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# Flora and vegetation of banded iron formations of the Yilgarn Craton: Perseverance Greenstone Belt

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## ABSTRACT

The Perseverance Greenstone Belt is located within the Eastern Goldfields Geological Province of Western Australia and is represented by low undulating hills of banded ironstone and basalt. This paper describes the flora and vegetation on these hills. Eighty eight taxa, including seven annuals and no introduced taxa, were recorded. Two priority taxa, *Grevillea inconspicua* and *Baeckea* sp. Melita Station (H. Pringle 2738), were found. Hierarchical classification of species presence/absence data identified four floristic communities. The main floristic differences occurred between communities occurring on basalt, or mafic, substrates (Communities 1 and 4) and those occurring on the ironstone hills (Communities 2 and 3). Significant differences were found in the soil chemistry between these substrates. None of the Perseverance Greenstone Belt is within the Western Australian conservation estate.

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

## INTRODUCTION

Banded iron formations (BIF) are finely laminated deposits of alternating iron rich/silica rich layers (Page 2001) laid down approximately 3.8 to 2.5 billion years ago. The conditions and processes that led to the formation of this distinct lithology, whether of sedimentary origin or from secondary diagenetic modification of an unknown rock precursor, or a combination of both, are still being debated (Page 2001). Within Western Australia, BIF are found on the Pilbara and Yilgarn Cratons, part of the earth's crust that have been stable for the past 2.4 billion years. The Yilgarn Craton is considerably larger than the Pilbara Craton with 80% consisting of granite-greenstone terrane (Trendall 1990).

In this study, the BIF occur as part of the Perseverance Greenstone Belt and are expressed as a series of low hills associated with basalt and other mafic bedrock. Extensive mining and exploration have been undertaken in the area, beginning in the late 19th century (Beard 1976). Nickel is the primary focus of mining, with three mining operations: the Mount Keith, Leinster-Perseverance and Yakabindie mines on the Greenstone Belt. The development of mining in the 1930s was followed by the expansion the pastoral industry, which now one of the primary land uses of the area.

High levels of plant endemism have been shown to occur in the BIF ranges (Gibson *et al.* 2007). Analysis of 25 BIF ranges in the Yilgarn Craton found that 10% of declared rare flora (DRF) and priority taxa, under the Western Australian Wildlife Conservation Act, occurred on these ranges (Gibson *et al.* 2007). This study is part of a series of papers studying the floristic communities of BIF on the Yilgarn Craton. The aim of this paper is to describe the flora and vegetation communities on the Perseverance Greenstone Belt, focusing on those communities occurring on BIF.



### Geology

The ironstone hills described in this study are part of the Perseverance Greenstone Belt in the Eastern Goldfields Province, which occupies the eastern third of the Yilgarn Craton (Griffin 1990). The major component of the Perseverance Greenstone Belt comprises metamorphosed ultramafic and mafic rocks, such as basalts, which include the Violet Range, immediately west of the survey (Fig. 1). Mafic is a term derived by contracting "magnesium" and "ferric", reflecting that the rocks are high in these minerals (Eggleton 2001). Associated meta-sedimentary rocks, which included BIF, are widespread within the belt but are poorly exposed as a discontinuous ridge. The BIF and chert units of the greenstone belt are generally less than a few metres thick and are commonly associated with shales and quartz mica-schists (Liu *et al.* 1998).

### Climate

The climate of the region is desert with bimodal rainfall distribution (Beard 1976). Winter rainfall is generally light and is associated with low pressure systems off the south

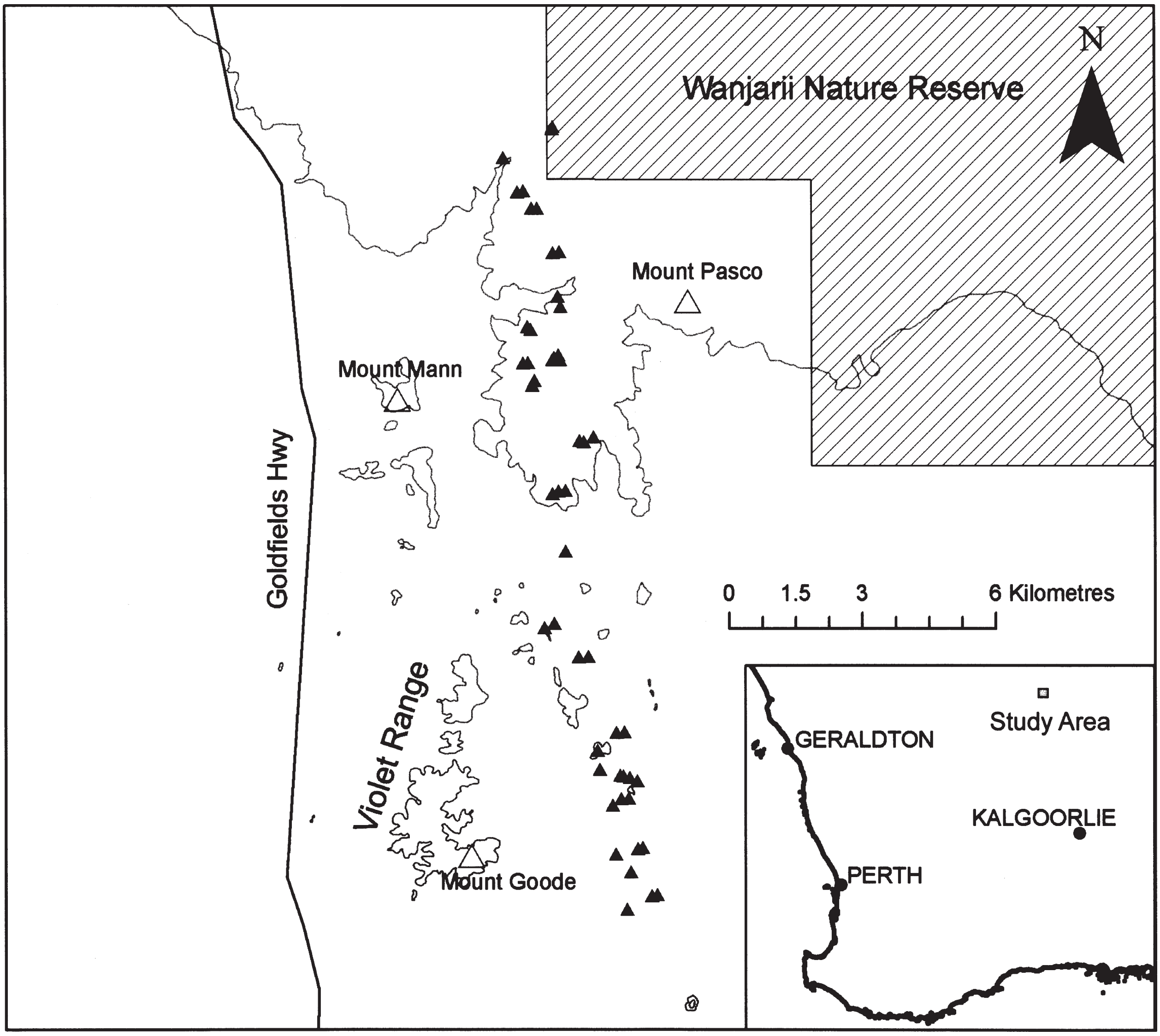


*Figure 1. Location of the Perseverance Greenstone Belt study area, showing the location of 50 sites (▲). The 520 m contour is shown with the highest peaks, Mt Mann (554 m), Mount Goode (598 m) and Mount Pasco (549 m).*

