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Flora and vegetation of greenstone formations of the Yilgarn Craton: southern Bullfinch Greenstone Belt

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ABSTRACT

The Bullfinch Greenstone Belt has long been recognised for its mineral wealth, yet comparatively little attention has been given to its floristic diversity. Fifty permanent quadrats were established in the southern portion of the greenstone belt, with all vascular flora and a suite of environmental parameters recorded. A total of 224 taxa were identified, representing 51 families and 125 genera. Favourable conditions during the survey contributed to a high presence of annuals, with 85 taxa recorded. Three taxa of conservation significance were recorded for the area, including *Tricoryne* sp. Wongan Hills (BH Smith 794), which represents a significant range extension (c. 230 km) and a potentially new taxon. Weeds were prevalent across the study area with 24 taxa identified, reflecting its long history of land use and disturbance. The six vegetation communities described from the survey had strong associations with edaphic factors. Although the southern Bullfinch Greenstone Belt has had a long history of land use, the area remains an important repository for floristic diversity. Future mineral exploration should ensure that these conservation values are retained.

Keywords: classification, Coolgardie, eastern goldfields, floristic diversity, ultramafics, vegetation patterns.

INTRODUCTION

The greenstone belts of the Yilgarn Craton have long been recognised for their mineral potential. The Bullfinch Greenstone Belt was one of the earliest locations identified for gold exploration, with the first payable gold east of Perth being discovered at Golden Valley in the southern part of the belt (Ralph 2007). The flora and vegetation of the area has been poorly documented, but recent surveys of the flora on banded ironstone ranges and allied greenstone belts have recorded high beta-diversity between the different terrain types (Gibson et al. 2007). This study is a continuation of the surveys on greenstone belts of the Yilgarn Craton that document the flora, plant communities and their associated environmental parameters (see Gibson et al. 2012).

STUDY SITE

The Bullfinch Greenstone Belt is situated in the central western area of the Coolgardie Bioregion, near the boundary with the Avon Wheatbelt Bioregion (Interim Biogeographic Regionalisation of Australia—IBRA; Thackway & Cresswell 1995). The greenstone belt extends c. 75 km north-north-west from the township of Bullfinch, approximately 35 km north-west of Southern Cross (Fig. 1). After approximately 20 km, the belt trends northwards to encompass the Highclere and Woongaring Hills. This study covers the southern extent of the Bullfinch Greenstone Belt south of Lake Deborah West and east of Lake Baladjie, an area of c. 20 km from north to south and c. 8–9 km from west to east. The latitudinal and longitudinal boundaries of the study area are roughly 30° 45" S, 31° 00" S and 118° 55" E, 119° 105" E, respectively. The land tenure for the greenstone belt, located within Yilgarn Shire, includes freehold land, the Golden Valley pastoral lease, unallocated crown land and crown reserve.

Land use history

Gold was first discovered in the Bullfinch area in 1887, with the townsite gazetted in 1910. Mining then occurred sporadically throughout the 1900s. At present, active mineral exploration leases are held over the Bullfinch Greenstone Belt, but no mines are active. The region supports several pastoral leases and farms (Chin & Smith 1983), with additional economic activity associated with resource exploration and extraction undertaken at the nearby Marda-Diemals Greenstone Belt.

In 1912, following the discovery of gold, government geologist HP Woodward undertook a reconnaissance of the Bullfinch Greenstone Belt and areas to the north (Chin & Smith 1983). Additional geological surveys and exploration identified economically viable deposits of iron ore in the Koolyanobbing area, with minor amounts of silver production only associated with gold extraction

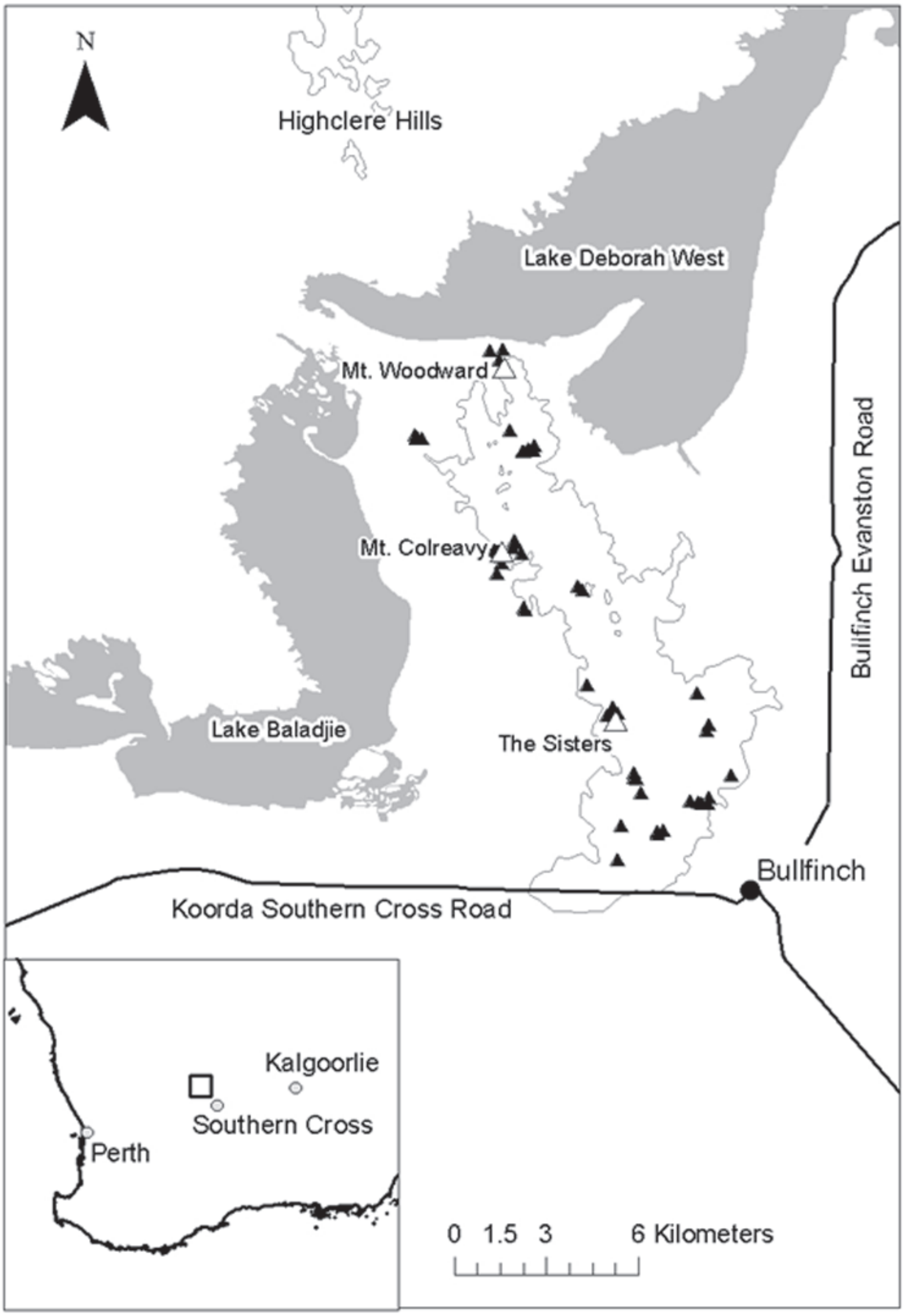


Figure 1. Map showing the location of the southern Bullfinch Greenstone Belt, with major landforms and landmarks indicated. The locations of the 50 permanent quadrats are marked by solid triangles (▲).

(Chin & Smith 1983). The presence of nickel and copper has been identified, but neither discovery has resulted in any production in the region.

Climate

Bullfinch sits in the central western portion of the Coolgardie Bioregion, which has a semi-arid climate with warm summers and mild winters. Rainfall events occur throughout the year, with most rain falling between May and August (Bureau of Meteorology 2010). Mean annual rainfall at Southern Cross (c. 35 km south-east of Bullfinch) is 294.5 mm, based on records from 1889 to 2007, with June and December having the highest (40.7 mm) and lowest (12.6 mm) average monthly rainfall, respectively. The average annual maximum is 25.5 °C and minimum is 10.7 °C, based on records between 1907 to 2007. The highest temperatures occur between December and March, with mean maximum temperatures exceeding

30 °C. The lowest daily minimum temperatures occur between May and September, where mean minimum temperatures are below 8 °C.

Geology

The geology of the Bullfinch Greenstone Belt has been mapped and described on the Jackson 1:250,000 geological sheet (Chin & Smith 1983). Greenstone locally refers to outcrops of ultramafics and mafics associated with Archaean meta-volcanic and meta-sedimentary rock sequences (Cole 1992). The Bullfinch area is characterised by low rock outcrops and lateritic duricrust, surrounded by undulating sandplains and alluvial valleys associated with a paleodrainage system (Chin & Smith 1983). The highest point in the survey area is Mt. Woodward (412 m), with the nearby salt lakes of Lake Baladjie and Lake Deborah West at c. 330 m above sea level.

The Bullfinch Greenstone Belt is part of the Archaean Yilgarn Craton, a tectonically stable region within the Pre-Cambrian Western Shield (Anand & Paine 2002), formed between 3000 and 2600 Ma (Myers 1993; Myers & Swagers 1997). Within the Yilgarn Craton, Bullfinch sits on the western boundary of the Southern Cross Domain (SCD) within the Youanmi Terrane (Cassidy et al. 2006).

