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Flora and vegetation of banded iron formations of the Yilgarn Craton: western Narryer Terrane

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ABSTRACT

The Narryer Terrane is the oldest component of the Yilgarn Craton, located in the north-western part of the Murchison Interim Biogeographic Regionalisation of Australia (IBRA) region. Previous work has surveyed the flora and vegetation of Jack Hills, the main greenstone belt within the terrane. This paper describes the flora and vegetation of the remaining occurrences of banded iron formations on the Narryer Terrane. One hundred and fifty one taxa were recorded from the western Narryer Terrane, with two species of conservation significance, *Philotheca citrina* and *Calytrix erosipetala*. Three range extensions were recorded including *Swainsona rotunda*, previously only known from the type specimen. Four communities were determined from hierarchical classification and the distribution of plant communities was correlated with soil nutrients. The most widespread community occurred across all positions in the landscape, on sites with greater fertility and less acidic soil. All communities occurred on relatively low terrain, characterised by gently inclined slopes, low rock cover and shallow soils. Vegetation within the survey region was in poor condition due to grazing by feral goats. The ironstone ranges are currently within mining tenements but no current exploration is underway. None of the ranges are within the Western Australian conservation estate.

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

INTRODUCTION

The Narryer Terrane is the most ancient known component of the Yilgarn Craton and contains the oldest known rocks and zircon crystals in metasedimentary rocks in Australia, dating to c. 3.73 Ga (Kinny *et al.* 1998) and c.4.4 Ga (Wilde *et al.* 2001) respectively. The terrane is located in the north western part of the Murchison Interim Biogeographic Regionalisation of Australia (IBRA) (Environment Australia 2000) region, with pastoralism the predominant land use in the area.

Previous surveys in the area have concentrated upon broadscale descriptions of the vegetation (Beard 1976, Curry *et al.* 1994). A more recent survey of the Terrane has described the flora and vegetation of Jack Hills (Meissner & Caruso 2008a), the main greenstone belt within Narryer Terrane. The remaining occurrences of banded iron formation (BIF) on the terrane occur west of the Murchison River, from Mt Narryer to Mt Nairn, across three pastoral leases, and are the focus of this paper.

The objective of the study is to describe the flora and plant communities of the banded ironstone ranges on the western Narryer Terrane and their relationships with environmental variables, and to provide baseline information for future management.

Geology and Geomorphology

The Narryer Terrane is composed mainly of granite rocks and granitic gneisses from early to midddle Archaean (>2.2 Ga) interbedded with minor deformed and metamorphosed banded iron formations, mafic and ultramafic intrusive rocks and metasedimentary rocks (Cassidy *et al.* 2006). Banded iron formations occur either within the Mindle metasedimentary rocks as orthopyroxene-bearing BIF, cropping discontinuously as thin bands in gneisses northeast of Mount Narryer, or within Meeberrie and Dugel gneisses, as metamorphosed banded and granular iron formations (Williams & Myers 1987). The occurrences of BIF increase around Meegea Hill and north towards Mount Nairn (Williams *et al.* 1983).

The geomorphology of the region is variable, dominated by areas of low relief to localised areas of high relief composed of more resistant rocks. Mount Dugel and Mt Narryer form the highest points at the southern and northern ends of a low strike ridge, composed mainly of quartzites and gneisses, 27km long and 3km wide (Williams & Myers 1987).

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. The two highest mean monthly rainfalls at Errabiddy Station (120km NE of Mt Dugel) occur in January and June (31.2mm and 30.5mm respectively), with the highest ever daily rainfall of 143.8mm occurring in January 1963. Mean annual rainfall at Errabiddy is 210.3mm, with much variation (80.9mm 1st decile; 354.0mm 9th decile; recorded 1936 to 2005).

Summer rainfall is influenced by cyclonic activity off the north-west coast of Western Australia and 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 (January mean maximum temperature 39.7 °C and mean 16.4 days above 40 °C). Winters are mild with lowest mean maximum temperatures recorded for July of 20.6 °C. Temperatures rarely fall below 2 °C in winter, with a mean minimum of 7.4 °C in July.

Vegetation

The Narryer Terrane occurs within the Byro sub-region of the Murchison phytogeographic region (Beard 1976). The Byro sub-region is dominated by *Acacia aneura* (mulga) in the northeast, occurring as continuous sparse woodlands, or as scattered trees in *Acacia ramulosa* scrub (Beard 1976). In particular, Beard (1976) mapped the hills around Mt Narryer, Mt Dugel, Meegea Hill and Mt Nairn as various associations of *A. aneura* scrub. The most common association was characterised by *A. aneura*, *Acacia atopa*, *Acacia ramulosa*, *Acacia kempeana*, *Eremophila fraseri*, *Eremophila foliosissima*, *Eremophila platycalyx*, *Schoenia cassiniana*, *Myriocephalus guerinae* and *Podolepis auriculata*.

A flora and vegetation survey of Jack Hills, the nearest ironstone range approximately 50km to the east of Mt Narryer, described six vegetation communities (Meissner & Caruso 2008a). These communities were characterised by *A. aneura* shrublands with associations of different *Acacia* spp. and *Eremophila* spp. An unusual and restricted spinifex community was recorded on the higher elevations, and was composed of a different suite of species to communities recorded elsewhere across the range.