coast, while summer rainfall events, are usually short and intense, originating from cyclonic events to the north-west which degenerate into rain bearing depressions (Hall & Milewski 1994). Mean annual rainfall at Yeelerie Station (c. 55km northwest of the survey) is 237.8mm, with moderate seasonal variation over the 81 years of record (1928–2009: decile 1, 120.9mm; decile 9, 400.2mm). Rainfall is spread throughout the year, with little winter-summer difference. The highest maximum temperatures occur during summer, with January the hottest month (mean maximum temperature 37.9°C and a mean of 10.9 days above 40°C -1973–2009). Winters are mild with the lowest mean maximum temperatures of 19.3°C recorded in July. Temperatures occasionally fall below 0°C in winter (a mean 7.7 days below 0°C), with a July mean minimum of 3.5°C.

## Vegetation

The Perseverance Greenstone Belt occurs within the Murchison Interim Biogeographic Regionalisation for Australia (IBRA) region (Department of the Environment and Water Resources 2004), dominated by *Acacia aneura* low woodlands and abundant ephemerals. Several biological surveys have been undertaken in the eastern goldfields including Wanjarri Nature Reserve, adjacent to the ironstone hills. Hall *et al.* (1994) described vegetation occurring within broad valleys, undulating plains and breakaways, but did not include any ironstone landforms. The ironstone hills in this survey have been described broadly by Beard (1976), who generalised the vegetation cover as shrublands and mulga scrub and described the rocky hills covered with *A. aneura*, *A. quadrimarginea*, *A. grasbyi* and *Hakea lorea* over *Senna* sp., *Eremophila* sp., *Ptilotus obovatus*, *Clianthus formosus*, *Podolepis auriculata*, *Swainsona incei* and *Waitzia aurea*.

The Perseverance belt covers two land systems as described by Pringle *et al.* (1994). A land system describes a combination of landform, soil and vegetation that occur in a recurring pattern (Pringle *et al.* 1994). The Bevon land system covers the northern part of the survey and is described as irregular low ironstone hills with stony lower slopes supporting mulga shrublands. The system includes landforms such as breakaways, footslopes, hillslopes, ridges, stony plains and lateritic plains. To the south, the survey area occurs within the Violet Range land system, named after the Violet Range, which lies west of the current survey. The land system is defined as undulating stony and gravely plains and low rises, supporting mulga shrublands.

Both land systems are dominated by stony ironstone mulga shrublands (SIMS) vegetation, scattered to moderately close *A. aneura* (mulga) tall shrublands. This vegetation type is characterised by 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* and *S. artemisioides* subsp. *x sturtii*) over shrublands of *Sida calyxhymenia*, *Solanum lasiophyllum*, *Spartothamnella teucriiflora*, *Maireana* spp. (*M. convexa*, *M. georgei*, *M. triptera*, *M. villosa*) and *Ptilotus* spp. (*P. obovatus* and *P. schwartzii*) (Pringle *et al.* 1994). In both land-systems, SIMS vegetation mainly grades into 'lateritic' hardpan mulga shrublands (LHMS), usually on soils with a conspicuous mantle of ferruginous gravel (Pringle *et al.* 1994). This vegetation is characterised by mulga tall shrublands dominated by *A. aneura* and other *Acacia* spp. (*A. pruinocarpa*, *A. ramulosa* and *A. tetragonophylla*), *Eremophila* spp. (*E. fraseri*, *E. macmillaniana*, *E. forrestii* and *E. margarethae*), *Scaevola spinescens*, *Rhagodia eremaea*, *P. obovatus* and *P. schwartzii*.

## 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 (Markey & Dillon 2008a,b; Meissner & Caruso 2008a,b,c). Fifty 20 x 20 m quadrats were established on the crests, slopes and foot slopes of banded ironstone of the Perseverance 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 are recorded and collected for later identification at the Western Australian Herbarium (PERTH). Nomenclature generally follows Paczkowska & Chapman (2000).

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 10 cm 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 $CaCl_2$ 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 excluding singletons. This was to facilitate comparison with other analyses of banded ironstone ranges and remove any temporal variations in annuals numbers that could 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 & 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 and not based upon the assumptions of linearity, or any 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).

## RESULTS

### Flora

Eighty eight vascular taxa (species, subspecies, varieties, forms and hybrid taxa) were collected within and adjacent to survey plots on the Perseverance Greenstone Belt. The flora consisted of 83 perennials, seven annuals and no introduced taxa in 24 families. The best represented families were Mimosaceae (*Acacia*) (23 taxa), Chenopodiaceae (10 taxa), Caesalpiniaceae (*Senna*) (10 taxa), Myoporaceae (*Eremophila*) (8 taxa) and Malvaceae (6 taxa).

### Priority Flora

Two priority species, as defined by Atkins (2008), were collected from the Perseverance Greenstone Belt. Priority taxa are considered to be poorly known, potentially rare or threatened (Atkins 2008). Both taxa have been recorded previously from the area.

- *Baeckea* sp. Melita Station (H. Pringle 2738) (Priority 3) is a myrtaceous shrub growing to 2.5m with characteristic hooked golden green leaves and white flowers. This taxon is an ironstone endemic within the Murchison IBRA region. It was recorded from three sites at the southern end of the hills between crests and lower slopes of banded ironstone.
- *Grevillea inconspicua* (Priority 4) is an intricately branched shrub growing to 2m with white or grey flowers in a terminal raceme. It is commonly found growing on drainage lines along rocky outcrops and creeklines within the Murchison IBRA region. It was found opportunistically growing on a lower slope of a basalt hill with surficial ironstone fragments.