The greenstone belts of the SCD trend primarily in a north-north-west direction, with Bullfinch having undergone powerful deformation to form a tightly folded structure (Griffin 1990). The Bullfinch Greenstone Belt is a typical greenstone formation, with sequences of mafic and sedimentary rocks over a lower succession of mafic and ultramafic rocks (Chin & Smith 1983; Griffin 1990). Within the southern portion of the Bullfinch Greenstone Belt, the dominant rock types are metamorphosed komatiitic basalt, metabasalt and metagabbro (Chin & Smith 1983). Isolated occurrences of talc schist, peridotite, metamorphosed conglomerate and quartz-muscovite schist are found within the study area (Chin & Smith 1983). The survey area also includes foliated granites on the eastern boundary of the greenstone. Quaternary colluvium deposits dominate the slopes and pediments adjacent to the main greenstone belt, which are then surrounded by aeolian and alluvial deposits associated with the salt lakes to the west (Lake Baladjie) and to the north (Lake Deborah West; Chin & Smith 1983).

Beard (1990) described the soils of the Coolgardie Bioregion as predominantly brown calcareous earths. Within the Bullfinch region, soils are typically shallow calcareous loams associated with rocky hills and brown calcareous earths on the slopes and adjacent pediments (Beard 1981). Natural red earths characterise areas that have undergone extensive weathering (Beard 1981).

Vegetation

The Bullfinch Greenstone Belt is part of the Coolgardie Botanical District within the South West Interzone (Beard 1990). The interzone represents the transitional boundary between the floristically-rich south-west and the desert communities of the interior. *Eucalyptus* woodlands are the predominant vegetation community; on calcareous substrates, eucalypt densities are reduced, coupled with increasing presence of the chenopod understorey (Beard 1990).

Beard (1981) mapped the southern Bullfinch Greenstone Belt as eucalypt woodland, bounded on the north by the salt lake, Lake Deborah West. The greenstone belt was described as the Yilgarn Hills, part of the Yilgarn Vegetation System; however, the northern portion of the Yilgarn Hills had greater affinity to the Highclere System to the north of Lake Deborah West (Beard 1980). The central portion of the greenstone-belt study area was described as mixed *Eucalyptus longicornis* and *E. lesoufeii* woodland with *E. salmonophloia* – *E. lesoufeii* woodlands to the northeast and *E. longicornis* – *E. salmonophloia* woodlands to the south-west (Beard 1981). Beard (1981) described the Highclere System as dominated by *E. longicornis* – *E. corrugata* woodlands on the hills with an *Atriplex* sp. understorey. Other elements of the vegetation system include the tree species *Casuarina pauper*, *Brachychiton gregorii*, *Callitris columellaris* and the shrubs *Acacia tetragonophylla*, *A. ramulosa* and *Santalum spicatum* (Beard 1980). Where the greenstone hills approach Lake Deborah West, the eucalypt woodland communities known to persist on the hills occur further downslope on the adjacent colluvium (Beard 1980). There are limited occurrences of ironstone ridges in the Yilgarn Hills, dominated by *A. quadrimarginea*, with the occasional specimen of *Casuarina cristata*, *B. gregorii* and *Pittosporum phylliraeoides*.

The eastern goldfields regional survey provided an overview of the vegetation in the Jackson–Kalgoorlie area. The adjacent Highclere Hills were described as supporting *Eucalyptus corrugata* woodlands on the stony upland sites, with *E. salmonophloia* and *E. salubris* woodlands downslope on the colluvial deposits (Newbey & Hnatiuk 1985). Less frequently encountered were *Acacia acuminata* and *A.* aff. *aneura* shrubland communities, found occasionally on rocky rises, and *E. longicornis* woodlands associated with more alkaline colluvial soils (Newbey & Hnatiuk 1985).

A detailed vegetation survey of the central Bullfinch Greenstone Belt, at Highclere Hills, recorded 217 native and 25 weed taxa (Gibson & Lyons 2001). Five dominant vegetation communities with two additional sub-groups were identified from the survey, each strongly influenced by edaphic factors. Characteristic of the Coolgardie Bioregion, *Eucalyptus* woodlands defined one of the community types, featuring *E. longicornis*, *E. salubris* and/or *E. corrugata* with a chenopod understorey (i.e. *Atriplex* sp., *Maireana* sp., *Scleroleana* sp.). Other vegetation communities included *Acacia acuminata* shrublands with *Casuarina pauper* and *A. tetragonophylla* and *Scaevola spinescens* associations. A single laterite community featured *Allocasuarina campestris*, *Baeckea elderiana* and *Grevillea paradoxa* (Gibson & Lyons 2001).

Broad-scale vegetation mapping (Beard 1980, 1981) and survey (Newbey & Hnatiuk 1985) have provided a regional context. The survey undertaken on the Highclere Hills represents the only detailed information on the flora and vegetation of the Bullfinch Greenstone Belt. This study aimed to record the floristic diversity, describe vegetation patterns and examine environmental parameters associated with the southern Bullfinch Greenstone Belt, between Lake Deborah West and the Bullfinch township. Our study addresses the deficiency of information on an area that has had over a century of mineral interests and exploration.

METHODS

In early September 2009, fifty 20 × 20 m permanent quadrats were established across the southern Bullfinch Greenstone Belt. The quadrats were environmentally stratified in order to represent the topographical, geological and geomorphological variation across the length and breadth of the belt. However, the sampling design was biased (non-random), due to access issues and the infrastructure present (i.e. water tanks). The sites were selected to capture the vegetation communities associated with the greenstone belt and its associated geologies. Landscape positions of the sites encompassed a broad topological sequence from hill crests downslope to the colluvial deposits. Methods used follow those of previous surveys on greenstone belts in the Yilgarn Craton (e.g. Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c). Quadrats were located in areas subject to minimal disturbance or modification, although the whole region has been the focus of both past mineral exploration and present-day pastoral activities. Thus, sites where evidence of heavy grazing, clearing or exploration-related disturbance were obvious were avoided.

The quadrats were marked by four steel fence droppers and their location recorded with a Garmin Map76 GPS. Photographs were taken at a set distance of 5 m from each corner. Site physical characteristics (landform, slope, aspect, litter and bare ground cover, size of coarse fragments, cover of surface rock fragments and bedrock, soil colour and texture) were recorded as a series of descriptive attributes and semi-quantitative scales, as defined by McDonald et al. (1998). Landform description was based on topographical position (crest, upper slope, mid slope, lower slope or flat) and landform element type (e.g. hillcrest, hillslope, breakaway; McDonald et al. 1998). Coarse fragments and rock outcrop data were recorded as specific geologies present and as part of a seven-point scale representing percent (%) cover. The seven cover classes were: zero % cover (0); <2% cover (1); 2–10% (2); 10–20% (3); 20–50% (4); 50–90% (5); >90% (6). Site disturbance was ranked between zero and three, with zero (0) representing no effective disturbance and three (3) being extensively cleared. Runoff was assigned to a scale of six classes (0 = no runoff, 1 = very slow, 2 = slow, 3 = moderately rapid, 4 = rapid, 5 = very rapid; McDonald et al. 1998).

Vegetation structure was determined by assigning the dominant taxa to the relevant stratum in the landscape, noting emergent taxa where appropriate, based on McDonald et al. (1998). All vascular plants were recorded from within the plot and assigned a cover class (D >70%, M 30–70%, S 10–30%, V <10%, I = isolated plants and L = isolated clumps). Material was collected for verification and vouchering at the Western Australian Herbarium (WA Herbarium). Additional specimens were collected adjacent to the plots, contributing to the overall species list for the survey area. Species were designated as 'weeds' based on the classification of the WA Herbarium, which classifies invasive species as those introduced or alien to the area (2010). Where sufficient representative plant material was available, it was lodged at the WA Herbarium. Nomenclature generally follows Florabase (Western Australian Herbarium 2010).

Soil chemical attributes were analysed for each quadrat. Soil was collected from 20 regularly-spaced intervals across the quadrat, bulked and sieved. The <2 mm fraction was analysed by a Inductively Coupled Plasma – Atomic Emission Spectrometer (ICP–AES) for B, Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, S and Zn using the Mehlich No. 3 procedure (Mehlich 1984). Soil pH was measured on 1:5 soil-water extracts in 0.01 M $CaCl_2$ (method S3, Rayment & Higginson 1992). Organic carbon content was measured using a modified Walkley–Black method (method 6A1) and the calculation of soil nitrogen (N) was based on a modified Kjeldahl digest (method S10, Rayment & Higginson 1992).

The classification and ordination analyses were undertaken on a presence/absence data matrix of the 87 perennial taxa that occurred at more than a single site, which is consistent with previous greenstone belt studies (Gibson 2004a, 2004b). The dissimilarity between sites was determined using the Bray–Curtis measure and the Resemblance routine in PRIMER v6 (Clarke & Gorley 2006). The Bray–Curtis measure is a widely-used assessment of ecological distance, which reflects differences in both relative abundance and compositional change (Legendre & Legendre 1998; Anderson & Robinson 2003), and provides quantitative output for similarity between samples (Faith et al. 1987). Using the Bray–Curtis similarity matrix, the site by species similarity matrix was classified based on the flexible unweighted pair-group mean average method (UPGMA, $\beta = -0.1$), using PATN v3.11 (Belbin 1989). The resulting dendrogram provided the basis for placing the taxa into ecological groups. A two-way table was created from the classification. The species–site similarity matrix was then subjected to Non-metric Multi-dimensional Scaling (NMS). An environmental data matrix that included soil chemical properties and site physical characteristics was created, which was then fitted to the NMS ordination using Spearman correlation values in Primer v6. The continuous environmental variables were normalised prior to fitting the environmental vectors.

