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Flora and vegetation of banded iron formations of the Yilgarn Craton: Barloweerie and Twin Peaks Greenstone Belts

RACHEL MEISSNER AND JESSICA WRIGHT

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

ABSTRACT

The Twin Peaks and Barloweerie Greenstone Belts are located within the Youanmi Terrane and are represented by two ranges, separated by 24km. This paper describes the flora and vegetation of these ranges and their relationship with environmental attributes. One hundred and ninety nine taxa, including 90 ephemerals and four introduced taxa, were recorded from the hills. Seven priority taxa, including one endemic, *Baeckea* sp. Mount Barloweerie (J.Z. Weber 5079), were recorded from the ranges. Hierarchical classification identified three floristic communities on the ranges. Geomorphology differentiated the communities into upland and lowland communities. Significant differences were found between soil depth, rock outcrops and surface fragments as well as some difference in trace elements. No representative areas of the Twin Peaks and Barloweerie Greenstone Belts are within Western Australian conservation estate.

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

INTRODUCTION

Banded iron formations (BIF) are ancient sedimentary rocks formed in the Archaean period approximately 3.8 to 2.5 billion years ago. Within the Yilgarn Craton, BIFs occur as relatively thin deposits associated with Archaean greenstone belts (Page 2001) and as they are more resistant to erosion, BIF form distinct ranges and hills within the region.

The Twin Peaks and Barloweerie Greenstone Belts are located in the Murchison Interim Biogeographic Regionalisation for Australia (IBRA) (Department of the Environment and Water Resources 2004), which is characterised by *Acacia aneura* low woodlands and abundant ephemerals. Within the Murchison region, the primary land use is pastoralism and the greenstone belts occur across Wooleen, Billabalong and Boolardy Stations. Wooleen and Billabalong Stations were part of the first blocks settled by 1874 and 1880, respectively, in the region along the Murchison River (Curry *et al.* 1994). The Barloweerie Greenstone Belt occurs largely within the Pia Wadjarri aboriginal reserve.

Previous vegetation surveys of ironstone ranges on the Yilgarn Craton have shown that each range supports plant communities distinct from other ironstone ranges and often have unique and rare flora (Markey & Dillon 2008a,b; Meissner & Caruso 2008 a,b,c). The objective of this study is to describe the flora and plant communities of the banded ironstone ranges on the Twin Peaks and Barloweerie Greenstone Belts and their relationships with environmental variables, and to provide baseline information for future management.

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Geology

The ironstone ranges surveyed are part of two greenstone belts, Twin Peaks and Barloweerie and occur within the Youanmi Terrane of the Yilgarn Craton (Watkins 1990). The BIF occur within the Windaning Formation, which is defined as a succession of jaspilite BIF and grey-white chert units interlayered with felsic volcanic, volcaniclastic, and volcanogenic rocks, and minor amounts of basalt (Watkins & Hickman 1990). The Windaning formation occurs throughout the Youanmi Terrane and is a distinct stratigraphic marker (Watkins & Hickman 1990).

The main exposure of BIF in the Twin Peak Greenstone Belt is represented by a range approximately 8km along a relatively low strike ridge along a northeast bearing (Fig. 1). South of this range, the exposure near Mount Hope is poor and very weathered (Baxter 1974). Within the Barloweerie Greenstone Belt, 24km to the east of the Twin Peaks belt, the ironstone is exposed in a narrow fold that forms the dominant ridge of Mount Barloweerie, the highest peak in the area (Fig. 1).