### Plant Communities

The similarity profile (SIMPROF) analysis identified four significant groups ($p < 0.05$; Clarke & Warwick 2001). Fifty one perennial taxa, occurring in two or more sites, were analysed. The first division in the dendrogram separated Community 1, found on mafic and ultramafic basalt sites, from the other three communities (Fig. 2). The next division in the dendrogram separated Community 4, found on crests and slopes of basalt hills, from Community 2, found on banded ironstone hills in the southern part of the range, and Community 3 on banded ironstone and chert hills and ferruginous colluvium.

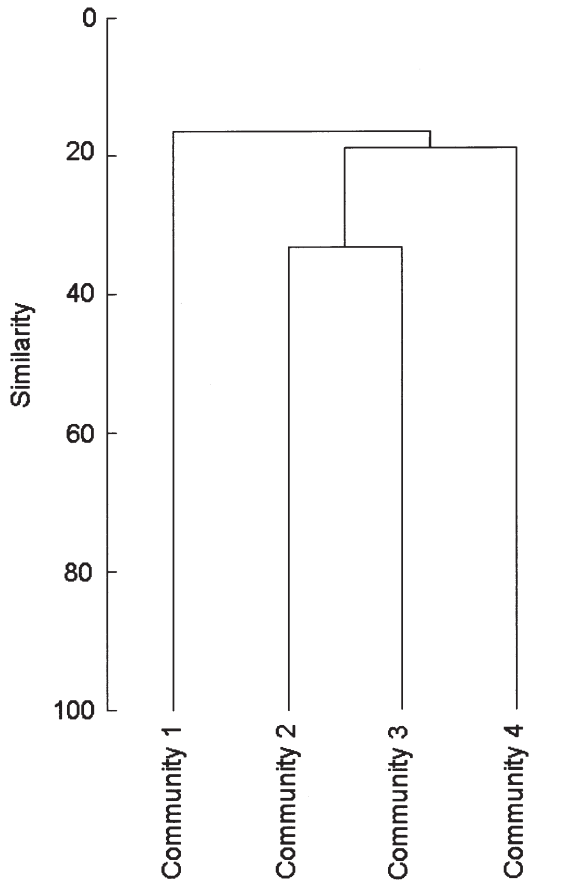


*Figure 2. Dendrogram of the 4 group level classification of 50 quadrats established on the Perserverance Greenstone Belt.*

Community One – This community consisted of six sites commonly found on crests and mid-slopes of ultramafic and metabasalt derived hills. This community is described as open to sparse shrubland of *Acacia* cf. *resinimarginea* and *A. grasbyi* over open to sparse shrubland of *Senna* spp. (*S. artemisioides subsp. helmsii* and *Senna* sp. Meekatharra (E. Bailey 1–26)) over isolated to open shrubland of *Cheilanthes sieberi* subsp. *sieberi*, *Calytrix desolata* or *Harnieria kempeana* subsp. *muelleri* (Table 1). The community had a mean species richness of 8.7 taxa (± 1.3) per plot and indicator species were *A.* cf. *resinimarginea*, *S. artemisioides subsp. helmsii* and *Acacia aneura* var. *fuliginea*.

Community Two – This was the most widespread community on the hills and occurred mostly in the southern part of the range. It occurred mainly on the crests and slopes of banded ironstone and iron-rich chert but also on basalt and felsic rocks. The community is described as open to sparse shrubland of *A. aneura* and *A. quadrimarginea* over isolated to sparse shrubland of *Eremophila* spp. (*Eremophila latrobei*, *Eremophila foliosissima* and *Eremophila galeata*) and *Thryptomene decussata* over isolated to sparse shrubland of *Ptilotus schwartzii* (Table 1). The community had the lowest mean species richness with 7.5 taxa (± 0.4) per plot. There were two indicator species, *Acacia aneura* var. *microcarpa* and *P. schwartzii*.

Community Three – This was the next most widespread community and was found along the entire range on crests and slopes of banded ironstone and iron rich chert. The community is described as open to sparse shrubland of *A. aneura*, *Grevillea berryana*, and *Acacia* spp. (*A. quadrimarginea*, *A. tetragonophylla* and *A.* cf. *resinimarginea*) over open to sparse shrubland of *Scaevola spinescens* and *Eremophila latrobei* and *Senna* sp. Meekatharra (E. Bailey 1–26) over isolated to sparse shrublands of *Ptilotus* spp. (*P. obovatus* and *P. schwartzii*) and *M. georgei* (Table 1). This community had the highest mean species richness of 12.3 taxa (± 1.1) per plot and indicator species were *Sida ectogama*, *A. tetragonophylla*, *P. schwartzii*, *Acacia aneura* var. *microcarpa*, *Cymbopogon ambiguus* and *Senna artemisioides* subsp. x *artemisioides*.

Community Four – This community was recorded at eight sites located on the lower slopes and colluvium derived from metabasalt and ultramafic rocks. This community is described as open to sparse dominated *A. aneura* shrublands and other *Acacia* spp. (*A. pruinocarpa*, *Acacia kempeana* and *A. grasbyi*) over open to sparse shrublands of *Sida ectogama*, *S.* sp. Meekatharra (E. Bailey 1–26*)* and *Eremophila pantonii* over open to sparse shrubland of *M. georgei* and *M. triptera* (Table 1). The community had a mean species richness of 8.5 taxa (± 0.7) per plot and indicator species were *Eremophila oldfieldii*, *M. triptera*, *E. pantonii*, *Acacia oswaldii*, *Hakea preisii* and *A. tetragonophylla*.

### *Environmental correlates*

Prior to analysis, cadmium and molybdenum were removed from the dataset as both were below detectable limits. Non–parametric analysis of variance found ten of the eighteen soil parameters were significantly different between the communities (Table 2) while only one of the eleven site attributes was significant (Table 3). The analyses showed a clear differentiation between Community 2 from Communities 1 and 4. Post-hoc tests failed to discriminate differences between individual community types for iron despite a significant difference ($p < 0.05$).

In terms of site attributes, all communities were similar except for disturbance (Table 3). The plant communities were found in all landscape and morphological types (hill crests, slopes and hillocks) on the Greenstone Belt. The survey area consisted of gentle slopes, low abundance of small surface coarse fragments with very little cover of rock outcrops, on shallow to deep soils.

The soils of the basalt communities (Communities 1 and 4) were less acidic, higher concentrations in elements higher in mafic rocks (Ca, Co, Cu, Mn and K) and higher ECEC than Community 2, which occurred on soils derived from chert and banded ironstone (Table 3). Community 2 occurred on the most acidic sites and less fertile sites. Community 3 had intermediate soil nutrients between the basalt communities (1 & 4) and Community 2 (ironstone). The few exceptions were higher concentrations of potassium and calcium than Community 2 and lower concentrations of copper than Community 1.