The similarity percentages (SIMPER) analysis provided information on those species typically found within each community. The SIMPER routine in PRIMER determines those taxa that contribute the most to similarity within a community and dissimilarity amongst communities (Clarke & Warwick 2001). Those taxa contributing 10% or more to the similarity within each community type are reported. Where no individual species contribution reached the 10% threshold, taxa constituting 50% cumulative contribution were included. When ties occurred at the 50% level, all taxa in the tie were reported.

Relationships between environmental variables were examined using the non-parametric Spearman rank correlation routine in Statistix 7.1 (Analytical Software, Tallahassee, Florida). The environmental variables were subjected to Kruskal–Wallis one-way non-parametric analysis of variance and post-hoc significance testing of means $\alpha = 0.05$ (Sokal & Rolf 1995) for differences between community groups.

RESULTS

A total of 218 taxa were recorded in the permanent quadrats, representing 51 families and 125 genera. An additional six taxa were recorded from areas adjacent to the survey plots. The families with the highest number of taxa were: Asteraceae (47 taxa), Chenopodiaceae (20 taxa), Poaceae (16 taxa), Fabaceae (14 taxa) and Scrophulariaceae (nine taxa). At the level of genus, the greatest representation was within *Eremophila* (nine species), *Rhodanthe* (seven species), *Acacia* (six species), *Maireana* (five species, plus two hybrids) and *Ptilotus* (five species). The presence of weed taxa was notable during the survey, with 24 weed species recorded, accounting for 224 records.

Species richness within the survey plots varied considerably, ranging from five to 61 taxa. The mean species richness was 39.7 ± 14 SD. Representation of annuals was high, with 85 taxa. Eight taxa, including the *Maireana* hybrids, were combined into three species complexes for the analyses. The analyses excluded all annuals, singletons and indeterminate specimens, resulting in a matrix of 87 species × 50 sites.

Priority taxa

Three taxa of conservation significance were recorded during the survey (Table 1). Two of the species, *Caesia* sp. Ennuin (N Gibson & MN Lyons 2737) and *Austrostipa blackii*, were known from the Bullfinch Greenstone Belt north of the survey area. Only one collection of the undescribed *Caesia* sp. Ennuin (N Gibson & MN Lyons 2737) exists on record in the WA Herbarium. This survey identified a single individual of this priority-listed taxon, c. 10 km south of the known locality. The specimen is in good condition with flowers and may facilitate a formal taxonomic description of the species. *Austrostipa blackii* is a perennial grass known from 18 collections scattered in the Coolgardie, Avon Wheatbelt and Yalgoo Bioregions. The survey at Bullfinch identified three new populations of *A. blackii*.

Tricoryne sp. Wongan Hills (BH Smith 794) is a Priority 2 species, known from seven collections from the Avon Wheatbelt and Geraldton Sandplain Bioregions. Two specimens with strong resemblance to the *Tricoryne* sp. Wongan Hills (BH Smith 794) were collected from rocky sites c. 230 km from the nearest recorded population. Without a formal description of *Tricoryne* sp. Wongan Hills (BH Smith 794) available to ascertain the validity of the identification, the specimens from this survey were lodged as *Tricoryne* sp. Wongan Hills (BH Smith 794). Further clarification regarding the taxonomic identity of the Bullfinch collections is required, particularly with regard to the geographic disparity between collection sites, the smaller overall size of the Bullfinch specimens, and differing substrates on which the specimens have been found (G Keighery, pers. comm.).

Range extensions

Two range extensions were recorded during the survey, including the P2 *Tricoryne* sp. Wongan Hills (BH Smith 794) anomaly already mentioned. The second range extension was of the biennial herb *Cirsium vulgare*, a recognised weed taxon. *Cirsium vulgare* has been recorded through the south-west of Western Australia. The Bullfinch collection represents a c. 150 km range extension north-east of the nearest population in the Avon Wheatbelt.

Hybrids

Two hybrids were collected during the surveys on the northern Bullfinch Greenstone Belt. One of the hybrids, *Maireana georgei* × *Enchylaena tomentosa*, is recognised in the collection of the WA Herbarium. The second hybrid, *M. georgei* × *E. lanata*, has not been recorded in the WA Herbarium. However, there were eight collections of this hybrid confirmed by Chenopodiaceae taxonomist, Paul Wilson.

Floristic communities

Seven species groups (A–G) were identified, based on hierarchical clustering within the classification routine (Table 2). Species group E contained the most widespread taxa, with representation across all community types,

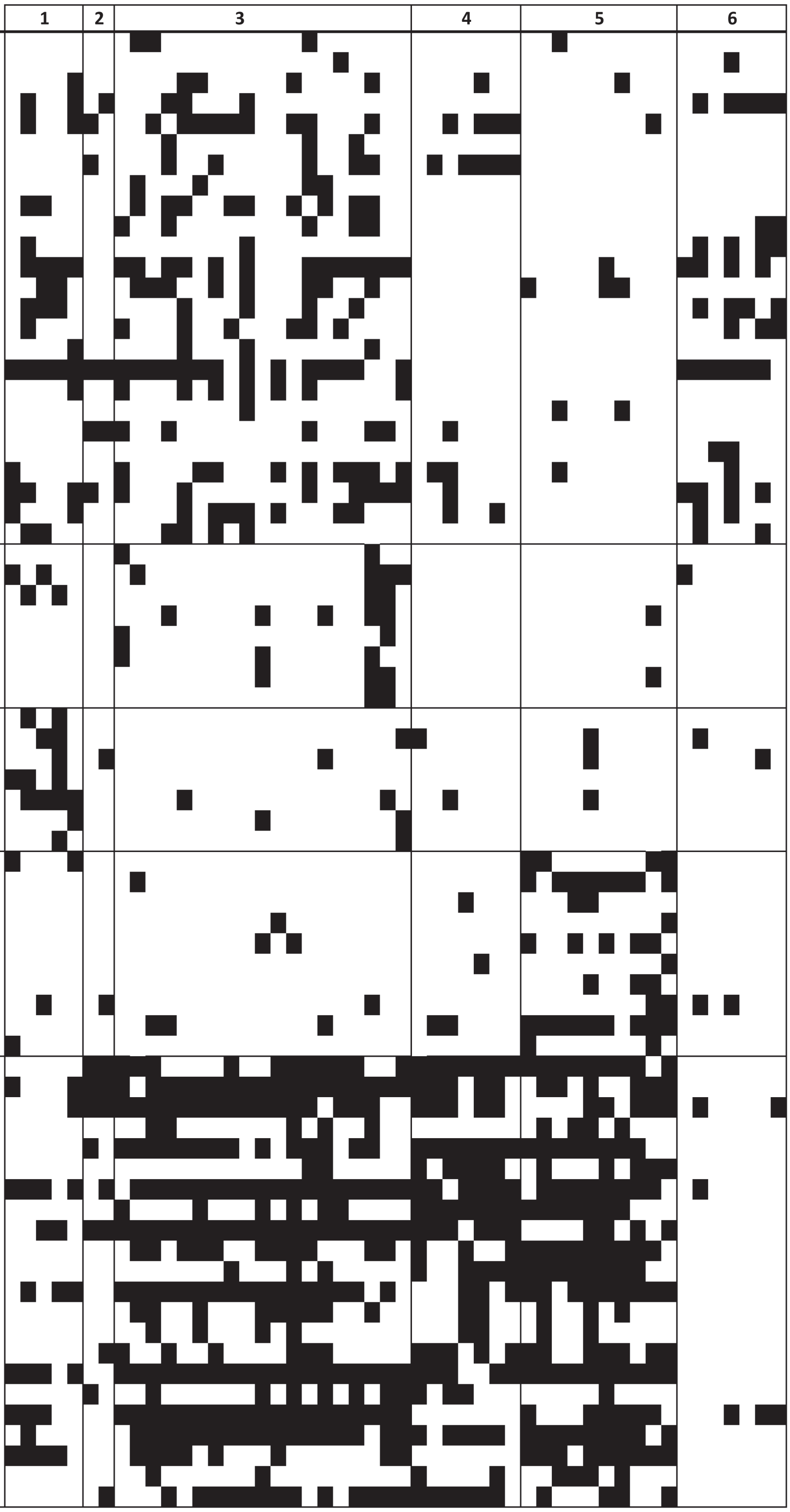
Table 1

Priority taxa recorded from the southern Bullfinch Greenstone Belt. Bioregion abbreviations: COO = Coolgardie, YAL = Yalgoo, GS = Geraldton Sandplain, AW = Avon Wheatbelt, JF = Jarrah Forest.

Family	Taxon	Status for Bullfinch	Priority	Bioregion
Hemerocallidaceae	*Caesia* sp. Ennuin (N Gibson & MN Lyons 2737)	New record	P1	COO
Hemerocallidaceae	*Tricoryne* sp. Wongan Hills (BH Smith 794)	New record	P2	AW, GS, JF
Poaceae	*Austrostipa blackii*		P3	COO, YAL, AW

Table 2

Two-way table of community types (columns) and species groups (rows) for the Bullfinch Greenstone Belt. Each square represents the presence of a species in that survey quadrat within the particular community type.



