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Flora and vegetation of the banded iron formations of the Yilgarn Craton: Yalgoo

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ABSTRACT

A floristic survey was undertaken on the Gnows Nest Range, Wolla Wolla and Woolgah–Wadgingarra Hills, which are hills and ranges of metavolcanics and banded iron formation (BIF) situated within a semi-arid region of Western Australia. These landforms are located near the township of Yalgoo, in the Midwest region of the state. Data from 55 permanent quadrats, established over a catena on varied geological substrates, were used to compile a flora list and describe the floristic communities. A total of 243 taxa (234 native) and four putative hybrids were recorded, of which five taxa were of conservation significance and two were near-endemic taxa. Six floristic community types were defined by numerical classification of the species presence/absence dataset, using Bray–Curtis dissimilarities and UPGMA clustering. Both ANOVA and nmMDS found that floristic composition varied with geomorphology and soil chemical composition. Mining and exploration tenements cover these ranges in their entirety, and none of these communities, nor these populations of uncommon taxa, are currently reserved on conservation estate.

Keywords: banded iron formation, conservation, flora, vegetation communities, Yilgarn.

INTRODUCTION

Outcroppings of Archaean metamorphosed banded iron formation (BIF) and volcanics (mafics and felsics) form distinctive landforms that are common within the northern and eastern Yilgarn Craton of Western Australia. Ironstone ranges in both Western Australia and in other countries are notable for their physical isolation, unique microhabitats, distinctive and unique floristic communities, endemic species and high β diversity (Gibson et al. 2007; van Etten & Fox 2004; Jacobi et al. 2007). Furthermore, these uplands are often isolated refugia which harbour endemic and naturally scarce species (Department of Environment and Conservation 2007; Gibson et al. 2007). This pattern holds for the ranges in the southern Yalgoo – Mt Gibson region (Markey & Dillon 2008a, 2010a; Meissner & Caruso 2008a, 2008b; Woodman Environmental Consulting 2007). These metalliferous substrates are also currently subject to considerable exploration and mining interests. The Yalgoo – Mt Singleton greenstone belt is one such mineral belt with extensive BIF outcroppings in the Yalgoo region, and is the subject of this study.

Over the past decade, floristic surveys of greenstone and BIF ranges in the eastern and northern goldfields have focussed on the vegetation communities of individual ranges. This survey is one in a series that, in combination, aim to provide a regional overview of the flora on approximately 25 individual ranges of banded iron formation within the northern Yilgarn Craton (Gibson et al. 1997; Gibson & Lyons 1998, 2001a, 2001b; Gibson 2004a, 2004b; Gibson et al. 2007; Markey & Dillon 2008a, 2008b, 2009, 2010a, 2010b; Meissner & Caruso 2008a, 2008b, 2008c; Meissner et al. 2010a, 2010b, 2010c). These surveys are in response to the recent surge in significant developments in the area, particularly mining activities. Four of these papers consider the ranges of the Yalgoo – Paynes Find region (Markey & Dillon 2008a, 2010a; Meissner & Caruso 2008a, 2008b), which are immediately south of the current study area. This study has targeted the Woolgah, Wadgingarra and Wolla Wolla Hills, and the northern half of the Gnows Nest Range. As these ranges and hills are centred on the township of Yalgoo; these are referred to collectively as the Yalgoo survey area (Fig. 1).

SURVEY AREA

The Yalgoo survey area is located c. 400 km north-north-east of Perth. Hills and ridges were targeted within a rectangular area spanning approximately 41 km east to west and 44 km north to south, within a latitudinal range from 28° 13’ S to 28 ° 37’ S, and a longitudinal range from 116°

