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Flora and Vegetation of the banded iron formations of the Yilgarn Craton: the Weld Range

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ABSTRACT

A survey of the flora and floristic communities of the Weld Range, in the Murchison region of Western Australia, was undertaken using classification and ordination analysis of quadrat data. A total of 239 taxa (species, subspecies and varieties) and five hybrids of vascular plants were collected and identified from within the survey area. Of these, 229 taxa were native and 10 species were introduced. Eight priority species were located in this survey, six of these being new records for the Weld Range. Although no species endemic to the Weld Range were located in this survey, new populations of three priority listed taxa were identified which represent significant range extensions for these taxa of conservation significance.

Eight floristic community types (six types, two of these subdivided into two subtypes each) were identified and described for the Weld Range, with the primary division in the classification separating a dolerite-associated floristic community from those on banded iron formation. Floristic communities occurring on BIF were found to be associated with topographic relief, underlying geology and soil chemistry. There did not appear to be any restricted communities within the landform, but some communities may be geographically restricted to the Weld Range. Because these communities on the Weld Range are so closely associated with topography and substrate, they are vulnerable to impact from mineral exploration and open cast mining. At present, no areas of the Weld Range are within conservation estate. It is recommended that the distribution of these communities is further surveyed to ensure informed management, given the extent of proposed activities on the Weld Range.

INTRODUCTION

The Weld Range greenstone belt is a series of parallel ridges extending a length of c. 50 km, c. 3 km wide and approximately 55 km south west of Meekatharra. This range is one of several belts of metamorphic sediments and metavolcanics in the immediate area which provide some topographic relief within the surrounding subdued landscape, and represent the northern extent of the greenstone belts on the Yilgarn Craton. These ranges have had a long history of exploitation. However, it is the current expansion in mineral exploration and proposed iron ore mining that may have the greatest impact on these landforms. Although the vegetation of the general area has been mapped on a board scale (Beard 1976) and has been addressed in two regional surveys (Curry et al. 1994; Speck 1963), a detailed knowledge of the flora and vegetation communities specific to the Weld Range is lacking. This study aims to redress this deficiency. Furthermore, this study is one of c. 25 surveys being conducted by the Western Australian Department of Conservation (DEC, formerly known as the Department of Conservation and Land Management (CALM)) that are documenting the flora and floristic communities on BIF ranges in the Northern Yilgarn (Gibson et al. 2007). These surveys will ultimately place the flora and floristic communities of the Weld Range within a wider regional context, and assist in the conservation and management of unique taxa and communities.

Study Locality

The Weld Range consists of a series of parallel linear ridges of banded iron formation (BIF), interbedded within greenstones (primarily ultramafic and mafic metavolcanics), which are situated c. 60 km north-west of Cue and c. 85 km south-west of Meekatharra, in the Murchison Region of Western Australia. This range has a north-east trending stratigraphy, with several north-trending faults (Elias 1982). The Weld Range is c. 55 km long, and extends over a latitudinal range of 26.76–27.03 º S, and longitudinal range of 117.43–117.90 º E, consequently including parts of the Madoonga, Glen, Beebyn and Annean pastoral leases and the Wilgie Mia Aboriginal Reserve. Much of the area was vacant crown land until 1900, after which there was a rapid expansion of pastoral leases into the region over the following three decades (Curry et al. 1994). These pastoral leases are still active and primarily run sheep. Gold mining first became established in the Meekatharra district in the late 19th century, with gold and iron exploration occurring on the Weld Range in the early 20th century. However, the oldest mineral excavations on the Weld Range occurred at the site of Wilgie Mia ochre deposit, which had been mined for over 1000 years (Elias 1982). The lands around this site are currently within the Wilgie Mia Aboriginal Reserve, which is part of a Wajarri Yamatji native title claim by the Yamatji Land and Sea Council

Climate

The study area is bounded by the 190–240 mm isohyets and lies within the desert or arid zone bioclimatic region (Beard 1976, 1990; Curry et al. 1994). The climate of the region has typically hot, dry summers and mild winters. Rainfall is unreliable and bimodal, falling in either the summer or winter months (Beard 1976). Winter rainfall is derived from southerly rain-bearing cold fronts, whilst summer rainfall is derived from both thunderstorms and the infrequent and erratic passage of northerly depressions which are the remnants of tropical cyclones (Curry et al. 1994). The study site lies in an area of high evaporation rate, and the trend is for annual rainfall to decline in a north-easterly direction over the general Murchison region (Beard 1976; Curry et al. 1994).

The nearest meteorological centres to the Weld Range are Cue and Meekatharra, where the annual rainfall for both centres is 231 mm (Australian Bureau of Meteorology 1908 –). The highest recorded daily rainfall for Cue (119 mm) has fallen within the summer months. In contrast to these extreme deluges, the average monthly summer rainfall (November–April) for Cue is 20.0 mm, whilst the average winter monthly rainfall (May–October) is 18.5 mm (Australian Bureau of Meteorology 1908–). Using Cue as the nearest metrological station for temperature data, the mean maximum January temperature is 37.8° C, with an average summer temperature (December–February) of 36.9° C, and the average temperature exceeds 30° C during the months from November to March. The coldest temperatures are experienced during the winter months (June–August), when the average maximum temperature is 28.7° C.

Geology

The Weld Range is located within the Murchison geological province, within the Yilgarn Craton Superprovince (Blake & Kilgour 1998). As with much of the area of the Yilgarn Craton, the landscape associated with the Weld Range is subdued and consists of gently undulating plateaux of low relief (which Mabbutt (1963) refers to as 'the Murchison Plains') which are interrupted by hills, ranges and ridges. The Weld Range itself reaches elevations from 20 to > 200 m, with its highest peak at 739 m (Gnanagooragoo Peak). It is approximately 55 km long and between 3 and 4.5 km wide. The geology of the larger area around the Weld Range has been described and mapped over two geological sheets, Cue 1:250 000 (SG/50-15) and Belele 1:250 000 (SG50-11) (Elias 1982; Watkins et al. 1987). This landform is one of several greenstone belts in the province which are set in the Archaean granitoids and gneisses, all of which constitute the Yilgarn Craton. These metamorphic greenstone belts contain mafic and felsic volcanics, mafic, ultramafic and felsic intrusives, into which banded iron formation is interbedded (Elias 1982). Erosion of these Archaean and overlying Proterozoic rocks has occurred since the Tertiary to produce the sediments which overlie much of the surrounding plains. Laterization of these during the Oligocene - Miocene, and further erosion during the Quaternary has removed much of the lateritic duricrust and further exposed the greenstones and granitoids (Elias 1982; Watkins et al. 1987).

The Weld Range greenstone belt has been a topographic feature since before the Tertiary (Elias 1982). This greenstone belt is predominantly dolerite in which is bedded red (hematite), black (magnetite) and white (silica) banded iron-formation and jaspilite (Elias 1982; Watkins et al. 1987). It is this erosion-resistant banded iron-formation along the length of the strike which forms the parallel, steep ridges of the range. Erosion products from the exposed bedrock and laterites form colluvium which accumulates on scree slopes, on the margins of outcrops, and in alluvial fans which decline to gently sloping sheetwash plains (Elias 1982). Significant iron ore reserves occur on both the Weld Range and adjacent Jack Hills (c. 100 km north of Weld Range), which have formed from mineralization of banded iron-formation during the tertiary laterization (Elias 1982).

The soils of the Weld Range vary from shallow to skeletal stony soils and stony loams (lithosols) on the rocky slopes of the hills and ridges, grading to stony red earths and red earths on lower slopes and outwashes (Litchfield 1963). These soils are associated with the exposed, steep, weathering bedrock and soils derived from weathered parent rock include calcareous soils from mafic rocks (Litchfield 1963). Soils of the Weld Range and of the general region are typically infertile and acidic, with increments in pH and fertility occurring in local, depositional parts of the landscape and in calcareous soils (Curry et al. 1994; Litchfield 1963).

Flora

The Weld Range is located within the centre of the Upper-Murchison sub-region, in the Austin Botanical District of the Eremaean Botanical Province of Beard (1976, 1990), the Austin district later being adopted by Thackway & Cresswell (1995) and renamed the Murchison Interim Biogeographic Region (Environment Australia 2000). This district is dominated by mulga low woodland on the plains, whilst *Acacia grasbyi*, *Acacia ramulosa*, *Acacia aneura* and *Acacia tetragonophylla* appear on resistant outcrops. The Jack Hills and Weld Range are the main ranges of the Upper Murchison sub-region and, in his regional survey of the Murchison (1:1000 000), Beard (1976) mapped the Weld Range and Jack Hills as the same structural formation. On the Weld range, Beard (1976) noted that there were two dominant *Acacia* species on the BIF ridges (*Acacia aneura* and *Acacia quadrimarginea*), over *Eremophila latrobei*, *Eremophila oppositifolia*, *Scaevola spinescens*, *Ptilotus obovatus*, *Olearia stuartii* and *Lepidium* sp., which graded to *Acacia aneura* and *Acacia ramulosa* var. *linophylla* on the lower slopes.

On a finer scale than Beard (1976), a further two studies addressed the vegetation communities of the Weld Range as part of a larger regional survey of rangelands. Speck (1963) described vegetation communities and Mabbutt et al. (1963) described land systems in a regional survey of the Wiluna–Meekatharra area. In these studies, two land systems were described for the Weld Range, the Weld land system (on the Weld Range and Jack Hills) and the Gabanintha land system (on the far eastern extent of the Weld Range). Later, Curry et al. (1994) used these same land systems of Mabbutt et al. (1963) in their regional survey of rangelands within the Murchison River Catchment. The advance on Speck's (1963) communities was the use of multivariate analysis of floristic and physical data to resolve communities within the greater area.

Speck (1963) reported five communities on the main Weld land system which corresponded to different positions over the topographic profile, and three of these were restricted to the shallow stony soils on hill crests and slopes. The *Acacia sibirica–Eremophila fraseri* community was a distinctive community limited to rocky ridges in the Weld System. Two other communities were more widespread among hills in the region, these being a sparse *Acacia aneura* community (stunted *Acacia aneura* over *Ptilotus obovatus*, *Solanum ellipticum* and *Senna* spp.), and the *Acacia aneura–Eremophila macmillaniana* community (*E. macmillaniana* and sparse shrubs with a variable *A. aneura* overstorey). The *Acacia aneura–Acacia ramulosa* var. *linophylla* community occurred on the lower slopes and outwashes, and consisted of a tall shrubland over *Eremophila forrestii*, *Eremophila latrobei*, *Eremophila exilifolia*, *Calytrix* sp., *Ptilotus obovatus*, *Dodonaea* spp. and *Senna* spp. over sparse perennial grasses. On the alluvial and colluvial outwashes and footslopes was a sparse shrubland of *Acacia aneura–Acacia tetragonophylla* over *Eremophila fraseri*, *Solanum ellipticum* and *Ptilotus obovatus*, small chenopods (*Sclerolaena*) and short annual grasses.

Curry et al. (1994) revisited the Weld land system of Mabbutt et al. (1963) and retained their three altitudinal zones on the landform. Unlike Speck (1963), they did not resolve the vegetation on hill crest and slopes to be any more than a single vegetation community unit. The ranges, peaks and summits were dominated by a Rocky Hill Mixed Shrubland vegetation type, which consisted of *Acacia* aff. *citrinoviridis* and / or *A. aneura* shrublands, and commonly included *Acacia pruinocarpa, Acacia quadrimarginea, Acacia grasbyi* and *Acacia ramulosa*; over mid shrubs of the same *Acacia* species and *Thryptomene decussata*, *Eremophila georgei*, *Eremophila glutinosa, Eremophila latrobei, Eremophila linearis* and *Dodonaea viscosa* over a variety of low shrubs and perennial grasses. The footslopes and interfluves supported a Stony Mulga Mixed Shrubland vegetation type, which was essentially scattered mixed *Acacia* shrubland dominated by the same species as occurring upslope, over mid shrubs of *Eremophila freelingii*, *Eremophila macmillaniana*, *Eremophila cuneifolia* and low shrubs such as *Senna sturtii*, *Ptilotus* spp. and perennial grasses. The valley floors supported the Creekline Shrubland vegetation type, which consisted of tall *Acacia ramulosa* shrublands (with *Acacia aneura* and *Acacia pruinocarpa*) and trees on sandy floors over sparse shrubs. Curry et al. (1994) did not distinguish the communities of the Weld Range to be floristically distinct from those on the Jack Hills or other hilly landforms within the region. The aim of the present survey is to resolve floristic communities within the Weld Range at a finer scale than has been attained by these regional surveys.