Group	Species
A	*Abutilon oxycarpum*
	Acacia jennerae
	Arthropodium curvipes
	Atriplex nummularia
	Austrostipa trichophylla
	Chenopodium curvispicatum
	Comesperma integerrimum
	Einadia nutans subsp. *eremaea*
	Eremophila alternifolia
	Eremophila oppositifolia subsp. *angustifolia*
	Eremophila scoparia
	Eriochiton sclerolaenoides
	Erodium aureum
	Eucalyptus corrugata
	Exocarpos aphyllus
	Hypoxis glabella var. *glabella*
	Maireana trichoptera
	Maireana triptera
	Marsdenia australis
	Pittosporum angustifolium
	Pterostylis mutica
	Rhagodia drummondii
	Sclerolaena diacantha
	Senna artemisioides
	Zygophyllum ovatum
B	*Alyxia buxifolia*
	Atriplex paludosa subsp. *baudinii*
	Austrodanthonia caespitosa
	Cheilanthes lasiophylla
	Cleretum papulosum subsp. *papulosum*
	Lepidium oxytrichum
	Maireana planifolia
	Senna charlesiana
C	*Atriplex vesicaria*
	Austrostipa nitida
	Austrostipa variabilis
	Dodonaea viscosa subsp. *angustissima*
	Maireana georgei complex
	Santalum spicatum
	Sclerolaena obliquicuspis
D	*Acacia ramulosa* var. *ramulosa*
	Allocasuarina dielsiana
	Austrostipa blackii
	Cheilanthes sieberi subsp. *sieberi*
	Goodenia occidentalis
	Prasophyllum gracile
	Sida petrophila
	Sida sp. Golden calyces glabrous (HN Foote 32)
	Thysanotus speckii
	Wurmbea tenella
E	*Acacia* sp. narrow phyllode (BR Maslin 7831)
	Acacia tetragonophylla
	Austrostipa elegantissima
	Brachychiton gregorii
	Cheilanthes adiantoides
	Dianella revoluta var. *divaricata*
	Dodonaea inaequifolia
	Drosera macrantha subsp. *macrantha*
	Enchylaena tomentosa / lanata
	Eremophila clarkei
	Eremophila serrulata
	Goodenia berardiana
	Philotheca brucei subsp. *brucei*
	Prostanthera althoferi subsp. *althoferi*
	Pterostylis sp. inland (AC Beauglehole1880)
	Ptilotus obovatus
	Rhyncharrhena linearis
	Scaevola spinescens
	Sida sp. dark green fruits (S van Leeuwen 2260)
	Solanum lasiophyllum
	Solanum petrophilum
	Thysanotus manglesianus

Table 2 (cont.)

Group	Species	1	2	3	4	5	6
F	*Acacia erinacea*			■			■
	Dodonaea stenozyga						■
	Eremophila ionantha						■
	Eucalyptus longissima			■	■		■
	Eucalyptus yilgarnensis				■		■
	Olearia pimeleoides			■			■
	Santalum acuminatum						■
G	*Eucalyptus ewartiana*				■		
	Goodenia mimuloides		■		■		
	Hakea recurva subsp. *recurva*		■				
	Hybanthus floribundus subsp. *floribundus*		■		■		
	Melaleuca hamata				■		
	Mirbelia microphylla				■		
	Ptilotus spathulatus forma *spathulatus*		■	■	■		
	Tricoryne sp. Wongan Hills (BH Smith 794)				■		

except one (community type 6). Using the clustering of samples and the SIMPROF routine, six community types were identified (Fig. 2). The dendrogram highlighted the relationship between community types, in particular, the separation of community type 6 is notable, as well as the close relationship between communities types 4 and 5. One pair of sites is discussed as community group 2; however, they were not analysed with the remaining community types. The cluster analysis identified them as a distinct group, but there were too few locations to warrant their inclusion in the analyses. The two-way table highlights the relationships between the site and species groups (Table 2). The NMS routine displays the interrelationship between sites, based on the resemblance matrix (2D stress = 0.15, 3D stress value = 0.11) with environmental vectors superimposed based on the line of best-fit in multi-dimensional space (Fig. 3). Strong correlation occurred between environmental vectors and community groups. Soil chemical parameters, soil pH, electrical conductivity, B, Ca, Mg and P exhibited the greatest correlation ($r_s \geq 0.7$).

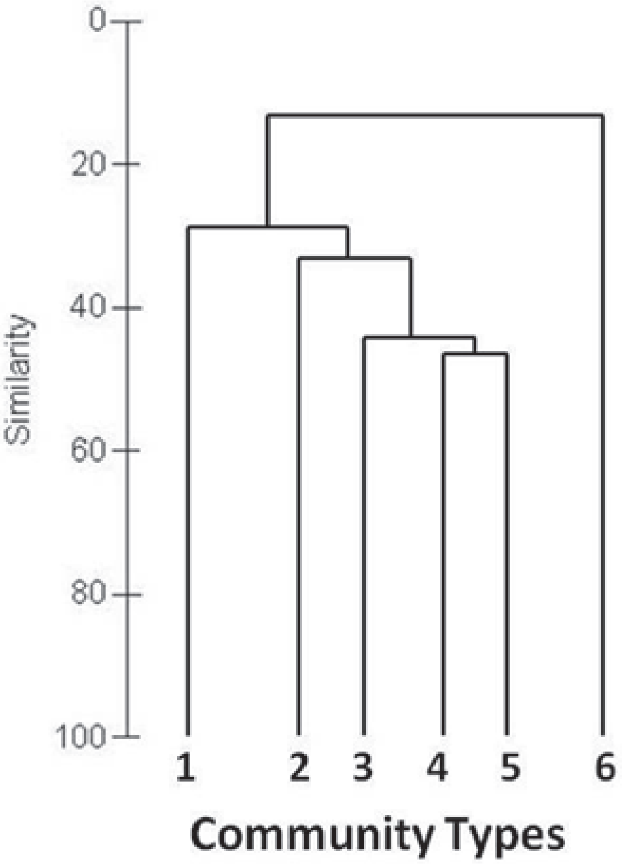


Figure 2. Summary dendrogram of community types for the southern Bullfinch Greenstone Belt. The six community types displayed in the dendrogram are derived from the classification analyses of the 87 taxa from 50 sites.

Community type 1 contained five quadrats, generally associated with lower topographical positions and gentle slopes. The exception was a single, mid-slope locality with a steep gradient. Overstorey species included *Eucalyptus corrugata* or *Acacia ramulosa* var. *ramulosa*. The understorey was dominated by *Dodonaea inaequifolia*, *Ptilotus obovatus*, *Solanum lasiophyllum* and chenopod shrubs, including *Atriplex vesicaria*, *Eriochiton sclerolaenoides*, *Maireana georgei* and *M. trichoptera*. This community type was allied with species groups A, C and D, with a complete absence of species from groups F and G (Table 2). Species richness was variable across sites, ranging from 28 to 46 taxa per quadrat (mean 36.2 ± 7.2 SD).

Soils from this community were neutral (pH 7.2–7.7) sandy clay loams. Ca concentrations were predominantly high and moderate to high concentrations of other major soil cations (K, Mg, Na) were recorded (Table 3). No exposed bedrock was present and coarse fragments were predominantly composed of basalt with mixed metasediments and calcrete. Cover of bare ground was high, with very sparse to sparse cover of leaf litter (4–15%).

Community type 2 was represented by a pair of lowland quadrats (BLFN 42 and 47) on gentle slopes. Community structure was dominated by open shrubland of *Acacia* sp. narrow phyllode (BR Maslin 7831), *A. tetragonophylla* and *Pittosporum angustifolium* over chenopod shrubs, including *Enchylaena* sp. and *M. trichoptera* over *Goodenia mimuloides* and *Austrostipa elegantissima*. The community was primarily associated with species groups A, D and G, with an absence of species from group B (Table 2). Species richness was 37 and 29