The present study area includes four different land systems, the Agamemnon, Mindura, Narryer and Thomas, as defined by Curry *et al.* (1994). Land systems describe an area based on landform, geological features and major vegetation types. All four land systems have similar landforms and geomorphology that encompass a caternary sequence of rocky hills and ridges, rounded summits, stony slopes to stony plains, drainage flats, floors and channels.

The rocky hills, low hills and breakaways of Agamemnon, Mindura and Thomas land systems support Rocky Hill Mixed Shrublands characterised by *Acacia grasbyi*, *Eremophila glutinosa*, *Solanum ashbyae*, *Tribulus platypterus*, *Cheilanthes austrotenuifolia* and *Spyridium* sp. (Curry *et al.* 1994). These give way to Stony Mulga Mixed Shrubland on the stony slopes, footslopes and plains, dominated by *A. aneura*, *A. pruinocarpa*, *A. grasbyi*, *Eremophila macmillaniana*, *E. spathulata*, *E. fraseri*, *E. freelingii*, *E. spathulata*, *Solanum lasiophyllum*, *Ptilotus rotundifolius*, *Senna helmsii*, *Ptilotus obovatus* and *Ptilotus schwartzii*. Footslopes of Narryer and Thomas land systems are typified by Stony Snakewood Shrubland, characterised by *A. aneura*, *A. victoriae* and *Hakea preissii* with either *Senna* or *Eremophila* species as mid-stratum and high cover of chenopod species in the lower stratum (Curry *et al.* 1994).

METHODS

The study area encompasses three pastoral leases, Mt Narryer, Milly Milly and Boolardy Stations. Fifty one 20 x 20 m quadrats were established on the crests, slopes and foot slopes of the ironstone hills on the pastoral leases, in August 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.

Data on topographical position, disturbance, abundance, size and shape of coarse fragments on the surface, the amount of exposed bedrock, cover of leaf litter and bare ground were recorded following McDonald *et al.* (1990). Additionally, growth form, height and cover were recorded for dominant taxa in each stratum (tallest, 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). pH was measured in 0.01M $CaCl_2$ at soil to solution ratio of 1:5.

Quadrats were classified on the basis of similarity in species composition on perennial species only, to be consistent with previous studies of banded ironstone ranges (Gibson 2004 a, b). The quadrat and species classifications were undertaken using flexible UPMGA of Bray and Curtis similarities (unweighted pair-group mean average; $\beta = 0$; Belbin 1989). 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 a Bray and Curtis similarity resemblance matrix, were used to