The three dimensional SSH ordination (2; stress = 0.1998) showed similar patterns to the univariate analysis. Communities 1 and 4 are well separated from Community 2 on the ordination while Community 3 appears to be intermediate between them (Fig. 3a and 3b). Communities 1 and 4, the basalt communities, correlate with high values of Mg, eCEC, pH, Mn, Cu, Ca, and Co (Fig. 3c and 3d). Community 2 has lower concentrations of these nutrients and correlates with higher disturbance, sulphur and surficial rock (rock outcrop), with the latter not significant in univariate analysis.

## DISCUSSION

### Flora

The flora of the Perseverance Greenstone Belt was depauperate in comparison to the flora of other ironstone ranges, reflected by the low number of taxa and low species richness. The Booylgoo Range, the nearest surveyed range, 75km to the south-west, recorded 209 taxa, with 142 perennial taxa (Markey & Dillon 2010), compared to a total of 88 taxa, with 81 perennial taxa in this survey. Dominance by similar of families was observed in the two areas, with Mimosaceae, Myoporaceae, Chenopodiaceae and Caesalpiniaceae as the dominant perennial families. This composition is typical of communities found in the Murchison IBRA region (Beard 1976; Pringle *et al.* 1994). The paucity of taxa may be associated with increasing aridity expressed as lower rainfall and greater evaporation rates (Hall & Milewski 1994). Low rainfall in the months preceding the survey resulted in the near absence of annuals in the survey.

Endemism and a higher occurrence of priority species are characteristic of some ironstone ranges (Meissner & Caruso 2008 a,b,c; Markey & Dillon 2008 a,b; Gibson *et al.* 2007). Despite the low number of taxa recorded, two priority taxa were recorded during the survey. Both species are regional endemics, with *Grevillea inconspicua* primarily found on rocky mafic substrates within in the Murchison IBRA. *Baeckea* sp. Melita Station (H. Pringle 2738) has been recorded previously on several ironstone ranges within the Murchison (Markey & Dillon 2010; Meissner *et al.* 2009 b,c). In addition to priority species, several ironstone endemics were also recorded, namely *T. decussata* and *S. ectogama*.

### Plant Communities

This survey described four communities found on the Perseverance Greenstone Belt. The greatest floristic differences occurred between the basalt and ironstone communities. The communities on mafic/basalt sites (Communities 1 and 4) and the ironstone communities (2 and 3) were characterised by different species groups and different indicator species. Nearby Booylgoo Range also had floristic differences between communities associated with metabasalt and mafic substrates and those associated with BIF lithologies (Markey & Dillon 2010).

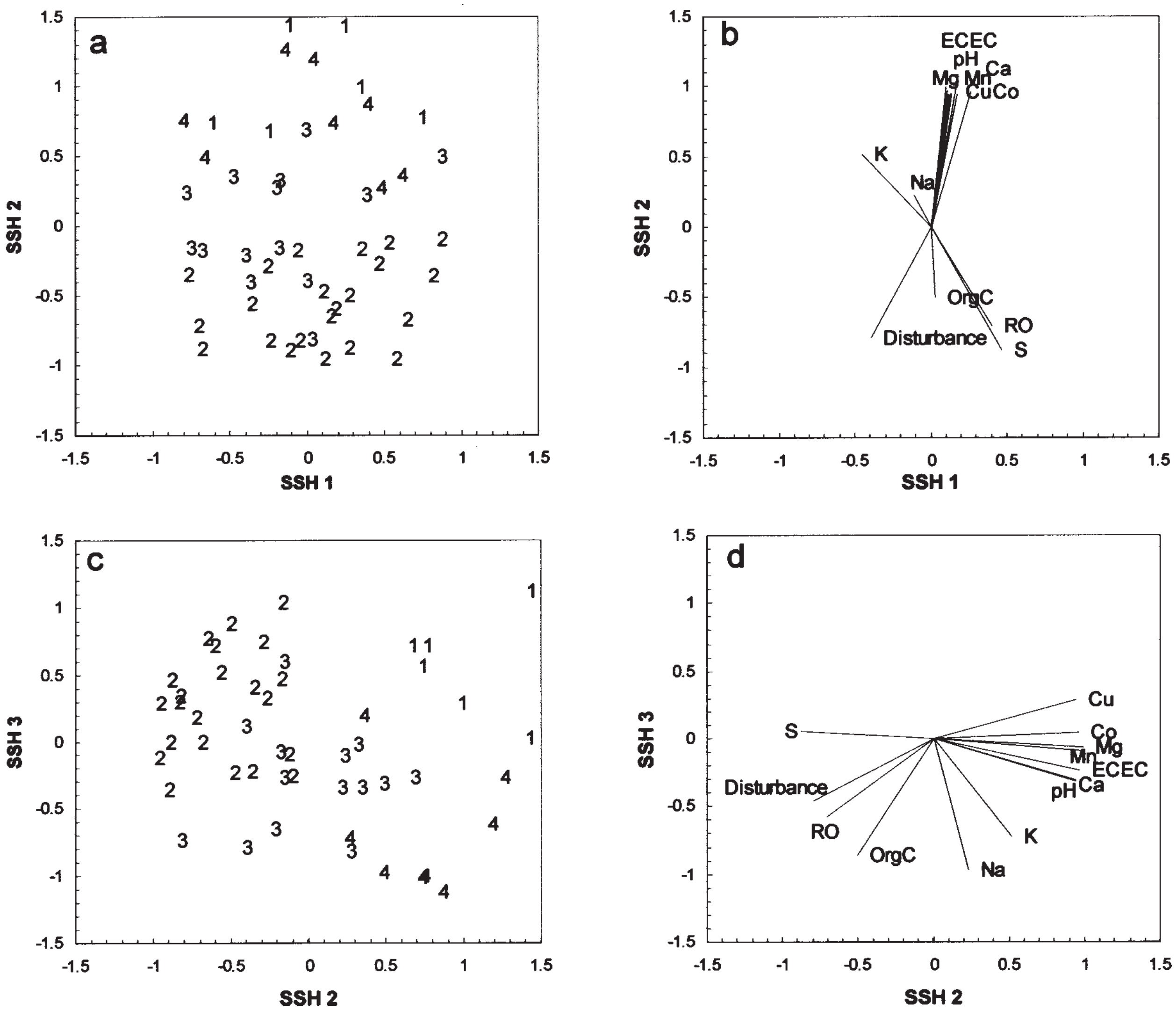


*Figure 3. Three dimensional SSH ordination showing SSH Axes 1, 2 and 3 of the 50 quadrats established on Perseverance Greenstone Belt. The four communities are shown and lines represent the strength and direction of the best fit linear correlated variables (P<0.05).*

The soil chemical composition reflects the underlying geology of the hills, whether basalt (mafic) or banded ironstone and cherts. Mafic rocks tend to be characterised by higher amounts of trace elements such as cobalt, copper and nickel, as well as higher amounts of calcium, magnesium and potassium. These elements are typical of basalts and tend to increase in availability in the soil as the parent rock becomes more mafic (Gray & Murphy 2001).