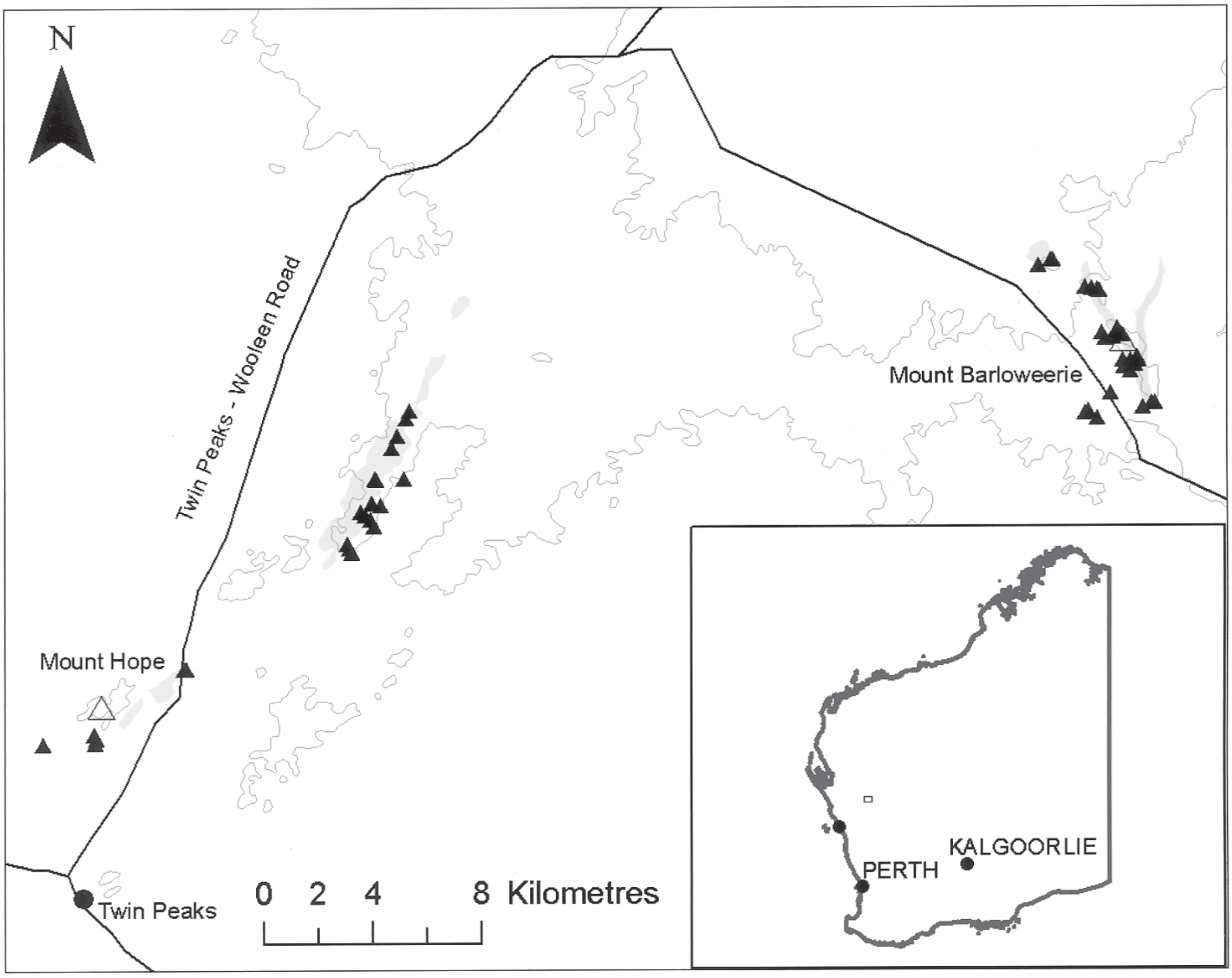

Figure 1. Location of the 51 plots (▲) established on the Twin Peaks and Mount Barloweerie Greenstone Belts. The 300 m contour is shown with the highest peaks of Mount Hope (330m) and Mount Barloweerie (428m). Shaded grey represent banded iron formation of the Windaning formation.

Climate

The climate of the region is classified as arid and characterised by hot, dry summers and mild winters. Rainfall is bimodal, with significant rainfall events occurring in winter and summer (Beard 1976). The two highest mean monthly rainfalls at Murchison Settlement (ca. 50km north of Mount Hope) occur in January and June (31.2mm and 30.5mm respectively), with highest recorded daily rainfall of 143.8mm in January 1963. Mean annual rainfall at Murchison Settlement is 245.1mm, with large variation (139.2mm 1st decile; 402.5mm 9th decile; recorded 1989 to 2009).

Summer rainfall is influenced by cyclonic activity off the north west coast of Western Australia with convectional activity bringing either isolated thunderstorms in localised areas, or widespread rainfall (Curry *et al.* 1994). In contrast, winter rainfall is associated with low pressure systems originating in the Southern Ocean. The cold fronts arising from the south west systems often weaken as they move inland and result in isolated showers and strong winds (Curry *et al.* 1994).

The highest maximum temperatures occur during summer, with the January as hottest month (mean maximum temperature 39.2 °C and mean 14.4 days above 40 °C). Winters are mild with lowest mean maximum temperature of 20.9 °C recorded for July. Temperatures rarely fall below 2 °C in winter and there is a mean minimum of 6.1 °C in July.

Vegetation

Beard (1976) mapped the ranges of the Twin Peaks and Barloweerie Greenstone Belts as several vegetation associations. The lower and colluvial slopes were mapped as *A. aneura* shrublands over *Eremophila spathulata* and *Eremophila* sp. aff. *compacta* shrublands. The BIF vegetation on the Twin Peaks Greenstone Belt was mapped as *A. aneura* and *Acacia quadrimarginea* open shrublands, while the vegetation on Mount Barloweerie was mapped as *A. aneura* and *Acacia* spp. (*A. ramulosa* var. *linophylla*, *A. effusifolia*) shrublands over *Thryptomene johnsonii*, *Eremophila forrestii*, *Solanum lasiophyllum*, *Maireana* *convexa*, *Eremophila* sp. over *Myriocephalus guerinae* and *Brachyscome* sp.

In a more recent rangeland condition survey, the BIF of the Twin Peaks and Mount Barloweerie Greenstone Belt are characterised by the Gabanintha land system (Curry *et al.* 1994). Land systems are used to assess rangeland resources and describe recurring patterns of geomorphology, vegetation and soils (Curry *et al.* 1994). The Gabanintha land system is characterised as ridges, hills and footslopes of various greenstones, supporting sparse *Acacia* and other mainly non-halophytic shrublands.

Typically, the crests and upper slopes of the ranges were characterised by either Rocky Hill Mixed Shrublands or Stony Mulga Mixed Shrublands vegetation types, with the latter characterising the lower slopes and stony plains (Curry *et al.* 1994). The Rocky Hill Mixed Shrublands are dominated by *A. aneura*, *Eremophila macmillaniana* and *Ptilotus obovatus* and several species found only within this vegetation type, *Acacia grasbyi*, *Eremophila glutinosa*, *Solanum ashbyae*, *Tribulus platypterus*, *Cheilanthes austrotenuifolia* and *Spyridium* sp. (Curry *et al.* 1994). The Stony Mulga Mixed Shrubland on the stony slopes, footslopes and plains was dominated by *A. aneura*, *A. pruinocarpa*, *A. grasbyi*, *Eremophila macmillaniana*, *E. spathulata*, *E. fraseri*, *E. freelingii*, *E. spathulata*, *Solanum lasiophyllum*, *Ptilotus rotundifolius*, *Senna helmsii*, *P. obovatus* and *Ptilotus 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 and Dillon 2008a,b; Meissner and Caruso 2008a,b,c). Fifty one 20 x 20 m quadrats were established on the crests, slopes and foot slopes of the Twin Peaks and Mount Barloweerie Greenstone Belts in August 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 position was determined using a Global Positioning System (GPS) unit. Presence/ absence of 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 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 vertical stratum of vegetation (tallest, mid- and lower) to describe the structure of plant communities following McDonald *et al.* (1990).