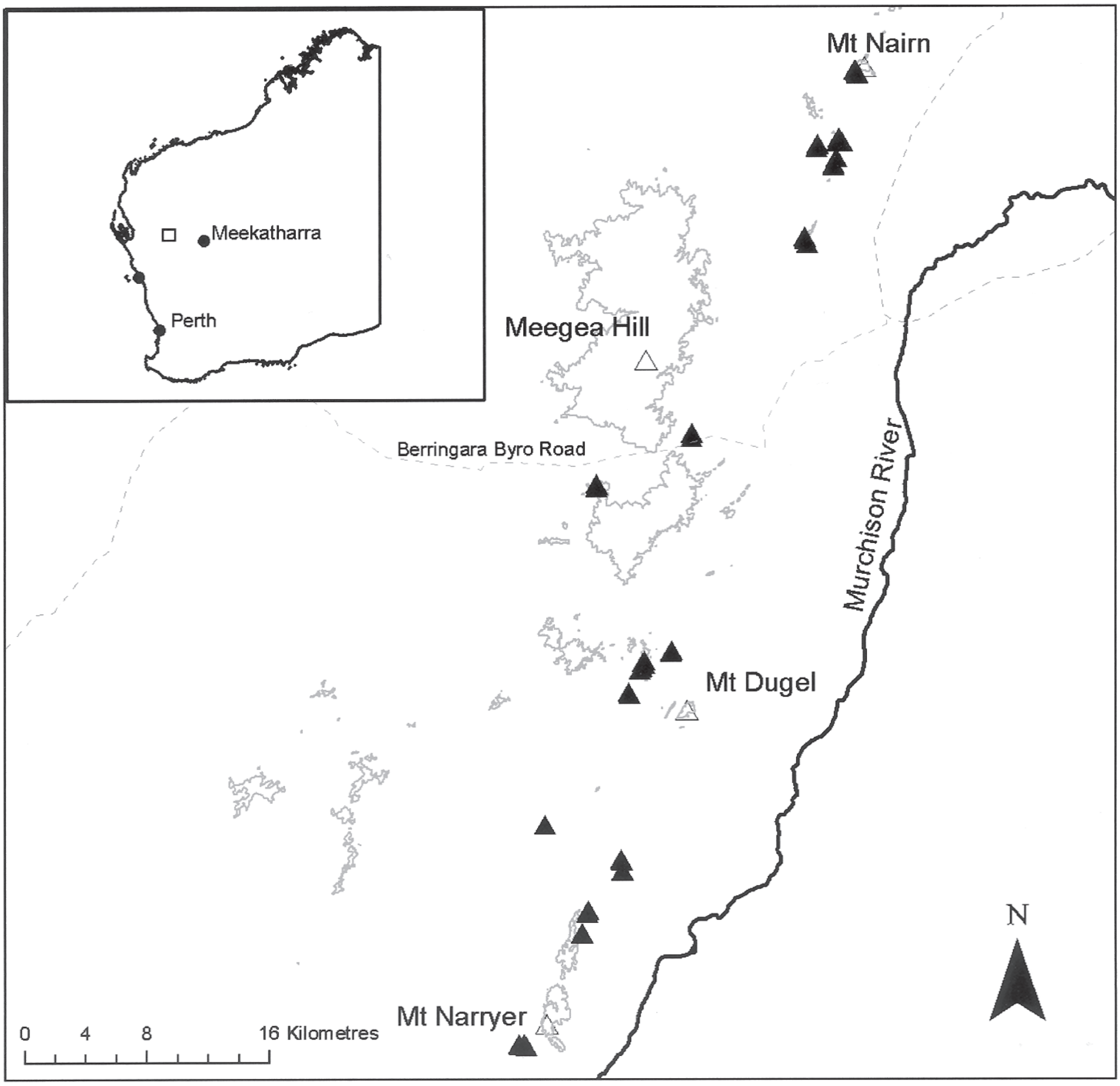

Figure 1. Location of the western Narryer Terrane study area, showing the location of the 51 sites (▲). The 340 m contour is shown with the highest peaks, Mt Narryer (514m) and Mt Dugel (461m).

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). PCC is a routine that runs multiple linear regressions on the variables and the ordination coordinates, resulting in a vector for each variable within the ordination plot. The MCAO is a Monte-Carlo permutation test that determines the robustness of the PCC results by randomly assigning values of variables to objects and then running the PCC routine (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 151 species within 74 genera and 38 families were recorded on the ironstone ranges of the terrane. Forty one taxa were ephemerals and no introduced taxa were recorded. The flora was dominated by Asteraceae (nine taxa), Chenopodiaceae (13), Mimosaceae (18), Myoporaceae (13) and Poaceae (12). Seven taxa were unidentifiable due either to grazing by goats, resulting in stunted growth, or in the case of the ephemeral genera, they had not begun to flower.

A. aneura, commonly known as mulga, was the dominant species within the vegetation, occurring in nearly every plot. Mulga is a highly variable species, consisting of *A. aneura* and close relatives, and can be difficult to identify in the field and the herbarium (Miller *et al.* 2002). Currently, a project is underway to clarify the genetic relationships and determine characters for identification of *A. aneura* variants (B. Maslin, pers. comm.[1]). To this end, we have classified our collections of mulga into morphotypes, based upon phyllode dimensions and shape, presence of glands on new growth, and ribbing on the branchlets, that may prove to be useful characters (B. Maslin pers. comm.[2]).

Taxonomic interest

Two taxa were collected that had sufficient material to be of taxonomic interest. *Acacia* sp. Yellow Pulvinus (R. Meissner & G. Owen 1607) is a shrub to 5m and is possibly related to *Acacia coolgardiensis*. It has a distinctive bright yellow pulvinus at least 1mm at the base of a terete phyllode and was found growing on a small laterised banded ironstone hill near Mount Narryer.

Wurmbea sp. Boolardy (Meissner & Owen 1502) was originally identified as *Wurmbea deserticola* but upon further examination by the taxonomic authority on *Wurmbea*, it was found to be a unique species (Macfarlane pers. comm.[2 3]). It was collected on the laterite crest and is a cormous, perennial herb to 25 cm, with three leaves. It was fruiting at the time of collection. This is the only known collection of this taxon and may be an endemic to the area.

Rare and Priority Flora

Priority taxa are considered to be poorly known, potentially rare or threatened taxa (Atkins 2008). Two priority species were collected during the survey, *Philotheca citrina* (Priority 1) and *Calytrix erosipetala* (Priority 3).

Philotheca citrina (P1) is a perennial shrub to 1.3 m with pale yellow flowers. It was discovered in 1985 during a survey of the Murchison Basin (Wilson 1992). It is restricted to a small area of the northwest Murchison IBRA region, mainly growing on laterite breakaways and granite outcrops. It has been collected previously from the area, on Byro and Milly Milly Stations. In this survey, it was found growing in laterite breakaway in the Mt Dugel area.

Calytrix erosipetala (P3) is a low shrub to 60 cm with pink flowers. It is closely related to *Calytrix warburtonensis*, but differs in having an erose to suberose petal margin, sub-orbicular thecae and longer hypanthium with a shorter free region (Craven 1987). The erose to suberose petal margin is characteristic of this species and is known in only two other species found in the Northern Territory (Craven 1987). It was recorded on laterised ironstone breakaway, a characteristic habitat, in the Mt Dugel area. As well as an additional population record, the collection also marks a range extension, with the nearest population 200km to the south east.

Range Extensions

This survey recorded range extensions for three species are defined as any new record more than 100km from the nearest population.

Swainsona rotunda is a leguminous prostrate herb with lilac flowers. It was previously known only from the type specimen, collected near the Pink Hills, 150km north of the collections from this survey. This species is characterised by medifixed hairs and 1–4 flowers per inflorescence (Thompson 1993). In addition, previous collections from Jack Hill were redetermined as *S. rotunda*.

Dodonaea pinifolia is a dioecious shrub to 1 m, flowering from October to January, growing on laterite on hills, granite or sandstone outcrops. In this survey, the specimens collected were heavily grazed and found growing near Mount Dugel, on ironstone and sandstone hills. The nearest know populations is located 250km to the southwest.

Iseilema eremaeum, or Flinders Grass, is a tufted grass to 29 cm, collected mostly on clay soils and seasonally wet areas. It also occurs in South Australia, Northern Territory and Queensland. The nearest populations occur 200km north-east and 200km north-west of the study area.