METHODS

Fifty two 20 x 20 m quadrats were established over the survey area, during the spring season in late August 2005. Sites were only established where road access was adequate, and much of the Weld Range was inaccessible due to heavy rains and poor track conditions. Sites were also not established within the Wilgie Mia Aboriginal Reserve. Plots were placed on the crests, slopes and outwashes associated with the Weld land system of Curry et al. (1994), and were placed strategically to encompass the topographical profile of the ranges and the general range of variation of geological landforms and associated floristic communities in the area. A similar method has been used to survey greenstone and BIF ranges in the eastern goldfields (Gibson 2004; Gibson & Lyons 2001).

Quadrats were marked with four steel fence droppers, their position and altitude (alt) recorded by GPS and photographed at a set distance (0–5m) near each corner. The presence and cover of all vascular plant species (angiosperms, gymnosperms and pteridiophytes) were recorded in each plot, with specimens collected for verification at the Western Australian Herbarium. Representative specimens of all taxa were lodged at the Western Australian Herbarium, and geographical distributions were obtained from online records at the Western Australian Herbarium (1998–). Vegetation structure was described according to McDonald et al. (1998). All data on topographical position, aspect, slope, % litter, % bare ground, % rock cover class of both surface deposits and exposed bedrock, shape of surface rock fragments, soil colour and soil texture were noted according to the definitions of McDonald et al. (1998). Percentage surface rock fragment cover class (Rock Frag), maximum rock fragment size (MxR) and exposed bedrock outcrop (%Rock) cover were all coded on a semi-quantitative scale. Percentage surface rock fragment cover classes were scored on seven point scale; 0 % cover (0); < 2 % cover (1); 2–10%, (2); 10–20% (3); 20–50% (4); 50–90% (5); > 90% (6). Maximum rock size was classed on a six point scale; 2–6 mm (1); 6–20 mm (2); 20–60 mm (3); 60–200 mm (4); 200–600 mm (5); 600 mm–2m (6). Leaf litter and bare ground were visual estimates of the percentage of ground cover. Topographic position (Tp) in the landscape was coded on a five point scale which was semi-quantitative: outwash (1); lower slope (2); mid slope (3); upper slope or low ridge (4); crest (5).

For each plot a bulked soil sample was collected, this being compiled from 20 smaller samples collected regularly over the area of the plot. Soils were analysed for a suite of 12 elements at the Chemistry Centre of Western Australia, using inductively coupled plasma atomic emission spectrometry (ICP AES). This involved the simultaneous determination of a suite of elements (P, K, S, Ca, Mg, Na, B, Co, Cu, Fe, Mg and Zn) using the Mehlich No. 3 soil test procedure (Melich 1984, Walton and Allen 2004). Soil pH was determined in an aqueous 0.01M $CaCl_2$ solution, and effective cation exchange capacity (eCEC) was calculated from the summation of exchangeable bases (Ca, Mg, Na and K) after their conversion from concentrations to charge equivalents by dividing by 200.4, 121.6, 230, and 390 respectively (Rayment & Higginson 1992, Soil and Plant Council, 1999, D. Allen, pers. comm.[1]). Estimates of climatic variables (mean annual temperature (Tann), mean annual rainfall (Rann) and rainfall coefficient of variation (Rcv) were obtained from BIOCLIM (Busby 1986).

Pattern analysis was conducted on a presence / absence data matrix of 89 perennial taxa, the singleton and annual taxa having being omitted from the data matrix prior to analysis. Singletons (taxa that appeared in a single plot) were omitted as preliminary analyses found that these contained little information. Annuals (including facultative, short term perennials) were excluded as their distribution and abundance are a function of the previous season's rainfall, and are expected to exhibit high inter-annual variation (Beard 1990; Mott 1972, 1973). The omission of annuals and singletons allows for these results to be comparable with other data collected from other seasons and years, and is consistent with previous surveys on other greenstone and BIF communities (Gibson 2004; Gibson & Lyons 1998, 2001). Resemblance matrices, using the Bray-Curtis measure of association, were compared using the 2 Stage algorithm in Primer (Clark & Gorley 2006) to confirm that there was little information being lost from the dataset by the omission of these taxa.

Pattern analysis was conducted using PATN (V3.03) (Belbin 1989). The Bray-Curtis coefficient was used for the association matrix for sites and species classification and the semi-strong hybrid (SSH) multidimensional scaling for ordination of sites (Belbin 1991). Agglomerative, hierarchical clustering was used to generate a species and site classification, using flexible UPGMA ($\hat{a}$ = -0.1) (Sneath & Sokal 1973). A sorted two-way table was generated that was ordered by these site and species classifications. The number of site and species groups were arbitarily decided at the six and eight group levels respectively, with subgroups described within two of the site groups. These decisions were based on field observations and structure observed within the sorted two way table. Three dimensional semi-strong hybrid (SSH) multidimensional scaling was implemented for the ordination of the presence / absence quadrat data, using 1000 random starts and 50 iterations.

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Principal Component Correlation (PCC) runs multiple linear regression of extrinsic variables on the three dimensional ordination (Belbin 1989). The environmental variables were not standardized or transformed before PCC analysis as the Monte-Carlo procedure (MCAO) was employed in PATN as a bootstrap analysis to evaluate the significance of these correlation coefficients. This was done by implementing PCC on the same ordination using a simulated dataset of randomized values for each environmental variable (Belbin 1989). The Kruskal-Wallis non-parametric analysis of variance was used to determine differences in environmental parameters among floristic community groups, followed by Dunn's posthoc multiple comparisons test when required to identify dissimilar groups (Zar 1984). Indicator species analysis was calculated using PC-Ord (McCune and Mefford 1999), using the methods of Dufrêne and Legendre (1997). Indicators values (INDVAL) were used to determine the significant indicator species for each floristic community type at the eight group level, the statistical significance each indicator species values being determined using 1000 replicates of a MCAO site randomization procedure. Indicator species are defined as the most characteristic species of each floristic community type, and the INDVAL measures for each species at a particular level in the classification is calculated from its specificity and fidelity to a community type (Dufrêne & Legendre 1997).

RESULTS

Flora

At total of 244 taxa (species, subspecies, varieties and hybrids) from 50 families of vascular plants were record within or adjacent to the 52 quadrats. Fifteen of these taxa were undescribed or informally named entities, four were novel entities with affinities to known species, five taxa were postulated to be hybrids and 10 species were introduced (Appendix 1). Introduced species consisted of annual grasses and weedy herbs; the most common introduced species being the annual grass, *Rostraria pumila*, which was present in 19% of quadrats. At the time of the survey, good rainfalls had promoted the excellent growth of annuals, which accounted for 52% of recorded taxa. The best represented families in this survey are the Asteraceae (44 native and 2 introduced taxa), Poaceae (19 native, 2 introduced and one putative hybrid), Mimosaceae (13 taxa), Chenopodiaceae (10 taxa and one putative hybrid), Myoporaceae (12 taxa), Amaranthaceae (11 taxa) and Goodeniaceae (10 taxa). The five main genera are *Acacia* (13 taxa), *Eremophila* (12 taxa), *Ptilotus* (10 taxa), *Rhodanthe* (8 taxa) and Senna (7 taxa). These common families and genera are typical of the floras of the Austin Botanical District of the Eremaean province (Beard 1976, 1990).

Priority taxa

Eight taxa of conservation significance were collected in this survey (Table 1), all of which were found on rocky substrates associated with the uplands of the Weld Range greenstone belt. Six of these priority taxa had not been previously collected from or near the Weld Range, and therefore represent new populations. The collection of *Stenanthemum patens* was a significant range extension for the species, which was previously known from two other BIF and greenstone hills near Leonora, over 400 km southeast of the Weld Range (Rye 2001). There are four previously known locations of *Phyllanthus baeckeoides*, three being collected in the eastern Goldfields > 400 km southeast of the Weld Range and the closest previously known population located some 170 km north-west on Windimurra Station, Mt Magnet (H. Pringle 3973). The Weld Range is a new location for *Sauropus* sp. Woolgorong (M. Officer S.N. 10/8/94), which is 200 km west from the only other known population on Woolgorong Station. As with a population of *Prostanthera petrophila*, these populations on Woolgorong Station occur on the deep sands and associated scrub of Wanderrie sand country. Although *P. petrophila* is known from other rocky habitats, this is the first reported occurrence of *Sauropus* sp. Woolgorong on rocky banded iron formation and dolerite substrates.

For two other priority taxa, their collection from the Weld Range represented new populations, albeit with less extreme range extensions. *Dodonaea amplisemina* is known from banded iron formation substrates as far south as the Paynes Find region and north of Meekatharra (Shepherd et al. 2007). The nearest known location is the Cue townsite, 70 km south of the Weld Range. Similarly, *Prostanthera petrophila* has been previously collected from near the Cue town centre (E. Wittwer W 1265) but has not been previously known from the Weld Range. This species is currently known from only five locations, all restricted to a moderately small area within the Murchison and Yalgoo IBRA regions. *Acacia speckii* and *Micromyrtus placoides* are more widely distributed in the Murchison region than the previously discussed priority species, and have also been previously recorded from the Weld Range. All three of these latter species were found along the length of the Weld Range.

Prostanthera ferricola (formerly known as Prostanthera sp. Murchison (G. Byrne 239) was first collected near Meekatharra in 2003, and subsequent collections from various BIF ranges in the north Yilgarn have proved enough material to have this entity described as a new species (Conn & Shepherd 2007). *Prostanthera ferricola* has not been allied to any other taxa, but is morphologically similar to both *P. centralis* and *P. magnifica* (Section Prostanthera; Conn 1988) (Conn & Shepherd 2007). It is disjunct in its distribution from *P. magnifica*, which occurs in the Avon and Yalgoo IBRA regions immediately south west of *P. ferricola*, and *P. centralis,* which ranges from far eastern WA into the Northern Territory (Conn 1988; Western Australian Herbarium 1998 –). This entity is currently only known from six populations located within in the Gascoyne and Murchison IBRA regions. In all locations, this species was recorded as growing on rocky soils associated with BIF or quartz outcrops. This entity has been recently listed as having Priority Three conservation status (DEC conservation codes for Western Australia, Atkins (2006)), based on its limited geographical distribution and low number of known populations. Four of these six known populations occur on highly prospectable BIF ranges that are covered by mining tenements.

There are seven other priority taxa recorded for the Weld Range by the Western Australian Herbarium (1998 –) which were not located in this survey, these being *Beyeria* sp. Murchison (B. Jeanes s.n. 7/7/2005) (P2), Baeckea sp. Melita Station (H. Pringle 2738) (P3), *Grevillea inconspicua* (P4), *Grevillea stenostachya* (P3), *Grevillea pauciflora* (P3), *Ptilotus beardii* (P3) and *Calytrix verruculosa* (P1). The results from this current study bring the total number of priority taxa known to occur on the Weld Range to fifteen.