Twenty soil samples were collected from the upper 10 cm of the soil profile within each quadrat. The samples were bulked and the 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 maintain consistency with previous ironstone surveys (Meissner and Caruso 2008 a,b,c). Preliminary analysis showed high correlations between the similarity matrix derived from the full data set and that with the annual species and singletons were removed ($r = 0.793$).

The quadrat and species classifications were undertaken using the Bray and Curtis coefficient followed by Flexible Unweighted pair-group mean average (UPGMA; Clarke & Gorley 2006) clustering. The Bray and 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 and 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 assuming 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).

Taxonomic nomenclature generally follows Paczkowska and Chapman (2000).

RESULTS

Flora

A total of 199 taxa, including 91 genera from 36 families, were recorded from the Twin Peaks and Mount Barloweerie Greenstone Belt. These were dominated by Asteraceae (27 taxa), Mimosaceae (25), Chenopodiaceae (20), Poaceae (17), Myoporaceae (11) and Caesalpiniaceae (10). The dominant genera were *Acacia* (24), *Eremophila* (nine), *Senna* (10), *Ptilotus* (eight) and *Maireana* (eight). Ninety ephemerals and four introduced taxa were recorded.

Rare and Priority Flora

Priority taxa are considered to be poorly known, potentially rare or threatened taxa (Atkins 2008). Seven priority flora, as defined by Atkins (2008), were recorded in this survey, with two new records for the study area.

- *Hemigenia tysonii* (Priority 3) is a low spinescent and divaricate shrub found on rocky slopes and flats. The taxon is distinguishable from it's closest relatives by dendritic indumentum and larger bracteoles (Guerin 2008). It is only known from 13 specimens within the State Herbarium but was locally abundant on footslopes and plains in the survey area.
- *Eremophila simulans* subsp. *megacalyx* (Priority 3) is a shrub to 2m with distinct serrated leaves. It is restricted to the area around Boolardy and Wooleen stations, where this survey was undertaken. It was found growing on lateritic slopes and crests adjacent to Mount Barloweerie. It is distinguished from *E. simulans* subsp. *simulans* by larger petals and sepals with a mixture of glandular and eglandular hairs (Chinnock 2007).
- *Acacia* sp. Muggon Station (S. Patrick & D. Edinger SP 3235) (Priority 2) is a low, flat topped shrub to 1m, characterised by three nerved, erect phyllodes. It is currently known from only three specimens, growing on rocky ridges and slopes. The taxon was found at two separate locations on the Twin Peaks range on rocky outcrops.
- *Prostanthera petrophila* (Priority 1) is shrub to 1.5m with small white flowers with violet striations on the lobes. The type was collected from Mount Barloweerie with other populations found on the Twin Peaks range. Since the original description (Conn 1988), it has been found on the Weld range (Markey & Dillon 2008b). It grows on rocky slopes and crests as well as laterite.
- *Micromyrtus placoides* (Priority 3) is a myrtaceous shrub to 2m with white flowers and a distinctive laterally swollen hypanthium (Rye 2006). It was recorded growing on the slopes and crests of Mount Barloweerie and is a new record for the area. It has been collected from other nearby ironstone ranges, namely Weld Range and Tallering Peak.
- *Baeckea* sp. Mount Barloweerie (J.Z. Weber 5079) (Priority 1) is a myrtaceous shrub to 2m. Prior to this survey, it was known from only two collections from Mount Barloweerie. This survey found new populations on the Twin Peaks Greenstone Belt growing on the mid and lower slopes of the range. This species appears to be highly restricted and endemic to the two ranges.
- *Gunniopsis divisa* (Priority 1) is a prostrate annual herb with pale white flowers. This species is distinctive with wiry branchlets and flowers with many stamens (Venning 1984). It has been collected previously from the area occurring in areas of drainage and the footslopes of ranges, and appears to be an ephemeral.

Flora of taxonomic interest

Three taxa were collected during the survey that could not be identified beyond genus, even with sufficient floral and fruiting material. Further taxonomic work and additional collections need to be made to determine their significance and status.

- *Solanum* aff. *sturtianum* (Meissner & Wright 2083) is a shrub to 2m with a distinct dense tomentum of short & long multiseriate hairs on the leaves. The specimen was collected from a single site on the crest of Mount Barloweerie. It differs from *Solanum sturtianum* in the indumentum, which has sessile porrect-stellate hairs (Symon 1981). *Solanum* aff. *sturtianum* matches another collection from the area, and identified as *S. sturtianum* (PERTH 03699218) but was noted on the specimen, at the time of the *Solanum* revision (Symon 1981), to be an atypical example. Further collections with fruit and flowers are needed to clarify the status of this taxon.
- *Hemigenia* aff. *ciliata* (Meissner & Wright 2080) is a shrub to 60 cm, with conduplicate leaves and large purple flowers. It was growing on an outcrop of banded ironstone on the midslope of the Twin Peaks range with *Mirbelia rhagodioides* and *Baeckea* sp. Mount. Barloweerie (J.Z. Weber 5079). It differs from *Hemigenia ciliata* mainly in the size of the flowers, with the calyx lobes shorter than the tube of the corolla and the corolla from *Hemigenia* aff. *ciliata* nearly three times as large. This population occurs approximately 130km north west of the nearest population of *Hemigenia ciliata,* but without further collections it is difficult to determine whether the

population is atypical and may be at an extreme end of variation.

- *Hibiscus* aff. *solanifolius* is a shrub to 60 cm found growing on the slopes of both greenstone belts. The collections are similar to those made from Robinson Ranges (Meissner *et al.* 2009) and differed from *H. solanifolius* with fewer epicalyx lobes, the calyx lobes did not exceed the capsule and the capsule had appressed silky hairs rather than tomentose. *Hibiscus solanifolius sensu stricta* is found mainly on the Central Ranges of Western Australia, near the South Australian border.

