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Flora and vegetation of the greenstone ranges of the Yilgarn Craton: Warriedar Fold Belt

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ABSTRACT

The Warriedar Fold Belt is an Archaean greenstone belt composed of banded ironstone formations and basalts, located in the Yalgoo IBRA Bioregion of Western Australia. Previous systematic surveys on the banded ironstone formation highlighted an area rich in endemic flora and restricted communities. This paper discusses the flora and vegetation on the basalt hills. A total of 286 taxa, with 137 annuals, were recorded during the survey. Twenty-three priority flora were recorded, with a significant new population of *Allocasuarina tessellata* discovered, as well as several taxa that are restricted to the basalt hills. Six vegetation communities were described from the Warriedar Fold Belt, with a clear differentiation between communities on the Bullajungadeah Hills from communities on the Rothsay and Mulgine hills. The species turnover from the western to eastern hills is associated with a rainfall gradient.

Keywords: greenstone, floristics, ranges, vegetation communities, Yilgarn

INTRODUCTION

The Warriedar Fold Belt is a series of low undulating hills of Archaean greenstone, composed of banded ironstone and basalts, in the Murchison Region of Western Australia. The belt occurs in an area rich in rare and endemic flora (Gibson et al. 2007; Markey & Dillon 2008). Previous surveys on the fold belt focussed upon the vegetation growing on the banded ironstone associated with the Blue Hills and Gnows Nest range (Markey & Dillon 2008), but there is little detailed knowledge of the vegetation occurring on the basalt hills to the south. This paper is part of a continuing series of surveys describing the flora and vegetation of the greenstone ranges within the Yilgarn Craton, which aim to provide a regional context and baseline information for future land management. The main aim of this study was to describe the flora and vegetation and associated environmental variables on the southern basalt hills within the Warriedar Greenstone Belt and to examine if similar levels of endemism occur on the basalt hills compared with the adjacent banded ironstone hills.

Land use

Over 100 years of mining and pastoralism have occurred on and around the Warriedar Fold Belt; activities that can impact heavily on the environment. The study area occurs across three ex-pastoral leases: Karara, Warriedar and Thundellarra, which are now managed by the Department of Parks and Wildlife (CALM 2004). These pastoral leases were originally established in the second half of the 19th century and were still being settled in the early 1900s as the gold mining boom began (Hennig 1998). The mines established in late 19th and early 20th century have since closed and the towns abandoned (Murray et al. 2011). Today, there are still several gold mines active on the Blue Hills, but most mining activity in the area now centres on open-cut iron ore mining in the banded iron formations in the Karara area.

Geology

Greenstone belts are metamorphosed volcanic rocks, such as basalt, associated with sedimentary rocks, such as banded ironstone, that occur within Archaean and Proterozoic cratons, and are generally expressed at the surface as a series of ranges or hills. The name greenstone comes from the green hue of the mafic rocks, a type of volcanic rock, predominantly basalt or gabbro that is high in magnesium and iron. The Warriedar Fold Belt encompasses the larger area of the Blue Hills, Gnows Nest Range, Bullajungadeah Hills, Pinyalling Hill and the unnamed hills in the south-west surrounding Mount Mulgine and the abandoned town of Rothsay (Fig. 1). The belt consists of metamorphosed Archaean rocks in a defined sequence of more than 10 km thick (Lipple et al. 1983). The Blue Hills are composed predominantly of banded iron formations and are located north of the more predominantly mafic associations of the Bullajungadeah Hills and Rothsay and Mount Mulgine areas. The area of interest for this study was the southern base of the Blue Hills, which contains the oldest units of mafic rock.

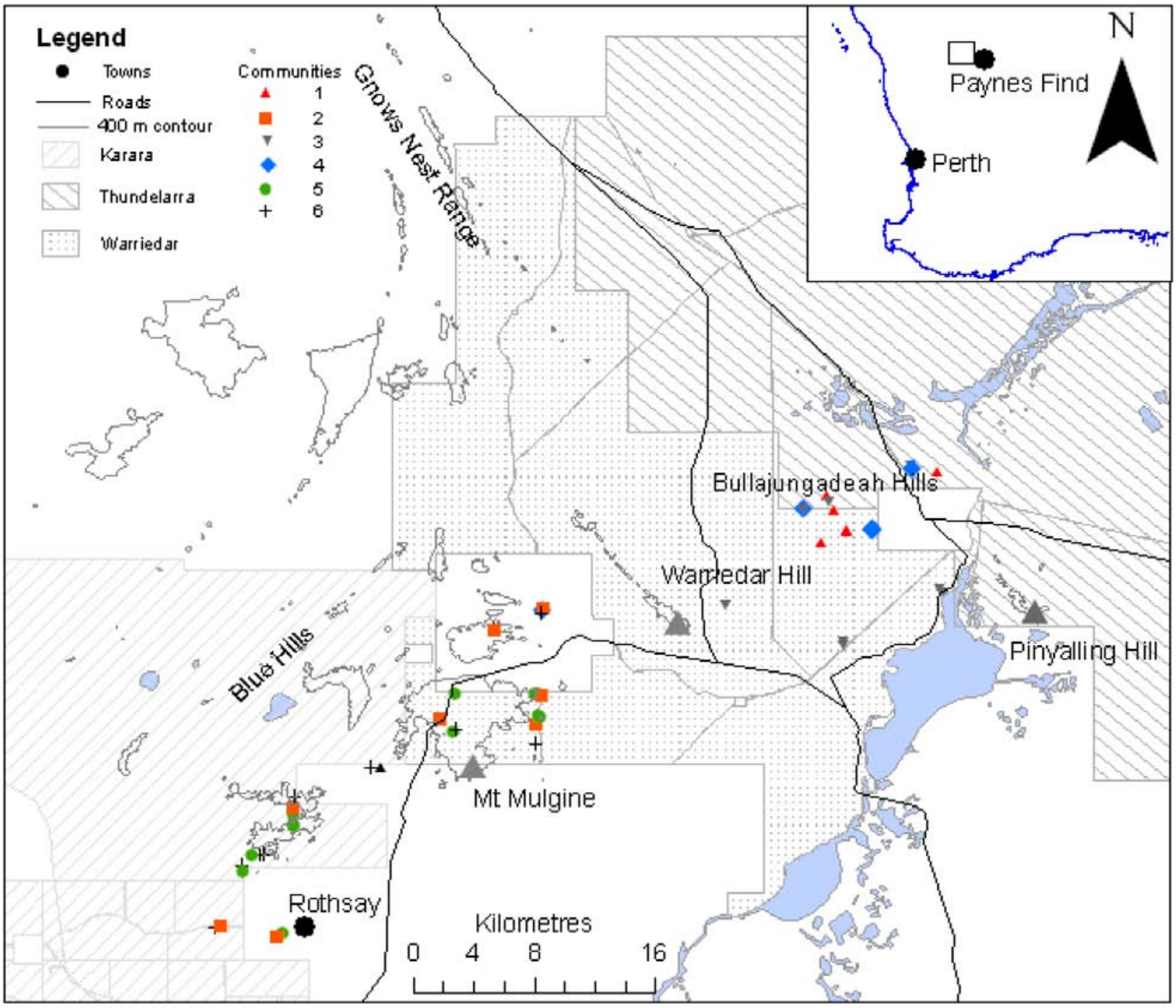

Figure 1. Location of the study area, approximately 100 km east of Morawa. Fifty quadrats were established on the Warriedar Fold Belt with six plant communities identified.

The mafic hills can been separated into two main survey areas: the mafic hills in the Rothsay and Mt Mulgine area, which generally reach between 420–480 m above sea level, with the highest point the granite intrusion of Mt Mulgine (513 m); and the Bullajungadeah Hills, east of Warriedar Hill (546 m), which consists of more subdued hills up to 386 m. The surrounding plains occur approximately 280 m above sea level. The mafic formations at Rothsay and Mt Mulgine are over 8 km thick, consisting mainly of basalt flows with thin subvolcanic intrustions of dolerite and gabbro (coarse-grained, intrusive, mafic igneous rocks; Baxter & Lipple 1985). The Bullajungadeah Hills are composed of mafic volcanic rocks including metamorphosed gabbros and thin metamorphosed basaltic flows. Thin layers of banded ironstone separate some of these flows (Lipple et al. 1983).