Flora of Interest

A number of entities were collected from the Weld Range which are currently undescribed and remain as taxa of interest (Appendix 1). Among these is *Acacia* sp. Weld Range (A. Markey & S. Dillon 2994) which was found to be widely distributed across the Weld Range. This taxon is poorly collected, with only nine records having been lodged in the Western Australian Herbarium at the time of this survey. Prior to this survey, there was only one collection of *Acacia* sp. Weld Range (A. Markey & S. Dillon 2994) from the Weld Range. *Acacia* sp. Weld Range (A. Markey & S. Dillon 2994) is a wide – phyllode variant allied to the *Acacia xanthocarpa* species complex (B. Maslin, pers. comm. [2]) Given that this taxon has yellow, hairy pods which are superficially similar to *Acacia citrinoviridis*, this is probably the taxon that was referred to as "*Acacia* aff. *citrinoviridis*" by Curry et al. (1994) and noted by them as the dominant taxon for both the Jack Hills and Weld Range. Recent collections confirm that *Acacia citrinoviridis s.s.* does occur on the Jack Hills (Meissner & Caruso 2008). *Acacia* sp. Weld Range (A. Markey & S. Dillon 2994) can be distinguished from this latter species, red leaf margins which become yellow with age (red margins do not develop on *A. citrinoviridis*), relatively broader phyllodes, spreading hairs on long receptacles, short peduncles, and patent and relatively sparser pod hairs (B. Maslin, pers. comm. [2]).

A taxon of *Sida* was identified which was found to have morphological affinities to the species complex, *Sida* sp. spiciform panicles (E. Leyland s.n. 14/8/90), but was sufficiently morphologically different to be considered as a distinct entity (R. Barker, pers. comm. [3]). Because there are very few collections of this entity and the taxonomy of *Sida* is still under review, the taxonomic status of this entity is currently unknown.

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[3] Robyn Barker, Research Associate, South Australian Department of Environment and Heritage, State Herbarium of South Australia, Kent Town

Cynoglossum sp. Inland Ranges (C.A. Gardner 14499) is a new entity that is a Western Australian variant of *Cynoglossum australe*. Among distinctive characters are its' large white flowers and having the corolla tube exceeding the calyx. This entity is restricted to inland ranges in Western Australia (G. Keighery, pers. comm. [4]), where it appears to be widely distributed.

Hybrids and Intergrades

Five hybrid entities were encountered on the Weld Range. Intergrades of *Maireana planifolia* x *villosa,* with intermediate characters are known from over the range of the parental species. Wilson (1984; P. Wilson, pers. comm. [5]) acknowledges that these species are variable and that this intermediate may represent a distinct taxon. Less frequently encountered was the putative hybrid, *Eriachne mucronata* x *helmsii*. *Eriachne mucronata* and *Eriachne helmsii* are very similar in morphology, are closely related and putative hybrids have been previously reported (Lazarides 1995). An intergrade was found with floral characters (namely the lemma indumentum) which were intermediate between the two taxa. Whilst *Eriachne mucronata* x *helmsii* has been reported from other states (Lazarides 1995), only a single collection has been lodged in the Western Australian Herbarium. This material was collected from Black Range Station (D.J. Edinger and G. Marsh DJE 4012), c. 180 km SE from the Weld Range, and its' identity confirmed by M. Lazarides.

Hybridization has been well documented among taxa within *Senna* (Randall & Barlow 1998), so it is not unexpected that this survey has identified two additional putative hybrid combinations new to the collections at the Western Australian Herbarium. *Senna glaucifolia* x sp. Meekatharra (A. Markey & S. Dillon 3149) was identified by its intermediate morphology between the assumed parental taxa, and this was verified by M. Trudgen. A second putative hybrid, *Senna stricta x artemisioides* subsp. *petiolaris* (E.N.S. Jackson 2888), was collected from both the Weld Range and Jack Hills (Meissner & Caruso 2008). These collections were matched to material previously determined as *Senna stricta* (E.N.S. Jackson 2888) and which had been subsequently cited in the treatment of the genus as examples of this taxon (Randall & Barlow 1998). However, closer examination of this particular voucher found inconsistencies with the published species description (Randall & Barlow 1998) and herbarium material previously confirmed to be *Senna stricta* and *Senna artemisioides* subsp. *petiolaris.* Instead, this distinct entity possessed characters that were intermediate between *Senna artemisioides* subsp. *petiolaris* and *Senna stricta*, namely that the petals were < 10 mm long and sparsely hirsute on outer surface, the petiole was subterete, the leaflets were not ventrally but laterally compressed and the extrafloral nectaries were raised. It was concluded that this was a putative new hybrid combination and distinct morphological entity within an exceedingly complex genus.

Range extensions

There are several notable range extensions for common taxa. The collections of *Crassula extrosa* and *Crassula tetramera* were extensions of 190 km north and c. 700 km east from their respective known ranges. However, range extensions of species of *Crassula* are more likely to be due to poor collection than actual scarcity in the Murchison region. Additionally, a variant of *Crassula tetramera* was collected from the Weld Range. This variant (*Crassula* aff. *tetramera*) differed from the former taxon by pentamerous floral parts, although *Crassula tetramera* itself is poorly collected for the State (with only ten collections currently lodged in the Western Australian Herbarium) and therefore it is difficult to gauge how unusual this aberrant form is.

The collection of *Stenanthemum petraeum* is a new record for this species on the Weld Range and represents a minor range extension of 120–160 km west of two known populations at Yoothapina Station (R.J. Cranfield 5678) and Youno Downs (A. Thompson 3703). This species is otherwise known from rocky substrates in central and northern Western Australia. The Weld Range population of the sheoak, *Allocasuarina acutivalvis* subsp. *acutivalvis* is a 200 km range extension north of its main distribution along the margins of the South West Botanical Province. This species was located as two small patches on the Weld Range. Only two male plants were observed at one site approximately 4 km east of 'The Gap' (Figure 1), and a small thicket was sampled on the eastern extent of the study area. In both instances, these tall shrubs were growing on the rocky, moderately steep mid-upper slopes of banded iron formation.

The apparent range extensions of species of *Cheilanthes* into the Murchison region may be artifacts of poor collection and misidentification rather than genuine increments in their known distribution. The collection of *Cheilanthes adiantoides* and *Cheilanthes distans* represent 200 km northern range extensions. In the case of the former species, the last recorded collection was from Burnerbinmah Station (Paynes Find), which was itself a new record outside the typical range for this species (Patrick 2002). However, *Cheilanthes adiantoides* was commonly encountered in this survey and it is suspected that either this species has been overlooked for collection or that previous collections in the Murchison region have been misidentified. Similarly, past collections of *Cheilanthes brownii* suggest that this species is more typical of the Kimberley and Pilbara regions that the Murchison. However, recent surveys of the Jack Hills, Weld Range and ranges south of Yalgoo have found this species to be also widespread in the Midwest region of Western Australia. Similarly, the poorly collected *Cheilanthes sieberi* subsp. *pseudovillea* is known only from northern sites, and,

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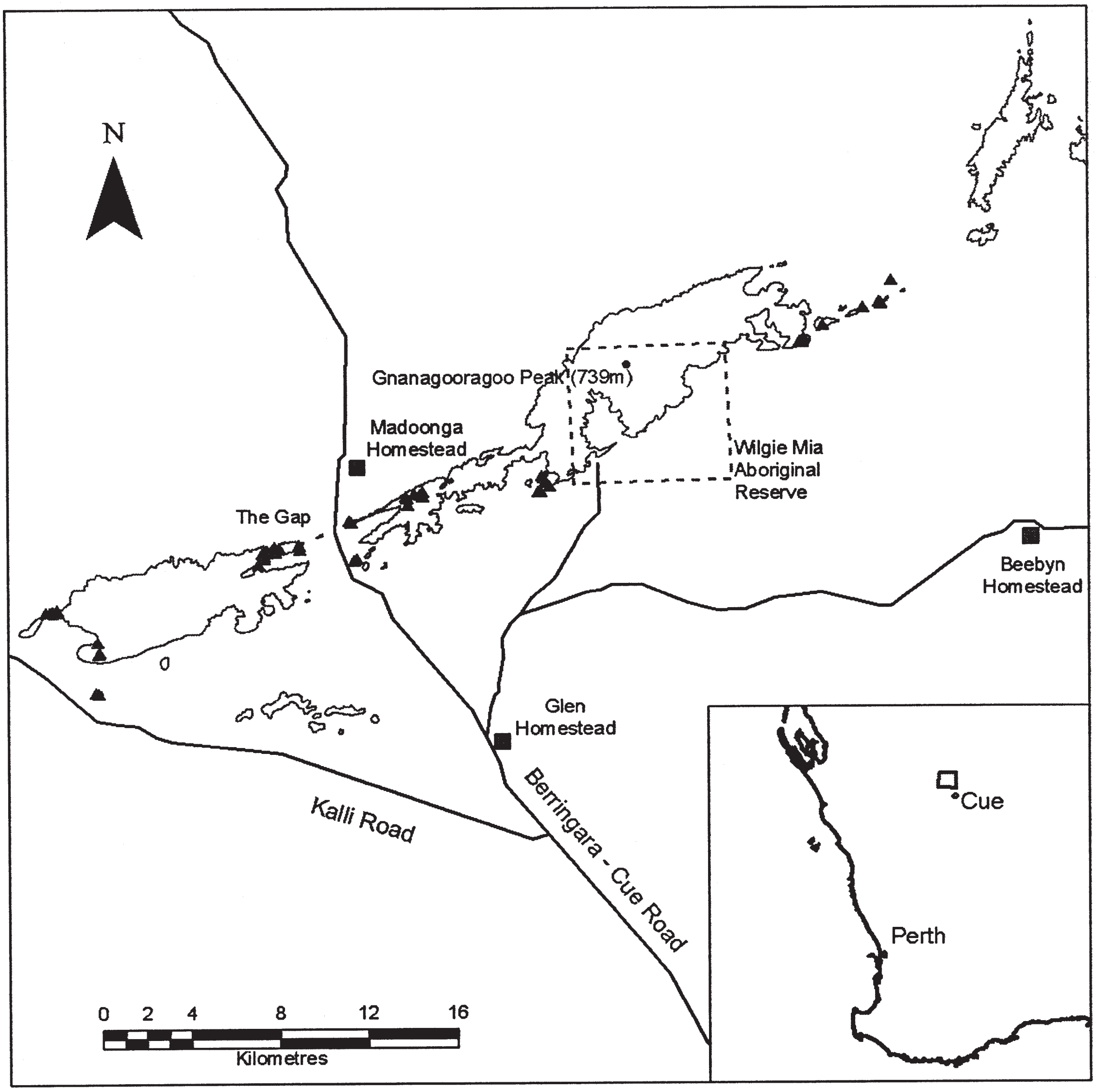

Figure 1. Map showing the location of the Weld Range relative to other landmarks, and distribution of vegetation quadrats established during the floristic survey.

if the identity of the Weld Range collection is confirmed as this taxon, this would represent a southern range extension in excess of 400 km.

Because it was not flowering the time of the survey, the *Triodia* collected in this survey could only be tentatively named as *Triodia* cf. *melvillii*, and this determination was based on the characteristically resinous leaves (Lazarides 1997, Lazarides et al. 2005). Should this population's identity be confirmed, the occurrence of *T.* cf. *melvillei* is an interesting range extension south for this taxon, being over 100 km from previous known collection location of 20 miles east of Meekatharra (S.J.J. Davies s.n.) and 100 km south of a new record for its occurrence on the Jack Hills. However, Speck (1963) reported scattered patches of *Triodia melvillei* among a ground layer of *Austrodanthonia* and *Eragrostis* under *Acacia ramulosa* var *linophylla* on sandplains north of the Weld Range. Curry et al. (1994) did not list this species in their inventory of the region. Whilst this species has been collected growing on massive BIF in the Pilbara (e.g. Karijini, S. van Leeuwen 3817), these are the southern-most records for this species on massive ironstone. A few individual plants of this species were found growing on rocky, sparsely vegetated slopes of hematite hills in the far south-eastern extent of the Weld Range. It is interesting to note that at the Jack Hills, this species forms a dominant stratum in a rare and restricted *Triodia* community which grows in a similar situation (Meissner & Caruso 2008). A *Triodia* community may also exist on the slopes of the Weld Range, but could not be confirmed in this survey due to the inaccessibility of the terrain. More extensive surveys would be required to ascertain if a *Triodia* community occurs on the Weld Range.