Plant communities

Prior to analysis, several varieties within *A. aneura* were combined into morphological groups, as the current taxonomy of this group is still under study. Taxa that could not be determined to subspecies level were also combined (e.g. *E. forrestii*). The final analysis included 75 perennial taxa.

Three plant communities were described for the Twin Peaks and Barloweerie Ranges. Four sites were species poor and could not be classified into a community type. The species poor sites, on the left of the dendrogram, were the first sites to be separated in the classification (Table 1). Communities 1 and 2 were the most similar to each other, with Community 1 occurring mainly on the crests, upper and mid slopes of both greenstone belts, and Community 2 found mainly on the lower slopes and footslopes, predominately on the Twin Peaks Greenstone Belt. Community 3 occurred on lateritic breakaways derived from meta-basalt, located on the Barloweerie Greenstone Belt. Table 1 shows the patterns of species occurrence across the communities and unclassified plots.

Community one – This community was found on the crest and upper slopes of both ranges and has an as isolated to sparse shrublands of *A. aneura* and *A. ramulosa* over open to sparse shrublands of *Thryptomene decussata*, *Eremophila latrobei*, *Eremophila glutinosa* and *Acacia scleroclada* over open to sparse shrublands and grasslands of *Sida* sp. Golden calyces glabrous (H.N. Foote 32), *P. obovatus*, *P. schwartzii*, *Eriachne pulchella* and *Aristida contorta*. Mean species richness was 13.4 taxa (±0.8) per site. The indicators species were *Cheilanthes sieberi* subsp. *sieberi*, *E. latrobei* subsp. *latrobei* and *T. decussata*.

Community two – This community occurred mainly on the lower slopes and footslopes of the Twin Peaks Greenstone Belt. It is characterised by open to sparse shrublands of *A. aneura* and *A. ramulosa* over open to sparse shrublands of *Acacia tetragonophylla*, *Senna artemisioides* subsp. *helmsii*, *Senna* sp. Meekathara (E. Bailey 1–26), *Eremophila* spp. (*E. macmillaniana*, *E. simulans* and *E. glutinosa*) over mid-dense to open forbland and grassland of *P. obovatus*, *Aristida contorta* and *Eriachne pulchella*. Mean species richness was 14.3 taxa (±0.8) per site. The indicators species were *S. artemisioides* subsp. *helmsii*, *Sida ectogama*, *Acacia aneura* subsp. *alata*, *E. galeata* and *Maireana triptera*.

Community three – This community occurred on laterite breakaways surrounding Mount Barloweerie and is described as open to sparse shrublands of *A. aneura* and *A. aulacophylla* over open to sparse shrublands of *Philotheca sericea* over sparse shrublands and forblands of *P. schwartzii* and *Stylidium longibracteatum*. The mean species richness was 12.2 taxa (±1.5) per site and indicator species were *A. aulacophylla*, *Stylidium longibracteatum*, *Philotheca sericea* and *Acacia* aff. *sibirica*.

Environmental variables

Non-parametric analysis found four of the eighteen soil attributes (Table 2) and seven of the twelve site attributes (Table 3) were significantly different between vegetation communities. Community 1, the upland sites found on both greenstone belts, occurred on less acidic soils than Community 3 and sites with higher organic carbon and iron content than Community 2. This community occurred on stony sites with greater cover of exposed bedrock, and as consequence, the soils were shallower.

The lowland community (Community 2) occurred mainly on the Twin Peaks Greenstone Belt, and frequently on the footslopes and lower slopes. This community had less acidic and deeper soils than Communities 1 and 3. The soil of Community 2 was lower in organic carbon and iron than Community 1 and higher in a several trace elements, boron, cobalt and manganese, than Community 3. The community occurred on gentle slopes with lower surficial rock, smaller coarse fragments.

Community 3, found on lateritic breakaways, had the greatest cover of surficial rock and shallowest soil. These soils were the most acidic and had the highest concentration of iron of all communities but lowest concentration of boron. The sites assigned to Community 3 occurred on gentle slopes with the highest cover of bare soil.

Three dimensional SSH ordination (stress = 0.2228; Fig. 2) show similar patterns to univariate analysis. Communities 1 and 2 are clearly separated on the ordination (Fig. 2a & 2c), with Community 3 intermediate between the two. From the PCC, rock outcrop abundance, coarse fragment size, steeper slopes, higher iron, organic carbon and nitrogen concentrations were higher in Community 1 and lower in Community 2 (Fig. 2b & 2d) confirming the results of the univariate analysis.

DISCUSSION

Flora

Species richness of the Twin Peaks and Barloweerie Greenstone Belt was similar to other ironstone ranges, Jack Hills (208 taxa; Meissner & Caruso 2008a) and the Weld Range (239 taxa; Markey & Dillon 2008b). Both surveys occurred following an above average rainfall that resulted in a high abundance of ephemeral taxa. Prior to the current survey approximately 60mm of rain was recorded at Murchison Settlement and abundant