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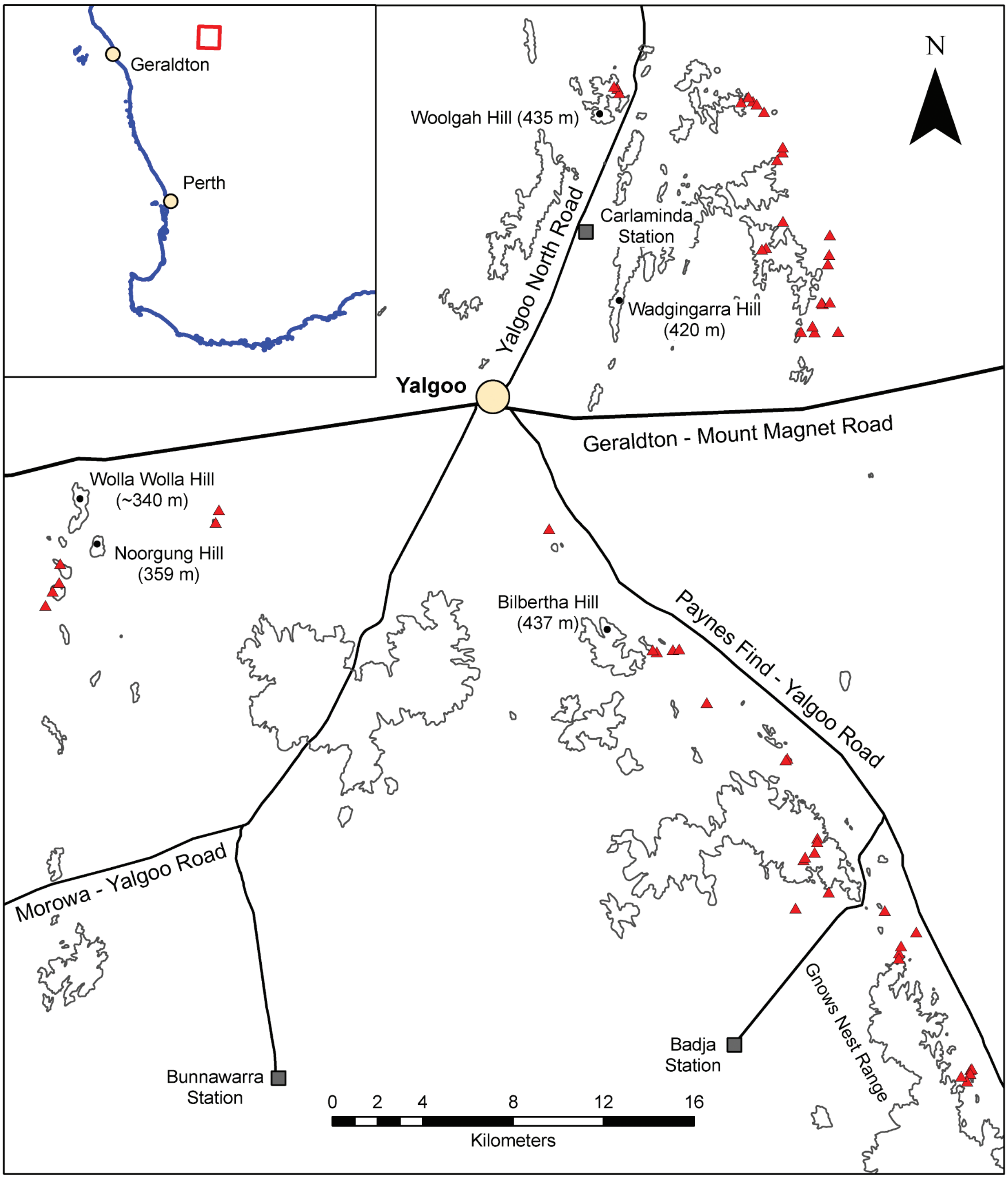

Figure 1. Map showing the location of the of the Yalgoo region relative to major centres in the Yilgarn region of Western Australia (insert), and location of the specific ranges, landforms and landmarks within the Yalgoo survey area. Locations of the 55 floristic quadrats are marked by triangles (▲), and contour lines outline areas ≥ 410 m elevation.

28' E to 116° 54' E (Fig. 1). The study area extends over the Muralgarra, Badja, Bunnawarra, Wagga Wagga and Carlaminda Stations, within the Shire of Yalgoo.

With the exception of the Gnows Nest Range, most ranges in the survey area are unnamed topographic features, therefore they have been referred to in this report by the name of nearby hills (Woolgah, Wadgingarra and Wolla Wolla Hills). The survey area was subdivided into three main areas. The Woolgah–Wadgingarra Hills are 15 km east and north of Yalgoo (on Carlaminda and Wagga Wagga Stations; Fig. 1). The northern end of the Gnows Nest Range is 18 km south-east of Yalgoo township and the range trends in a north-south direction from approximately Minjar Hill to Bilbertha Hill. The name Wolla Wolla Hills has been applied here to the BIF ridges close (<0.5 km) to the granitic Wolla Wolla and Noorgung Hills. These hills are c. 21 km southwest of Yalgoo township (Fig. 1).