Floristic Communities

Only collections which were identifiable to at least species level were used in the analysis, which amounted to a total of 228 taxa. Seven taxa were amalgamated for the pattern analysis, namely those which were species complexes, (e.g. *Sida* sp. dark green fruits (S. van Leeuwen 2260) and *Sida* aff. sp. dark green fruits (S. van Leeuwen 2260)), closely related taxa which could not be resolved due to intergrades or an absence of flowering material (e.g. *Eriachne helmsii* and *E. mucronata*). The exception to amalgamating intergrades and hybrids were those of *Maireana planifolia* x *villosa* and *Senna* spp., as these are distinctive entities. The mulga complex, (*Acacia aneura* and related species), was resolved to four morphotypes which approximated the varieties described by Pedley (2001). This approach was the best means to recognize taxa within an exceedingly difficult species complex that is currently being revised (Miller et al. 2002).

Of these 228 taxa, 118 taxa were annuals and 21 taxa were perennial singletons. A comparison of the full dataset and the perennial dataset without singletons found a 76 % correlation between similarity matrices. For the 52 quadrats, the average species richness per quadrat was 37.3 ± 8.8, ranging from 18 to 56 taxa per quadrat. The floristic classification of the 52 sites using the perennial dataset resulted in recognition of eight community types and subtypes, which is illustrated in Figure 2. This summary dendrogram shows that the first major division separated Community type 6 from the other sites. This division is also discernable on the two-way table sorted by site and species classification (Appendix 2). This main division distinguished between sites on dolerite - influenced substrates from those on ironstone. Below this primary level of divergence, five floristic communities were identified for the crests, slopes and foothills on the BIF of the Weld Range. Two of these communities (1 and 5) were further resolved into subtypes. Indicator species analysis was used to resolve characteristic taxa for each community type or, occasionally, two community types (ie: *Eremophila latrobei* subsp *latrobei*, *Senna glaucifolia* and *Dodonaea pachyneura*) (Table 2).

Community type 1 is a moderately species rich group and had high representation of taxa from Species group F, and few or no species from Species groups B, G, H and I. The subdivision of this community is based largely on E and F Species groups, with community type 1b being more speciose. This subdivision also corresponds to a topographical separation. **Community type 1a** is typically dominated by *Acacia aneura*, *A. ramulosa* var *linophylla*, and / or *Acacia* sp. Weld Range (A. Markey & S. Dillon 2994) over a sparse shrub cover of *Eremophila* spp. Structurally, it consists of open shrublands on hillslopes with moderately inclined gradients, very rocky terrain and outcroping of BIF. This vegetation type occurred across the topographical profile of the range, from the lower slopes to hill tops, but was located mostly on the mid – upper slopes. The average species richness for this community type (32.7 ± 1.0 taxa per quadrat) is within the middle range for all community types, and it is only moderately rich in annuals (19.3 ± taxa per quadrat) (Table 3). Significant indicator species include *Eremophila glutinosa*, *Eremophila latrobei* subsp. *latrobei* (which is also an indicator species for Community type 1b) and

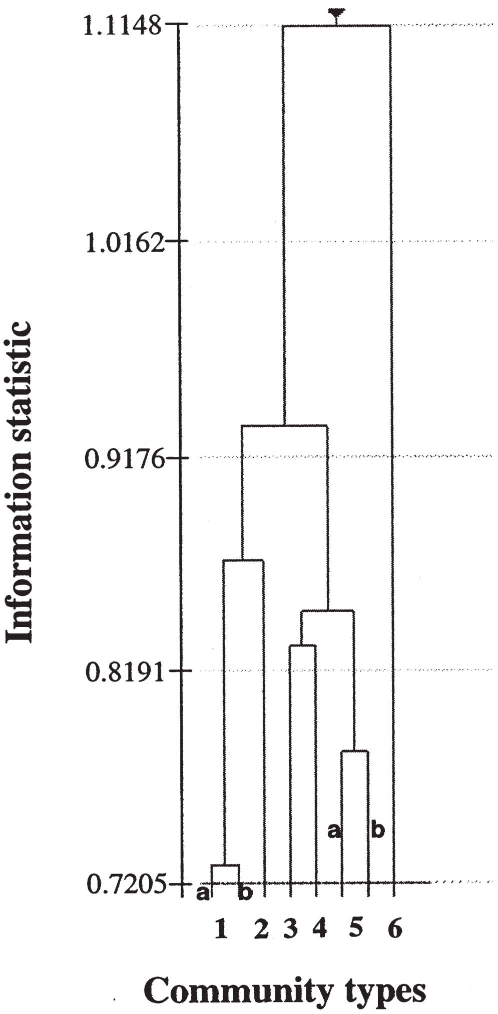

Figure 2. Summary dendrogram of the floristic community types on the Weld Ranges resolved from a data matrix of 89 taxa from 52 quadrats. Dendrogram resolved to the six group level, with subtypes resolved in floristic community types 1 and 5

Santalum spicatum (a species with few occurrences but with most of these within Community type 1a) (Table 2). The average species richness for this community is lower than for community type 1b (32.7 ± 1.0 vs 39.2 ± 5.9 taxa per quadrat) (Table 3).

Community type 1b typically consists of open shrublands and sparse shrublands of *Acacia aneura* (cf. var. *microphylla*, *aneura* and *argentea*), *Acacia* sp. Weld Range (A. Markey & S. Dillon 2994), and *Grevillea berryana* over a shrub layer of various species of *Eremophila* (*E. georgei*, *E. latrobei* subsp. *latrobei* and *E. glutinosa*) (Appendix 2). This community occurs mostly on rocky, gentle - moderate inclines, on higher slopes than type 1a. This community is the most commonly sampled, with 14 of the 52 sites falling within this category. *Eremophila latrobei* subsp. *latrobei* and *Thryptomene decussata* are the only two significant indicator species (Table 2). However, *Ptilotus schwartzii*, *Ptilotus obovatus*, *Grevillea berryana*, *Eremophila georgei* and *Thysanotus manglesianus* are also notable species within this community subtype (Appendix 2). The characteristic of rocky ironstone species, *Prostanthera petrophila* and *Cheilanthes sieberi* subsp. *sieberi* are found to be both almost exclusive to Community type 1 (1a and 1b).

Community type 2 consists of sparse – open shrublands of *Acacia aneura* cf. var. *microcarpa* and / or *A. aneura* cf. var. *aneura* over the mid-stratum shrub layer which includes species such as *Thryptomene decussata*, *Philotheca brucei* subsp *brucei* and numerous species of *Eremophila* (Appendix 2). This community is associated with massive outcrops and rocklands of BIF on moderate - steep hillslopes. Notable indicator species are *Cheilanthes adiantoides*, *Philotheca brucei* subsp. *brucei*, *Micromyrtus sulphurea*, *Dodonaea pachyneura* (also shared with Community type 4) and *Stylidium longibracteatum* (Table 2). These species typically grow in crevices and fissures formed in exposed outcrops of bedrock. Other common species were *Ptilotus obovatus* subsp. *obovatus* and *Harniera kempeana* subsp. *muelleri* (Appendix 2). This was a relatively species rich community, averaging 43.9 ± 6.4 taxa per quadrat. It was also rich in annuals, with a mean of 25.4 ± 7.2 annual taxa per quadrat. There was representation from Species groups D, part of Group E and some representation from the uncommon Species groups A, B and G (Appendix 2). This community type had species from Species group E in common with Community type 1b, which can be attributed to both community types occupying similar topographical locations.

Community type 3 is only represented by two sites, and is closest to community type 4, from which it is distinguished by a paucity of taxa from across all Species groups (Appendix 2). This community type is relatively species poor, with an average of 20.5 ± 3.5 taxa per quadrat and an average of 15 ± 2.8 annual taxa per quadrat (Table 3). This compares with the average species richness for Community type 4 at 32.7 ± 7.2 taxa per quadrat. More sampling will verify if this community is a subset of community type 4 or a distinctive community of the lower hillslopes. These species - depauperate shrublands are located on middle- and lower hillslopes on a moderate gradient (12°), with no outcropping BIF but an abundance of loose ironstone gravels and scree. The two sites sampled were both an open shrubland of *Acacia aneura* over isolated shrub species such as *Solanum ashbyae* and *Tribulus suberosus*. Only *Cheilanthes* cf. *sieberi* subsp. *pseudovillea* is identified as a significant indicator species of this community. However, the analysis was limited by the small sample size.

Community type 4 consists of open shrublands of *Acacia aneura* and emergent trees of *Acacia pruinocarpa* over shrublands of *Philotheca brucei* subsp. *brucei* and *Eremophila* spp. Only three sites are classified as this community type. The community is most similar to floristic community type 3, but is more species-rich and located further upslope on steep, rocky hillslopes with relatively high levels of exposed bedrock. The best indicator species include *Abutilon oxycarpum*, *Dodonaea pachyneura* and *Enneapogon caerulescens*, which are characteristic species of fractured rocky substrates.

Community type 5 has taxa from across most species groups (Appendix 2), and typically consists of open tall *Acacia* shrublands (*Acacia pruinocarpa*, *Acacia aneura* var. *tenuis* and *Acacia ramulosa* var. *linophylla*) mostly on lower slopes and outwashes of ironstone colluvium. This community appears to be distinguished from the other BIF communities by a more limited representation from Species Groups E and F, and some shared floristic affinities to Community type 6 (Species groups G, H and I). The split between Community type 5a and type 5b was marked by good representation in Species group C and an absence of taxa from Species groups G, H , I and a subset of species from Group F for the former subgroup. Community type 5a also has a relatively low species richness, averaging 28.0 ± 5.2 taxa per quadrat and a correspondingly low cover of annuals (Table 3). This compares with Community type 5b which, at an average of 36.2 + 3.4 taxa per quadrat, is more diverse.

Community type 5a consists of isolated, emergent trees of *Acacia pruinocarpa* above *Acacia aneura* / *Acacia ramulosa* var *linophylla* over an open mid-stratum of shrubs. This community is found on the gentle – moderately inclined lower hillslopes and outwash plains, with some low outcroppings of banded iron formation on the footslopes. Occasionally this unit is repeated on middle- and upper slopes. There are no significant indicator species unique to this community type, although *Acacia aneura* cf. var. *tenuis* has a moderate indicator value and was frequent within this community type (Table 2, Appendix 2). A trio of species from group F, namely *Acacia aneura* cf. var. *argentea*, *Sida* sp. Golden calyces glabrous fruit (H.N. Foote 32) and *Acacia pruinocarpa,* distinguish this community type from Community type 5b (Appendix 2).

Community type 5b is typically a sparse open *Acacia* shrubland (*A. aneura* cf. var. *tenuis*, *A. aneura* cf. var. *aneura* and / or Acacia *coolgardiensis* subsp. *effusa*) over sparse layer of shrubs of *Senna* spp. and *Tribulus suberosus*. The best indicator species include *A. aneura* cf. var. *tenuis*, *Senna glaucifolia* and *Hibiscus sturtii* (Table 3). Some species (groups G and H) are shared with Community type 6, in particular the species *Enneapogon caerulescens, Tribulus suberosus, Senna glaucifolia* and *Sida* sp. dark green fruits (S. van Leeuwen 2260). There was one uncharacteristic mid-slope site in this floristic community, which may have been due to this one steep, rocky slope spanning the steep transition from an upper slope Community type 1b to type 5b.

Community type 6 is a distinctive floristic community which separated from the other community types at the highest level in the dendrogram (Figure 2). It is also the community type which is solely associated with dolerite substrates. One site was located on a hillcrest of exposed volcanic rocks, whilst most other sites were located on mid –lower slopes, footslopes and a colluvial fan. Community type 6 consists of sparse – open shrubland of *Acacia* sp. Weld Range (A. Markey & S. Dillon 2994), *Acacia aneura* and *Acacia speckii* over sparse mid-stratum of *Eremophila macmillaniana*, *Eremophila mackinlayi* subsp. *spathulata* and *Senna* spp. Significant indicator species include *Senna glaucifolia*, *Sida* sp. dark green fruits

(S. van Leeuwen 2260), *Maireana georgei*, *Eremophila mackinlayi* subsp. *spathulata* and *Heliotropium ovalifolium* (Table 3). Species groups H and I are strongly associated with this community type (Appendix 2), and these species groups not only include significant indicator species (Table 2), but also other species of *Senna* and *Eremophila macmillaniana*. At an average of 49.8 ± 3.7 taxa per quadrat (Table 3), the species richness of Community type 6 was considerably higher than most other community types; with the exception of Community type 2.