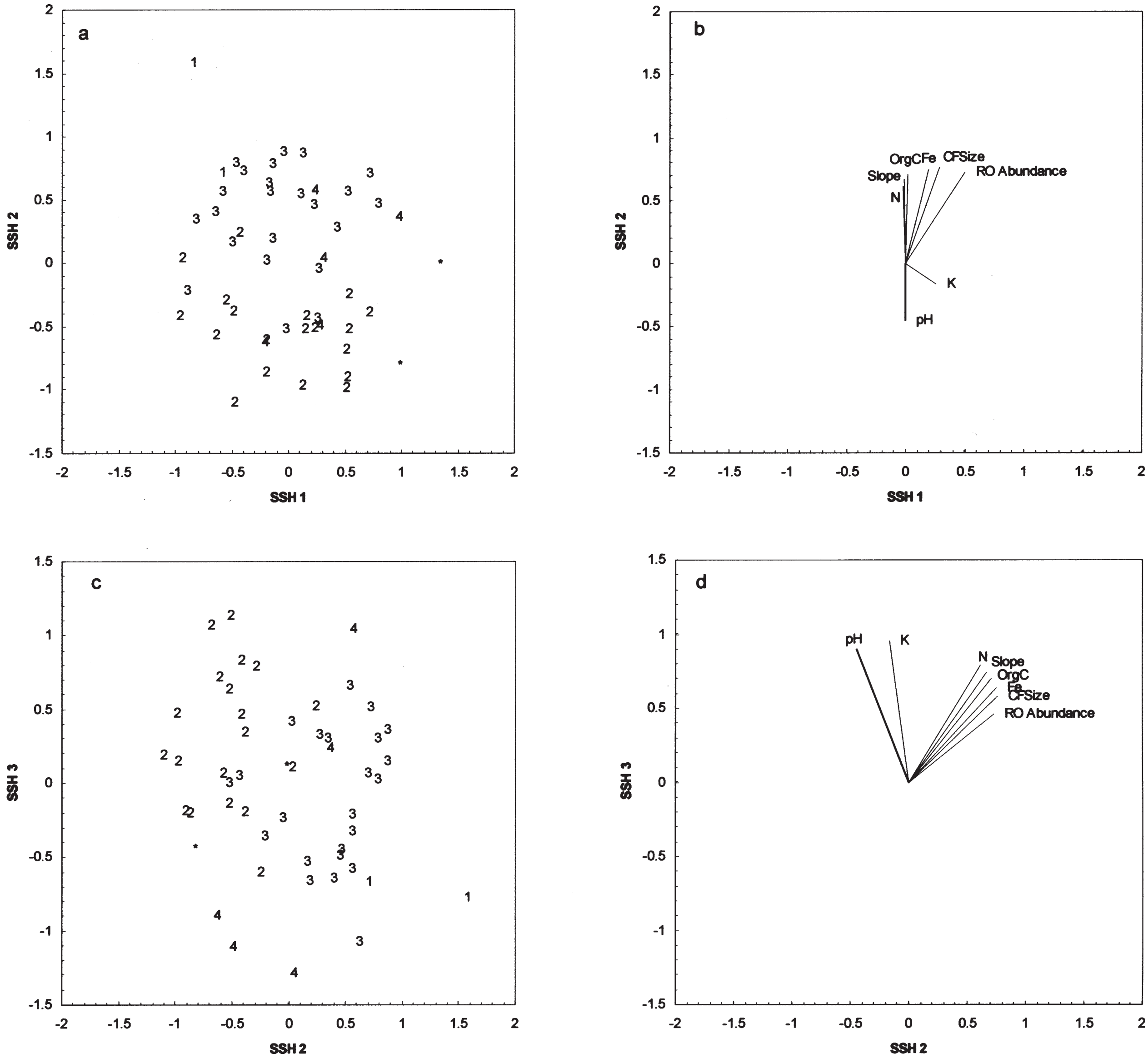

Figure 2. Three dimensional SSH ordination of the 51 quadrats established on Twin Peaks and Barloweerie Greenstone Belts. The three communities are shown and lines represent the strength and direction of the best fit linear correlated variables (P<0.05).

ephemerals were recorded. Ephermerals comprised approximately 44% of the taxa recorded in this survey with the majority belonging to Asteraceae, a pattern typical of winter rainfall in the Murchsion (Mott 1972).

Endemism and high occurrence of priority taxa are characteristic of ironstone ranges within the Yilgarn Craton (Gibson *et al.* 2007). In this survey, high numbers of priority taxa were recorded from the ranges, with the highest number from Mount Barloweerie. As well as being a priority taxon, *Baeckea* sp. Mount Barloweerie (J.Z. Weber 5079) is also endemic to the ranges. Originally this species was only found on Mount Barloweerie but several other collections were made from the Twin Peaks Range. Two ironstone and regional endemics were also recorded, namely *Mircomyrtus placoides* and *Prostanthera petrophila*. Endemism associated with the arid ranges has been hypothesised to act as evidence of refugia during periods of climatic change (Byrne 2008).

Vegetation

These three communities in this survey were determined by geomorphology which inturn influenced soil properties. The two main communities occurred in different positions in the landscape, upland (Community 1) and lowland (Community 2), with Community 3 found only on laterite. The upland communities had skeletal soil and higher cover of exposed bedrock, while the lowland communities had deeper soils and little to no surficial rock. A soil moisture gradient, which was not measured in this survey, may contribute to the distribution of the communities, where the more skeletal soil found on the upland community will retain little water in comparison to deeper soils in the lowland community.

In addition to a possible soil moisture gradient, there were some differences in the concentration of several trace and mobile elements between the upland and lowland communities. With weathering, the mobile elements in the soil are leached from the crests and enrich the lower slopes (Ben-Shahar 1990). This is consistent with the soil chemistry at each community; boron, cobalt and manganese were highest in Community 2 (lowland) and lowest in Community 3 (upland). Differences between upland and lowland communities have been observed on other ironstone ranges (Meissner & Owen, in review a) and in the catenas of Eastern Transvaal in South Africa and was attributed to soil nutrients (Ben-Shahar 1990). The laterite community (Community 3) was also lower in some mobile elements and higher in iron, a characteristic of the laterite communities, which are the product of extensive weathering in the Tertiary (Cornelius *et al.* 2007; Britt *et al.* 2001).