Climate

The climate of the Warriedar Fold Greenstone Belt is a semi-desert Mediterranean climate, with mild, wet winters and hot, dry summers (Beard 1990). Mean annual rainfall recorded at Paynes Find is 283.3 mm, and rainfall is highly variable in the region (181 mm 1st decile; 387.1 mm 9th decile; recorded 1919–2012; BOM 2012). Rain primarily falls in winter, although some summer rainfall does occur. The highest maximum temperatures occur during summer, with January as the hottest month (mean maximum temperature 37.4 °C and mean 8.5 days above 40 °C). Winters are mild, with the lowest mean maximum temperatures recorded for July of 18.4 °C. Temperatures occasionally fall below 0 °C in winter (a mean 2.9 days below 0 °C), with a mean minimum of 5.5 °C in July.

Vegetation

The Warriedar Fold Belt occurs within the Yalgoo IBRA Bioregion, with 60% of the vegetation represented by *Acacia* woodlands and shrublands (Department of Sustainability, Environment, Water, Population and Communities 2012). The Yalgoo IBRA Bioregion lies in a transitional region between the Eremaean flora of the arid zone and the flora of south-western Western Australia (Beard 1976). The vegetation retains taxa characteristic of the Eremaean flora, and is dominated by *Acacia aneura* (mulga) but, with an increase in rainfall towards the south-west, mulga is gradually replaced by other species of *Acacia* and finally eucalypts (Beard 1976).

In addition to the targeted survey of the banded ironstone by Markey & Dillon (2008), several broad-scale surveys have been conducted within the Warriedar Fold Greenstone Belt. Payne et al. (1998) undertook a rangeland condition survey and described the country in terms of land systems that were primarily characterised by four different vegetation habitats: SIMS (stony ironstone mulga shrubland), SIAS (stony ironstone acacia shrubland), GHAS (greenstone hill acacia shrubland) and GHMW (greenstone hill mixed woodland or shrubland). The Bullajungadeah Hills are described by only one land system, the Gabanintha (greenstone ridges and hills), and are characterised by SIMS, SIAS and GHAS on the hillcrests, hillslopes and stony plains. Rothsay and Mulgine hills are described by three landsystems: Graves (basalt and greenstone rises and low hills) characterised by SIAS, GHAS and GHMW; Moriarty (low greenstone rises and stony plains) characterised by SIMS and GHMW; and Singleton (rugged greenstone ranges) characterised by SIAS, GHAS and GHMW.

METHODS

The methods used in this survey follow the standard procedure used in previous vegetation surveys of other ironstone and greenstone ranges in Western Australia (Markey & Dillon 2008; Meissner & Caruso 2008). Fifty 20 × 20 m quadrats were established on the stony crests and slopes of the greenstone ranges of the Warriedar Fold Belt during September 2011 (Fig. 1). The greenstone traverses two areas, Bullajungadeah Hills and the Rothsay and Mulgine hills. The Bullajungadeah Hills occur on the eastern extent of the survey area on the ex-Warriedar and Thundelarra pastoral stations, east of Warriedar Hill. The Rothsay and Mulgine hills occur on the western extent of the survey area mainly on ex-Karara and ex-Warriedar pastoral stations (Fig. 1). Quadrats were established to cover the broader geographical and geomorphological variation found within the study area. The quadrats were strategically placed across the hills in a toposequence, from crests to foot slopes and plains. Each quadrat was permanently marked with four steel fence droppers and their positions determined using a GPS unit (Garmin GPS map 60CSx). 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 abundance of rock outcrops (defined as the cover of exposed bedrock), cover of leaf litter and bare ground were recorded following McDonald et al. (1990). Additionally, growth form, estimated height and cover were recorded for dominant taxa in each strata (tallest, mid and lower). The qualitative data were used to describe the plant communities following McDonald et al. (1990).

Twenty soil samples were collected from the upper 10 cm of the soil profile within each quadrat. The samples were bulked and the 2 mm fraction analysed for Al, B, Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, S and Zn using an Inductively Coupled Plasma – Atomic Emission Spectrometer (ICP–AES). Electrical conductivity (EC), organic C, N and pH were determined using alternative methods, which are fully described in Meissner and Wright (2010).

Quadrats were classified on the basis of similarity in species composition, based upon presence-absence data on perennial species only and excluding species that only occurred in one quadrat. This was to remove any temporal variations in the numbers of annuals that may confound comparisons with other greenstone and banded ironstone ranges (Markey & Dillon 2008, Meissner & Caruso 2008). The quadrat and species classifications were undertaken using the Bray–Curtis coefficient followed by hierarchical clustering (using group-average linking). Quadrat classification was followed by similarity profile (SIMPROF) testing to determine the significance of internal group structures using permutation testing (Clarke & Gorley 2006). Community groups were determined based upon the SIMPROF results and detailed field knowledge. Indicator species for community groups were determined following De Cáceres et al. (2010) using the 'indicspecies' package in the R statistical language (De Cáceres & Legendre 2009), and determined for each community. Following the classification, the quadrat data was ordinated using non-metric multidimensional scaling (MDS), a nonparametric approach that is not based upon the assumptions of linearity, or presumption of any underlying model of species response gradients (Clarke & Gorley 2006).

To determine the environmental variables that best explained the community pattern, the BEST analysis using BIOENV algorithm in PRIMER v6 (Clarke & Gorley 2006) was undertaken on a Euclidean Distance resemblance matrix based on normalised environmental data. Prior to normalisation, EC, Na and Ni were transformed using $\log(x+1)$. The BEST routine selects environmental variables that best explain the community pattern, by maximising a rank correlation between their respective resemblance matrices (Clarke & Warwick 2001). In the BIOENV algorithm, all permutations of the following environmental variables were tried and up to five of the best variables selected. In addition to BEST analysis, the environmental variables were fitted to the MDS ordination and Pearson correlation values were calculated (r > 0.6) to determine linear relationships between the variables and the vegetation communities.

Nomenclature generally follows Western Australian Herbarium (1998–).

RESULTS

Flora

A total of 286 taxa (species, subspecies, varieties and forms) represented by 36 families were recorded from the Warriedar Fold Belt. The most speciose families were Asteraceae (56 taxa), Fabaceae (36), Chenopodiaceae (19), Poaceae (17) and Myrtaceae (15). Of the 91 genera recorded, the dominant genera were *Acacia* (23 taxa), *Eremophila* (13), *Rhodanthe* (11), *Ptilotus* (8) and *Senna* (8). A total of 137 annuals and 14 introduced taxa were recorded.

Prior to the survey, there were good seasonal rains which resulted in an abundance of ephemeral species, mainly from the Asteraceae, Goodeniaceae and Amaranthaceae. The annual species that occurred in more than 40% of sites were *Calandrinia eremaea*, *Cephalipterum drummondii*, *Haloragis trigonocarpa*, *Stenopetalum filifolium*, *Pentameris airoides* subsp. *airoides*, *Podolepis canescens*, *Trachymene ornata*, *Velleia rosea*, *Goodenia berardiana*, *Ptilotus helipteroides*, *Cuscuta planiflora*, *Schoenus nanus*, *Crassula colorata* var. *acuminata, Erodium cygnorum*, *Schoenia cassiniana*, *Calocephalus multiflorus*, *Calotis hispidula*, *Plantago debilis*, *Waitzia acuminata* var. *acuminata*, *Phyllangium sulcatum* and *Lobelia rhytidosperma*.

Priority flora

Twenty-two taxa of conservation significance were recorded during the survey, including one significant new population of the Priority 1 taxa, *Allocasuarina tessellata*, previously known only from a single population (Table 1). These taxa are listed as priority flora according to Department of Parks and Wildlife conservation codes for Western Australia (Smith 2012). No taxa are listed under the *Environment Protection and Biodiversity Act 1999*. There were 12 taxa that were endemic to the area, with three taxa, *Acacia diallaga, A. sulcaticaulis* and *Chamelaucium* sp. Warriedar (AP Brown & S Patrick APB 1100), endemic to the Mulgine and Rothsay hills, and one taxon, *Eremophila grandiflora*, restricted to the Bullajungadeah Hills (Table 1). Endemics are defined as taxa restricted to an area within 100 km and near-endemics defined as having most populations located within an 100 km radius with one to two outlying disjunct populations (Markey & Dillon 2008).