In this survey, the relief of the range was gentle occurring as undulating hills, as opposed to the steep strike ridges of other ironstone ranges in the Yilgarn Craton (Markey & Dillon 2008a,b; Meissner & Caruso 2008 a,b,c). The lack of any significant topography is reflected in the absence of any floristic distinction between colluvial slopes or crests of the hills. Previous surveys of ironstone communities have found that topography is also important in distinguishing communities. The lower colluvial slopes of the ironstone ranges are generally more fertile with more mobile elements and a different community is found here (Markey & Dillon 2008a,b; Meissner & Caruso 2008 a,b,c).

All four communities found on the Greenstone Belt roughly correspond in general terms to the stony ironstone mulga shrublands (SIMS) and share similar dominants with the 'lateritic' hardpan mulga shrublands described in the rangeland condition survey (Pringle *et al.* 1994). However, the rangeland condition survey failed to discriminate between the basalt and ironstone lithologies of the Perseverance belt communities, as the communities were mapped within the same two land systems known as Violet and Bevon. This is not surprising, considering that this survey is at a much finer scale than was mapped for the rangeland condition survey.

## Conservation

Although the Wanjarri Nature Reserve is nearby, BIF does not occur within this reserve area (Hall *et al.* 1994). A preliminary comparison of the species recorded within this survey and the Wanjarri Nature Reserve found only 30% similarity based on presence/absence data (Bray-Curtis; Clarke & Gorley 2006). Although several taxa recorded in this survey have been recorded within Wanjarri, a comparison of the floristic communities of Wanjarri with those described here shows no similarity. The ironstone communities are similar in structure to the communities on laterite breakways, characterised as *A. aneura* low woodlands, but the latter lacked of the key indicator species found on the two ironstone communities, such as *P. schwartzii* (Hall & Milewski 1994).

To date, mining tenements cover the entire area and exploration is currently underway in the northern part of the survey area. Although this exploration is not targeting banded iron formation, the ecology of these areas has been adversely affected. None of the ironstone hills within this survey is at present within secure Conservation Reserves.

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## REFERENCES

Atkins KJ (2008) *Declared Rare and Priority Flora List for Western Australia, 26 February 2008.* Dept of Environment and Conservation. Como, W.A.

Beard JS (1976) *Vegetation Survey of Western Australia. Murchison 1:1000000 Vegetation Series. Explanatory Notes to Sheet 6. Vegetation of the Murchison Region.* University of Western Australia Press, Perth.

Belbin L (1989) *PATN Technical Reference.* CSIRO Division of Wildlife and Ecology, ACT.

Belbin L McDonald C (1993) Comparing 3 classification strategies for use in ecology. *Journal of Vegetation Science* **4**, 341–348.

Clarke KR Gorley RN (2006) *PRIMER v6: User Manual/Tutorial.* PRIMER-E, Plymouth.

Clarke KR Warwick RM (2001) *Change in Marine Communities: an Approach to Statistical Analysis and Interpretation*, 2nd ed. PRIMER-E: Plymouth.

Clarke KR Somerfield PJ Chapman MG (2006) On resemblance measures for ecological studies, including taxonomic dissimilarities and zero-adjusted Bray-Curtis coefficient for denuded assemblages. *Journal of Experimental Marine Biology and Ecology*, **330**, 55–80.

Department of the Environment and Water Resources (2004) *Interim Biogeographic Regionalisation for Australia (IBRA), Version 6.1.* http://www.environment.gov.au/parks/nrs/science/bioregion-framework/ibra/index.html

Dufréne M Legendre P (1997) Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs* **67**, 345–366.

Eggleton RA (2001) The *Regolith Glossary: Surficial Geology, Soils and Landscapes.* CRC for Landscape Evolution & Mineral Exploration, Floreat WA. 144p.

Gibson N Coates DA Thiele KR (2007) Taxonomic research and the conservation status of flora in the Yilgarn Banded Iron Formation ranges, *Nuytsia* **17**, 1–12.

Gray J Murphy B (2002) Parent material and soil distribution. *Natural Resource Management* **5**, 2–12.

Griffin (1990) Eastern Goldfields Province. In: *Geology and Mineral Resources of Western Australia: Western Australia Geological Survey, Memoir 3*, p 77–119. State Printing Division, Perth.

Hall NJ Milewski AV (1994) Physical Environment. In: The biological survey of the eastern Goldfields of Western Australia. Part 10. Sandstone-Sir Samuel Laverton-Leonora. *Records of the WA Museum Supplement* **47**, 9–23.

Hall NJ McKenzie NL Keighery GJ eds. (1994) The biological survey of the eastern goldfields of Western Australia. Part 10, Sandstone-Sir Samuel and Laverton-Leonora study area. *Records of the Western Australian Museum Supplement* **47**, 166pp.

Liu SF Griffin TJ Wyche S Westaway JM Ferguson KM (1998) *Geology of the Sir Samuel 1:100 000 sheet: Geological Survey of Western Australia, 1:100 000 Geological Series Explanatory Notes*, 26p. Geological Survey of Western Australia, Perth.

Markey AS Dillon SJ (2008a) Flora and vegetation of the banded iron formations of the Yilgarn Craton: the central Tallering Land System. *Conservation Science of Western Australia* 7, 121–149.

Markey AS Dillon SJ (2008b) Flora and vegetation of the banded iron formations of the Yilgarn Craton: the Weld Range. *Conservation Science of Western Australia* 7 151–176.

Markey AS Dillon SJ (2010) Flora and vegetation of the banded iron formations of the Yilgarn Craton: the Booylgoo Range. *Conservation Science of Western Australia* 7, 503–529.

McCune B Mefford MJ (1999) *PC-ORD. Multivariate Analysis of Ecological Data, Version 4.* MjM Software Design, Gleneden Beach, Oregon, USA.

McDonald RC Isbell RF Speight JG Walker J Hopkins MS (1990) *Australian Soil and Land Survey: Field Handbook.* 2nd ed. Department of Primary Industries and Energy and CSIRO, Australia.