Land Use History

Pastoralism in the wider Yalgoo area commenced in the 1870s, and the numerous pastoral properties within the Yalgoo survey area were established between 1873 and 1894 (Hennig 1998a). Wool and meat production have persisted over the subsequent century, and most pastoral leases within the survey area are currently active. Feral goat harvesting supplements income from pastoral leases. The Yalgoo township and Yalgoo Goldfields were established soon after gold discoveries in the region in the 1890s (Hennig 1998a). Several mining centres (Yalgoo, Noongal, Carlaminda and Bilbertha) were established over the following decade within the survey area (Hennig 1998a; Muhling & Low 1977). Mining activity has varied with the economic climate over the century, and currently there has been an upsurge in interest in both gold and iron ore deposits. While there are no active mines within the survey area, a number of proposed mining projects currently target BIF and mafic landforms on the Gnows Nest Range, Wagingarra Hills and Wolla Wolla Hills (Department of Industry and Resources 2007). Consequently, BIF landforms within the Yalgoo survey area are covered in their entirety by mining and exploration tenements.

Climate

The Yalgoo study region experiences a semi-desert, Mediterranean climate with cool, wet winters and hot, dry summers (Beard 1976a, 1990). It is located within the 250 mm isohyet for annual rainfall (cf. Leighton 1998). Rainfall is variable, and falls mostly over the winter months (Beard 1976a; Leighton 1998). Meteorological data is available for Yalgoo township (Bureau of Meteorology 1908–2007), where the annual mean rainfall is 259 mm. The average summer daily maximum (December–January) is 36.3 °C, the average winter maximum (June–August) is 19.1 °C, and average daily minima below 10 °C occur between June and September.

Geology, Landform and Soils

The Yalgoo survey area is located within the Murchison domain, a geological subdivision of the Yilgarn Craton (Cassidy et al. 2006). The Yilgarn Craton is predominately (c. 65%) composed of granites and gneisses of Archaean age (3–2.6 Ga). The remaining bedrock consists of belts of intruded metamorphosed sedimentary and volcanic rocks, which are known as greenstone belts (Champion & Smithies 2001; Cornelius et al. 2007; Wyche 2008). Much of the land surface of the Yilgarn Craton, including the wider Yalgoo region, was extensively weathered during the Tertiary to form a subdued landscape overlain with Tertiary laterites and Cenozoic sediments (Cornelius et al. 2007). It is these exposed outcroppings of greenstone and granites that provide significant topographical relief above the gently undulating plains of regolith. In a survey of landforms in the Sandstone – Yalgoo – Paynes Find region, five Land Systems (geomorphological units) were mapped for the survey area: the Gabanintha, Wiluna, Tallering, Jundee and Tindalarra Land Systems (Payne et al. 1998).

Greenstone belts outcrop as north-west trending, narrow, elongate ridges, and consist of mafic to ultramafic volcanics and felsic volcanics, and metasedimentary rocks of shale, siltstone, chert, jaspilite and BIF (Muling & Low 1977). Talus accumulates on the lower slopes of these ridges, and colluvial deposits and transported alluvium form extensive colluvial stony plains and outwashes in the lowlands around hills and uplands (Johnson 1998). The soils associated with greenstone ranges are lithosols, and are typically shallow or skeletal (<50 cm) on the ridges, rises and hills, becoming progressively deeper on the lower slopes and outwashes (Henning 1998b). Soils associated with BIF outcrops are relatively rich in nutrients and trace elements, with large concentrations of P, K, Cu, Ni, Zn, Mn and Fe (Foulds 1993).