Other communities not in classification

There were species-poor shrublands that were not fully sampled in this survey as the classification analyses are affected by the low number of taxa shared with other sites. These shrublands were typically dominated by only one or two species of myrtaceous shrubs such as *Homalocalyx echinulatus*, *Micromyrtus placoides* and *Aluta aspera* subsp. *hesperia*. These patches of shrubland are considered to be a relatively depauperate subset of the adjacent vegetation and part of a structural mosaic of vegetation on the lower slopes of these ironstone ranges, and a repository of uncommon shrubs which can be of conservation significance (e.g. *Micromyrtus placoides*).

Environmental Correlates

Owing to the small sample sizes of Community types 3 and 4, these were omitted from univariate analyses. Comparisons of environmental parameters are therefore conducted between the remaining six community types (Table 3). The elements cadmium, molybdenum and boron were omitted from analysis owing to levels being below the limit of instrument detection in over half of the soil samples. The remaining soil elemental concentrations, soil pH and effective cation exchange capacity (eCEC) were compared for intercorrelation using the Spearman rank correlation coefficient, the results of which are presented in Table 4. Most soil parameters are intercorrelated, except for potassium, sodium and lead (Table 4). The highest intercorrelations are among calcium, magnesium and eCEC, and only iron and phosphorus are correlated with the majority of site physical parameters (Table 4). Otherwise, only slope is positively correlated with soil chemistry, and it is inferred that sites of lower gradient are mineral enriched as they receive colluvium and leachates, whilst soils developing on steep terrain are relatively depauperate and leached (Litchfield 1963, Cole 1973, Gibson & Lyons 1998, Gray & Murphy 2002).

Univariate Analyses

Descriptions of the community types clearly suggest that topography (slope, altitude) and substrate are major correlates with community type. Of the physical site parameters, there were significant differences among groups for slope, topographical position, max size of surface rock, % cover category of exposed bedrock and altitude (Table 3). Rock fragment size was not significantly different among the community types, and this is not surprising as much of the surrounding slopes and outwash plains around the ranges were covered in rock fragments. Therefore, maximum surface rock size and percentage bedrock cover class were more meaningful measures of the terrain.

Community type 2 had, on average, steeper slopes, whilst the least inclined slopes were found in Community types 5a and 6. Community types 5b and 6 also occupied the lowest positions in the topographical profile and, consequently, the lowest altitudes. Community types 1a, 1b, 2 and 4 occupied the highest altitudes and topographical positions, steeper slopes, and highest amount of exposed bedrock cover. Among these four communities, Community type 2 had the highest values. Community types 3, 5a, 5b and 6 occurred at the lowest altitudes (on average) and Community types 3 and 6 with the lowest amount of exposed bedrock, whilst Community types 1b and 2 had the highest cover of exposed rock. It is important to note that there can be minor discrepancies between 'altitude' and 'topographic postion', since low crests and outcroppings were still scored as high points in the local landscape, although these were at lower altitudes than hill tops and ridges. This accounts for relatively high scores for topographical profile but low absolute altitudes in some community types (e.g. Community type 5a).

Non parametric analysis of variance found significant differences in all soil parameters except sodium among the remaining community types (Table 3). Whilst all soils were, on average, below neutral pH, Community types 1a and 1b had the most acidic soils (pH < 4.5), whilst the dolerite-associated Community type 6 was the least acidic. Although not compared statistically, community type 3 had acidic soils on a par with 1a and 1b. The average eCEC was higher in soils from community types 6. Community type 6 was also relatively rich in the minerals, calcium, cobalt, manganese, nickel, and had the lowest levels of lead, sulfur and iron (Table 3). To a lesser extent, soils from Community type 4 were also relatively rich in minerals and had a high eCEC although this community type was under-sampled and could not be compared statistically to the other communities.

SSH MDS Ordination

Relationships among the floristic community types are represented in a three dimensional ordination using SSH multidimensional scaling of the floristic data with a stress level of 0.21 (Figure 3 a and b). Among the community types, Community type 6 is the most clearly segregated. From principal axis correlation, it is evident that there are distinct environmental gradients associated with the site ordination. Vectors of environmental variables with a well supported correlation (from MCAO) are superimposed on the ordination (Figure 3). There are two major trends across the ordination; one that is associated with a soil nutrient gradient, and a second trend associated with site physical parameters (topography and substrate). As indicated by their co-linearity, groups of soil variables are highly correlated (Figure 2, Table 4). One intercorrelated set (eCEC, pH, Ca, Mg, Mn, Co and Ni) aligns with

Community type 6 on the ordination. This reiterates the previous findings from the univariate analysis that this Community type is associated with soils that are the least acidic, richer in exchangeable cations and the heavy metals Ni and Co, and are lowest in S. These were the soils mostly derived from weathered dolerites. Community type 5b is, to a lesser degree, also aligned along the high end of this gradient and is associated with relatively higher levels of Cu and K. This is probably associated with the lower-slope soils receiving leachates and colluvium from both BIF and dolerite sources (*cf.* Gray & Murphy 2002). Community type 2 and to a lesser extent, Community type 4 are aligned with relatively high Fe, Na, K, Zn and P levels, which suggests that the soils associated with these communities are being influenced by BIF parent rock. Sites classified as Community types 1a and 5a, and to a lesser extent community type 1b, all align at the lower extremes of these nutrient gradients (Figure 3). There were varying degrees of correlation between soil nutrients and site physical parameters, with Fe and P being the most co-linear with slope and altitude.

There was a strong gradient of correlated site physical variables (slope, topographic position, altitude, exposed bedrock cover and maximum size of surface rocks) (Figure 3). Community types 1b and 2 aligned with the most positive extremes of this gradient, and therefore were associated with steep terrain at higher altitudes and higher positions in the topographical profile (i.e. upper hill slopes and crests). Conversely, Community types 3 and 5b were the most associated with flat, terrain at lower topographic

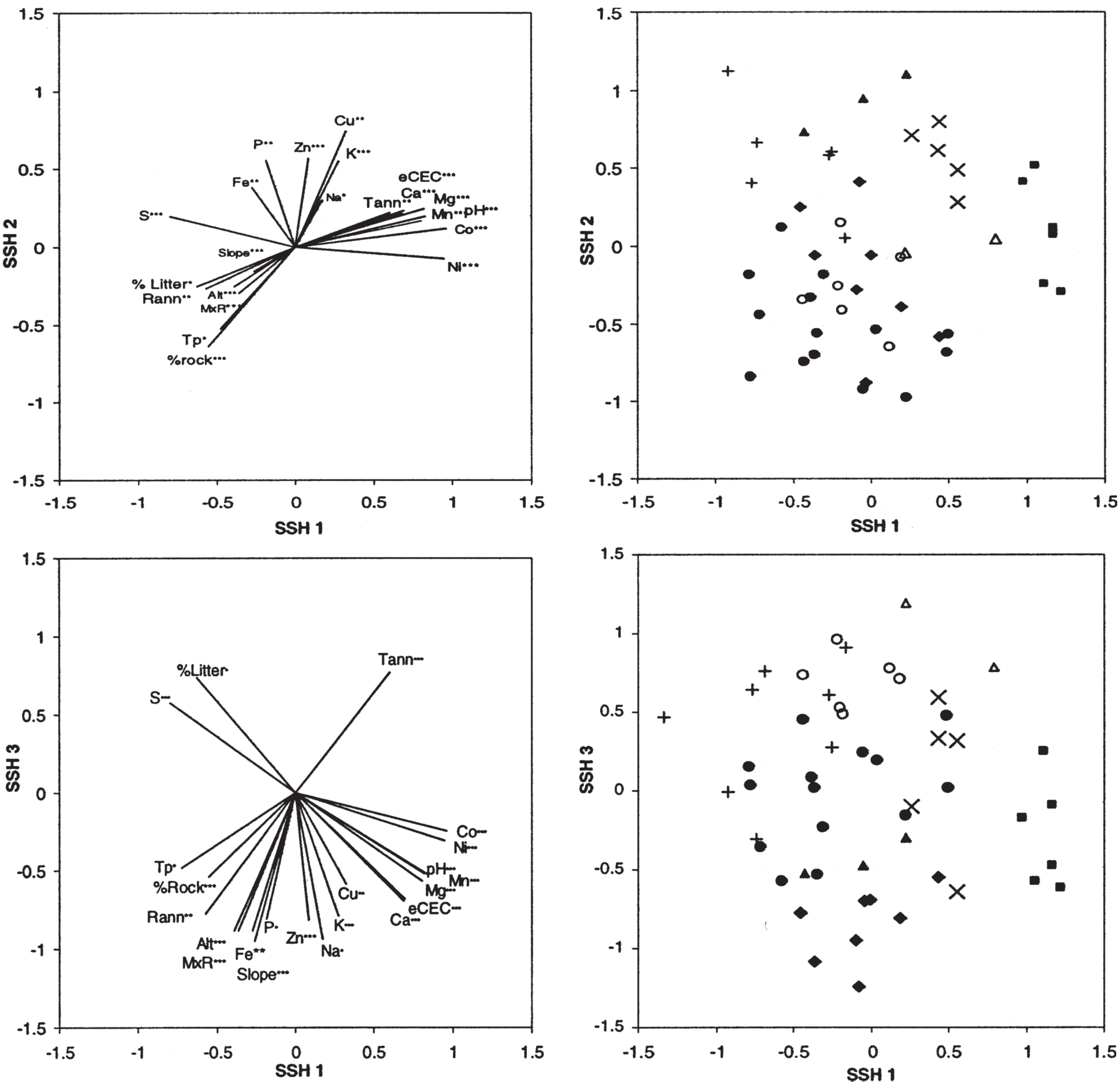

Figure 3. Ordination and vector diagrams of Weld Range floristic data, labelled by community type (1a ○,1b ●, 2 ◆ , 3 ▲, 4 Δ, 5a +, 5b ×, 6 ■). Vectors indicating best linear fit are drawn in positive direction. Only vectors with a significant correlation (from MCAO) are illustrated, with the level of significance for each parameter indicated by asterices (= p < 0.05, ** = p < 0.01, *** = p < 0.001). See methods for environmental parameter codes. (a) Ordination axes 1 versus 2. (b) Ordination axes 1 versus 3.*

positions and lacking extensive outcropping of bedrock and large, rocky debris. A gradient of leaf litter was not correlated with other site parameters, and highest cover was aligned with Community types 1a and 5a, and lowest with Community types 6 and 5b. Although there was a climatic gradient across the ordination which was co-linear with altitude, there was no corresponding regional gradient (Figure 3). This reiterates the results from univariate analyses, where absolute differences between groups were found to be insignificant (Table 3).

DISCUSSION

Flora

Prior to this study, the flora and vegetation communities of the Weld Range had only been addressed within the context of larger regional surveys (Beard 1976; Curry et al. 1994; Speck 1963). This study addressed this dearth of information, and increased the number of taxa recorded for the Weld Range from 124 (collated from herbarium records immediately prior to this survey) to 244 taxa. Approximately 6 % of the flora has not been formally described. New records of priority taxa, undescribed entities and range extensions demonstrate the importance of the Weld Range as a habitat for uncommon and poorly known taxa, and suggest a continual need for biological survey the northern Yilgarn.