Acacia diallaga (Priority 2) is restricted to a small area surrounding the Mulgine hills. When under drought stress, this species exhibits diallagy, a change in foliage cover from glaucous to a purple-red, and reverts back to glaucous when conditions improve (Maslin & Buscumb 2008a).

Acacia karina (Priority 2) is more commonly found on banded ironstone but in this survey was collected on basalts and other mafic rocks within the Warriedar Fold Belt. *A. karina* is a straggly perennial shrub to 1.5 m, characterised by long, terete phyllodes and long, cylindrical inflorescences with flowers loosely arranged (Maslin & Buscumb 2007).

Table 1

The 23 priority taxa recorded from the survey, their conservation status within Western Australia (Western Australian Herbarium 1998–) and their endemicity to the Warriedar Fold Belt (including the banded ironstone ranges).

Family	Species	Conservation Code	Endemic
Aizoaceae	*Gunniopsis rubra*	P3	N
Araliaceae	*Hydrocotyle* sp. Warriedar (PG Wilson 12267)	P1	Y (basalt)
Asteraceae	*Millotia dimorpha*	P1	Y
Asteraceae	*Rhodanthe collina*	P1	N
Casuarinaceae	*Allocasuarina tessellata*	P1	Near endemic
Cyperaceae	*Lepidosperma* sp. Blue Hills (A Markey & S Dillon 3468)	P1	Y
Fabaceae	*Acacia diallaga*	P2	Y (basalt only)
Fabaceae	*Acacia karina*	P2	Y
Fabaceae	*Acacia subsessilis*	P3	N
Fabaceae	*Acacia sulcaticaulis*	P1	Y (granite/basalt)
Hemerocallidaceae	*Tricoryne* sp. Morawa (GJ Keighery & N Gibson 6759)	P3	N
Myrtaceae	*Chamelaucium* sp. Warriedar (AP Brown & S Patrick APB 1100)	P1	Y (basalt only)
Myrtaceae	*Micromyrtus acuta*	P3	N
Myrtaceae	*Micromyrtus trudgenii*	P3	Y
Orchidaceae	*Cyanicula fragrans*	P3	N
Poaceae	*Austrostipa blackii*	P3	N
Portulacaceae	*Calandrinia* sp. Warriedar (F Obbens 04/09)	P2	Y
Proteaceae	*Grevillea scabrida*	P3	Y
Proteaceae	*Grevillea subtiliflora*	P3	Y
Proteaceae	*Persoonia pentasticha*	P3	N
Rhamnaceae	*Stenanthemum poicilum*	P3	N
Sapindaceae	*Dodonaea amplisemina*	P4	N
Scrophulariaceae	*Eremophila grandiflora*	P3	Y

Acacia subsessilis (Priority 3) is shrub to 2 m high with short pungent phyllodes. This species was only collected on Bullajungadeah Hills. It is closely related to *Acacia diallaga* but differs in that it has thinner, narrowly linear to linear-triangular phyllodes and also exhibits diallagy.

Acacia sulcaticaulis (Priority 1) is a multi-stemmed, obconic shrub to 4 m with longitudinally smooth, fluted stems (Maslin & Buscumb 2008b). This species occurs within the *Acacia coolgardiensis* group and is highly restricted and found only on the slopes of Mulgine Hill on dolerite or quartz. This was an opportunistic collection.

Allocasuarina tessellata (Priority 1) is a shrub to 4 m with distinctive female cones, and is closely related to *Allocasuarina campestris*. During the survey, the species was collected from Mulgine and Rothsay basalts. This is a significant new population as the taxon was previously known only from Mount Singleton, approximately 50 km to the south-east. Single collections have been made from the Die Hardy Ranges (ca. 250 km south-east) and a granite outcrop between Mullewa and Morawa, and it is unknown whether there are significant populations at either location.

Austrostipa blackii (Priority 3) is a perennial tufted grass found mainly in the eastern states of Australia. It was collected from the Rothsay and Mulgine greenstone hills.

Calandrinia sp. Warriedar (F Obbens 04/09; Priority 2) is a small, succulent annual herb known from only five collections, mainly from Warriedar Station where the Bullajungadeah Hills are situated. A single collection was made during the survey from Bullajungadeah Hills.

Chamelaucium sp. Warriedar (AP Brown & S Patrick APB 1100; Priority 1) is a shrub to 0.6 m with small, nondescript white flowers. It is highly restricted and known only from the basalts found on Mulgine and Rothsay.

Cyanicula fragrans (Priority 3) is an orchid with light blue flowers. This species is found within the Yalgoo IBRA Bioregion, mostly on granite substrates. In this survey, we found it at two locations in the Mulgine hills.

Dodonaea amplisemina (Priority 4) is a shrub to 1 m high with distinctive three-horned fruit and large seeds. This species occurs on a variety of geology, including banded ironstone and basalts (Shepherd et al. 2007). In the survey, this species was found on the Bullajungadeah Hills only.

Eremophila grandiflora (Priority 3) is a perennial shrub to 3 m high with large, light purple flowers. It is the most southerly member of the *Eremophila fraseri* complex (Brown & Buirchell 2007). This species is known only from the Bullajungadeah Hills from five collections. Further populations were discovered during the survey at other locations within these hills.

Grevillea scabrida, *Grevillea subtiliflora* and *Persoonia pentasticha* are all proteaceous shrubs listed as Priority 3. *G. scabrida* is an intricate shrub with short, scabrid leaves, while *G. subtiliflora* is a shrub to 5 m high with dissected leaves. *Persoonia pentasticha* is a small shrub to 2 m with small yellow flowers and grows on both banded ironstone and basalt geologies. This species has a much wider distribution than the *Grevillea* spp., which are restricted to the Warriedar Fold Belt and Mount Singleton. *G. scabrida* and *G. subtiliflora* were well represented on the Mulgine and Rothsay hills, while only three collections were made of *P. pentasticha* on these hills.

Micromyrtus acuta and *M. trudgenii* (both Priority 3) are shrubs restricted to the Warriedar Fold Belt. *M. trudgenii* was more widely collected in the survey from the Mulgine hills area, while only a single collection was made of *M. acuta* on an ironstone substrate. The former species is more commonly found growing on ironstone but in this survey it found growing on basalt on the crests on the hills.

Hydrocotyle sp. Warriedar (PG Wilson 12267; Priority 1) is an annual herb known only from six collections from the Warriedar Fold Belt and surrounding pastoral stations. The species was found on the crests and slopes in the Mulgine hills area.

Lepidosperma sp. Blue Hills (A Markey & S Dillon 3468; Priority 1) is a sedge related to *L. costale* (Markey & Dillon 2008) This species is known from only six collections and is found growing on a variety of soils but restricted in distribution to the Warriedar Fold Belt and ca. 50 km south on Charles Darwin Reserve. This species was an opportunistic collection along a creekline within the Mulgine hills area.

Millotia dimorpha (Priority 1) is a small, yellow-flowered daisy characteristically with two rows of glandular involucral bracts. This species has been collected from the area previously. In this survey, it was found at only one location on Rothsay.

Rhodanthe collina (Priority 1) is an annual daisy with small, delicate flowers. It is known mainly from the pastoral stations near Paynes Find on flats and water-gaining sites. It was found in several locations across the whole study area.

Stenanthemum poicilum (Priority 3) is a small shrub to 0.5 m previously collected from the region from rocky hills and slopes. In the survey it was found in the Mulgine hills growing on the lower slope of a basalt hill.

Tricoryne sp. Morawa (GJ Keighery & N Gibson 6759; Priority 3) is a tuberous herb with small, delicate, yellow flowers. It is known from the Yalgoo IBRA Bioregion and is commonly found in a variety of habitats. In the survey it was found at a single site on the lower slope of a basalt hill in the Mulgine area.

Plant communities

Six communities were determined from the classification (Fig. 2; Table 2). An outlier was removed from the analysis as it consisted of an isolated, single quadrat that contained a high proportion of banded ironstone bedrock. This quadrat was dominated by BIF taxa found in the surrounding BIF hills (Markey & Dillon 2008). The first two divisions in the dendrogram separated community 1, occurring on the slopes of Bullajungadeah Hills on laterised ironstone and greenstone, from the remaining five communities, and community 2, the woodland communities on the lower slopes in Rothsay and Mulgine,

Table 2

Summary of the six communities found on the Warriedar Fold Belt by locality, topography and geology.