Plant Communities

One hundred and forty three taxa were recorded in the 51 quadrats with twelve taxa removed due to taxonomic uncertainty (ie. unidentifiable to species level). Ephemerals and singletons were removed resulting in a total of seventy taxa used in the final analysis. Eight taxa were combined into four species groups, such as *Eremophila phyllopoda* subsp. *phyllopoda* and *Eremophila phyllopoda* combined into *E. phyllopoda*.

Four communities were determined by SIMPROF ($p<0.05$). The first division in the dendrogram separates Communities 1 and 2 from Communities 3 and 4 at approximately 17 % similarity (Fig. 2). Community 1, found at two sites, then splits from Community 2, found on the upper slopes and crests of the western Narryer Terrane. The remaining two communities, separate at *c.* 20 % similarity. Community 3 was found mainly on laterite breakaways while Community 4 was the most widespread community on slopes and crests of the terrane.

Community 1 consisted of two sites found on a lower slope near Meegea Hills and a mid-slope on Mt Nairn.

[1] Bruce Maslin, Western Australian Herbarium, Department of Environment and Conservation, Kensington

[2] Terry Macfarlane, Department of Environment and Conservation, Manjimup.

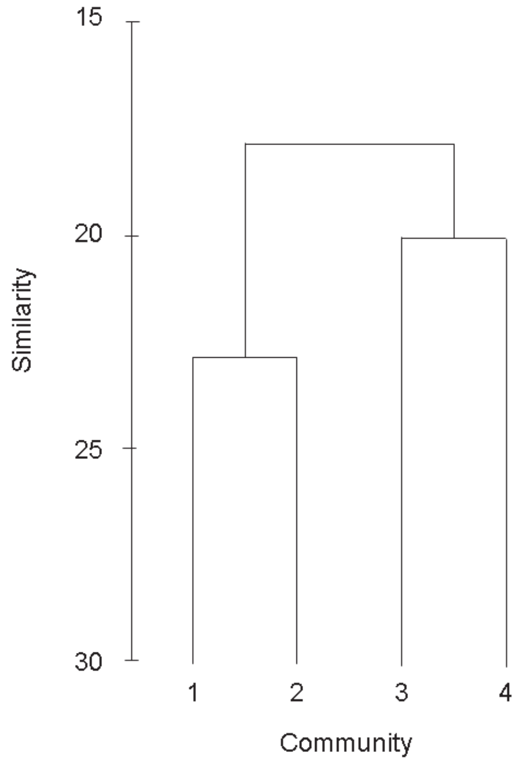

Figure 2. Dendrogram of the 4 group level classification of 51 quadrats established on the western Narryer terrane.

This community was characterised by open shrublands of *A. aneura* over shrublands of *E. phyllopoda* with a mean species richness of 9.5 ± 3.5se taxa per site. This community had the lowest species richness and may be a species poor representation of Community 2. The typifying species of Community 1 were *E. phyllopoda*, *Wurmbea inframediana* and *A. aneura* (terete/compressed morphotype; Table 1).

Community 2 comprised six sites found across the range on upper slopes and crests with low cover of rock outcrop. It can be described as open shrublands of *A. aneura* and *Grevillea berryana* over shrublands of *Eremophila latrobei* subsp. *latrobei* and *E. glutinosa* over sparse grassland of *Monachather paradoxus*. The community shares the highest species richness of 16.0 ± 5.7se taxa per site. It was characterised by key species of *M. paradoxus*, *E. latrobei* subsp. *latrobei*, *E. glutinosa* and *G. berryana* (Table 1).

Community 3 was found on slopes and summits of laterised ironstone breakaways and consisted of nine sites with five of the sites occurring in surrounding area of Mt Dugel. The community was characterised by sparse to open woodlands and shrublands of *A. aneura*, *Acacia citrinoviridis* and *Acacia pruinocarpa* over sparse to open shrublands of *E. phyllopoda*, *Dodonaea viscosa* subsp. *mucronata*, *Micromyrtus sulphurea*, *Calytrix erosipetala*, *Philotheca citrina*, *Philotheca brucei* subsp. *cinerea*, *Eremophila georgei*, *Thryptomene decussata* and *Ptilotus obovatus*. The community had a species richness of 15.0 ± 4.6se taxa per site and typifying taxa were *Ptilotus obovatus*, *Solanum ashbyae / lasiopetalum* complex, *A. aneura* (ribbed morphoptype) and *Monachather paradoxus* (Table 1).

Community 4 was the most common community found on the ironstone hills with 35 sites on slopes and crests. It is described as sparse to open woodlands and shrublands of *A. aneura* and other *Acacia* spp. (*Acacia citrinoviridis*, *Acacia tetragonophylla*, *Acacia quadrimarginea*, *Acacia pruinocarpa*, *Acacia demissa* and *Acacia rhodophloia*), *Hakea preissii*, *Grevillea berryana* and *E. macmillaniana* over sparse to open shrublands of *Eremophila* spp. (*E. phyllopoda*, *Eremophila spathulata*, *E. glutinosa*, *E. jucunda* subsp. *jucunda*, *E. latrobei* subsp. *latrobei* and *Eremophila galeata*), *Senna* spp. (*Senna artemisioides* subsp. *petiolaris*, *Senna artemisioides* subsp. *helmsii*, *Senna* sp. Meekatharra (E. Bailey 1–26) and *Senna glaucifolia*), *Acacia craspedocarpa* and *Dodonaea viscosa* subsp. *mucronata* over isolated grasslands of *Cymbopogon ambiguus.* The community shared the highest species richness of 16.0 ± 4.7se taxa per quadrat with Community 2. The characteristic taxa were *A. aneura* (glandular morphotype), *E. macmillaniana*, *Acacia tetragonophylla*, *Ptilotus obovatus*, *E. phyllopoda* and *Wurmbea inframediana* (Table 1).