The Weld Range flora is dominated by relatively common and widespread taxa and distinguished by more geographically restricted or uncommon taxa Much of the flora is characteristic of the surrounding Yalgoo and Murchison IBRA regions of the Eremaean Province, although there is representation from taxa more characteristic of the Pilbara (e.g. *Heliotropium ovalifolium*) and a few taxa more typical of the Avon Wheatbelt, Mallee or Coolgardie IBRA regions (e.g. *Allocasuarina acutivalvis* subsp. *acutivalvis*). However, this survey did not locate taxa endemic to the Weld Range. This is not the first instance where no endemic taxa have been reported for greenstone and BIF ranges in the Western Australian goldfields; such is the case for the Jack Hills (Meissner & Caruso 2008) and Highclere Hills (Gibson & Lyons 2001). However, it did find taxa which are known from only a few, highly disjunct populations, these species are often restricted to rocky substrates, e.g. *Dodonaea amplisemina*. Future development proposals must consider that, as a large and isolated BIF landform, the Weld Range is a refuge for taxa of conservation significance.

Floristic communities

This study resolved more floristic communities on the Weld Range than had been previously described for the landform (Beard 1976; Curry et al. 1994; Speck 1963). The communities described for the Weld Range by Beard (1976), Speck (1963) and Curry et al. (1994) are only broadly comparable to those described in this survey. This is mostly due to differences in analytical methodology, nomenclature and because the previous authors described these communities for broad scale surveys.

It is possible that some floristic communities may be restricted to the Weld Range. Previous surveys (Beard 1976; Curry et al. 1994; Speck 1963), had considered the Weld Range and the nearby Jack Hills (c. 100 km north) to belong to the same geomorphological land system, and therefore share the same communities. However, other, more detailed studies on greenstone and BIF ranges in the eastern goldfields have found distinct differences in floristic communities between ranges that are only 100 km apart (Gibson & Lyons 1998). Furthermore, there are substantial differences in the geology of the two ranges, the Jack Hills possessing mainly banded iron-formation, chert, mica and quartz (Elias 1982). Therefore, it is not unreasonable to expect differences in floristic composition between the Weld Range and the Jack Hills.

Compared to the Weld Range, the vegetation of the Jack Hills is floristically depauperate and structurally sparse (Meissner & Caruso 2008). This may reflect the greater aridity of a region which is 100 km north of the Weld Range. Furthermore, the Jack Hills have a different suite of perennial taxa, and the floristic communities are different from those found on the Weld Range (Mattiske Consulting Pty Ltd 2005; Meissner & Caruso 2008). Of a combined flora of 306 native taxa, there are only 40 % of species in common (data from Meissner & Caruso (2008)). Even taxa common to both ranges were more restricted in their distribution over the topographical profile. For example, *Acacia pruinocarpa* is restricted to creeklines on the Jack Hills whilst it occurs at all elevations of the Weld Range (A. Markey, pers. obs).

Characteristic Jack Hills communities include an unusual spinifex hummock grassland community (*Triodia melvillei* and *Acacia cockertoniana*) on rocky upper slopes, *Acacia rhodophloia* woodlands and an open woodland of *Acacia aneura* and *Acacia citrinoviridis* (Mattiske Consulting Pty Ltd 2005; Meissner & Caruso 2008). Interestingly, *Acacia citrinoviridis* was not collected on the Weld by this survey, although Curry et al. (1994) noted the predominance in the hillslope shrublands of an entity they identified as *Acacia* aff. *citrinoviridis*. It is assumed that Curry et al. (1994) was referring to *Acacia* sp. Weld Range (Markey & Dillon 2995). One commonality shared between the two ranges is the predominance of *Acacia aneura* in the overstorey, although these mulga shrublands are floristically different. Another similarity is the distinctive influence of Pilbara vegetation for both sites, but this appears to be greater for the Jack Hills (Meissner & Caruso 2008), whilst the vegetation on the Weld Range contains more southern species such as *Allocasuarina acutivalis* subsp. *acutivalvis*. Both underlying geological and climatic differences between the Weld Range and adjacent Jack Hills, and differences in the biogeographical history of these two regions may also account for current floristic differences. Because of these differences in floristic composition, an effort must be made to ensure adequate and representative conservation for both of these ranges.

Despite the Weld Range being a linear landform spanning approximately half a degree of latitude and longitude, there was no geographical segregation of the floristic communities along the range. Either the length of the survey area (42 km) did not span a large enough range of climatic variation to have an effect on the vegetation, or the topography and substrate are uniform over the extent of the range. More sampling is required to address this, particularly in the far eastern extent of the range (where faulting has tipped the strike to a northern orientation), which was inaccessible at the time of this survey. This part of the Weld Range has been classified by Curry et al. (1994) as belonging to a different land system unit than the rest of the range, this being the Gabaninatha land system. Therefore, this area may harbour a different suite of floristic communities to those already described by this survey. Curry et al. (1994) mapped this land system as occurring south to Mt Magnet and supporting Stony Mulga Mixed Shrubland or Rocky Hill Mixed Shrubland with dominant species that differ from the eastern Weld Range (*Acacia aneura* and / or *Acacia quadrimarginea*). There were no instances on either the Weld Range (this study) or on the Jack Hills (Meissner & Caruso 2008) where *Acacia quadrimarginea* was recorded. Given more sampling on this far eastern extent of the Weld Range, this or a similar species may be located which corresponds to the community described by Curry et al. (1994).

The eight community types and subtypes described for the Weld Range differed in their associated edaphic and topographic parameters. The Weld Range consists of folded belts of BIF alternating with strata of dolerite, often with massive outcrops of the resistant BIF forming the hill crests and steep upper slopes whilst the middle - lower slopes and outwashes are colluvium derived from volcanic rocks (Elias 1982, Watkins et al. 1987). The primary division in the classification segregated floristic communities on dolerite from those growing on BIF. This association between floristic composition and geological substrate may, at least in part, relate to differences in soil chemistry as this reflects parent rock composition, particularly in erosional parts of the landscape where there is *in situ* soil development (Cole 1973; Britt et al. 2001; Gray & Murphy 2002). Soils derived from mafic and felsic volcanics were found to be the most mineral rich, iron deficient and least acidic (this study). Despite this, all the soils for the survey area were generally found to be of a low pH (< 6.0), although these values were within the range documented for the Weld land system (Curry et al. 1994). The range of soil pH reported here for the Weld Range is far less than has been documented for other studies on greenstone ranges, where the generation of calcretes from eroded greenstones produces basic (pH > 8.0) soils (Curry et al. 1994; Gibson & Lyons 2001; Litchfield 1963). It may be that such calcretes from eroded mafic rocks exist on the Weld Range and, consequently, these soils are likely to harbour a distinct floristic community on such basic soils (*cf.* Gibson & Lyons 2001).

Among ironstone communities, there were differences in their topographical distribution associated with slope, rock outcrop and edaphic factors and water retention in these habitats. This association has been documented in other ironstone communities in the Pilbara (van Etten and Fox 2004), the eastern goldfields (Gibson 2004; Gibson & Lyons 1998, 2001), the midwest (Meissner & Caruso 2008, Markey and Dillon 2008) and in both Brazil and Africa (Jacobi et al. 2007). Topography has some bearing on soil chemistry, although a direct relationship was not obvious in these analyses. However, soil development has been reported to be strongly correlated with altitude and topographic relief, with these factors exerting some influence on the vegetation (Cole 1973; Gibson & Lyons 1998, 2001). Considering soils overlying BIF bedrock, soils on rocky, upper slopes are skeletal or shallow, and are mineral poor except for iron and phosphorus. Conversely, soils on the colluvial outwash of greenstone ranges are deeper and tend to be mineral and nutrient enriched (Gibson & Lyons 1998, 2001; this study). These factors all appear to influence the distribution of floristic communities on the Weld Range.

Conservation

BIF ranges of the Yilgarn Craton are unique and relatively isolated environments which are at particular risk from a number of threatening processes. The Weld Range is covered by active pastoral leases and small area of Aboriginal Reserve (Wilgie Mia), and no portion of the Weld Range is within a conservation reserve. However, the vegetation of the Weld Range was found to be intact along the extent of the range, relatively free of invasive weeds and in reasonably good condition. This agrees with Curry et al. (1994), who found only 5% of the total Weld land system was in poor condition. Being of low pastoral potential, grazing pressure from livestock is minimal in the hilly terrain of the Weld and Gabanintha land systems, (Curry et al. 1994). However, feral goats are a problem in this area, and both large flocks (> 40 animals) and heavily browsed vegetation were frequently encountered over the length of the range. Despite this, it is appreciated that individual station managers have undertaken eradication programs on their leases. More effective control on a larger scale may require a regional approach coordinated between adjoining leases.

Local environmental damage from past mining activities is still evident after thirty years, and there was little evidence to suggest that these areas had been or would be rehabilitated. Such impacts include road and campsite clearings, graded drill pads and grid lines, abandoned sample bags and drill cores and even abandoned tailing dams. A new phase of mineral exploration commenced in late 2005, and it is urged that these current activities adhere to more strict guidelines for minimizing and ameliorating any impacts in an environment which is slow to recover.

Large scale, open cast mining activity poses the greatest threat to the floristic communities of the Weld Range, given they are closely associated with the physical environment along a topographic catena and may be geographically restricted to this particular landform. Complete restoration of these floristic communities within the immediate excavation area is unlikely given the magnitude of the impact that iron ore extraction will have on the underlying landform. As none of these communities are known from a conservation reserve, careful management of the communities on the Weld Range is required given that much of this range is under mining tenement and exploration activities have already commenced.

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Table 1

Taxa of conservation significance collected on the Weld Range. New records are where the species has not been previously known from the Weld Range. Disjunctions are where the Weld Range populations are discrete and over 100 km distant from the known range of the species. Widespread species are those not restricted to an area within a 100 km radius.

Family	Taxon	Conservation status	Population status	Distribution
Euphorbiaceae	*Phyllanthus baeckeoides*	P1	new record	disjunct
Euphorbiaceae	*Sauropus sp. Woolgorong*	P1	new record	disjunct
Lamiaceae	*Prostanthera petrophila*	P1	new record	widespread
Mimosaceae	*Acacia speckii*	P3	known	widespread
Myrtaceae	*Micromyrtus placoides*	P1	known	widespread
Sapindaceae	*Dodonaea amplisemina*	P1	new record	widespread
Rhamnaceae	*Stenanthemum patens*	P1	new record	disjunct
Lamiaceae	*Prostanthera ferricola*	P3	new record	widespread

Table 2

Significant indicator species and their indicator values (INDVAL %) for six floristic community types on the Weld Range, collated from indicator species analysis of quadrat floristic data at the eight group level. Only significant taxa, as determined from permutation testing, are included (level of significance, * = p < 0.05, ** = p < 0.01, *** = p < 0.001). Relatively high indicator values for each species are highlighted (Dufrêne & Legendre 1997).