Community	Vegetation	Locality	Topography	Geology
1	*Acacia ramulosa* and mulga shrublands	Bullajungadeah Hills	Crests and slopes	Laterised ironstone and basalt
2	*Eucalyptus* woodlands	Rothsay and Mullgine hills	Lower slopes	Basalt
3	*Acacia* shrublands	Bullajungadeah Hills	Crests and slopes	Basalt
4	*Acacia umbraculiformis* and *Acacia burkittii* shrublands	Bullajungadeah Hills and one quadrat on Mullgine hills	Crests and slopes	Gabbro or basalt
5	*Allocasuarina dielsiana*, *Acacia burkittii* or *Melaleuca hamata* woodlands	Rothsay and Mullgine hills	Crests and midslopes	Basalt
6	*Acacia* spp. and *Allocasuarina dielsiana* shrublands	Rothsay and Mullgine hills	Crests and slopes	Basalt

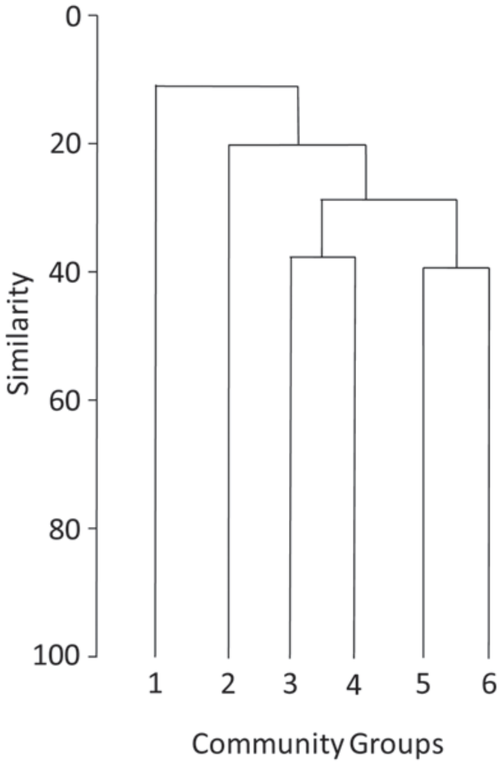

Figure 2. *Dendrogram of the six-group-level classification of 49 quadrats established on the Warriedar Fold Belt.*

from the remaining four communities. The subsequent divisions separated communities 3 and 4 found on Bullajungadeah Hills, from communities 5 and 6, found on Rothsay and Mulgine.

Community 1 was characterised by open shrublands (10–30% cover) to shrublands (30–70% cover) of *Acacia ramulosa* var. *ramulosa* and *Acacia* spp. (*A. incurvaneura*, *A. sibina*, *A. caesaneura*), over open shrublands of *Aluta aspera* subsp. *hesperia*, *Eremophila latrobei*, *E. forrestii* and *Philotheca* spp. (*P. brucei* and *P. sericea*), over various ephemeral species (*Waitzia acuminata*, *Goodenia occidentalis*, *Calocephalus multiflorus*). Quadrats characterised in this group (n = 6) occurred on the slopes and crests of laterised ironstone and greenstone at Bullajungadeah Hills. Indicator species (Table 2) were *Monachather paradoxus*, *Aluta aspera* subsp. *hesperia*, *Philotheca brucei* subsp. *brucei*, *P. sericea*, *Sida* sp. Golden calyces glabrous (HN Foote 32), *Acacia assimilis* subsp. *assimilis*, *Acacia incurvaneura*, *Mirbelia bursarioides*, *Cheiranthera simplicifolia*, *Eremophila latrobei*, *E. glutinosa*, *Hemigenia benthamii* and *H.* sp. Yalgoo (AM Ashby 2624). Mean species richness was 13.8 (±2.2 SE) perennial taxa per plot.

Community 2 was characterised by open woodlands (<10% cover) to open forests (30–70% cover) of *Eucalyptus loxophleba* subsp. *supralaevis* or *Eucalyptus clelandii*, over sparse shrublands (<10%) of *Eremophila* spp. (*E. oppositifolia* subsp. *angustifolia* or *E. pantonii*), *A. tetragonophylla*, *A. andrewsii*, *Senna artemisioides* subsp. *filifolia* and *Exocarpos aphyllus*, over low shrublands (30–70% cover) of *Ptilotus obovatus*, *Maireana trichoptera*, *M. georgei*, *Acacia erinacea* and various ephemeral species. Quadrats characterised in this group (n = 8) occurred in *Eucalyptus* woodland communities on the lower slopes of the Rothsay and Mulgine basalt hills. Indicator species are *Exocarpos aphyllus*, *Eucalyptus loxophleba* subsp. *supralaevis*, *Acacia erinacea*, *Maireana georgei*, *M. marginata*, *Austrostipa elegantissima*, *Eremophila pantonii*, *Sclerolaena fusiformis*, *S. diacantha* and *S. patenticuspis* (Table 2). Mean species richness was 19.9 (±1.6 SE) perennial taxa per plot.

Community 3 was characterised by sparse tall shrublands (<10% cover) to open tall shrublands (10–30% cover) of *Acacia umbraculiformis* and other *Acacia* spp. (*A. subsessilis*, *A. ramulosa* subsp. *ramulosa* or *A. burkittii*), over sparse shrublands (<10% cover) of *Thryptomene costata* and *Eremophila grandiflora*, over sparse low shrublands (30–70% cover) of *Ptilotus obovatus*, *Austrostipa nitida*, *Aristida contorta* and various ephemerals. Quadrats characterised in this group (n = 8) were found on the Bullajungadeah Hills, mostly on the crests and slopes of the basalt hills. Indicator species were *Thryptomene costata* and *Eremophila grandiflora* (Table 2). Mean species richness was 13.8 (±0.9 SE) perennial taxa per plot.

Community 4 was characterised as open tall shrublands (10–30% cover) to tall shrublands (30–70% cover) of *Acacia umbraculiformis* and *A. burkittii*, over shrublands (30–70% cover) of *Senna* spp. (*S. artemisioides* subsp. *filifolia* and *S.* sp. Austin [A Strid 20210]), *Eremophila pantonii* and *Acacia acuaria*, over low shrublands (30–70% cover) of *Ptilotus obovatus* and *Austrostipa nitida* (Table 2). Quadrats characterised in this group (n = 5) were primarily found on the crest and slopes of gabbro or basalt hills within Bullajungadeah Hills, with one site found within the Mulgine Hills area. Indicator species were *Acacia acuaria*, *Ptilotus schwartzii* and *Senna* sp. Austin (A Strid 20210). Mean species richness was 19.2 (±2.2 SE) perennial taxa per plot.

Community 5 was characterised by open woodlands (<10% cover) of *Allocasuarina dielsiana*, *Acacia burkittii* or *Melaleuca hamata*, over shrublands (30–70% cover) of *Allocasuarina tessellata*, over forbland (30–70% cover) of *Borya sphaerocephala* and *Chamelaucium* sp. Warriedar (AP Brown & S Patrick APB 1100) and other ephemerals. Quadrats characterised in this group (n = 12) were located within the Rothsay and Mulgine areas, mainly on the crests and mid-slopes of basalt hills. Indicator species were *Allocasuarina tessellata*, *Chamelaucium* sp. Warriedar (AP Brown & S Patrick APB 1100), *Micromyrtus trudgenii* and *Melaleuca hamata* (Table 2). Mean species richness was 12.4 (±0.6 SE) perennial taxa per plot.

Community 6 was characterised by open tall shrublands (10–30% cover) of *Acacia umbraculiformis*, *A. burkittii*, *A. tetragonophylla* and *Allocasuarina dielsiana*, over shrublands (30–70% cover) of *Grevillea scabrida*, *Ptilotus obovatus* over various ephemerals. Quadrats characterised in this group (n = 10) were located on the basalt crests and slopes in the Rothsay and Mulgine areas. Indicator species were *Austrostipa trichophylla* and *Acacia kochii* (Table 2). Mean species richness was 17.2 (±0.6 SE) perennial taxa per plot.