Physical Parameters

Community 1 consisted of two sites and as a consequence was not included in the statistical analysis. Community 1 was generally lower in nutrients than the other sites, with the lowest values for phosphorus, organic carbon and nitrogen, but the highest mean value for potassium.

Non-parametric analysis of variance found significant differences between Communities 2, 3 and 4. Community 4 was significantly different in 12 of the 17 soil nutrients. It was more fertile than Community 2 and 3, with higher values of P, K, Mg, and Total N, with K and Mg statistically significant (Table 2). In addition, soils were also significantly higher concentrations of Ca, Co, Cu, Fe, Mn, Ni and Zn and had significantly levels of lower Na and S (Table 2).

Communities 2 and 3 were similar in soil chemical composition (Table 2). Soils from both communities were more acidic than Community 4 and lower in major and trace elements (Table 2). Sodium concentration was the only significant difference between the two, with Community 3 having significantly higher concentrations than Community 2 (Table 2).

All three communities had similar site attributes (Table 3). The communities were relatively low in the landscape, with a mean elevation of 368.2 ± 3.3 m above sea level. In comparison, the highest points in the area are Mt Narryer (514m) and Mt Dugel (461m). The sites can be characterised as generally gently inclined (6.4 degrees ± 0.6), rock outcrop cover up to 20%, moderate cover of coarse fragments (20–50%) and mainly shallow soils. Only coarse fragment size was significantly different between communities. Community 3 had significantly higher abundance of surface fragments than Community 4 with Community 2 intermediate between the two (Table 3).