Indicator Species	Community type							
	1a	1b	2	3	4	5a	5b	6
Eremophila latrobei subsp. *latrobei* ***	29	25	16	0	3	2	1	0
Eremophila glutinosa **	43	15	1	0	0	0	0	2
Monachather paradoxus *	25	6	6	6	0	14	16	0
Santalum spicatum *	33	0	8	0	0	0	0	0
Thryptomene decussata *	13	32	7	0	0	3	0	0
Cheilanthes adiantoides ***	0	2	75	0	0	0	0	0
Philotheca brucei subsp. *brucei* ***	2	7	44	0	0	1	2	0
*Micromyrtus sulphurea**	0	0	38	0	0	0	0	0
Stylidium longibracteatum *	0	0	38	0	0	0	0	0
Cheilanthes cf. *sieberi* subsp. *pseudovillea* *	0	1	0	44	0	0	0	0
Abutilon oxycarpum ***	0	0	1	0	73	0	0	2
Dodonaea pachyneura ***	0	3	41	0	41	1	0	0
Enneapogon caerulescens *	0	0	0	0	46	1	7	20
Acacia aneura cf. var. *tenuis* **	1	2	0	0	4	16	40	1
Senna glaucifolia *	1	1	0	0	4	1	38	27
Hibiscus sturtii var. *forrestii* *	0	0	1	0	0	0	34	10
Sida sp. dark green fruits ***	5	2	10	0	0	0	7	41
Acacia speckii **	0	0	6	0	0	0	0	64
Maireana georgei **	0	0	0	0	0	0	0	67
Eremophila mackinlayi subsp. *spathulata* **	0	0	0	0	0	0	0	67
Heliotropium ovalifolium **	0	0	0	0	0	0	0	67
Calytrix desolata *	0	0	0	0	0	0	0	50
Sclerolaena densiflora *	0	0	0	0	0	0	0	50
Sclerolaena eriacantha *	0	0	0	0	0	0	0	50
Senna artemisioides subsp. *helmsii* *	0	0	0	0	8	0	3	51
Dodonaea amplisemina *	0	0	3	0	0	0	0	40
Eremophila aff. *georgei* *	0	0	18	0	0	0	3	33
Number of quadrats	6	14	8	2	3	8	5	6

Table 3

Summary statistics (average ± s.e.) of environmental parameters for the upland floristic community types for the Weld Range. Differences between average rank of community types 1a, 1b, 2, 5a, 5b and 6 were tested using Kruskal-Wallis non-parametric analysis of variance (NS denotes $p > 0.05$, * indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$), followed by Dunn's multiple comparison test (LSD, $p < 0.05$) when significant differences where detected from Kruskal Wallis AOV. Despite significant results for AOV, posthoc tests were insignificant for K, Pb and altitude. Units for parameters; eCEC = cmol(+)/kg, minerals = mg/kg, annual temperature (Tann) = ° C and annual rainfall (Rann) = mm. Abbreviations: Rock Frag = surface rock fragment cover, Rock Max Size = maximum surface rock size category.

	Community type							
Variable	**1a**	**1b**	**2**	**3**	**4**	**5a**	**5b**	**6**
Soil parameters								
eCEC ***	1.01 ± 0.06 ^{ab}	1.18 ± 0.11^{ab}	1.88 ± 0.18 ^{bc}	0.85 ± 0.20	2.75 ± 0.45	0.77 ± 0.11 ^{a}	1.68 ± 0.38 ^{abc}	3.40 ± 0.33 ^{c}
pH ***	4.22 ± 0.02 ^{a}	4.32 ± 0.05 ^{a}	4.64 ± 0.12 ^{ab}	4.15 ± 0.05	4.63 ± 0.20	4.26 ± 0.10 ^{a}	4.66 ± 0.12 ^{ab}	5.67 ± 0.09 ^{b}
Ca ***	105.5 ± 10.2 ^{ab}	128.1 ± 13.5 ^{ab}	203.8 ± 21.5 ^{bc}	63.0 ± 14.0	306.7 ± 35.3	78.9 ± 13.6 ^{a}	180.2 ± 43.6 ^{abc}	398.3 ± 53.2 ^{c}
Co ***	0.09 ± 0.04 ^{ab}	0.10 ± 0.02 ^{ab}	0.46 ± 0.16 ^{abc}	0.17 ± 0.11	0.76 ± 0.57	0.07 ± 0.02 ^{a}	0.76 ± 0.22 ^{bc}	3.24 ± 0.45 ^{c}
Cu **	0.60 ± 0.04 ^{a}	0.66 ± 0.02 ^{a}	0.79 ± 0.08 ^{ab}	0.60 ± 0.10	3.60 ± 2.70	0.61 ± 0.05 ^{a}	0.78 ± 0.17 ^{ab}	1.40 ± 0.19 ^{b}
Fe *	42.7 ± 3.7 ^{ab}	68.4 ± 18.5 ^{ab}	102.9 ± 24.6 ^{b}	31.0 ± 5.0	144.3 ± 65.0	36.8 ± 7.0 ^{a}	69.0 ± 40.3 ^{ab}	39.8 ± 2.0 ^{ab}
K *	100.0 ± 3.4	105.5 ± 8.7	124.9 ± 15.7	120.0 ± 20.0	193.3 ± 43.3	79.1 ± 8.1	142.2 ± 40.3	117.0 ± 7.8
Mg ***	25.2 ± 1.8 ^{ab}	30.6 ± 3.1 ^{ab}	62.0 ± 5.3 ^{bc}	23.5 ± 7.5	82.0 ± 19.2	18.8 ± 2.4 ^{a}	48.4 ± 7.9 ^{abc}	131.7 ± 19.2 ^{c}
Mn ***	19.7 ± 2.5 ^{a}	23.6 ± 2.8 ^{a}	40.0 ± 10.7 ^{ab}	20.0 ± 6.0	75.7 ± 28.0	14.1 ± 4.1 ^{a}	46.2 ± 10.9 ^{ab}	113.2 ± 10.1 ^{b}
Na ^{NS}	4.3 ± 1.3	4.3 ± 0.7	8.5 ± 2.4	7.0 ± 3.0	10.3 ± 7.0	4.6 ± 2.4	3.4 ± 1.4	7.8 ± 3.3
Ni ***	0.11 ± 0.02 ^{ab}	0.15 ± 0.04 ^{ab}	0.21 ± 0.01 ^{abc}	0.15 ± 0.05	0.20 ± 0.06	0.08 ± 0.01 ^{a}	0.24 ± 0.04 ^{bc}	1.08 ± 0.27 ^{c}
P **	11.3 ± 3.1 ^{ab}	26.1 ± 10.4 ^{b}	47.1 ± 14.7 ^{b}	7.5 ± 2.5	103.0 ± 59.9	9.0 ± 2.9 ^{ab}	46.2 ± 41.0 ^{ab}	4.8 ± 0.95 ^{a}
Pb *	0.48 ± 0.02	0.45 ± 0.03	0.32 ± 0.03	0.35 ± 0.05	1.33 ± 1.08	0.48 ± 0.03	2.04 ± 1.64	0.43 ± 0.02
S ***	9.2 ± 0.6 ^{bc}	7.6 ± 0.2 ^{bc}	6.1 ± 0.4 ^{ab}	10.0 ± 1.0	8.7 ± 3.2	9.6 ± 0.5 ^{c}	6.4 ± 0.5 ^{abc}	2.5 ± 0.2 ^{a}
Zn *	1.37 ± 0.37 ^{a}	1.68 ± 0.18 ^{ab}	2.95 ± 0.38 ^{b}	0.95 ± 0.25	5.67 ± 1.16	1.34 ± 0.29 ^{a}	3.50 ± 1.69 ^{ab}	1.90 ± 0.16 ^{ab}
Ca:Mg ^{NS}	4.2	4.3	3.3	2.8	4.0	4.1	3.6	3.3
Climate estimates								
Tann ^{NS}	21.4 ± 0.0	21.3 ±0.01	21.3 ±0.01	21.6 ±0.0	21.4 ±0.1	21.4 ±0.1	21.5 ±0.1	21.5 ±0.1
Rann ^{NS}	211.0 ± 0.5	212.7 ±1.0	213.0 ±0.9	208.5 ±1.5	211.7 ±1.4	210.8 ±1.1	210.4 ±1.9	209.8 ±1.1
Rcv ^{NS}	52.3 ± 0.1	52.0 ±0.2	52.0 ±0.1	52.6 ±0.0	52.1 ±0.2	52.3 ±0.1	52.0 ±0.2	52.4 ±0.2
Physical Site Parameters								
Slope ***	11.5± 0.7 ^{abc}	14.4± 1.8 ^{bc}	23.4± 3.2 ^{c}	12.0± 0.0	19.3± 1.8	5.5± 0.8 ^{a}	11.0± 4.6 ^{abc}	6.8± 1.1 ^{ab}
Topography **	3.6 ± 0.5 ^{ab}	3.8 ± 0.3 ^{b}	3.7 ± 0.3 ^{ab}	2.5 ± 0.5	3.5 ± 1.0	2.8 ± 0.6 ^{ab}	2.1 ± 0.4 ^{ab}	1.8 ± 0.3 ^{a}
Rock Frag ^{NS}	4.7 ± 0.4	4.6 ± 0.1	4.6 ± 0.3	5.0 ± 0.0	5.0 ± 0.0	5.0 ±0.3	5.0 ± 0.3	5.2 ± 0.2
Rock max size **	4.8 ± 0.3 ^{ab}	5.1 ± 0.2 ^{ab}	5.6 ± 0.2 ^{b}	4.5 ± 0.5	5. 7 ± 0.3	4.4 ± 0.2 ^{a}	5.0 ± 0.3 ^{ab}	4.2 ± 0.2 ^{a}
% Rock *	2.8 ± 0.7 ^{ab}	3.6 ± 0.3 ^{b}	3.5 ± 0.4 ^{b}	0.0 ± 0.0	3.0 ± 1.0	1.4 ± 0.7 ^{ab}	1.2 ± 0.6 ^{ab}	0.3 ± 0.3 ^{a}
% litter ^{NS}	19.2 ± 6.6	8.6 ± 1.8	8.4 ± 3.8	9.0 ± 6.0	3.7 ± 1.3	14.6 ± 4.6	12.4 ± 5.4	3.0 ± 0.9
% bare ^{NS}	72.7 ± 3.6	74.6 ± 3.2	72.8 ± 4.8	79.5 ± 7.5	70.0 ± 15.3	71.2 ± 5.8	56.0 ± 12.1	83.7 ± 3.1
Altitude *	544.5 ± 4.6	563.6 ± 9.5	573.8 ± 10.0	516.5 ± 6.5	551.7 ± 15.5	534.4 ±10.4	542.4 ± 19.0	537.8 ± 11.7
Latitude ^{NS}	-26.952±0.021	-26.955±0.014	-26.922±0.015	-26.975±0.017	-26.962±0.007	-26.987±0.007	-26.958 ± 0.006	-26.939±0.014
Longitude ^{NS}	117.59± 0.069	117.61± 0.037	117.70± 0.043	117.52± 0.070	117.60± 0.040	117.51± 0.020	117.61 ± 0.021	117.67± 0.038
Number of species / quadrat								
All taxa [1]	32.7 ± 1.0	39.2 ± 5.9	43.9 ± 6.4	20.5 ± 3.5	32.7 ± 7.2	27.9 ± 5.2	36.2 ± 3.4	49.8 ± 3.7
Annuals only	19.3 ± 2.7	23.6 ± 5.0	25.4 ± 7.2	15.0 ±2.8	22.0 ± 6.9	17.2 ± 4.5	21.8 ± 5.1	30.3 ± 4.2
Number of quadrats	6	14	8	2	3	8	5	6

[1:] including singleton taxa

Table 4

Matrix of Spearman rank correlation coefficients for environmental variables collated from 52 quadrats established on the Weld Range. Only correlations significant at p < 0.01 are shown. Full details of environmental parameter codes are given in the methods section.