Environmental correlates

Nonparametric analysis of variance found that 18 of the 20 soil parameters were significantly different (Table 4), while seven of the 12 site attributes were significantly different between the six communities (Table 5). The main differences were between community 1, the laterite community found on Bullajungadeah Hills, and community 2, the *Eucalyptus* woodland community found on the lower slopes of Rothsay and Mulgine. Communities 3 and 4, on Bullajungadeah Hills, and communities 5 and 6, on Rothsay and Mulgine, showed similar soil chemistry apart from higher Al concentrations in the soil from communities 5 and 6. Community 5 also had higher organic C content while communities 5 and 6 also had significantly lower P than community 2.

Community 1 was found on laterite landforms, on

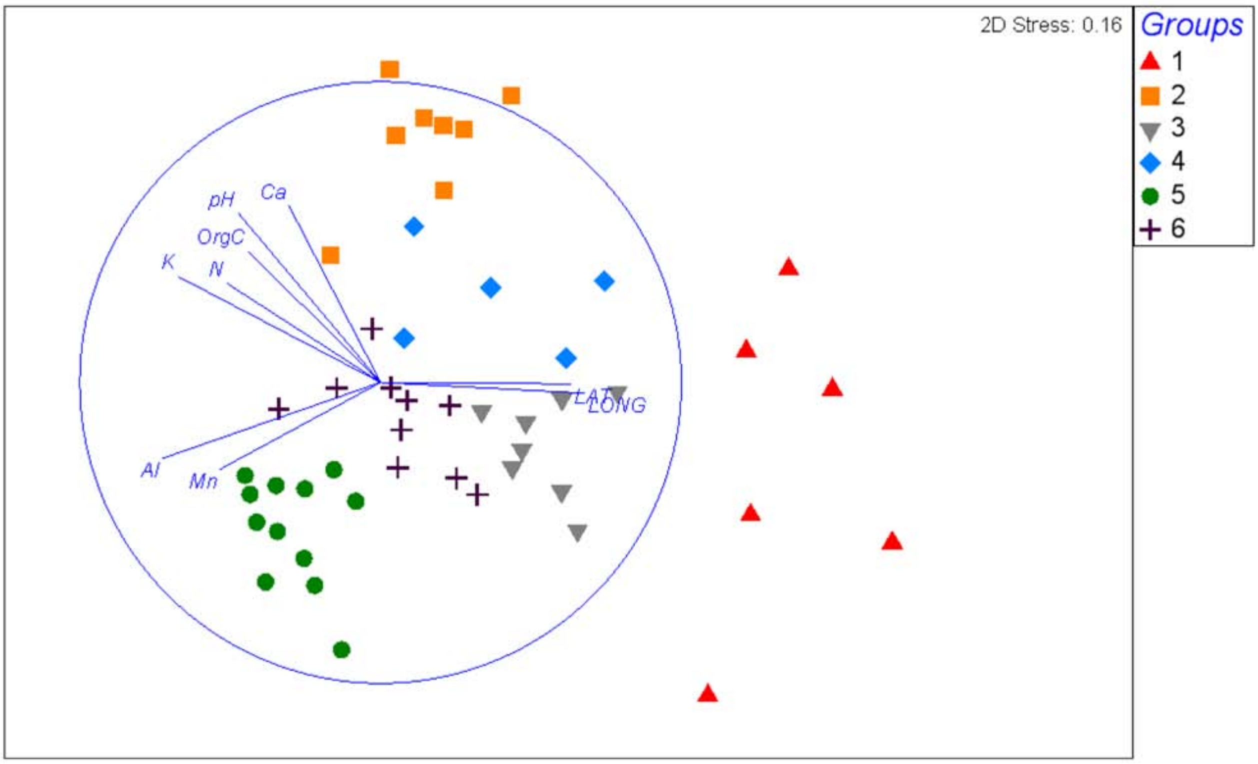

Figure 3. *Two dimensional ordination of the 49 quadrats established on Warriedar Fold Belt. The six communities are shown and lines represent the strength and direction of the nine environmental variables correlated with the MDS using Pearson rank correlation (r > 0.6).*

Table 3

Sorted two-way table of the quadrats established on the Warriedar Fold Belt showing species by community type. Taxa shaded black within a community are indicator species determined by 'indicspecies' (De Cáceres & Legendre 2009) at the six-group level ($p < 0.05$).

	Species	1	2	3	4	5	6
Group a	*Eremophila eriocalyx*						
	Eremophila granitica						
	Astroloma serratifolium						
	Cyanicula fragrans						
	Austrostipa scabra						
Group c	*Thysanotus pyramidalis*						
	Cheilanthes sieberi subsp. *sieberi*						
	Dodonaea rigida						
	Ptilotus schwartzii						
	Cheiranthera simplicifolia						
	Hemigenia sp. Yalgoo (A.M. Ashby 2624)						
	Hemigenia benthamii						
	Mirbelia bursarioides						
	Philotheca brucei subsp. *brucei*						
	Philotheca sericea						
	Eremophila latrobei						
	Monachather paradoxus						
	Sida sp. Golden calyces glabrous (H.N. Foote 32)						
	Acacia assimilis subsp. *assimilis*						
	Aluta aspera subsp. *hesperia*						
	Acacia incurvaneura						
	Eremophila glutinosa						
	Acacia ramulosa var. *ramulosa*						
	Thysanotus manglesianus						
Group d	*Sclerolaena gardneri*						
	Eucalyptus clelandii						
	Acacia andrewsii						
	Maireana marginata						
	Hemigenia sp. Yuna (A.C. Burns 95)						
	Santalum spicatum						
	Dodonaea inaequifolia						
	Eremophila oldfieldii subsp. *oldfieldii*						
	Solanum nummularium						
	Eriochiton sclerolaenoides						
	Sclerolaena fusiformis						
	Acacia acanthoclada subsp. *glaucescens*						
	Austrostipa elegantissima						
	Maireana georgei						
	Rhagodia drummondii						
	Eucalyptus loxophleba subsp. *supralaevis*						
	Exocarpos aphyllus						
	Eremophila oppositifolia subsp. *angustifolia*						
	Acacia erinacea						
	Eremophila pantonii						
	Sclerolaena patenticuspis						
	Senna stowardii						
	Maireana trichoptera						
	Sclerolaena diacantha						
Group e	*Persoonia pentasticha*						
	Comesperma integerrimum						
	Enchylaena lanata						
	Dianella revoluta var. *divaricata*						
	Maireana thesioides						
	Acacia acuaria						
	Senna sp. Austin (A. Strid 20210)						
Group f	*Senna artemisioides* subsp. *helmsii*						
Group g	*Eremophila grandiflora*						
	Eremophila forrestii subsp. *forrestii*						
	Thryptomene costata						
	Acacia subsessilis						
	Sclerolaena densiflora						
	Dodonaea amplisemina						
	Maireana carnosa						
	Abutilon oxycarpum subsp. prostratum						
	Solanum ellipticum						
Group h	*Scaevola spinescens*						
	Eremophila clarkei						
	Acacia kochii						
	Mirbelia microphylla						
	Rytidosperma caespitosum						
	Wurmbea sp. Paynes Find (C.J. French 1237)						
Group i	*Cryptandra micrantha*						
	Eremophila georgei						
Group j	*Austrostipa eremophila*						
	Austrostipa trichophylla						
	Grevillea scabrida						
	Borya sphaerocephala						
	Acacia burkittii						
	Allocasuarina dielsiana						
	Arthropodium dyeri						
	Cheilanthes adiantoides						
	Austrostipa nitida						
	Ptilotus obovatus						
	Acacia umbraculiformis						
	Solanum lasiophyllum						
	Acacia tetragonophylla						
	Sida sp. dark green fruits (S. van Leeuwen 2260)						
	Austrostipa blackii						
	Grevillea subtiliflora						
	Melaleuca hamata						
	Acacia karina						
	Melaleuca radula						
	Caesia sp. Wongan (K.F. Kenneally 8820)						
	Allocasuarina tessellata						
	Chamelaucium sp. Warriedar (A.P. Brown & S. Patrick APB 1100)						
	Acacia diallaga						
	Micromyrtus trudgenii						

skeletal soils with the lowest fertility (significantly lower N and P), pH and EC, but the highest S content (Table 3; Table 4). In contrast, community 2, the eucalypt woodlands, was the most fertile community, with the least acidic soils with the highest EC (Table 4). This community also had significantly lower coarse fragment abundance and size and significantly greater soil depth and leaf litter cover (Table 5).