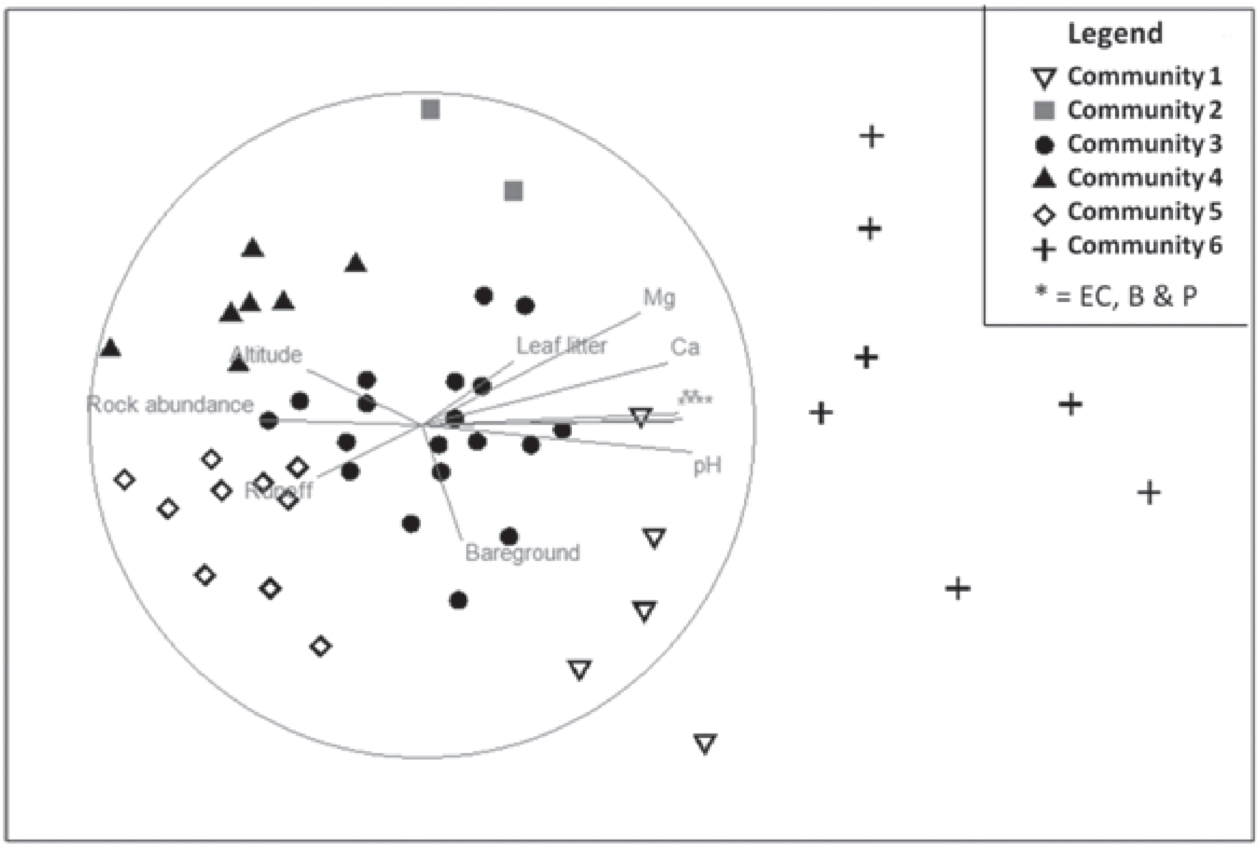


Figure 3. 2D graph of the first two axes of the NMS ordination (2D stress value = 0.15) of survey plots for the southern Bullfinch Greenstone Belt. Survey plots are separated by community groups overlain with environmental vectors, using the lines of best-fit in a multi-dimensional space. Vectors extending close to the edge of the circle indicate stronger correlation to those communities. The soil parameters (soil pH, electrical conductivity, Ca, Mg, B and P) that had the greatest correlation with community groups ($r_s \geq 0.7$) are shown. For comparison, the vectors of the top five site physical characteristics (abundance of coarse fragments and leaf litter, runoff, altitude and bare ground) are also shown. Data are a matrix of 87 perennial species from 50 survey sites.

taxa per quadrat, respectively; lower than the mean for all of the survey plots. Soils were acidic (pH 5.3) clay loam sands at BLFN 42 and mildly alkaline (pH 7.9) sandy clay loam at BLFN 47. Bare ground was prevalent with very sparse cover of leaf litter.

Community type 3 was the most widespread of all vegetation types, recorded within 19 quadrats. This was a predominantly woodland community found on upper slopes with moderate to steep gradients. Species richness was generally high (mean taxa per quadrat 49.1 ± 8.3 SD), ranging from 29 to 61 taxa per quadrat. Taxa were principally associated with species groups A, B and E, with minor representation in C and D (Table 2). Dominant overstorey species varied, but included *Eucalyptus ewartiana* and *Brachychiton gregorii.* A group of sites within this community type were more typical of shrubland communities and lacked dominant tree species; however, further surveys are required to clarify their status as a potential sub-type or separate community. Other key taxa included *Acacia tetragonophylla*, *Dodonaea inaequifolia*, *Enchylaena* sp., *Ptilotus obovatus*, and *Scaevola spinescens* over *Goodenia berardiana* and *Sida* sp. dark green fruits (S van Leeuwen 2260).

Soils were sandy loam to sandy clay loam, varying from acidic to mildly alkaline (pH 5–7.7). Coarse fragments were very abundant across all sites, with the majority of sites also having exposed bedrock. Regolith composition was primarily ironstone (some banded) and metabasalt. Leaf litter was sparse to moderate, with a high proportion of bare ground present. Ca concentrations were comparatively high at most of the plots (Table 3). Other soil cation concentrations were concomitantly high, except for Na, which had moderate concentrations compared with other community types.

Community type 4 was a group of mallee shrubland sites with highly acidic soils (pH 5.1–5.6), found on gentle gradients across a range of topographical positions. Species richness was high, ranging from 41 to 53 taxa per quadrat (mean 46.9 ± 4.3 SD); taxa were predominantly associated with species groups A, E and G (Table 2). There was a complete absence of taxa from group B. The dominant mallee species was *Eucalyptus ewartiana.* Other eucalypts included *E. longissima* and *E. yilgarnensis.* Typical shrub taxa included *Acacia* sp. narrow phyllode (BR Maslin 7831), *Dodonaea inaequifolia* and *Enchylaena* sp. Other typical taxa included the geophyte *Cheilanthes*

Table 3

Summary statistics for environmental variables, separated by community type, for the southern Bullfinch Greenstone Belt. Mean values with standard deviation are listed for community types with greater than a single locality recorded. Differences were determined using Kruskal–Wallis non-parametric analysis of variance. Only community types with >2 representative quadrats were included in the analyses. Significance values are indicated by * ($p < 0.05$ = *; $p < 0.01$ = **; $p < 0.001$ = ***; $p < 0.0001$ = ****) and $^{+}$ equates to no significant difference of means; post-hoc differences were set at $\alpha = 0.05$. Units of measurements for the parameters are: soil chemicals = mg/kg; abundance of fragments and outcrop abundance = categorical maximum (0 = 0%, 1 = <2%, 2 = 2–10%, 3 = >10–20%, 4 = >20–50%, 5 = >50–90%, 6 = >90%); topographical position: 1 = crest, 2 = upper slope, 3 = mid-slope, 4 = lower slope, 5 = flat; species richness = number of taxa per quadrat.

	Community Types					
Soil Parameters	**1**	**2**	**3**	**4**	**5**	**6**
B****	1.36 ± 0.78 [ab]	1.0 ± 0.78	1.3 ± 0.7 [ab]	0.4 ± 0.2 [c]	0.6 ± 0.1 [bc]	4.8 ± 1.8 [a]
Ca****	3340.0 ± 1636.5 [ab]	3600.0 ± 2687	2838.9 ± 1786.1 [ab]	1247.1 ± 349.5 [a]	1069.0 ± 226.5 [a]	5500.0 ± 0.0 [b]
Cd*	0.019 ± 0.013 [ab]	0.015 ± 0.007	0.040 ± 0.06 [a]	0.017 ± 0.008 [ab]	0.011 ± 0.008 [b]	0.016 ± 0.008 [ab]
Co****	3.1 ± 1.3 [ab]	3.7 ± 3.8	3.3 ± 1.9 [a]	5.6 ± 1.5 [a]	4.7 ± 1.1 [a]	0.5 ± 0.2 [b]
Cu*	3.9 ± 1.2 [ab]	4.5 ± 0.8	7.3 ± 4.8 [a]	4.9 ± 2.2 [ab]	4.7 ± 2.5 [ab]	2.7 ± 1.3 [b]
EC****	29.2 ± 23.7 [a]	9.0 ± 4.2	13.3 ± 6.6 [ab]	5.7 ± 2.4 [bc]	4.5 ± 1.4 [c]	23.6 ± 10.4 [a]
Fe***	45.8 ± 9.1 [ab]	46.5 ± 31.8	58.3 ± 16.3 [bc]	74.6 ± 12.2 [c]	59.2 ± 7.4 [bc]	37.9 ± 6.0 [a]
K**	442.0 ± 81.7 [a]	370.0 ± 99.0	390.0 ± 80.1 [a]	328.6 ± 67.7 [ab]	286.0 ± 51.7 [b]	438.6 ± 83.6 [ab]
Mg***	492.0 ± 97.8 [ab]	620.0 ± 240.4	481.1 ± 290.6 [a]	407.1 ± 250.2 [a]	247.0 ± 57.0 [a]	975.7 ± 169.3 [b]
Mn***	194.0 ± 49.3 [a]	154.5 ± 78.5	166.1 ± 81.3 [a]	187.1 ± 43.5 [a]	211.0 ± 40.7 [a]	63.0 ± 20.7 [b]
N (total)**	0.10 ± 0.05 [ab]	0.11 ± 0.02	0.14 ± 0.06 [ab]	0.12 ± 0.04 [ab]	0.09 ± 0.02 [a]	0.22 ± 0.07 [b]
Na**	147.6 ± 165.1 [a]	29.5 ± 2.1	31.2 ± 16.3 [b]	24.6 ± 9.7 [b]	26.9 ± 12.2 [b]	89.6 ± 62.8 [ab]
Ni***	3.0 ± 1.9 [ab]	9.0 ± 9.9	6.0 ± 9.2 [ab]	8.8 ± 5.8 [a]	1.1 ± 0.3 [b]	1.7 ± 0.8 [b]
Organic C (%)**	1.1 ± 0.6 [ab]	1.2 ± 0.4	1.5 ± 0.7 [ab]	1.4 ± 0.6 [ab]	0.9 ± 0.2 [a]	2.9 ± 0.9 [b]
P****	8.4 ± 1.1 [ab]	7.0 ± 5.7	9.3 ± 5.3 [ab]	4.1 ± 0.7 [bc]	3.8 ± 0.9 [c]	27.3 ± 15.0 [a]
pH****	7.4 ± 0.3 [ab]	6.6 ± 1.8	6.7 ± 0.9 [b]	5.3 ± 0.2 [c]	5.7 ± 0.3 [bc]	7.9 ± 0.1 [a]
S***	13.2 ± 11.9 [ab]	10.0 ± 0.0	9.4 ± 3.9 [a]	10.0 ± 5.3 [ab]	5.7 ± 2.5 [a]	43.4 ± 25.0 [b]
Zn[NS]	2.2 ± 0.2	1.2 ± 0.4	3.0 ± 1.6	1.9 ± 0.4	3.5 ± 2.0	2.0 ± 1.1
Site Physical Parameters						
Altitude (m)**	349.0 ± 12.7 [a]	367.0 ± 8.5	382.0 ± 15.0 [b]	373.1 ± 8.5	388.5 ± 25.0 [b]	380.0 ± 14.8 [ab]
Bare ground (%)*$^{+}$	96.8 ± 1.3	96.5 ± 0.7	95.3 ± 1.5	94.4 ± 1.6	96.4 ± 1.3	95.0 ± 1.8
Abundance-fragments*$^{+}$	3.8 ± 1.8	4.0 ± 1.4	5.6 ± 0.6	4.9 ± 1.5	5.8 ± 0.6	4.9 ± 0.4
Leaf litter (%)**	8.4 ± 4.4 [a]	8.0 ± 2.8	9.3 ± 4.3 [a]	13.0 ± 6.5 [ab]	9.1 ± 4.2 [a]	31.1 ± 12.1 [b]
Topographical position*	4.4 ± 0.9 [a]	4.0 ± 0.0	2.3 ± 1.0 [b]	3.1 ± 1.3 [ab]	2.3 ± 1.1 [ab]	2.7 ± 1.4 [ab]
Outcrop abundance*$^{+}$	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 1.3	0.4 ± 0.8	1.3 ± 0.9	0.4 ± 0.8
Runoff***	1.3 ± 0.9 [a]	1.3 ± 0.4	2.8 ± 0.6 [b]	1.8 ± 0.9 [ab]	2.8 ± 0.9 [ab]	1.7 ± 0.8 [ab]
Species Richness	36.2 ± 7.2	33.0 ± 5.7	48.6 ± 8.0	46.9 ± 4.3	40.9 ± 6.0	11.6 ± 5.5
Number of quadrats:	**5**	**2**	**19**	**7**	**10**	**7**