	eCEC	pH	Ca	Co	Cu	Fe	K	Mg	Mn	Na	Ni	P	Pb	S	Zn	Tann	Rann	Rcv	Slope	Topography	Rock Frag	MxR	%Rock	%litter	%Bare	Altitude	Latitude
Soil Parameters																											
eCEC																											
pH	0.823																										
Ca	0.985	0.809																									
Co	0.740	0.764	0.729																								
Cu	0.677	0.726	0.659	0.696																							
Fe	0.586	.	0.566	.	0.363																						
K	0.745	0.560	0.701	0.413	0.502	0.656																					
Mg	0.958	0.816	0.920	0.770	0.638	0.514	0.668																				
Mn	0.749	0.810	0.744	0.819	0.821	.	0.551	0.698																			
Na	0.341	.	.	.	.	.	.	0.405	.																		
Ni	0.781	0.693	0.752	0.821	0.573	.	0.460	0.835	0.631	0.351																	
P	.	.	.	.	.	0.806	0.566	.	.	.	.																
Pb	-0.327	.	.	.	.	-0.502	-0.356	-0.383	.	.	.	-0.418															
S	-0.617	-0.654	-0.610	-0.747	-0.545	.	.	-0.686	-0.655	.	-0.635	.	.														
Zn	0.693	0.582	0.672	0.497	0.619	0.645	0.650	0.637	0.568	.	0.476	0.533	.	-0.425													
Climate Estimates																											
Tann	.	.	.	.	.	-0.339	.	.	.	.	.	-0.412	.	.	.												
Rann	.	.	.	.	.	0.385	.	.	.	.	.	0.436	.	.	.	-0.968											
Rcv	.	.	.	.	.	-0.362	.	.	.	.	.	-0.366	.	.	.	0.953	-0.948										
Physical Site Parameters																											
Slope	0.404	.	0.396	.	.	0.665	0.529	0.335	.	.	.	0.671	-0.317	.	0.610	-0.399	0.410	-0.363									
Topography	.	.	.	-0.369	.	0.557	.	.	.	.	.	0.678	.	.	0.343	-0.387	0.407	-0.339	0.394								
Rock Frag	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.							
MxR	.	.	.	.	.	0.623	0.429	.	.	.	.	0.718	-0.328	.	0.575	-0.445	0.421	-0.413	0.735	0.578	.						
%Rock		.	.	.	.	0.656	.	.	.	.	.	0.736	.	.	.	-0.493	0.503	-0.456	0.514	0.702	-0.527	0.690					
% litter	.	.	.	.	.	.	.	.	.	-0.391	-0.334	.	.	.	.	.	.	.	.	.	.	.	.				
%Bare	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.			
Altitude	.	.	0.329	.	.	0.540	0.350	.	.	.	.	0.520	.	.	.	-0.878	0.915	-0.862	0.553	0.411	.	0.523	0.558	.	.		
Latitude	0.455	0.364	0.479	0.425	.	.	.	0.460	.	.	0.467	.	.	-0.386	.	.	.	.	0.359	.	.	.	.	.	.	.	
Longitude	0.464	0.332	0.497	0.453	.	.	.	0.481	.	.	0.490	.	.	-0.391	.	.	.	.	.	.	.	.	.	.	.	.	0.953

APPENDIX 1

Flora list for the Weld Range, complied from field data. Nomenclature follows Packowska and Chapman (2000). Introduced taxa are denoted by an asterisk and phrase names (informal names) at the Western Australian Herbarium are followed by a reference collection number. Informal names are currently used at Western Australian Herbarium and refer to a taxon that is a new entity awaiting a formal, published description

Acanthaceae

Harnieria kempeana subsp. *muelleri*

Adiantaceae

Cheilanthes cf. *distans*
Cheilanthes cf. *sieberi* subsp. *pseudovillea*
Cheilanthes adiantoides
Cheilanthes brownii
Cheilanthes sieberi subsp. *sieberi*

Aizoaceae

* *Cleretum papulosum* subsp. *papulosum*
Tetragonia cristata

Amaranthaceae

Amaranthus mitchellii
Ptilotus aervoides
Ptilotus exaltatus
Ptilotus gaudichaudii var. *parviflorus*
Ptilotus grandiflorus var. *grandiflorus*
Ptilotus helipteroides
Ptilotus obovatus var. *obovatus*
Ptilotus polystachyus var. *polystachyus*
Ptilotus roei
Ptilotus rotundifolius
Ptilotus schwartzii

Anthericaceae

Arthropodium dyeri
Murchisonia volubilis
Thysanotus manglesianus

Apiaceae

Daucus glochidiatus
Hydrocotyle pilifera var. *glabrata*
Trachymene cyanopetala
Trachymene ornata
Trachymene pilbarensis

Asclepiadaceae

Marsdenia australis
Rhyncharrhena linearis

Asteraceae

Actinobole oldfieldianum
Actinobole uliginosum
Angianthus tomentosus
Brachyscome cheilocarpa
Brachyscome ciliocarpa
Brachyscome perpusilla
Calocephalus knappii
Calocephalus multiflorus
Calocephalus sp. Pilbara-Desert (M.E. Trudgen 11454)
Calotis hispidula
Calotis multicaulis
Cephalipterum drummondii
Chthonocephalus pseudevax
Chthonocephalus viscosus
Dielitzia tysonii
Gilberta tenuifolia
Gilruthia osbornei
Gnephosis brevifolia
Gnephosis tenuissima
Helipterum craspedioides
* *Hypochaeris glabra*
Isoetopsis graminifolia
Lawrencella davenportii
Lawrencella rosea
Lemooria burkittii
Millotia myosotidifolia
Minuria leptophylla
Myriocephalus guerinae
Myriocephalus pygmaeus
Myriocephalus rudallii
Olearia humilis
Olearia stuartii
Podolepis gardneri
Pogonolepis stricta
Rhodanthe battii
Rhodanthe charsleyae
Rhodanthe chlorocephala subsp. *splendida*
Rhodanthe citrina
Rhodanthe forrestii
Rhodanthe laevis
Rhodanthe maryonii
Rhodanthe oppositifolia subsp. *oppositifolia*
Senecio glossanthus
Senecio pinnatifolius
* *Sonchus oleraceus*
Waitzia acuminata var. *acuminata*

Boraginaceae

Cynoglossum sp. Inland Ranges (C.A. Gardner 14499)
Halgania cyanea var. Allambi Stn (B.W. Strong 676)
Heliotropium ovalifolium

Brassicaceae

Lepidium oxytrichum
* *Sisymbrium erysimoides*
Stenopetalum anfractum
Stenopetalum filifolium

Caesalpiniaceae

Senna artemisioides subsp. *oligophylla* x *helmsii* (G. Cassis PILB 193)
Senna artemisioides subsp. *helmsii*
Senna artemisioides subsp. x *sturtii*
Senna glaucifolia
Senna glaucifolia x sp. Meekatharra (A. Markey & S. Dillon 3149)
Senna sp. Meekatharra (E. Bailey 1-26)
Senna stricta x *artemesioides* subsp. *petiolaris* (E.N.S. Jackson 2888)

Campanulaceae

Wahlenbergia gracilenta
Wahlenbergia tumidifructa

Caryophyllaceae

Gypsophila tubulosa

Casuarinaceae

Allocasuarina acutivalvis subsp. *acutivalvis*

Chenopodiaceae

Chenopodium curvispicatum
Chenopodium melanocarpum f. *melanocarpum*
Chenopodium saxatile
Dysphania kalpari
Dysphania rhadinostachya subsp. *rhadinostachya*
Maireana georgei
Maireana melanocoma
Maireana planifolia x *villosa* (A. Markey & S. Dillon 3479)
Maireana villosa
Sclerolaena densiflora
Sclerolaena eriacantha

Crassulaceae

Crassula colorata var. *acuminata*
Crassula extrorsa
Crassula tetramera
Crassula aff. *tetramera* (pentamerous variant)

Convolvulaceae

Porana cf. *commixta*

Cucurbitaceae

* *Cucumis myriocarpus*

Cuscutaceae

* *Cuscuta epithymum*

Cyperaceae

Schoenus nanus

Euphorbiaceae

Euphorbia australis
Euphorbia boophthona
Euphorbia drummondii subsp. *drummondii*
Phyllanthus baeckeoides
Phyllanthus erwinii
Sauropus sp. Woolgorong (M. Officer s.n. 10/8/94)

Geraniaceae

Erodium cygnorum

Goodeniaceae

Brunonia australis
Goodenia berardiana
Goodenia havilandii
Goodenia macroplectra
Goodenia occidentalis
Goodenia tenuiloba
Scaevola spinescens
Velleia glabrata
Velleia hispida
Velleia rosea

Haloragaceae

Haloragis odontocarpa
Haloragis trigonocarpa

Juncaginaceae

Triglochin sp. B Flora of Australia (P.G. Wilson 4294)

Lamiaceae

Prostanthera althoferi subsp. *althoferi*
Prostanthera ferricola
Prostanthera petrophila
Spartothamnella teucriiflora

Lobeliaceae

Lobelia heterophylla
Lobelia winfridae

Loranthaceae

Lysiana murrayi

Malvaceae

Abutilon cryptopetalum
Abutilon oxycarpum subsp. *prostratum*
Hibiscus sturtii var. *forrestii*
Sida sp. dark green fruits (S. van Leeuwen 2260)
Sida aff. sp. dark green fruits (S. van Leeuwen 2260)
Sida sp. Excedentifolia (J.L. Egan 1925)
Sida sp. Golden calyces glabrous fruit (H.N. Foote 32)
Sida sp. (A. Markey & S. Dillon 3071)
Sida ectogama

Mimosaceae

Acacia aneura cf. var. *aneura*
Acacia aneura cf. var. *argentea*
Acacia aneura cf. var. *microcarpa*
Acacia aneura cf. var. *tenuis*
Acacia coolgardiensis subsp. *effusa*

Acacia exocarpoides
Acacia grasbyi
Acacia minyura
Acacia pruinocarpa
Acacia ramulosa var. *linophylla*
Acacia rhodophloia
Acacia sp. Weld Range (A. Markey & S. Dillon 2994)
Acacia speckii

Myoporaceae

Eremophila aff. *georgei* (A. Markey & S. Dillon 2928)
Eremophila clarkei
Eremophila exilifolia
Eremophila forrestii subsp. *forrestii*
Eremophila georgei
Eremophila glutinosa
Eremophila jucunda subsp. *jucunda*
Eremophila latrobei subsp. *latrobei*
Eremophila mackinlayi subsp. *spathulata*
Eremophila macmillaniana
Eremophila oppositifolia subsp. *angustifolia*
Eremophila simulans subsp. *simulans*

Myrtaceae

Aluta aspera subsp. *hesperia*
Calytrix desolata
Corymbia lenziana
Homalocalyx echinulatus
Micromyrtus placoides
Micromyrtus sulphurea
Thryptomene decussata

Nyctaginaceae

Boerhavia coccinea

Papilionaceae

Chorizema genistoides
Indigofera monophylla
Swainsona affinis

Plantaginaceae

Plantago aff. *hispida* (A. Markey & S. Dillon 3440)

Poaceae

Aristida contorta
Austrostipa elegantissima
Austrostipa nitida
Austrostipa scabra
Austrostipa trichophylla
Bromus arenarius
Cymbopogon ambiguus
Digitaria brownii
Enneapogon caerulescens
Eragrostis pergracilis
Eriachne helmsii
Eriachne mucronata
Eriachne mucronata x *helmsii* (A. Markey & S. Dillon 3228)
Eriachne pulchella subsp. *pulchella*
Monachather paradoxus
Neurachne minor
Paspalidium basicladum
* *Pentaschistis airoides*
* *Rostraria pumila*
Thyridolepis multiculmis
Triodia cf. *melvillei*
Tripogon loliiformis

Polygalaceae

Polygala isingii

Polygonaceae

* *Acetosa vesicaria*

Portulacaceae

Calandrinia creethae
Calandrinia eremaea
Calandrinia sp. The Pink Hills (F. Obbens FO 19/06)
Calandrinia sp. Bungalbin (G.J. Keighery & N. Gibson 1656)
Calandrinia translucens

Primulaceae

* *Anagallis arvensis* var. *caerulea*

Proteaceae

Grevillea berryana
Hakea preissii
Hakea recurva

Rhamnaceae

Stenanthemum patens
Stenanthemum petraeum

Rubiaceae

Psydrax latifolia
Psydrax rigidula
Psydrax suaveolens
Synaptantha tillaeacea var. *tillaeacea*

Rutaceae

Philotheca brucei subsp. *brucei*

Santalaceae

Exocarpos aphyllus
Santalum lanceolatum
Santalum spicatum

Sapindaceae

Dodonaea adenophora
Dodonaea pachyneura
Dodonaea petiolaris
Dodonaea amplisemina
Dodonaea viscosa subsp. *angustissima*

Solanaceae

Nicotiana cavicola
Nicotiana occidentalis subsp. *obliqua*
Nicotiana rosulata subsp. *rosulata*
Solanum ashbyae
Solanum coactiliferum

Stackhousiaceae

Stackhousia muricata

Stylidiaceae

Stylidium longibracteatum

Urticaceae

Parietaria cardiostegia

Zygophyllaceae

Tribulus suberosus
Zygophyllum lobulatum
Zygophyllum tesquorum

Appendix 2: Two-way table of sites and perennial species used in classification analysis, sorted by site and species classification. Species occurrences per quadrat are indicated by a filled cell.