The two dimensional MDS (stress = 0.16; Fig. 3) showed a similar pattern to the univariate analysis. All communities are clearly separated, with community 1 the most distinct but more variable of the six communities identified from the classification (Fig. 2).

Table 4

Mean values for soil chemistry parameters for each plant community (measured in mg kg^{-1} except pH and EC [mS m^{-1}]). Differences between ranked values were tested using Kruskal–Wallis nonparametric analysis of variance. Standard errors in parentheses. Superscript a, b and c represent significant differences between community types at $p < 0.05$ determined by Dunns post-hoc test (n = number of quadrats, p = probability).

	Community 1	**Community 2**	**Community 3**	**Community 4**	**Community 5**	**Community 6**	**p value**
n	6	8	8	5	12	10	
EC	3.5 (0.6)^{b}	15.1 (3.7)^{a}	3.9 (0.4)^{ab}	13 (3.1)^{ab}	5.4 (0.8)^{ab}	5.5 (2.1)^{b}	0.0014
OrgC	0.60 (0.04)^{ab}	1.35 (0.17)^{c}	0.48 (0.06)^{a}	0.82 (0.05)^{abc}	1.00 (0.10)^{b}	0.89 (0.06)^{abc}	<0.0001
pH	4.3 (0.0)^{a}	6.7 (0.2)^{b}	5.7 (0.1)^{abc}	6.7 (0.4)^{bc}	5.6 (0.0)^{ac}	5.8 (0.1)^{bc}	<0.0001
Al	476.7 (26.8)^{a}	608.8 (25.4)^{ab}	528.8 (27.6)^{a}	490 (42.1)^{a}	774.2 (26.5)^{b}	714 (21.5)^{b}	<0.0001
N	0.046 (0.003)^{a}	0.106 (0.0113)^{b}	0.052 (0.006)^{ac}	0.084 (0.004)^{abc}	0.088 (0.008)^{bc}	0.082 (0.004)^{bc}	<0.0001
B	0.09 (0.02)^{a}	0.89 (0.29)^{b}	0.14 (0.03)^{ab}	0.3 (0.11)^{ab}	0.26 (0.06)^{ab}	0.26 (0.06)^{ab}	0.0195
Ca	119.5 (30.1)^{a}	2838 (706.3)^{b}	550 (62.6)^{ac}	1940 (496.6)^{b}	1008 (70.8)^{bc}	1093 (71.8)^{bc}	<0.0001
Cd	0.005 (0)^{a}	0.014 (0.002)^{ab}	0.017 (0.003)^{b}	0.018 (0.006)^{ab}	0.016 (0.001)^{b}	0.02 (0.003)^{b}	0.0036
Co	0.19 (0.05)^{a}	2.11 (0.23)^{b}	5.63 (0.81)^{c}	4.52 (1.42)^{bc}	3.57 (0.28)^{bc}	3.57 (0.32)^{bc}	<0.0001
Cu	1.78 (0.57)	3.13 (0.46)	4.25 (0.71)	3.18 (0.43)	3.48 (0.32)	4.01 (0.74)	0.1241
Fe	33.0 (2.7)^{a}	61.1 (4.4)^{b}	58.0 (4.2)^{b}	55.4 (2.1)^{b}	50.0 (1.2)^{ab}	52.6 (2.0)^{ab}	0.0003
K	78.8 (5.5)^{a}	277.5 (17.3)^{b}	193.8 (15.7)^{ab}	244.0 (23.4)^{ab}	242.5 (14.4)^{b}	259.0 (11.1)^{b}	0.0002
Mg	30.5 (9.1)^{a}	498.8 (72.1)^{b}	407 (72.3)^{b}	270 (26.7)^{ab}	275 (23.6)^{b}	248 (21.5)^{ab}	0.0002
Mn	17.2 (1.5)^{a}	78.4 (15.1)^{ab}	139.1 (15.0)^{b}	82.8 (11.4)^{ab}	143.5 (8.0)^{b}	128.5 (8.1)^{b}	<0.0001
Mo	0.005 (0)	0.011 (0.004)	0.005 (0)	0.005 (0)	0.015 (0.004)	0.0175 (0.005)	0.064
Na	6.5 (2.0)^{a}	49.1 (7.9)^{b}	28.9 (2.3)^{ab}	52.0 (22.7)^{b}	32.3 (2.7)^{b}	24.9 (3.4)^{ab}	0.0006
Ni	0.3 (0.1)^{a}	2.2 (0.7)^{b}	3.4 (0.9)^{b}	3.8 (2.1)^{b}	1.1 (0.2)^{ab}	1.2 (0.3)^{ab}	0.0002
P	4.2 (0.4)^{ab}	5.9 (0.6)^{b}	3.8 (0.5)^{ab}	5.0 (1.3)^{ab}	2.8 (0.3)^{a}	3.3 (0.2)^{a}	0.003
S	17.5 (1.7)^{b}	10.8 (3.8)^{ab}	5.0 (0.9)^{a}	7.2 (2.1)^{ab}	6.3 (0.6)^{ab}	5.7 (1.3)^{a}	0.004
Zn	0.95 (0.17)^{a}	1.65 (0.24)^{ab}	3.73 (0.97)^{b}	1.48 (0.22)^{ab}	1.82 (0.13)^{ab}	1.76 (0.16)^{ab}	0.0255

Table 5

Mean values for physical site parameters for each plant community: aspect (degrees); slope (degrees); latitude and longitude (decimal degrees); morphology type (1 – crest, 2 – mid slope, 3 – lower slope, 4 – simple slope, 5 – hillock); landform (1 – hillcrest, 2 – hill slope, 3 – footslope, 4 – mound); maximum size of coarse fragments (CF Max) (1 – fine gravely to 6 – boulders); coarse fragment (CF) abundance (0 – no coarse fragments to 6 – very abundant coarse fragments); rock outcrop (RO) abundance (0 – no bedrock exposed to 4 – very rocky); Runoff (0 – no runoff to 4 – rapid), soil depth (1 – skeletal, 2 – shallow, 3 – deep), leaf litter (cover classes 1 – <10%, 2 – 10–30%, 3 – 30–70%, 4 – > 70%). Differences between ranks were tested using Kruskal–Wallis nonparametric analysis of variance. Standard errors in parentheses.

	Comm. 1	**Comm. 2**	**Comm. 3**	**Comm. 4**	**Comm. 5**	**Comm. 6**	**p value**
n	6	8	8	5	12	10	
Aspect	4.7 (1.4)	5 (0.8)	5.3 (0.9)	4 (1.3)	4.1 (0.8)	4.4 (0.9)	0.9463
Latitude	–29.0375 (0.0065)^{c}	–29.18103 (0.0259)^{ab}	29.07081 (0.0142)^{bc}	–29.0467 (0.0136)^{bc}	–29.1957 (0.0142)^{a}	–29.1942 (0.0192)^{a}	0.0001
Longitude	117.2065 (0.0104)^{bc}	116.9495 (0.0281)^{ab}	117.2074 (0.01553)^{c}	117.1754 (0.0397)^{bc}	116.9343 (0.0216)^{a}	116.9193 (0.0241)^{a}	0.0001
Slope	2.58 (0.74)	2.13 (0.54)	3.19 (0.64)	4.1 (1.36)	4.21 (0.71)	2.95 (0.63)	0.4135
Morph Type	1.8 (0.4)	3.1 (0.1)	2.4 (0.3)	1.6 (0.4)	1.8 (0.2)	1.6 (0.3)	0.0127
Landform	1.5 (0.2)	2 (0)	1.8 (0.2)	1.4 (0.2)	1.6 (0.1)	1.3 (0.2)	0.0593
CFMax	3.2 (0.5)^{ab}	3.1 (0.2)^{a}	4.3 (0.3)^{ab}	4.6 (0.4)^{b}	4.1 (0.2)^{ab}	4.3 (0.2)^{ab}	0.0054
CFAbundance	3.5 (0.4)^{ab}	2.9 (0.4)^{a}	4.6 (0.3)^{b}	3.6 (0.2)^{ab}	3.8 (0.2)^{ab}	3.4 (0.2)^{ab}	0.0093
ROAbund	0.7 (0.3)	0.3 (0.2)	0.6 (0.3)	1.4 (0.6)	0.3 (0.1)	0.3 (0.2)	0.3582
Soil Depth	1.7 (0.3)^{b}	2.8 (0.2)^{a}	1.8 (0.2)^{b}	1.8 (0.2)^{ab}	2 (0.2)^{ab}	2 (0.2)^{ab}	0.0192
Bare Ground	3.3 (0.2)	3.4 (0.2)	3.6 (0.2)	3.2 (0.2)	3.2 (0.1)	3.1 (0.1)	0.1899
Leaf Litter	1.3 (0.2)^{ab}	2.1 (0.1)^{a}	1 (0)^{b}	1.2 (0.2)^{ab}	1.7 (0.2)^{ab}	1.7 (0.2)^{ab}	0.0026