adiantoides and the climbers *Drosera macrantha* subsp. *macrantha* and *Thysanotus manglesianus*.

Soils were sandy clay loams. The abundance of coarse fragments was variable, with limited surface exposure of bedrock. Rock fragments were primarily composed of basalt with mixed metasediments. Leaf litter cover was generally low (3–20%; Table 3).

Community type 5 corresponded to *Allocasuarina* woodlands, typical of mid to upper slopes in the northern portion of the study area. Taxa were predominantly associated with species groups D and E (Table 2). Species richness was high, with 33 to 51 taxa per quadrat (mean 40.9 ± 6 SD). The dominant canopy species was typically *A. dielsiana*, with an understorey of *Acacia* sp. narrow phyllode (BR Maslin 7831), *Eremophila clarkei*, *Ptilotus obovatus* and *Solanum lasiophyllum* over *Goodenia berardiana* and *Sida* sp. dark green fruits (S van Leeuwen 2260), along with the climber *T. speckii*.

Soils were mildly to strongly acidic (pH 5.3–6.4) sandy clay loams. The abundance of coarse fragments was high, with exposed bedrock found at most sites. Basalt was the primary rock present, with some calcrete present, as indicated by moderate Ca concentrations (Table 3). Leaf litter was generally very sparse (3–15%).

Community type 6 was a heterogeneous group of *Eucalyptus* spp. woodland sites that were species-poor (mean taxa per quadrat 11.6 ± 5.5 SD). Predominantly found in the southern part of the survey area, the community was associated with species groups A and F, with a near absence of the ubiquitous taxa of group E and no species from group G (Table 2). The community was primarily *E. longissima* woodlands over chenopod shrubs, particularly *Atriplex nummularia* and *Maireana trichoptera*.

The sites were not associated with any particular topographical position, but were characterised by sandy loam to sandy clay loam and moderately alkaline soils (pH 7.8–8). Coarse fragments were abundant, up to 60 cm in size, but presence of exposed bedrock was limited. Relative to other communities at Bullfinch, the soils had high concentrations of Ca, moderate to high concentrations of organic carbon and low to moderate Fe content (Table 3).

Environmental variables

The southern Bullfinch Greenstone Belt was characterised by low hills and subtle topographic variation. Variation in altitude for the survey sites ranged from 330 to 413 m. The soils collected were skeletal to shallow in depth and typically brown and red brown sandy loams and sandy clay loams. The abundance of coarse rock fragments was high at most survey sites, with an average cover category of 5.18, representing 50–90% cover (Table 3). The presence of exposed bedrock was variable, with 26 sites having no surface bedrock. Where present, bedrock was identified as basalt, ironstone or undifferentiated greenstone. The majority of sites had a high proportion of bare ground (mean 95.5% ± 1.6 SD) and sparse leaf litter present (mean 12.7% ± 9.7 SD).

Soil pH varied from 5 to 8, with a mean of 6.5 ± 1.1 SD. Nearly half of the sites had soils that were acidic to strongly acidic; the remaining plots were evenly distributed between having neutral or alkaline soils. Those survey plots with alkaline soils (pH >7.5) also had the highest Ca concentration (Ca ≥ 4000 mg kg^{-1}) and high Mg content (Mg >450 mg kg^{-1}).

Strong intercorrelations existed amongst soil parameters (Table 4). Soil pH, electrical conductivity, organic carbon and the following soil chemical properties (B, Ca, K, Mg, N, Na, P and S) were positively intercorrelated ($p < 0.05$). All were negatively correlated with Fe ($p < 0.05$), except organic carbon, Mg and N ($p > 0.05$) and Co ($p < 0.05$). The strongest correlation was between organic carbon and N ($r_s = 0.97, p < 0.0001$). Species richness was positively correlated with Co, Cu, Fe, Mn, Ni and negatively correlated with soil pH, B, Ca, Mg, Na and P ($p < 0.05$).

Environmental attributes were examined for correlative relationships. Strong positive correlations existed between slope and runoff ($r_s = 0.77, p < 0.0001$). Positive inter-correlations were detected between altitude, abundance of coarse fragments and exposed bedrock, maximum rock fragment size and runoff ($p < 0.05$); all were negatively correlated with topographical position (i.e. 1 = crest to 5 = outwash; $p < 0.05$). Topographical position was positively correlated with disturbance ($r_s = 0.34$, $p < 0.05$), suggesting that disturbance was occurring more frequently on the lower slopes.

The Kruskal–Wallis analysis of variance determined whether significant differences in environmental variables occurred between community groups; community type 2 was excluded from the analyses due to paucity of representative sites (Table 3). Community type 6 was distinguished by having distinctly high or low means for many of the soil chemical parameters, with the highest mean value for B, Ca, Mg, N, S, organic carbon and soil pH and the lowest mean value for Co, Cu, Fe and Mn. In particular, concentrations of Co, Cu, Fe, Mg and Mn and soil pH were significantly different between community type 6 and community type 3. Concentrations of B, Ca, Co, Fe, Mg, Mn and P, soil pH and electrical conductivity were significantly different between community types 4 and 5 and community type 6. Significant differences in site physical parameters were more marked between community types 1 and 3 (altitude, topographical position and runoff). Percent cover of leaf litter exhibited patterns more similar to soil chemical parameters, with community type 6 having the highest mean value, which was significantly different from communities types 1, 3 and 5.

DISCUSSION

No systematic surveys of the flora or vegetation have been carried out in the southern Bullfinch Greenstone Belt, with only the central portion of the greenstone belt previously receiving attention by Gibson and Lyons (2001). In total, 218 taxa were identified during the survey, which was lower than the 242 taxa identified by Gibson and Lyons (2001), but comparable to other flora surveys of the

Table 4

Spearman rank correlation coefficients for select soil parameters and species richness. The upper value for each correlation is the correlation coefficient and the lower value represents significance at $p < 0.05$. Bold values represent highly significant correlations at $p < 0.0001$. Where no lower value is reported, the relationship is not significant ($p > 0.05$).