Mehlich A (1984) Mehlich 3 soil test extractant: a modification of Mehlich 2. *Communications of Soil Science and Plant Analysis* **15**, 1409–1416.

Meissner R Caruso Y (2008a) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Jack Hills. *Conservation Science of Western Australia*, 7, 89–103.

Meissner R Caruso Y (2008b) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Koolanooka and Perenjori Hills. *Conservation Science of Western Australia* 7, 73–88

Meissner R Caruso Y (2008c) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Mount Gibson and surrounding area. *Conservation Science of Western Australia* 7, 105–120.

Meissner R Owen G Bayliss B (2009a) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Cashmere Downs. *Conservation Science of Western Australia* 7, 349–361.

Meissner R Owen G Bayliss B (2009b) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Mount Forrest-Mount Richardson. *Conservation Science of Western Australia* 7, 377–389.

Meissner R Owen G Bayliss B (2009c) Flora and vegetation of the Banded Iron Formation of the Yilgarn Craton: Robinson Ranges and Mount Gould. *Conservation Science of Western Australia* 7, 363–376.

Metson AJ (1956) Methods of chemical analysis for soil survey samples. *New Zealand Department of Scientific and Industrial Research Soil Bureau Bulletin*,**12**, 1–108.

Paczkowska G Chapman AR (2000) *The Western Australian Flora: a Descriptive Catalogue.* Wildflower Society of Western Australia, Nedlands, W.A.

Page D (2001) Banded iron formations and palaeoenvironment: a problem in petrogenesis *Geology Today*, **17**, 140–143.

Pringle HJR Van Vreeswyk AME Gilligan SA (1994) *Pastoral Resources and Their Management in the North-Eastern Goldfields, Western Australia: an Interpretation of Findings from the Rangeland Survey of the North-Eastern Goldfields.* Department of Agriculture, Perth WA.

Rayment GE Higginson FR (1992) *Australian Laboratory Handbook of Soil and Water Chemical Methods.* Inkata Press, Melbourne.

Rengasamy P Churchman GJ (1999) Cation exchange capacity, exchangeable cations and sodicity. In: *Soil Analysis: an Interpretation Manual.* (eds. KI Peverill, LA Sparrow and DJ Reuter) p. 147–158. CSIRO Publishing, Collingwood, Victoria.

Siegel S (1956) *Non-Parametric Statistics for Behavioural Sciences.* McGraw-Hill, New York.

Trendall AF (1990) Introduction. In: *Geology and Mineral Resources of Western Australia: Western Australia Geological Survey, Memoir 3*, p11. State Printing Division, Perth.

Walkley A (1947) A critical examination of a rapid method for determining organic carbon in soils – effect of variations in digestion conditions and of inorganic constituents. *Soil Science*, **63**, 251–64.

Walton K and Allen D (2004) Mehlich No. 3 Soil Test: the Western Australian experience. In: *SuperSoil 2004: Proceedings of the 3rd Australian New Zealand Soils Conference, University of Sydney, Australia, 5–9 December 2004.* (ed B Singh) www.regional.org.au/au/assi/supersoil2004

Zar JH (1999) *Biostatistical Analysis.* 4th ed. Prentice-Hall, New Jersey.

## APPENDIX

Floristic list for the Perseverance Greenstone Belts, including all taxa from the sampling quadrats and adjacent areas. Nomenclature follows Paczkowska and Chapman (2000).

**Acanthaceae**
*Harnieria kempeana* subsp. *muelleri*

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

**Amaranthaceae**
*Ptilotus obovatus*
*Ptilotus roei*
*Ptilotus schwartzii*

**Asclepiadaceae**
*Marsdenia australis*

**Asteraceae**
*Helipterum craspedioides*
*Rhodanthe maryonii*

**Brassicaceae**
*Lepidium oxytrichum*
*Lepidium platypetalum*

**Caesalpiniaceae**
*Senna artemisioides* subsp. *filifolia*
*Senna artemisioides* subsp. *helmsii*
*Senna artemisioides* subsp. x *artemisioides*
*Senna artemisioides* subsp. x *sturtii*
*Senna charlesiana*
*Senna glaucifolia*
*Senna glutinosa* subsp. x *luerssenii*
*Senna manicula*
*Senna* sp. Meekatharra (E. Bailey 1–26)
*Senna stricta* x *artemisioides* ssp. *petiolaris* (E.N.S. Jackson 2888)

**Casuarinaceae**
*Casuarina pauper*

**Chenopodiaceae**
*Dysphania rhadinostachya* subsp. *rhadinostachya*
*Enchylaena tomentosa* var. *tomentosa*
*Maireana convexa*
*Maireana georgei*
*Maireana georgei* x *Enchylaena tomentosa*
*Maireana thesioides*
*Maireana triptera*
*Rhagodia eremaea*
*Sclerolaena eriacantha*
*Sclerolaena fusiformis*

**Convolvulaceae**
*Duperreya sericea*

**Euphorbiaceae**
*Euphorbia boophthona*

**Geraniaceae**
*Erodium cygnorum*

**Goodeniaceae**
*Scaevola spinescens*

**Lamiaceae**
*Spartothamnella teucriiflora*

**Malvaceae**
*Hibiscus* cf. *gardneri*
*Hibiscus* cf. *solanifolius*
*Sida ectogama*
*Sida* sp. dark green fruits (S. van Leeuwen 2260)
*Sida* sp. Excedentifolia (J.L. Egan 1925)
*Sida* sp. Golden calyces glabrous (H.N. Foote 32)

**Mimosaceae**
*Acacia aneura*
*Acacia aneura* var. cf. *argentea* (short phyllode variant) (BRM 9300)
*Acacia aneura* var. *alata* (flat) (BRM 9689)
*Acacia aneura* var. *alata/microcarpa* (BRM 9083)
*Acacia aneura* var. *argentea* (narrow phyllode variant) (BRM 9745)
*Acacia aneura* var. *argentea* (short phyllode variant) (BRM 9300)
*Acacia aneura* var. *fuliginea*
*Acacia aneura* var. *macrocarpa*
*Acacia aneura* var. *microcarpa*
*Acacia aneura* var. *microcarpa* (broad, incurved phyllode variant) (BRM 9929)
*Acacia aneura* var. *tenuis* (BRM 9296)
*Acacia aneura* var. *tenuis* (flat) (BRM 9353)
*Acacia* cf. *resinimarginea*
*Acacia coolgardiensis*
*Acacia craspedocarpa*
*Acacia grasbyi*
*Acacia kempeana*
*Acacia oswaldii*
*Acacia pruinocarpa*
*Acacia quadrimarginea*
*Acacia ramulosa*
*Acacia sibirica*
*Acacia tetragonophylla*