The BEST analysis indicated that the best correlation with the species resemblance matrix was obtained with five environmental variables: coarse fragment abundance, pH, Al, Mn and S ($r = 0.651$). Nine of the 33 environmental variables correlated with the MDS ($r > 0.6$; Fig. 3). Latitude and longitude, used as surrogates for climate, correlated with the communities located on Bullajungadeah Hills, the communities further north and east. Al and Mn were positively correlated with community 5, while K, N, organic C, pH and Ca were positively correlated with community 2 but negatively correlated with community 1.

DISCUSSION

The greenstone hills within the Warriedar Fold Belt have a rich flora, with 286 taxa identified, including a high number of endemic flora. Similar patterns of species have been observed in other greenstone ranges predominantly composed of banded ironstone (Gibson et al. 2011), especially those ranges within the boundary of the South West Australian Floristic Region (SWAFR; Hopper & Gioia 2004). High species richness and endemism is not restricted to the banded ironstone but has been found on other greenstone ranges such as Digger Hatter's Hill and the Ravensthorpe Range, where greenstone and banded ironstone flora were both sampled along the SWAFR boundary (Gibson 2004; Markey et al. 2012).

Several of the endemic and priority species, such as *Grevillea scabrida* and *Acacia diallaga*, were found only on the basalt and not on the nearby ironstones. Their distribution tended to centre on the greenstone of Rothsay and Mulgine and nearby Mount Singleton, ~50 km south-east of Rothsay. Several taxa occurred predominantly on basalt but were occasionally found on ironstone, such as *Eremophila grandiflora*. The region around the Warriedar Fold Belt has been highlighted previously as a hotspot of species endemism (Gibson et al. 2012).

Similar species richness and turnover to this survey were found in the adjacent banded ironstone ranges within the Warriedar Fold Belt (Markey & Dillon 2008). A high species turnover from north to south along the ranges, in addition to many distinct communities and a significant number of endemic and priority taxa, were recorded on the banded ironstone formations of the Blue Hills and Gnows Nest Range (Markey & Dillon 2008). Despite the proximity of these banded ironstone ranges to the basalt hills of this survey, the species and communities are very different. In a combined flora list, only 205 species out of 460 species, including annuals, were common between the greenstones and banded ironstone. In addition, similar numbers of perennial taxa were recorded from both surveys (~200 vs. 150 taxa) but there was a difference in species richness between lithologies, with banded ironstone more species-rich than the greenstone. Both surveys covered similar areas, with the Blue Hills and Gnows Nest Range extending further north while the basalt hills in this survey extend further east, with both ironstone and basalt hills traversing a climatic gradient. It is more probable that the lithologies are influencing this difference in species richness.

In addition to high species richness, the survey also highlighted the high species turnover that is also common to greenstone ranges within the arid zone (Gibson et al. 2012). Even though the dominant communities on the basalt hills occur in similar positions in the landscape and have soils with similar chemistry, there was a clear distinction between the communities occurring on the Rothsay and Mulgine hills (communities 5 and 6) and the Bullajungadeah Hills (communities 3 and 4). Markey & Dillon (2008) found a similar species turnover heading northwards into more arid conditions. Likewise, Payne et al. (1998) also noted different land systems on the Bullajungadeah Hills compared to Rothsay and Mulgine. The Warriedar Fold Belt lies between the 250 and 300 mm rainfall isohyets and there is a gradual decrease in rainfall heading north and east into the interior. The increasing aridity appears to influence vegetation, as evidenced by the absence of the *Eucalyptus* communities on the lower slopes of the Bullajungadeah Hills, which is indicative of a shift from a more South West flora to a more Eremaean arid flora (Beard 1990).

With respect to the other communities present on the basalt hills, the laterite community (community 1) was very distinct when compared with the other communities found on the greenstones. Laterite soils are generally less fertile than other soils (Meissner & Wright 2010) as they are extremely weathered and the more mobile elements, such as Mg, are leached and transported out of the soil rapidly (Britt et al. 2001). Conversely, the soils of the *Eucalyptus* communities found on the lower slopes had higher fertility, a result of the deposition of the fertile elements and high organic matter produced by the *Eucalyptus* leaf litter. The high soil fertility and location of this community on the lower slopes is consistent with other *Eucalyptus* communities found on other arid ranges (Meissner & Wright 2010).

Conservation

The high number of priority and endemic taxa present on the Warriedar Fold Belt makes it an area of high conservation value. Currently the majority of the mafic hills are within ex-pastoral leases purchased for the purpose of conservation; however, there are many exploration and mining tenements within the area which could provide potential land use conflicts in the future.

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APPENDIX

Flora list for the Warriedar Fold Belt, including all taxa from the sampling quadrats and adjacent areas. Nomenclature follows the Western Australian Herbarium (1998–) and Conservation Codes follows Smith (2012).* indicates an introduced species.

Aizoaceae
**Cleretum papulosum*
Gunniopsis rubra
**Mesembryanthemum nodiflorum*

Amaranthaceae
Ptilotus aervoides
Ptilotus exaltatus
Ptilotus gaudichaudii subsp *eremita*
Ptilotus gaudichaudii var. *gaudichaudii*
Ptilotus helipteroides
Ptilotus macrocephalus
Ptilotus obovatus
Ptilotus schwartzii

Apiaceae
Daucus glochidiatus
Xanthosia bungei

Apocynaceae
Alyxia buxifolia

Araliaceae
Hydrocotyle pilifera var. *glabrata*
Hydrocotyle sp. Warriedar (PG Wilson 12267) P1
Trachymene cyanopetala
Trachymene ornata

Asparagaceae
Arthropodium dyeri
Thysanotus manglesianus
Thysanotus pyramidalis

Asteraceae
Actinobole uliginosum
Asteridea athrixioides
Bellida graminea
Blennospora drummondii
Brachyscome ciliaris
Brachyscome ciliocarpa
Calocephalus aff. *multiflorus* (Markey & Dillon 3464)
Calocephalus multiflorus
Calotis hispidula
Calotis multicaulis
Cephalipterum drummondii
Ceratogyne obionoides
Chthonocephalus pseudevax
Erymophyllum glossanthus
Gilruthia osbornei
Gnephosis arachnoidea
Gnephosis brevifolia
Gnephosis eriocephala
Gnephosis tenuissima
Helipterum craspedioides
Hyalosperma demissum
Hyalosperma glutinosum subsp. *venustum*
Hyalosperma zacchaeus
**Hypochaeris glabra*
Isoetopsis graminifolia
Lawrencella rosea
Lemooria burkittii
Millotia dimorpha P1
Millotia myosotidifolia
Myriocephalus guerinae
Olearia humilis
Olearia pimeleoides
Podolepis canescens
Podolepis gardneri
Podolepis lessonii
Podotheca gnaphalioides
Pogonolepis stricta
Rhodanthe battii
Rhodanthe chlorocephala subsp. *rosea*
Rhodanthe chlorocephala subsp. *splendida*
Rhodanthe citrina
Rhodanthe collina P1
Rhodanthe laevis
Rhodanthe manglesii
Rhodanthe maryonii
Rhodanthe oppositifolia subsp. *oppositifolia*
Rhodanthe polycephala
Rhodanthe stricta
Schoenia cassiniana
Senecio lacustrinus
**Sonchus oleraceus*
Trichanthodium skirrophorum
Triptilodiscus pygmaeus
Vittadinia humerata
Waitzia acuminata var. *acuminata*
Waitzia nitida

Boraginaceae
Halgania cyanea var. Allambi Stn (BW Strong 676)
Omphalolappula concava

Boryaceae
Borya sphaerocephala

Brassicaceae
**Brassica tournefortii*
Lepidium oxytrichum
Menkea australis
Stenopetalum anfractum
Stenopetalum filifolium
Stenopetalum lineare var. *lineare*

Campanulaceae
Lobelia rhytidosperma
Lobelia winfridae
Wahlenbergia gracilenta
Wahlenbergia preissii

Caryophyllaceae
**Silene nocturna*
Stellaria filiformis

Casuarinaceae
Allocasuarina acutivalvis subsp. *prinsepiana*
Allocasuarina dielsiana
Allocasuarina tessellata P1

Celastraceae
Stackhousia muricata
Chenopodiaceae
Dysphania glandulosa
Enchylaena lanata
Enchylaena sp.
Enchylaena tomentosa

Appendix (cont.)