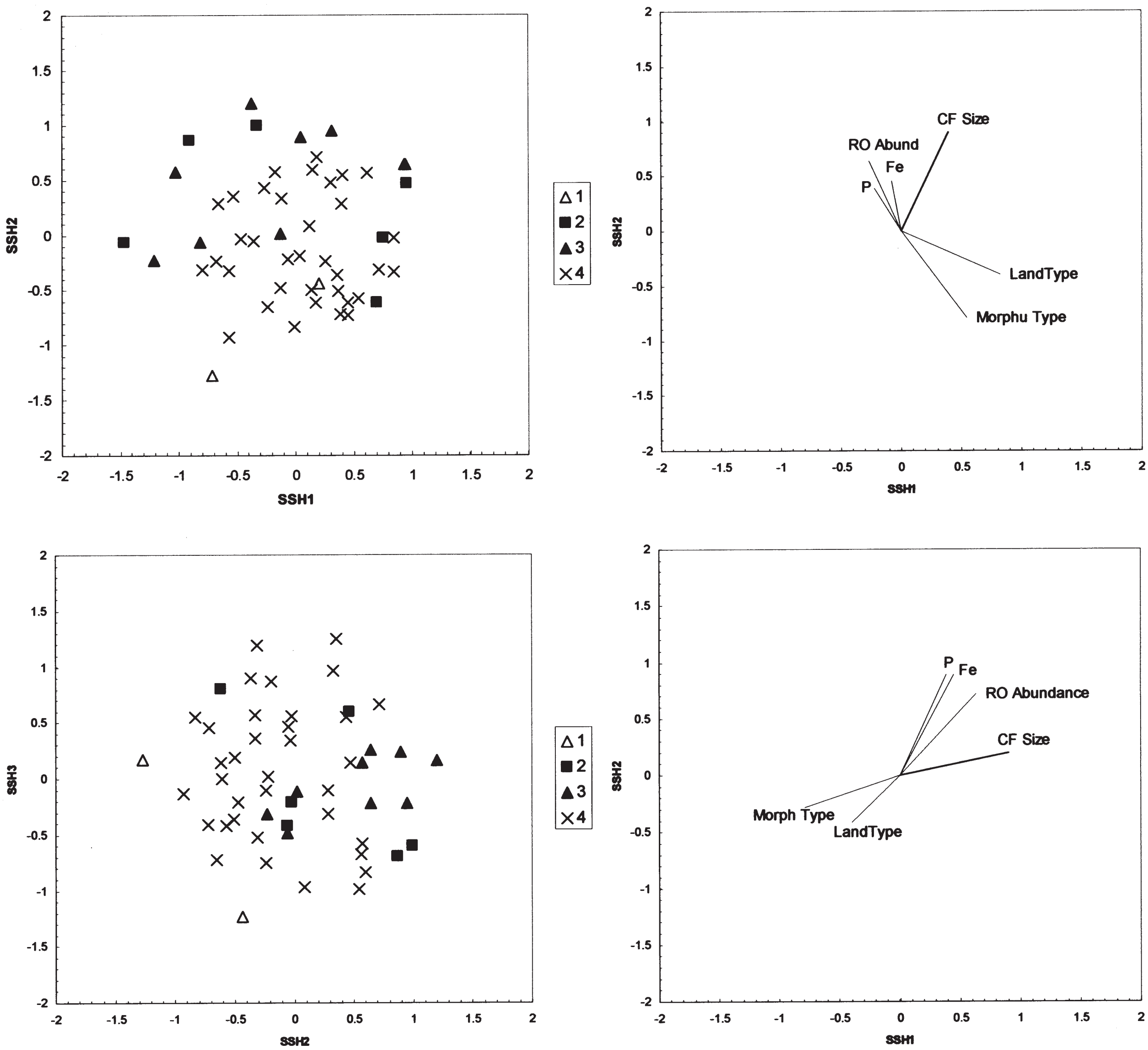

Figure 3. Three dimensional SSH ordination showing Axis 1, 2 and 3 of the 51 quadrats established on the western Narryer Terrane. The four communities are shown and lines represent the strength and direction of the best-fit linearly correlated variables (P<0.05).

The three dimensional SSH ordination shows some overlap between communities (stress = 0.1938; Fig. 3). Community 4, commonly found across the terrane, is concentrated in the centre of the ordination on all 3 axes (Fig. 3). Community 3, on the lateritic sites and breakaways, partly overlaps Community 4 indicating some commonality. It occurs in the upper (Fig. 3a) and right quadrants (Fig. 3b). Community 2 also overlaps Community 4, but is more widely dispersed than community 3, while Community 1 in lower left quadrant on axes 2 and 3 (Fig. 3b).

The relationships between the three dimensional SSH ordination and the environmental variables were poor, with correlations between 0.15 and 0.2. This was most probably due to a non-linear relationships with Community 4, located in the middle of the ordination, it has higher concentrations of soil nutrients than the communities spread around the edge. Rock outcrop abundance, coarse fragment size, phosphorus and iron are all higher in the upper half of the ordination (Fig. 3a). Morphology and land type generally increase in the opposite direction, with sites on upper parts of the range, such as crests and summits, occurring in the lower right quadrant.

DISCUSSION

Flora

Prior to the survey, Jack Hills was the only ironstone range on the Narryer Terrance that had been surveyed for flora and plant communities (Meissner &Caruso 2008a). A total of 202 taxa were recorded at Jack Hills, with over 50%

ephemeral taxa (Meissner & Caruso 2008a). In comparison, the current survey recorded 151 taxa with only 105 taxa common to both areas. The western Narryer Terrane recorded less than 30% ephemeral taxa, mainly due to poor rainfall prior to the survey.

Endemism and high occurrence of priority species are characteristic of some ironstone ranges (Meissner & Caruso 2008 a,b,c; Markey & Dillon 2008 a,b,). In this survey, one endemic taxon was found, *Wurmbea* sp. Boolardy (R. Meissner & G. Owen 1502), and several priority species were recorded. In addition, taxa commonly associated with ironstone were recorded, such as *E. latrobei*, *E. jucunda* and *Thryptomene decussata*. More importantly, new collections were made of *S. rotunda*, a species previously known only from the holotype.

Plant Communities

This survey described four floristic communities on the west Narryer Terrane. Communities 2 and 4 roughly correspond to the Rocky Hill Mixed Shrublands and Stony Mixed Mulga Shrublands of Curry *et al.* (1994). However, these communities were broadly described and applied on other ranges. Curry *et al.* (1994) also described the vegetation on Jack Hills and the Weld Range as predominantly Rocky Hill Mixed Shrublands, both part of the same land system. Detailed surveys of Jack Hills and the Weld Range showed the communities on these ironstone ranges were very different and characterised by different suites of species (Markey & Dillon 2008b, Meissner & Caruso 2008a). A preliminary comparison of the community composition between the western Narryer Terrane and Jack Hills found the same pattern; the floristic communities on the two ranges were significantly different (ANOSIM Global $R = 0.306$, $P < 0.01$, Clarke and Warwick 2001).

The distribution of the communities within the western Narryer Terrane was largely influenced by soil nutrients, which in turn was influenced by the landform. The lateritic community (Community 3) was clearly distinguished from the other communities and contained species, such as *Philotheca citrina*, which did not occur elsewhere. These sites were characterised by a high abundance of pisoliths, as well as ferruginous duricrust and low levels of soil fertility (Cornelius *et al.* 2007).

In previous studies of ironstone ranges, the greatest floristic differences were often found between lowland and upland communities (Markey & Dillon 2008 a,b; Meissner & Caruso 2008 a,b,c). In this study, no differentiation was found between the lowland and upland communities. The most common community recorded, Community 4, characterised the landscape of the ironstone ranges of the western Narryer Terrane. It was found on the sites with greater fertility and less acidity that occurred in all positions in the landscape from colluvial areas and lower slopes to the crests of the ironstone hills.

Higher elevations have also previously been correlated with the occurrence of endemic and restricted communities on other ironstone ranges (Meissner & Caruso 2008b; Meissner *et al.* 2009). The communities were more uniform when compared to Jack Hills and there was no difference in elevation between communities.

The topography of the study area is more subdued that that of Jack Hills, where Mount Hale (697m) is the highest peak, and the location of the restricted spinifex community. In comparison, the highest peak of banded ironstone was Mt Nairn (430m). Although Mt Narryer (514m) is higher, it is composed of metamorphic gneiss, not ironstone, and was therefore not surveyed. The lower elevations and lack of extreme elevations of the ironstone hills may reduce the number of available habitats to support specialised communities such as Jack Hills.