	B	CA	CO	CU	EC	FE	K	MG	MN	N	NA	NI	ORG C	P	pH	S
CA	**0.7916**															
	0															
CO	**-0.7128**	-0.512														
	0	0.0002														
CU	-0.0902	0.056	0.395													
			0.0048													
EC	**0.7445**	**0.7502**	**-0.5685**	-0.0715												
	0	**0**	**0**													
FE	**-0.6259**	-0.5226	**0.6545**	0.2139	-0.4597											
	0	0.0001	**0**		0.0009											
K	**0.6508**	**0.668**	-0.3381	0.2006	**0.6774**	-0.4117										
	0	**0**	0.0167		**0**	0.0032										
MG	**0.5902**	**0.8202**	-0.3356	0.0017	**0.5625**	-0.1715	0.4178									
	0	**0**	0.0176		**0**		0.0027									
MN	**-0.5791**	**-0.5611**	**0.6678**	0.2237	-0.4066	0.2449	-0.2743	**-0.6438**								
	0	**0**	**0**		0.0036			**0**								
N	**0.6503**	**0.6341**	-0.4196	-0.0037	0.5333	-0.1269	0.5114	**0.6496**	**-0.6331**							
	0	**0**	0.0026		0.0001		0.0002	**0**	**0**							
NA	0.4294	0.487	-0.3332	-0.2422	**0.6499**	-0.3998	0.4637	0.3881	-0.1077	0.3619						
	0.002	0.0004	0.0185		**0**	0.0043	0.0008	0.0056		0.0102						
NI	-0.2143	0.0914	0.4289	0.2148	0.0408	**0.5496**	0.125	0.3333	0.0083	0.1281	-0.0674					
			0.0021			**0**		0.0184								
ORG C	**0.6516**	**0.5963**	-0.4577	-0.1002	0.5184	-0.1152	0.4629	**0.6174**	**-0.6314**	**0.9699**	0.3646	0.1383				
	0	**0**	0.0009		0.0001		0.0008	**0**	**0**	**0**	0.0096					
P	**0.8219**	**0.6129**	**-0.8039**	-0.2021	**0.748**	**-0.5521**	**0.5599**	0.4499	**-0.625**	**0.5751**	0.4298	-0.2143	**0.6018**			
	0	**0**	**0**		**0**	**0**	**0**	0.0012	**0**	**0**	0.002		**0**			
pH	**0.8262**	**0.8627**	**-0.6231**	-0.0159	**0.7133**	**-0.6913**	**0.5774**	**0.6546**	-0.512	0.3853	0.424	-0.2082	0.3337	**0.6612**		
	0	**0**	**0**		**0**	**0**	**0**	**0**	0.0002	0.006	0.0023		0.0183	**0**		
S	**0.6322**	**0.5494**	**-0.5662**	-0.1924	**0.6539**	-0.3292	**0.5523**	0.4553	-0.4854	**0.7883**	0.4925	-0.0292	**0.7966**	**0.6886**	0.3861	
	0	**0**	**0**		**0**	0.02	**0**	0.001	0.0004	**0**	0.0003		**0**	**0**	0.0059	
RICHNESS	-0.3064	-0.3021	0.4977	0.346	-0.149	**0.5667**	-0.0417	-0.314	0.2866	-0.0588	-0.3771	0.3804	-0.0827	-0.2916	-0.4068	-0.2264
	0.0309	0.0333	0.0003	0.0142		**0**		0.0268	0.0439		0.0073	0.0067		0.0403	0.0036	

greenstone belts within the Yilgarn Craton (e.g. Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c). The high representation of annuals (85 taxa) identified during the survey was probably associated with above average precipitation in the months preceding the survey. During the three months prior to the survey (June–August 2009), 129.8 mm of rain was recorded, whereas the mean rainfall for this period is 110.5 mm (Bureau of Meteorology 2010).

The survey recorded three priority taxa. The Highclere Hills survey only recorded two priority taxa—*Tricoryne* sp. Morawa (GJ Keighery & N Gibson 6759) and *Caesia* sp. Ennuin (N Gibson & MN Lyons 2737)—one of which, *Caesia* sp. Ennuin (N Gibson & MN Lyons 2737), was recorded during this survey. The *Tricoryne* sp. Wongan Hills (BH Smith 794) collected at Bullfinch requires further clarification, due to the differing substrate and geographic disparity when compared with the other collections. A formal taxonomic description may elucidate the identity of the collection. Considering the disjunct distribution and conservation status (P2), care should be taken to preserve the population of *Tricoryne* sp. Wongan Hills (BH Smith 794) in the Bullfinch Greenstone Belt.

The presence of weeds reflects the long history of disturbance in the area, as it was one of the earliest areas to be mined in the Goldfields region. There were 24 weed taxa recorded during the survey, which is comparable to the 25 weed taxa recorded at Highclere Hills (Gibson & Lyons 2001). However, there was an overlap of only 11 taxa. The Highclere Hills had a notable dominance of weed taxa from the Poaceae family (eight species), whereas Bullfinch had more weed taxa from the Asteraceae family (6) and only five Poaceae taxa. *Carrichtera annua* (Ward's weed), known to inhabit disturbed areas (Weber 2003) was the most dominant weed taxon, with records from 32 quadrats.

There were overlaps in taxa within species groups between the Highclere Hills study and this one. This was expected, as Highclere Hills is a continuation of the Bullfinch Greenstone Belt north of Lake Deborah West. For example, species group A and the Highclere Hills' species group G, which were associated with neutral to alkaline sites, have seven shared taxa. Common taxa within the species groups shared between surveys included *Atriplex nummularia*, *Austrostipa trichophylla*, *Eremophila oppositifolia*, *Eucalyptus corrugata*, *Exocarpos aphyllus*, *Maireana trichoptera* and *Sclerolaena diacantha*. Species group E contained a similar suite of species to the Highclere Hills' species group C: both groups were characterised by rather ubiquitous taxa. In particular, *Acacia tetragonophylla*, *Dianella revoluta* var. *divaricata*, *Eremophila serrulata*, *Prostanthera althoferi* subsp. *althoferi*, *Ptilotus obovatus*, *Scaevola spinescens* and *Solanum lasiophyllum* were shared taxa within the species groups. Species group F and Highclere Hills' species group H shared three taxa from the mid to upper stratum, including *Dodonaea stenozyga*, *Eucalyptus yilgarnensis* and *Santalum acuminatum*.

Specific community types were not directly analogous between this survey and the Highclere Hills survey (Gibson & Lyons 2001). Community type 6 in this study may be a species-poor variation of Highclere Hills' community type 1, both eucalypt woodland communities with chenopod species present in the understorey (e.g. *Atriplex* spp., *Maireana trichoptera* and *Sclerolaena diacantha*). Additional placement of survey quadrats within the Bullfinch Greenstone Belt may resolve the variation in community types, in particular differences that may be linked to geographic gradients or degree of weathering along the belt.

Environmental correlates

Soils were predominantly moderately acidic sandy loams and sandy clay loams. The sites with higher soil pH were associated with high Ca concentrations, suggesting the presence of calcrete. The soils were less acidic than in other greenstone belt areas in the Yilgarn Craton, which were characterised by highly acidic soils (Thompson & Sheehy 2011a, 2011b, 2011c), indicative of heavily weathered regolith (Slattery et al. 1999). However, vegetation communities were characterised by similar soil pH patterns (i.e. the division of acidic and alkaline sites) and affinities for specific geologies seen at Highclere Hills (i.e. ironstone vs. ultramafics; Gibson & Lyons 2001).

Weathering of the regolith influences the concentration of trace elements in the soils. Lower slopes and adjacent outwash areas are enriched by the movement of mobile elements from the upland regions (Ben-Shahar 1990). In particular, calcrete accumulation has been allied with lower slopes and pediments (Anand et al. 1997). However, this relationship was less evident within the Bullfinch Greenstone Belt, possibly related to the more gentle topographic gradients across survey sites. Relatively high Ca concentrations were recorded within community types 1 and 2, which had the two lowest mean altitudes and corresponding topographical positions across community types. However, community type 6 had the highest concentrations of Ca, S and organic carbon. The disparity in Ca concentration relative to topographical position may be indicative of different rates of weathering, as studies have shown that sulphides and carbonates are readily leached from the profile (Butt et al. 2000; Anand 2005). Furthermore, community type 6 had relatively low Fe concentrations, another element indicative of weathered soils and underlying bedrock (Gray & Murphy 2002).

Environmental parameters were important to the delineation of community types, with soil chemical parameters highly correlated with community groupings. Other studies of the flora and vegetation of the greenstone belts of the Yilgarn Craton have documented extensively the relationship between plant communities and environmental parameters, especially topographical position and edaphic factors (Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c; Thompson & Sheehy 2011a, 2011b, 2011c). In the Highclere Hills portion of the Bullfinch Greenstone Belt, vegetation patterns were predominantly influenced by soil parameters, rather than topographical position (Gibson & Lyons 2001). The relationship was generally similar for the southern part of the Bullfinch Greenstone Belt. In this study, the strong correlation between Mg concentrations and community types was not surprising, given the presence of mafic rocks in the greenstone belt. Soils within community types were also characterised by relatively consistent pH values.

Some plant communities, however, were strongly allied to topographical position. In particular, community type 1, which was typical of footslopes and adjacent pediments, occupied topographical postions significantly different to those where community type 3, a predominantly upland vegetation association, was found. The difference between communities types 1 (low) and 3 (high) were the same for runoff, which is related to slope and is often linked to topographical position. The reduced influence of topographical position on vegetation communities compared with other greenstone belt studies may be related to the more subdued topography of the Bullfinch Greenstone Belt (Gibson & Lyons 2001). Other greenstone belt studies in the Yilgarn Craton have focused on the banded ironstone formations (BIF), which are often ranges and outcropping with significant topographical gradients. Another consideration is the underlying geologic sequences and variation in weathering confounding the relationship of topographical position and vegetation communities; our soil samples and site physical parameters do not provide a complete substrate/geologic profile.