Enchylaena tomentosa × *Maireana georgei*
Eriochiton sclerolaenoides
Maireana carnosa
Maireana georgei
Maireana marginata
Maireana planifolia
Maireana thesioides
Maireana trichoptera
Rhagodia drummondii
Salsola australis
Sclerolaena densiflora
Sclerolaena diacantha
Sclerolaena fusiformis
Sclerolaena gardneri
Sclerolaena patenticuspis

Colchicaceae
Wurmbea sp. Paynes Find (CJ French 1237)

Convolvulaceae
**Cuscuta planiflora*
Duperreya sericea

Crassulaceae
Crassula closiana
Crassula colorata var. *acuminata*
Crassula colorata var. *colorata*
Crassula tetramera

Cyperaceae
Lepidosperma sp. Blue Hills (A Markey & S Dillon 3468) P1
Schoenus nanus

Dilleniaceae
Hibbertia arcuata
Hibbertia exasperata

Ericaceae
Astroloma serratifolium
Leucopogon sp. Clyde Hill (MA Burgman 1207)

Euphorbiaceae
Calycopeplus paucifolius
Euphorbia boophthona
Euphorbia drummondii
Euphorbia tannensis subsp. *eremophila*

Fabaceae
Acacia acanthoclada subsp. *glaucescens*
Acacia acuaria
Acacia andrewsii
Acacia anthochaera
Acacia assimilis subsp. *assimilis*
Acacia burkittii
Acacia caesaneura
Acacia caesaneura hybrid
Acacia diallaga P2
Acacia effusifolia
Acacia erinacea
Acacia exocarpoides
Acacia incurvaneura
Acacia karina P2
Acacia kochii
Acacia mulganeura
Acacia pteraneura
Acacia ramulosa var. *ramulosa*
Acacia sibina
Acacia subsessilis P3
Acacia sulcaticaulis P1
Acacia tetragonophylla
Acacia umbraculiformis
Gastrolobium laytonii
Leptosema aphyllum
**Medicago minima*
Mirbelia bursarioides
Mirbelia microphylla
Senna artemisioides subsp. *filifolia*
Senna artemisioides subsp. *helmsii*
Senna charlesiana
Senna glaucifolia
Senna glutinosa subsp. *chatelainiana*
Senna sp. Austin (A Strid 20210)
Senna sp. Meekatharra (E Bailey 1-26)
Senna stowardii

Geraniaceae
Erodium cygnorum

Goodeniaceae
Brunonia australis
Goodenia berardiana
Goodenia krauseana
Goodenia mimuloides
Goodenia occidentalis
Goodenia pinnatifida
Scaevola spinescens
Velleia hispida
Velleia rosea

Haloragaceae
Gonocarpus nodulosus
Haloragis odontocarpa forma *rugosa*
Haloragis trigonocarpa

Hemerocallidaceae
Caesia sp. Wongan (KF Kenneally 8820)
Dianella revoluta var. *divaricata*
Tricoryne sp. Morawa (GJ Keighery & N Gibson 6759) P3

Juncaginaceae
Triglochin isingiana

Lamiaceae
Hemigenia benthamii
Hemigenia sp. Yalgoo (AM Ashby 2624)
Hemigenia sp. Yuna (AC Burns 95)
Prostanthera althoferi
Prostanthera patens

Loganiaceae
Phyllangium sulcatum

Malvaceae
Abutilon oxycarpum subsp. *prostratum*
Alyogyne hakeifolia
Brachychiton gregorii
Sida sp. dark green fruits (S van Leeuwen 2260)
Sida sp. Golden calyces glabrous (HN Foote 32)

Myrtaceae
Aluta aspera subsp. *hesperia*
Calothamnus gilesii
Chamelaucium sp. Warriedar (AP Brown & S Patrick APB 1100) P1
Eucalyptus clelandii
Eucalyptus loxophleba subsp. supralaevis
Eucalyptus salubris
Melaleuca eleuterostachya

Melaleuca hamata
Melaleuca nematophylla
Melaleuca radula
Micromyrtus acuta P3
Micromyrtus clavata
Micromyrtus trudgenii P3
Thryptomene costata
Thryptomene decussata

Orchidaceae
Cyanicula fragrans P3
Pterostylis sp. dainty brown (N Gibson & M Lyons 3690)

Orobanchaceae
**Parentucellia latifolia*

Phyllanthaceae
Poranthera leiosperma
Poranthera microphylla

Pittosporaceae
Cheiranthera simplicifolia

Plantaginaceae
Plantago debilis

Poaceae
Anthosachne scabra
Aristida contorta
Austrostipa blackii P3
Austrostipa elegantissima
Austrostipa eremophila
Austrostipa nitida
Austrostipa scabra
Austrostipa trichophylla
Enneapogon caerulescens
Eriachne pulchella subsp. *pulchella*
Lachnagrostis plebeia
Monachather paradoxus
**Pentameris airoides* subsp. *airoides*
**Rostraria pumila*
Rytidosperma caespitosum
**Schismus barbatus*
Tripogon loliiformis

Polygalaceae
Comesperma integerrimum

Polygonaceae
**Acetosa vesicaria*

Portulacaceae
Calandrinia calyptrata
Calandrinia creethiae
Calandrinia eremaea
Calandrinia sp. Warriedar (F Obbens 04/09) P2
Calandrinia translucens

Primulaceae
**Lysimachia arvensis*

Proteaceae
Grevillea hakeoides subsp. *stenophylla*
Grevillea obliquistigma subsp. *obliquistigma*
Grevillea scabrida P3
Grevillea subtiliflora P3
Hakea preissii
Persoonia pentasticha P3

Pteridaceae
Cheilanthes adiantoides
Cheilanthes brownii
Cheilanthes sieberi subsp. *sieberi*

Rhamnaceae
Cryptandra micrantha
Stenanthemum poicilum P3

Rutaceae
Philotheca brucei subsp. *brucei*
Philotheca sericea

Santalaceae
Exocarpos aphyllus
Santalum acuminatum
Santalum spicatum

Sapindaceae
Dodonaea amplisemina P4
Dodonaea inaequifolia
Dodonaea rigida

Scrophulariaceae
Eremophila clarkei
Eremophila eriocalyx
Eremophila forrestii subsp. *forrestii*
Eremophila georgei
Eremophila glutinosa
Eremophila grandiflora P3
Eremophila granitica
Eremophila latrobei
Eremophila oldfieldii subsp. *oldfieldii*
Eremophila oppositifolia subsp. *angustifolia*
Eremophila pantonii
Eremophila platycalyx subsp. *platycalyx*
Eremophila sp. (Meissner & Coppen 4312)

Solanaceae
Nicotiana rotundifolia
Solanum ellipticum
Solanum lasiophyllum
Solanum nummularium
Solanum orbiculatum

Stylidiaceae
Levenhookia leptantha

Urticaceae
Parietaria cardiostegia

Violaceae
Hybanthus floribundus subsp. *curvifolius*
Zygophyllaceae
Zygophyllum lobulatum
Zygophyllum ovatum
Zygophyllum reticulatum