The main communities found on the ranges roughly correspond to the Rocky Hill Mixed Shrublands and Stony Mixed Mulga Shrublands vegetation types (Curry *et al.* 1994). The descriptions are generalised however it is difficult to make a precise comparison. These vegetation descriptions have been applied to other ironstone ranges on the Yilgarn, such as the nearest ranges, Wolla Wolla and Wadgingarra Hills, 50km south of Twin Peaks (Markey & Dillon in review). The main community from Markey & Dillon (in review) occurred on the crests and upper slopes of the hills and was typified by the presence of *Sida ectogama*, *Acacia umbraculiformis*, *Sida* sp. Golden calyces glabrous, *Hakea recurva* subsp. *arida*, *Arthropodium dyeri* and *Thryptomene decussata*. Some similarities exist between the Markey & Dillon (in review) community and the upland community in this survey, but several of its indicator species are absent *ie. A. umbraculiformis, Hakea recurva* subsp. *arida*, *Arthropodium dyeri*. The species turnover, even over a distance of 50km, is characteristic of the ranges within the Yilgarn (Meissner & Owen, in review b).

Conservation

The high number of endemic and priority taxa present on these ranges, especially on Mount Barloweerie, makes the ranges an important area for conservation. The majority of the Twin Peaks range occurs on a single pastoral lease while the bulk of Mount Barloweerie occurs within the Pia Wadjarri Aboriginal Reserve. Currently none of the ranges occur within conservation estate,

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APPENDIX

Floristic list for Twin Peaks and Barloweerie Greenstone Belts, including all taxa from the sampling quadrats and adjacent areas. Nomenclature follows Paczkowska and Chapman (2000). P1, P2 and P3 represent conservation status as per Atkins (2008) * introduced taxa

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

Aizoaceae
- *Cleretum papulosum*
- *Gunniopsis divisa* P1
- *Tetragonia cristata*
- *Tetragonia diptera*

Amaranthaceae
- *Ptilotus aervoides*
- *Ptilotus gaudichaudii* var. *gaudichaudii*
- *Ptilotus gaudichaudii* var. *parviflorus*
- *Ptilotus helipteroides*
- *Ptilotus macrocephalus*
- *Ptilotus obovatus*
- *Ptilotus polystachyus* var. *polystachyus*
- *Ptilotus schwartzii*

Anthericaceae
- *Thysanotus manglesianus*
- *Thysanotus speckii*

Apiaceae
- *Trachymene cyanopetala*
- *Trachymene ornata*
- *Trachymene pilbarensis*

Asclepiadaceae
- *Marsdenia australis*
- *Rhyncharrhena linearis*

Asteraceae
- *Brachyscome cheilocarpa*
- *Brachyscome ciliocarpa*
- *Calocephalus multiflorus*
- *Calotis hispidula*
- *Calotis multicaulis*
- *Cephalipterum drummondii*
- *Ceratogyne obionoides*
- *Chthonocephalus pseudevax*
- *Dielitzia tysonii*
- *Erymophyllum ramosum* subsp. *ramosum*
- *Gilruthia osbornei*
- *Gnephosis arachnoidea*
- *Helipterum craspedioides*
- *Lawrencella rosea*
- *Lemooria burkittii*
- *Myriocephalus guerinae*
- *Olearia stuartii*
- *Podolepis canescens*
- *Podolepis gardneri*
- *Pogonolepis stricta*
- *Rhodanthe battii*
- *Rhodanthe charsleyae*
- *Rhodanthe citrina*
- *Rhodanthe floribunda*
- *Rhodanthe maryonii*
- *Schoenia cassiniana*
- *Waitzia acuminata* var. *acuminata*

Boraginaceae
- *Trichodesma zeylanicum* var. *grandiflorum*

Brassicaceae
- *Lepidium oxytrichum*
- *Stenopetalum anfractum*

Caesalpiniaceae
- *Senna artemisioides* subsp. *filifolia*
- *Senna artemisioides* subsp. *helmsii*
- *Senna artemisioides* subsp. x *sturtii*
- *Senna charlesiana*
- *Senna glaucifolia*
- *Senna glutinosa* subsp. x *luerssenii*
- *Senna* sp. Austin (A. Strid 20210)
- *Senna* sp.
- *Senna* sp. Meekatharra (E. Bailey 1-26)
- *Senna stricta* x *artemisioides* ssp. *petiolaris* (E.N.S. Jackson 2888)

Chenopodiaceae
- *Atriplex codonocarpa*
- *Dysphania glomulifera* subsp. *eremaea*
- *Dysphania melanocarpa* forma *melanocarpa*
- *Dysphania rhadinostachya* subsp. *inflata*
- *Dysphania rhadinostachya* subsp. *rhadinostachya*
- *Enchylaena* sp.
- *Enchylaena tomentosa* var. *tomentosa*
- *Maireana carnosa*
- *Maireana convexa*
- *Maireana georgei*
- *Maireana planifolia*
- *Maireana* sp.
- *Maireana thesioides*
- *Maireana triptera*
- *Maireana villosa*
- *Rhagodia eremaea*
- *Salsola australis*
- *Sclerolaena densiflora*
- *Sclerolaena eriacantha*
- *Sclerolaena gardneri*

Colchicaceae
- *Wurmbea inframediana*

Crassulaceae
- *Crassula colorata* var. *acuminata*

Cuscutaceae
- **Cuscuta epithymum*
- **Cuscuta planiflora*

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

Frankeniaceae
- *Frankenia laxiflora*

Geraniaceae
Erodium cygnorum
Erodium sp. (Meissner & Wright 2273)

Goodeniaceae
Brunonia australis
Goodenia berardiana
Goodenia kingiana
Goodenia macroplectra
Goodenia occidentalis
Goodenia pinnatifida
Scaevola spinescens
Velleia hispida

Haloragaceae
Haloragis odontocarpa
Haloragis odontocarpa forma *octoforma*
Haloragis odontocarpa forma *pterocarpa*
Haloragis odontocarpa forma *rugosa*
Haloragis trigonocarpa

Lamiaceae
Hemigenia aff. *ciliata* (Meissner & Wright 2080)
Hemigenia tysonii P3
Prostanthera petrophila P1
Spartothamnella teucriiflora