**Myoporaceae**
*Eremophila foliosissima*
*Eremophila forrestii*
*Eremophila galeata*
*Eremophila granitica*
*Eremophila latrobei* subsp. *latrobei*
*Eremophila metallicorum*
*Eremophila oldfieldii* subsp. *angustifolia*
*Eremophila pantonii*

**Myrtaceae**
*Baeckea* sp. Melita Station (H. Pringle 2738) Priority 3
*Calytrix desolata*
*Thryptomene decussata*

**Poaceae**
*Cymbopogon ambiguus*
*Enneapogon caerulescens*
*Eriachne helmsii*
*Eriachne mucronata*
*Eriachne pulchella*

**Proteaceae**
*Grevillea berryana*
*Grevillea inconspicua* Priority 4
*Hakea preissii*
*Hakea recurva* subsp. *recurva*

**Rubiaceae**
*Psydrax latifolia*
*Psydrax rigidula*
*Psydrax suaveolens*

**Santalaceae**
*Santalum spicatum*

**Sapindaceae**
*Dodonaea petiolaris*
*Dodonaea rigida*

**Solanaceae**
*Solanum* cf. *lasiophyllum*

**Table 1**

Sorted two-way table of quadrats established on the Perseverance Greenstone Belt showing species by community type. Taxa shaded grey within a community are indicator species determined by Dufréne and Legendre (1997) at the 4group level ($p < 0.05$).

| | Species |
|---|---|
| A | *Acacia aneura* var. *argentea* |
| A | *Eremophila foliosissima* |
| A | *Psydrax suaveolens* |
| A | *Sida* sp. Golden calyces glabrous (H.N. Foote 32) |
| A | *Acacia aneura* var. *microcarpa* |
| A | *Ptilotus schwartzii* |
| A | *Eremophila latrobei* subsp. *latrobei* |
| A | *Maireana georgei* |
| A | *Ptilotus obovatus* |
| A | *Eremophila galeata* |
| A | *Senna glaucifolia* |
| A | *Acacia aneura* var. *tenuis* |
| A | *Acacia tetragonophylla* |
| A | *Senna* sp. Meekatharra (E. Bailey 1-26) |
| B | *Sida ectogama* |
| B | *Scaevola spinescens* |
| B | *Maireana convexa* |
| C | *Eremophila oldfieldii* subsp. *angustifolia* |
| C | *Maireana triptera* |
| C | *Eremophila pantonii* |
| C | *Hakea preissii* |
| D | *Acacia craspedocarpa* |
| D | *Acacia pruinocarpa* |
| D | *Maireana thesioides* |
| D | *Eremophila granitica* |
| D | *Harnieria kempeana* subsp. *muelleri* |
| D | *Psydrax rigidula* |
| E | *Acacia sibirica* |
| E | *Senna artemisioides* subsp. x *artemisioides* |
| E | *Cheilanthes sieberi* subsp. *sieberi* |
| E | *Sida* sp. Excedentifolia (J.L. Egan 1925) |
| E | *Cymbopogon ambiguus* |
| E | *Santalum spicatum* |
| E | *Enchylaena tomentosa* var. *tomentosa* |
| E | *Rhagodia eremaea* |
| E | *Eriachne helmsii* |
| F | *Cheilanthes sieberi* subsp. *pseudovellea* |
| F | *Marsdenia australis* |
| F | *Dodonaea petiolaris* |
| F | *Grevillea berryana* |
| F | *Eremophila forrestii* |
| G | *Acacia aneura* var. *fuliginea* |
| G | *Acacia* cf. *resinimarginea* |
| G | *Senna artemisioides* subsp. *helmsii* |
| G | *Acacia grasbyi* |
| G | *Acacia oswaldii* |
| H | *Acacia quadrimarginea* |
| H | *Eriachne mucronata* |
| H | *Thryptomene decussata* |
| H | *Senna stricta* x *artemisioides* subsp. *petiolaris* (E.N.S. Jackson 2888) |
| H | *Baeckea* sp. Melita Station (H. Pringle 2738) |