Despite the general lack of topographic zonation of the vegetation, Community 2 was clearly a community only found on the upper slopes and crests within the terrane. This community had the lowest fertility, lowest trace element concentration and most acidic soils. The typifying species, *E. glutinosa* and *E. latrobei*, are taxa commonly associated with ironstone ranges. These sites are typically lower in fertility (Markey & Dillon 2008 a,b; Meissner & Caruso 2008 a,b,c), and are probably the result of leaching by runoff as evidenced by lower concentrations of the more mobile elements, magnesium, calcium and sodium (Cornelius *et al.* 2007).

Conservation

The banded iron formations are a minor landform in a region dominated by granite and granitic gneiss ranges, such as Mount Narryer. To date, mining tenements cover the entire area but there is no current exploration. None of the ironstone ranges of this survey are currently within secure Conservation Estate.

The vegetation of the western Narryer Terrane was found to be in poor condition, with extensive evidence of grazing by feral goats. Grazing was greatest on the rocky hills, especially summits and crests, where extensive goat manure and high numbers of increaser species, such as *Chenopodium melanocarpum*, were recorded. Presence of feral goats, in addition to livestock, can prevent the regeneration of woody perennial species (Tiver & Andrew 1997). Currently, the elevated levels of herbivory by goats on the rocky hills can potentially have a large impact on the communities found in this survey.

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APPENDIX

List of the flora for Mt Narryer Terrane, including all taxa from the sampling quadrats and adjacent areas. Nomenclature follows Paczkowska and Chapman (2000).

Adiantaceae
Cheilanthes brownii
Cheilanthes sieberi subsp. *sieberi*

Aizoaceae
Tetragonia sp. indet

Amaranthaceae
Ptilotus aervoides
Ptilotus exaltatus
Ptilotus helipteroides
Ptilotus obovatus
Ptilotus roei
Ptilotus rotundifolius
Ptilotus schwartzii

Anthericaceae
Thysanotus manglesianus
Thysanotus speckii

Apiaceae
Trachymene pilbarensis

Asteraceae
Actinobole oldfieldianum
Brachyscome sp. indet
Brachyscome iberidifolia
Calotis hispidula
Helipterum craspedioides
Podolepis gardneri
Pogonolepis stricta
Rhodanthe battii
Rhodanthe maryonii

Boraginaceae
Heliotropium inexplicitum

Brassicaceae
Lepidium oxytrichum
Stenopetalum sp. indet
Stenopetalum anfractum
Stenopetalum filifolium

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

Chenopodiaceae
Chenopodium melanocarpum
Chenopodium saxatile
Dysphania rhadinostachya subsp. *rhadinostachya*
Enchylaena tomentosa var. *tomentosa*
Maireana planifolia x *villosus*
Maireana sp.
Maireana georgei
Maireana planifolia
Maireana thesioides
Maireana triptera
Maireana villosa
Rhagodia eremaea
Sclerolaena cuneata

Colchicaceae
Wurmbea cf. *densiflora*
Wurmbea densiflora
Wurmbea deserticola
Wurmbea inframediana

Cuscutaceae
Cuscuta cf. *epithymum*

Droseraceae
Drosera macrantha subsp. *macrantha*

Euphorbiaceae
Euphorbia boophthona
Sauropus crassifolius

Frankeniaceae
Frankenia sp. 1 indet
Frankenia sp. 2 indet
Frankenia sp. 3 indet

Geraniaceae
Erodium cygnorum

Goodeniaceae
Goodenia tenuiloba
Scaevola spinescens

Haloragaceae
Haloragis trigonocarpa

Lamiaceae
Spartothamnella teucriiflora

Loranthaceae
Amyema fitzgeraldii

Malvaceae
Abutilon sp.
Hibiscus burtonii
Sida sp.
Sida aff. *atrovirens*
Sida sp. dark green fruits (S. van Leeuwen 2260)
Sida cf. sp. unisexual (N.H. Speck 574)
Sida chrysocalyx

Mimosaceae
A. aneura (ribbed morphotype) (Meissner & Owen 1611)
A. aneura (terete/compressed morphotype) (Meissner & Owen 1608)
A. aneura (wide morphotype) (Meissner & Owen 1615)
A. aneura (glandular morphotype) (Meissner & Owen 1613)
Acacia citrinoviridis
Acacia craspedocarpa
Acacia cuthbertsonii subsp. *cuthbertsonii*
Acacia demissa

Acacia grasbyi
Acacia kempeana
Acacia palustris
Acacia pruinocarpa
Acacia quadrimarginea
Acacia ramulosa var. *linophylla*
Acacia rhodophloia
Acacia sp. Yellow Pulvinus (Meissner & Owen 1607)
Acacia synchronicia
Acacia tetragonophylla

Myoporaceae
Eremophila compacta
Eremophila exilifolia
Eremophila forrestii
Eremophila galeata
Eremophila georgei
Eremophila glutinosa
Eremophila jucunda
Eremophila jucunda subsp. *jucunda*
Eremophila latrobei subsp. *latrobei*
Eremophila macmillaniana
Eremophila phyllopoda
Eremophila phyllopoda subsp. *phyllopoda*
Eremophila spathulata

Myrtaceae
Aluta aspera subsp. *hesperia*
Calytrix desolata
Calytrix erosipetala (P3)
Micromyrtus sulphurea
Thryptomene decussata
Verticordia interioris