Malvaceae
Abutilon cryptopetalum
Abutilon oxycarpum
Hibiscus aff. *solanifolius* (Meissner & Wright 2307)
Hibiscus gardneri
Hibiscus sp.
Sida ectogama
Sida sp. dark green fruits (S. van Leeuwen 2260)
Sida sp. Golden calyces glabrous (H.N. Foote 32)

Mimosaceae
Acacia aff. *sibirica* (Meissner & Wright 2320)
Acacia aneura var. cf. *alata* (narrow phyllode variant) (BRM9058)
Acacia aneura var. cf. *argentea* (short phyllode variant) (BRM9300)
Acacia aneura var. *alata* (Fairman 238)
Acacia aneura var. *alata* (narrow phyllode variant) (BRM 9058)
Acacia aneura var. *alata/microcarpa* (BRM 9083)
Acacia aneura var. *argentea* (narrow phyllode variant) (BRM 9745)
Acacia aneura var. *fuliginea*
Acacia aneura var. *microcarpa* (BRM 9794)
Acacia aneura var. *microcarpa* (broad, incurved phyllode variant) (BRM 9929)
Acacia aulacophylla
Acacia citrinoviridis
Acacia craspedocarpa
Acacia cuthbertsonii subsp. *cuthbertsonii*
Acacia eremaea
Acacia grasbyi
Acacia pruinocarpa
Acacia ramulosa var. *linophylla*
Acacia ramulosa var. *ramulosa*
Acacia rhodophloia
Acacia scleroclada
Acacia sp.
Acacia sp. Muggon Station (S. Patrick & D. Edinger SP 3235) P2
Acacia tetragonophylla

Myoporaceae
Eremophila clarkei
Eremophila forrestii subsp. *forrestii*
Eremophila forrestii subsp. *hastieana*
Eremophila galeata
Eremophila georgei
Eremophila glutinosa
Eremophila latrobei subsp. *latrobei*
Eremophila macmillaniana
Eremophila simulans subsp. *megacalyx* P3

Myrtaceae
Aluta aspera subsp. *hesperia*
Baeckea sp. Mount Barloweerie (J.Z. Weber 5079) P1
Calytrix sp. Paynes Find (F. & J. Hort 1188)
Micromyrtus placoides P1
Micromyrtus sulphurea
Thryptomene decussata

Papilionaceae
Mirbelia rhagodioides

Poaceae
Aristida contorta
Austrostipa nitida
Austrostipa scabra
Austrostipa trichophylla
Cymbopogon ambiguus
Enneapogon caerulescens
Eragrostis dielsii
Eragrostis lanipes
Eragrostis pergracilis
Eriachne aristidea
Eriachne pulchella
Monachather paradoxus
Paspalidium basicladum
**Pentaschistis airoides* subsp. *airoides*
**Rostraria pumila*
Thyridolepis multiculmis

Portulacaceae
Calandrinia cf. *eremaea*
Calandrinia cf. *polyandra*
Calandrinia cf. *translucens*
Calandrinia creethae
Calandrinia eremaea complex
Calandrinia sp. Bullardoo (F. Obbens & F. Hort FO 57/04)
Calandrinia sp. The Pink Hills (F. Obbens FO 19/06)
Portulaca oleracea

Proteaceae
Grevillea berryana
Hakea recurva subsp. *arida*

Rubiaceae
Psydrax suaveolens
Philotheca brucei subsp. *brucei*
Philotheca sericea

Santalaceae
Santalum spicatum

Sapindaceae
Dodonaea pachyneura
Dodonaea petiolaris

Solanaceae

Nicotiana rosulata subsp. *rosulata*
Nicotiana simulans
Solanum aff. *sturtianum* (Meissner & Wright 2083)
Solanum lasiophyllum
Solanum nummularium