Conservation significance

Greenstone belts are poorly represented in the conservation estate and this has been highlighted over the years with respect to both flora and fauna values (Henry-Hall 1990; Chapman & Newbey 1995). Recent papers (e.g. Gibson et al. 2010; Gibson et al. 2012) have reiterated the importance of the plant species richness within the greenstone belts of the Yilgarn Craton, in particular the banded ironstone formations and the high beta-diversity (species turnover) between these areas. The long history of exploration, mining and pastoral use is evident in the landscape. In particular, it was observed repeatedly that where exploration and mining had occurred, there was a noticeable lack of rehabilitation. A history of poor environmental controls has left significant scars on the landscape. Establishment of quadrats was limited in many areas due to drilling (both pads and equipment) and existing mining and pastoral infrastructure on some of the hills. The prevalence of *Carrichtera annua* and other weed taxa at many sites during the survey reflects the high level of landscape disturbance. Overall, the southern portion of the Bullfinch Greenstone Belt does not represent the same repository of conservation taxa recorded elsewhere in the Yilgarn Craton (e.g. Markey & Dillon 2008b; Meissner & Caruso 2008a). However, the survey has identified the second population of an undescribed priority taxon record from the earlier assessment by Gibson and Lyons (2001), and a significant range extension of another undescribed priority taxon, which may be a new species. The areas containing these species should be protected from further degradation.

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APPENDIX 1

Flora list for the southern Bullfinch Greenstone Belt, including collections made outside of the survey quadrat boundaries. An asterix (*) indicates a weed taxon. Nomenclature follows Florabase (Western Australian Herbarium 2010).

Aizoaceae
**Cleretum papulosum* subsp. *papulosum*
**Mesembryanthemum nodiflorum*

Amaranthaceae
Ptilotus exaltatus
Ptilotus gaudichaudii var. *parviflorus*
Ptilotus holosericeus
Ptilotus obovatus
Ptilotus spathulatus forma *spathulatus*

Apiaceae
Daucus glochidiatus

Apocynaceae
Alyxia buxifolia
Marsdenia australis
Rhyncharrhena linearis

Araliaceae
Hydrocotyle pilifera var. *glabrata*
Trachymene ornata

Asparagaceae
Arthropodium curvipes
Arthropodium dyeri
Thysanotus manglesianus
Thysanotus speckii

Aspleniaceae
Pleurosorus rutifolius

Asteraceae
Actinobole uliginosum
**Arctotheca calendula*
Asteridea athrixioides
Blennospora drummondii
Brachyscome ciliaris
Brachyscome ciliocarpa
Brachyscome lineariloba
Brachyscome perpusilla var. *tenella*
Calotis hispidula
Cephalipterum drummondii
Ceratogyne obionoides
Chthonocephalus pseudevax
**Cirsium vulgare*
Erymophyllum ramosum subsp. *ramosum*
Hyalosperma demissum
Hyalosperma glutinosum subsp. *glutinosum*
Hyalosperma zacchaeus
**Hypochaeris glabra*
Isoetopsis graminifolia
Lawrencella rosea
Lemooria burkittii
Leucochrysum fitzgibbonii
Millotia myosotidifolia
Millotia perpusilla
**Monoculus monstrosus*
Olearia muelleri
Olearia pimeleoides
Podolepis canescens
Podolepis capillaris
Podolepis lessonii
Podotheca angustifolia
Podotheca gnaphalioides
Rhodanthe haigii
Rhodanthe laevis
Rhodanthe manglesii
Rhodanthe oppositifolia subsp. *oppositifolia*
Rhodanthe pygmaea
Rhodanthe rubella
Rhodanthe stricta
Schoenia cassiniana
Senecio glossanthus
Senecio pinnatifolius
**Sonchus oleraceus*
Trichanthodium skirrophorum
Triptilodiscus pygmaeus
**Ursinia anthemoides*
Waitzia acuminata var. *acuminata*

Boraginaceae
Cynoglossum sp. Inland Ranges (CA Gardner 14499)
Omphalolappula concava

Brassicaceae
**Brassica tournefortii*
**Carrichtera annua*
Lepidium oxytrichum
Menkea australis
Menkea sphaerocarpa
**Sisymbrium orientale*
Stenopetalum filifolium

Campanulaceae
Wahlenbergia gracilenta

Caryophyllaceae
**Silene nocturna*
Stellaria filiformis

Casuarinaceae
Allocasuarina dielsiana

Chenopodiaceae
Atriplex nummularia
Atriplex paludosa subsp. *baudinii*
Atriplex vesicaria
Chenopodium curvispicatum
Einadia nutans subsp. *eremaea*
Enchylaena lanata
Enchylaena tomentosa var. *tomentosa*
Eriochiton sclerolaenoides
Maireana georgei
Maireana georgei x *Enchylaena tomentosa*
Maireana georgei x *Enchylaena lanata*
Maireana planifolia
Maireana tomentosa
Maireana trichoptera
Maireana triptera
Rhagodia drummondii
Salsola australis
Sclerolaena diacantha
Sclerolaena obliquicuspis

Colchicaceae
Wurmbea tenella

Convolvulaceae
**Cuscuta planiflora*

Crassulaceae
Crassula colorata var. *acuminata*

Cyperaceae
Schoenus nanus

Droseraceae
Drosera macrantha subsp. *macrantha*

Fabaceae
Acacia erinacea
Acacia jennerae
Acacia ligulata
Acacia ramulosa var. *ramulosa*
Acacia sp. narrow phyllode (BR Maslin 7831)
Acacia tetragonophylla
Isotropis juncea
**Medicago minima*
Mirbelia microphylla
Senna artemisioides subsp. *filifolia*
Senna charlesiana
Senna stowardii
Swainsona sp.

Geraniaceae
**Erodium aureum*
**Erodium cicutarium*
Erodium cygnorum

Goodeniaceae
Goodenia berardiana
Goodenia mimuloides
Goodenia occidentalis
Scaevola spinescens
Velleia rosea

Haloragaceae
Haloragis sp.

Hemerocallidaceae
Caesia occidentalis
Caesia sp. Ennuin (N Gibson & MN Lyons 2737) P1
Dianella revoluta var. *divaricata*
Tricoryne sp. Wongan Hills (BH Smith 794) P2

Hypoxidaceae
Hypoxis glabella var. *glabella*

Juncaginaceae
Triglochin sp. A Flora of Australia (GJ Keighery 2477)

Lamiaceae
Prostanthera althoferi subsp. *althoferi*

Loganiaceae
Phyllangium sulcatum

Malvaceae
Abutilon cryptopetalum
Abutilon oxycarpum
Brachychiton gregorii
Sida calyxhymenia
Sida petrophila
Sida sp. dark green fruits (S van Leeuwen 2260)
Sida sp. golden calyces glabrous (HN Foote 32)

Myrtaceae
Eucalyptus corrugata
Eucalyptus ewartiana
Eucalyptus longissima
Eucalyptus salmonophloia
Eucalyptus yilgarnensis
Melaleuca hamata
Melaleuca lanceolata
Melaleuca pauperiflora subsp. *fastigiata*

Orchidaceae
Diuris pulchella
Prasophyllum gracile
Pterostylis aff. *spathulata*
Pterostylis mutica
Pterostylis sp. inland (AC Beauglehole 11880)

Orobanchaceae
**Parentucellia latifolia*

Pittosporaceae
Bursaria occidentalis
Pittosporum angustifolium

Plantaginaceae
Plantago debilis

Poaceae
Aristida contorta
Austrodanthonia caespitosa
Austrostipa blackii P3
Austrostipa elegantissima
Austrostipa nitida
Austrostipa scabra
Austrostipa tenuifolia
Austrostipa trichophylla
Austrostipa variabilis
**Avellinia michelii*
Bromus arenarius
**Bromus rubens*
Elymus scaber
**Hordeum leporinum*
**Pentaschistis airoides* subsp. *airoides*
**Vulpia myuros* forma *myuros*

Polygalaceae
Comesperma integerrimum

Polygonaceae
**Acetosa vesicaria*

Portulacaceae
Calandrinia calyptrata
Calandrinia eremaea s.l.

Proteaceae
Hakea recurva subsp. recurva

Pteridaceae
Cheilanthes adiantoides
Cheilanthes lasiophylla
Cheilanthes sieberi subsp. *sieberi*

Rhamnaceae
Trymalium myrtillus subsp. *myrtillus*

Rubiaceae
**Galium spurium*

Rutaceae
Philotheca brucei subsp. *brucei*

Santalaceae
Exocarpos aphyllus
Santalum acuminatum
Santalum spicatum

Sapindaceae
Dodonaea inaequifolia
Dodonaea stenozyga
Dodonaea viscosa subsp. *angustissima*

Appendix 1 (cont.)

Scrophulariaceae

Eremophila alternifolia
Eremophila clarkei
Eremophila decipiens subsp. *decipiens*
Eremophila interstans subsp. *interstans*
Eremophila ionantha
Eremophila miniata
Eremophila oppositifolia subsp. *angustifolia*
Eremophila scoparia
Eremophila serrulata

Solanaceae

Nicotiana occidentalis subsp. *obliqua*
Solanum lasiophyllum
Solanum orbiculatum subsp. *orbiculatum*
Solanum petrophilum

Thymelaeaceae

Pimelea microcephala subsp. *microcephala*

Urticaceae

Parietaria cardiostegia

Violaceae

Hybanthus floribundus subsp. *floribundus*

Zygophyllaceae

Zygophyllum eremaeum
Zygophyllum ovatum