Nyctaginaceae
Boerhavia coccinea

Papilionaceae
Glycine canescens
Indigofera monophylla
Mirbelia rhagodioides
Swainsona rotunda

Poaceae
Aristida contorta
Austrostipa elegantissima
Cymbopogon ambiguus
Enneapogon caerulescens
Eriachne helmsii
Eriachne mucronata
Eriachne pulchella
Iseilema eremaeum
Monachather paradoxus
Neurachne minor
Paspalidium basicladum
Tripogon loliiformis

Portulacaceae
Calandrinia eremaea complex
Calandrinia sp. The Pink Hills (F. Obbens FO 19/06)
Portulaca oleracea

Proteaceae
Grevillea berryana
Grevillea deflexa
Grevillea striata
Hakea preissii
Hakea recurva subsp. *arida*

Rubiaceae
Psydrax latifolia
Psydrax rigidula
Psydrax suaveolens

Rutaceae
Philotheca brucei subsp. *cinerea*
Philotheca citrina (P1)

Santalaceae
Santalum spicatum

Sapindaceae
Dodonaea petiolaris
Dodonaea pinifolia
Dodonaea viscosa subsp. *mucronata*

Solanaceae
Nicotiana occidentalis
Nicotiana occidentalis subsp. *obliqua*
Solanum ashbyae
Solanum lasiophyllum

Stackhousiaceae
Stackhousia muricata

Stylidiaceae
Stylidium longibracteatum

Tiliaceae
Corchorus crozophorifolius

Zygophyllaceae
Tribulus suberosus
Zygophyllum kochii

Table 1

Sorted two-way table of quadrats established on the western Narryer Terrane 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).

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, ns = not significant). Community 1 was excluded from analysis due to low quadrat number.

	Community Type				
	1	**2**	**3**	**4**	**P**
EC	2.0 (0.0)	2.0 (0.0)	3.7 (0.9)	4.3 (0.9)	0.1854
pH	4.6 (0.2)	4.2 (0.0)a	4.3 (0.1)a	5.2 (0.1)b	**<0.001**
P	8.0 (1.0)	15.5 (4.5)	20.6 (6.2)	20.9 (5.4)	0.4653
K	265.0 (35.0)	117.5 (19.8)a	112.3 (26.2)a	209.0 (16.7)b	**0.0010**
Mg	90.5 (19.5)	39.7 (6.3)a	55.6 (9.5)a	158.2 (16.2)b	**<0.0001**
Org C	0.32 (0.02)	0.40 (0.04)	0.51 (0.08)	0.40 (0.03)	0.2404
Total N	0.035 (0.001)	0.036 (0.003)	0.041 (0.005)	0.043 (0.003)	0.6850
B	0.18 (0.13)	0.05 (0.00)	0.07 (0.01)	0.13 (0.02)	0.0465
Ca	145.0 (15.0)	85.0 (12.4)a	129.9 (26.8)a	316.7 (30.2)b	**<0.0001**
Co	0.85 (0.57)	0.15 (0.04)a	0.08 (0.02)a	1.55 (0.19)b	**<0.0001**
Cu	0.55 (0.15)	0.50 (0.03)ab	0.37 (0.02)a	0.84 (0.08)b	**<0.0001**
Fe	36.5 (3.5)	36.0 (3.6)a	52.9 (9.8)ab	56.7 (4.7)b	**0.0433**
Mn	47.5 (28.5)	16.8 (2.9)a	9.8 (1.6)a	70.9 (7.9)b	**<0.0001**
Na	12.0 (10.0)	1.3 (0.4)a	6.2 (1.6)b	9.0 (3.9)b	**0.0080**
Ni	0.20 (0.10)	0.09 (0.01)a	0.12 (0.03)a	0.48 (0.07)b	**<0.0001**
S	3.5 (1.5)	6.7 (1.3)ab	7.9 (0.7)a	4.9 (0.6)b	**0.0017**
Zn	0.95 (0.15)	0.65 (0.10)a	0.80 (0.20)a	1.64 (0.18)b	**0.0002**
n=	2	6	9	35	

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, ns = not significant).

	Community Type				
	1	**2**	**3**	**4**	**p**
Elevation (m)	373.5 (13.5)	371.3 (9.5)	371.6 (7.3)	366.5 (4.2)	0.7970
Soil Depth	2.0 (0.0)	1.5 (0.2)	1.8 (0.1)	1.9 (0.1)	0.1265
Coarse Fragment Size	4.5 (0.5)	5.0 (0.4)	4.7 (0.3)	4.7 (0.2)	0.7326
CF Abundance	4.5 (0.5)	4.7 (0.4)ab	5.0 (0.0)a	4.3 (0.1)b	**0.0274**
Rock outcrop abundance	0.0 (0.0)	1.3 (0.5)	2.2 (0.5)	1.5 (0.3)	0.3397
Slope	5.5 (3.5)	5.3 (1.6)	5.4 (1.2)	6.8 (0.8)	0.6553
Runoff	2.0 (1.0)	1.7 (0.4)	1.7 (0.2)	1.9 (0.2)	0.8522
Morphology Type	3.5 (0.5)	2.0 (0.7)	2.0 (0.4)	2.9 (0.3)	0.1723
Landform Type	3.0 (0.0)	2.3 (0.2)	2.3 (0.6)	2.6 (0.2)	0.5255
n=	2	6	9	35	