Stackhousiaceae

Stackhousia muricata

Stylidiaceae

Stylidium longibracteatum

Zygophyllaceae

Tribulus astrocarpus
Tribulus forrestii
Tribulus suberosus
Zygophyllum eichleri

Table 1

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

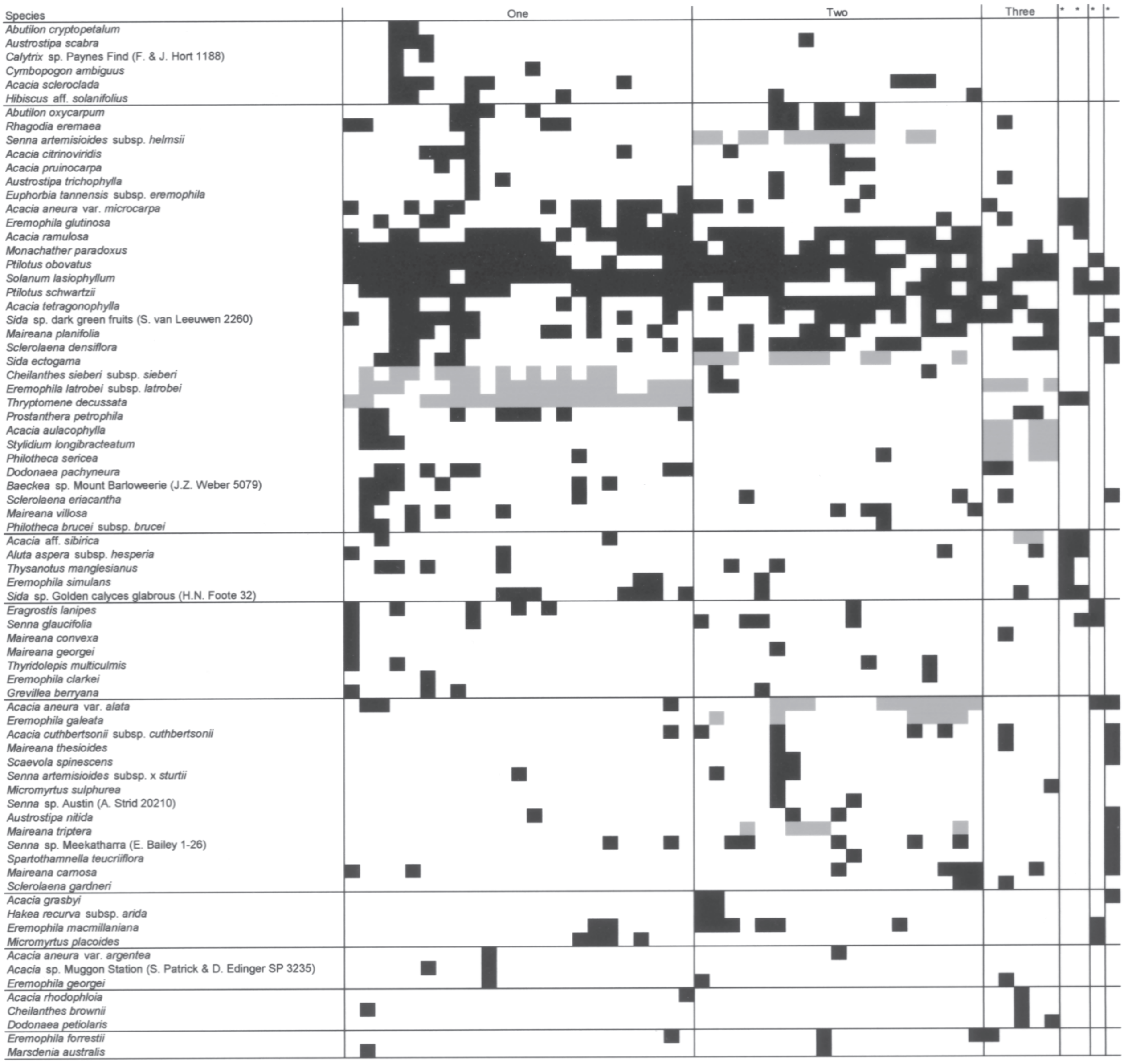

Table 2

Mean values for soil attributes (measured in mg/kg except pH and ECEC) 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 error in parentheses. a and b represent significant differences between community types at p < 0.05 (n = number of quadrats, p = probability).

	Community One	**Community Two**	**Community Three**	**P value**
n=	**23**	**19**	**5**	
pH(CaCl2)	4.4 (0.055)[a]	4.6 (0.071)[a]	4.18 (0.18)[b]	**0.0124**
ECEC	1.2 (0.12)	1.4 (0.13)	1.3(0.4)	0.3145
P	38 (13)	14 (1.4)	35 (21)	0.2369
K	99 (6)	113 (6.2)	86 (26)	0.055
Mg	37 (3.1)	47 (6.3)	45 (9.8)	0.3014
Total N	0.056 (0.0037)	0.045 (0.0027)	0.054 (0.012)	0.0865
OrgC	0.62 (0.055)[a]	0.41 (0.032)[b]	0.59 (0.15)[ab]	**0.0157**
B	0.07 (0.052)[ab]	0.1 (0.013)[b]	0.05 (0)[a]	**0.018**
Ca	122 (17)	135 (16)	126 (53)	0.5022
Co	0.1 (0.02)[b]	0.29 (0.049)[a]	0.074 (0.016)[b]	**0.0003**
Cu	0.61 (0.023)	0.67 (0.032)	0.62 (0.049)	0.3012
Fe	67 (12)[a]	32 (1.5)[b]	71 (21)[a]	**0.0006**
Mn	17 (2.9)[ab]	21 (3.1)[b]	9.4 (5.7)[a]	**0.0283**
Na	12 (2)	14 (2.5)	16 (2.2)	0.3006
Ni	0.1 (0.011)	0.12 (0.013)	0.08 (0.012)	0.2201
S	8 (0.56)	7.3 (0.5)	8.8 (1.1)	0.214
Zn	1.2 (0.25)	0.91 (0.061)	1.3 (0.95)	0.113
Pb	0.49 (0.041)	0.55 (0.049)	0.42 (0.08)	0.354

Table 3

P Mean values for site attributes by plant community type; Aspect (degrees); Slope (degrees); Morphology type (1 – crest, 2 – upper slope, 3 – mid slope, 4 – lower slope, 5 – simple slope); Land type (1 – summit, 2 – hill crest, 3 – hill slope, 4 – breakaway); 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	**Community Two**	**Community Three**	**P value**
n=	**23**	**19**	**5**	
Aspect	186 (19)[a]	185 (17)[a]	288 (18)[b]	**0.0335**
Slope	4.8 (0.61)[a]	2.6 (0.66)[b]	2.4 (1.4)[ab]	**0.0184**
Morph Type	1.9 (0.23)[a]	3.4 (0.42)[b]	1.4 (0.24)[a]	**0.0019**
Land Type*	2.4 (0.14)	2.8 (0.10)	4.2 (1.02)	**0.049**
Disturbance	0.35 (0.1)	0.53 (0.12)	0.8 (0.2)	0.1552
CF_Abundance	4.3 (0.13)	3.9 (0.14)	4.6 (0.24)	0.0655
CF_Size	4.8 (0.21)[a]	3.6 (0.22)[b]	4.2 (0.58)[ab]	**0.0043**
RO_Abundance	1.9 (0.29)[a]	0.53 (0.21)[b]	2.2 (0.58)[a]	**0.0012**
Runoff	1.9 (0.19)	1.5 (0.23)	2 (0)	0.2894
Soil Depth	1.7 (0.13)[b]	2.3 (0.17) [a]	1 (0) [b]	**0.0012**
%Leaf_Litter	1.1 (0.06)	1.1 (0.072)	1 (0)	0.7583
%Bare_Ground	3.9 (0.072)[a]	3.6 (0.12)[a]	4 (0)[b]	**0.0393**

* post-hoc analysis not significant