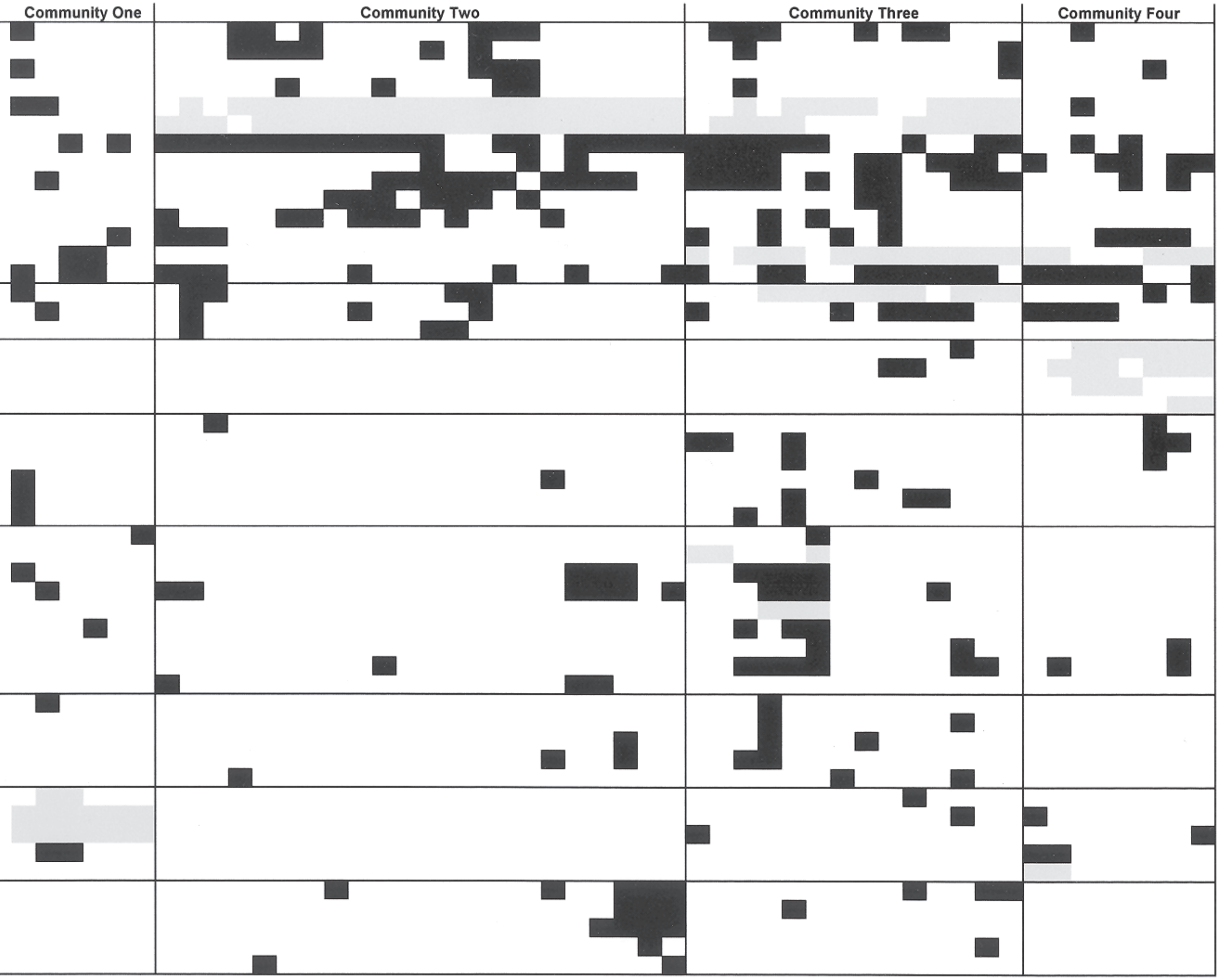

**Table 2**

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 and differences between communities determined using Dunn's *post–hoc* comparison. Standard errors in parentheses. a and b represent significant differences between community types at $p < 0.05$ (n = number of quadrats, p = probability). * *post–hoc* comparison showed no significant differences

| | Community | | | | |
|---|---|---|---|---|---|
| | **One** | **Two** | **Three** | **Four** | **p–value** |
| **Attribute** | **n=6** | **n=22** | **n=14** | **n=8** | |
| pH(CaCl2) | 5.5 (0.2)$^{a}$ | 4.1 (0.0)$^{b}$ | 4.6 (0.2)$^{ab}$ | 5.7 (0.3)$^{a}$ | **< 0.0001** |
| ECEC | 4.6 (0.6)$^{b}$ | 1.2 (0.1)$^{a}$ | 2.0 (0.2)$^{ab}$ | 5.6 (1.1)$^{b}$ | **< 0.0001** |
| P | 7.5 (1.0) | 10.0 (3.3) | 15.0 (4.4) | 8.5 (1.2) | 0.1405 |
| K | 100 (9)$^{a}$ | 76 (5)$^{b}$ | 99 (6)$^{a}$ | 120 (10)$^{a}$ | **0.0002** |
| Mg | 220 (55)$^{bc}$ | 44 (4)$^{a}$ | 80 (13)$^{ab}$ | 240 (37)$^{c}$ | **< 0.0001** |
| Total N | 0.044 (0.006) | 0.045 (0.003) | 0.053 (0.005) | 0.053 (0.004) | 0.1087 |
| OrgC | 0.39 (0.07) | 0.46 (0.04) | 0.52 (0.06) | 0.51 (0.04) | 0.0823 |
| B | 0.1 (0.0) | 0.1 (0.0) | 0.1 (0.0) | 0.1 (0.0) | 0.226 |
| Ca | 510 (78)$^{a}$ | 120 (9)$^{b}$ | 220 (25)$^{a}$ | 660 (160)$^{a}$ | **< 0.0001** |
| Co | 2.00 (0.22)$^{c}$ | 0.21 (0.03)$^{a}$ | 0.60 (0.24)$^{ab}$ | 1.60 (0.22)$^{bc}$ | **< 0.0001** |
| Cu | 1.60 (0.17)$^{b}$ | 0.68 (0.04)$^{a}$ | 0.84 (0.22)$^{a}$ | 1.50 (0.32)$^{ab}$ | **0.0003** |
| Fe* | 49 (3) | 42 (4) | 51 (8) | 46 (4) | **0.0443** |
| Mn | 86 (20)$^{b}$ | 17 (2)$^{a}$ | 42 (19)$^{ab}$ | 62 (10)$^{b}$ | **< 0.0001** |
| Na | 1.4 (0.4) | 2.0 (0.4) | 3.1 (0.8) | 11.0 (4.3) | **0.0326** |
| Ni | 2.1 (0.6) | 0.7 (0.1) | 1.1 (0.4) | 1.6 (0.6) | **0.0204** |
| Pb | 0.35 (0.06) | 0.44 (0.02) | 0.51 (0.07) | 0.54 (0.12) | 0.2903 |
| S | 2.3 (0.4)$^{a}$ | 7.5 (0.5)$^{c}$ | 5.6 (0.6)$^{bc}$ | 4.0 (1.0)$^{ab}$ | **< 0.0001** |
| Zn | 1.7 (0.4)$^{ab}$ | 0.8 (0.1)$^{a}$ | 1.3 (0.2)$^{ab}$ | 1.7 (0.3)$^{b}$ | **0.0032** |

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

| | Community | | | | |
|---|---|---|---|---|---|
| | **One** | **Two** | **Three** | **Four** | **p–value** |
| **Attribute** | **n=6** | **n=22** | **n=14** | **n=8** | |
| Aspect | 187.5 (49.9) | 155.5 (16.7) | 173.6 (24.0) | 123.8 (40.6) | 0.4207 |
| Slope | 1.8 (0.5) | 3.3 (1.1) | 4.1 (1.4) | 1.4 (0.3) | 0.7133 |
| Morph type | 1.8 (0.3) | 2.0 (0.2) | 2.2 (0.4) | 1.9 (0.4) | 0.9854 |
| Land type | 1.7 (0.2) | 1.7 (0.1) | 2.0 (0.3) | 1.6 (0.2) | 0.8454 |
| Disturbance | 0.5 (0.2)$^{a}$ | 1.0 (0.0)$^{b}$ | 1.0 (0.0)$^{b}$ | 0.9 (0.1)$^{ab}$ | **0.0006** |
| CF Size | 4.5 (0.4) | 4.4 (0.2) | 4.5 (0.3) | 4.0 (0.3) | 0.7765 |
| CF Abundance | 4.3 (0.2) | 4.1 (0.1) | 4.4 (0.2) | 4.6 (0.2) | 0.1897 |
| RO Abundance | 0.7 (0.3) | 1.2 (0.4) | 1.1 (0.4) | 0.1 (0.1) | 0.2702 |
| Runoff | 1.5 (0.2) | 1.5 (0.2) | 1.6 (0.2) | 1.3 (0.3) | 0.8511 |
| Soil Depth | 1.7 (0.2) | 1.8 (0.1) | 1.7 (0.2) | 1.9 (0.1) | 0.8607 |