8 (0.2)ab	4.1 (0.1)a	5.3 (0.2)b	4.5 (0.2)ab	**<0.0001**
P	4.8 (1.0)	11.7 (2.4)	7.4 (3.4)	20.6 (13.1)	0.1877
K	119.8 (25.0)ab	74.6 (6.6)a	170.2 (16.2)b	173.4 (35.7)b	**<0.0001**
Mg	71.8 (15.0)ab	37.8 (4.6)a	104.0 (11.5)b	37.0 (15.1)ab	**0.0002**
Org C	0.74 (0.08)ab	1.44 (0.10)a	0.78 (0.09)b	1.09 (0.29)ab	**0.0007**
Total N	0.058 (0.006)	0.099 (0.006)	0.072 (0.007)	0.092 (0.019)	**0.0237**
B	0.3 (0.1)ab	0.2 (0.0)a	0.4 (0.0)b	0.4 (0.1)ab	**0.0014**
Ca	415.0 (101.5)ab	220.2 (29.5)a	642.5 (106.6)b	356.0 (90.2)ab	**0.0008**
Co	1.4 (0.6)b	0.2 (0.1)a	1.7 (0.3)b	1.0 (0.7)ab	**<0.0001**
Cu	1.8 (0.3)ab	1.0 (0.1)a	2.3 (0.2)b	2.2 (1.0)ab	**<0.0001**
Fe	40.3 (3.6)b	76.4 (8.9)a	47.8 (3.4)b	71.8 (23.3)ab	**0.0071**
Mn	88.0 (31.1)ab	29.9 (6.6)a	104.3 (14.6)b	75.6 (39.4)ab	**<0.0001**
Na	5.8 (1.3)	4.0 (0.5)	7.0 (1.4)	5.8 (1.6)	0.1258
Ni	0.48 (0.11)ab	0.23 (0.03)a	0.58 (0.06)b	0.56 (0.26)ab	**<0.0001**
S	7.0 (2.0)ab	15.1 (1.0)a	7.3 (1.1)b	12.0 (2.4)ab	**0.0003**
Zn	1.4 (0.3)	1.2 (0.1)	1.9 (0.2)	2.1 (0.4)	0.0416
n	4	28	12	5	

Table 3

Mean values for site attributes by plant community type; Elevation (m); Soil depth (1 - skeletal, 2 – shallow, 3 – deep); 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); Slope (degrees), runoff (0 – No runoff, 1 – very slow, 2 – Slow, 3 – Moderately rapid); Morphology type (1= Crest, 2= Upper Slope, 3= Mid Slope, 4= Lower Slope, 5 = Simple slope, 6 = Hillock); Land type (1 = Hillcrest, 2 = Hill slope, 3 = Footslope, 4 = Summit, 5 = Mount, 6 = Breakaway. Differences between ranks tested using Kruskal–Wallis non-parametric analysis of variance. Standard error in parentheses. a, b and c represent significant differences between community types at P < 0.05 (n = number of quadrats, P = probability,).

	Community Type				
	1	2	3	4	p
Elevation (m)	480.8 (19.5)ab	536.1 (5.6)a	472.5 (6.5)b	471.6 (6.6)b	**<0.0001**
Soil Depth	2.3 (0.3)ab	1.7 (0.1)a	2.2 (0.1)b	2.4 (0.2)b	**0.0034**
Coarse Fragment Size	3.5 (0.5)b	5.2 (0.1)a	4.1 (0.3)b	4.4 (0.7)ab	**0.0061**
Rock outcrop abundance	0.0 (0.0)b	2.1 (0.3)a	0.6 (0.3)b	1.8 (0.9)ab	**0.0019**
Slope	5.0 (1.7)	7.3 (0.8)	6.6 (1.5)	7.2 (2.8)	0.8264
Runoff	1.5 (0.5)	2.0 (0.2)	2.1 (0.3)	2.0 (0.4)	0.8246
CF Abundance	3.3 (0.9)	4.2 (0.1)	3.8 (0.2)	3.6 (0.2)	0.1900
Land Type	4.3 (0.3)b	1.9 (0.2)a	3.3 (0.3)b	2.8 (0.8)ab	**0.0007**
Morph Type	2.5 (0.5)ab	1.4 (0.1)a	2.1 (0.2)b	1.8 (0.4)ab	**0.0060**
n	4	28	12	5	