The geology of the Yalgoo survey area has been described and mapped on the Yalgoo 1:250,000 geological sheet (SH/50-2; Muling & Low 1977). Targeted landforms within the study area were associated with the Yalgoo – Mt Singleton greenstone belt. These range in elevation from 295 m above sea level (ASL) on the outwash plains to over 400 m on the upland greenstone hills and ridges, with the highest points occurring on Bilbertha Hill (437 m ASL) and Woolgah Hill (435 m ASL; Fig. 1). The Gnows Nest Range has the highest outcroppings of Archaean BIF in the Yalgoo survey area. It consists of a series of parallel strike ridges of exposed BIF interbedded with metavolcanics (primarily basalt but also some dolerite), spanning 30 km north to south and 4 km east to west at the widest point (Fig. 1). Other prominent uplands occur around the Wadgingarra and Woolgah Hills. These hills are primarily metamorphosed mafics (namely gabbro and diorite), but narrow seams of BIF and other weathered metasediments form low, undulating pediments that flank the taller mafic hills. The Wagingarra hills area spans 17 km north to south and 4.5 km east to west (Fig. 1), while the Woolgah hill area consists of a narrow, arcuate band of BIF totalling 8 km in length and embedded in mafic rocks. The Wolla Wolla and Noorgung Hills are both granite domes surrounded by low or barely discernable outcrops of mafics, BIF and associated metasediments (Fig. 1). These BIF ridges are linear, 1–1.2 km wide and 2.5–3 km long, and form low hills and undulating pediments surrounded by colluvial deposits on a gently undulating stony plain.

Vegetation

The Yalgoo survey area occurs in the northern part of the Interim Biogeographic Regionalisation for Australia (IBRA) Yalgoo Bioregion (Department of Environment and Water Resources 2007), which is equivalent to Beard's (1976a, 1990) Yalgoo subregion of the Murchison Region, nested in the Eremaean Province. The area is close to the southern margin of the IBRA Murchison Bioregion, and is considered to be a region of transition from the mesic, speciose South West to the arid Eremaean Botanical Districts (Beard 1976a, 1990).

Few studies have addressed the flora and vegetation communities of the Yalgoo survey area. Beard (1976a) briefly described the vegetation on the Gnows Nest Range and surrounding greenstone hills, and a more detailed (1:250,000) vegetation map of the Perenjori area only covered the southern extent of the Gnows Nest Range range (Beard 1976b). Pringle (1998a) described vegetation communities of the wider Sandstone – Yalgoo – Paynes Find area using dominant perennial taxa. Associations between species composition and both geological substrate and landform (topographic position) were noted, and these communities were linked to the Land Systems of Payne et al. (1998). This more recent treatment by Pringle (1998a) described nine communities within the Yalgoo survey area. Five of these, namely: stony ironstone acacia (SIAS), ironstone ridge mixed shrubland (IRMS), stony ironstone mulga shrubland (SIMS), greenstone hill acacia shrubland (GHAS) and breakway mixed shrubland (BRXS), were associated with upland systems. Although some regional differentiation of some communities is noted over the wider area, the majority of these greenstone and BIF communities are widespread in the region and have been broadly defined and mapped at scale of 1:250,000 (Payne et al. 1998).

METHODS

Fifty-five permanent 20 x 20 m quadrats were established over the survey area during the spring season (August–September) of 2007. Quadrats were placed strategically across the topological profile of ranges in order to sample the maximum diversity of floristic communities. This methodology is consistent with that used on other greenstone ranges in Western Australia (e.g. Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c). Attempts were made to sample the least disturbed vegetation, although the entire survey area had significant levels of grazing. Each corner of the quadrats was marked with a steel fence dropper, and the altitude and position of each quadrat recorded by GPS (Garmin 76, Garmin Ltd, Kansas). Vegetation structure was described according to McDonald et al. (1998). The presence and cover class of all vascular plant species (spermatophytes and pteridiophytes) were recorded, and material collected for verification at the Western Australian Herbarium. Representative specimens of all taxa have been lodged at the Western Australian Herbarium. Growth forms of taxa were obtained from field observations and from online records (Western Australian Herbarium 1998–).

Both soil and site physical attributes were recorded for each quadrat. A number of site attributes—topographical position (Tp), aspect, slope, litter and bare ground cover (% cover estimates), surface rock size, surface rock and exposed bedrock cover, soil colour and soil texture)—were recorded according to the protocols and definitions detailed in McDonald et al. (1998). Topographic position (Tp), maximum surface rock fragment size (MxR) and cover (%RF), and exposed rock cover (outcrop) were all coded on a semi-quantitative scale (Table 3). Twenty soil samples were collected at regular intervals within each quadrat, bulked into a single sample, sieved and the 2 mm fraction analysed at the Chemistry Centre of Western Australia. Concentrations of 16 elements (Al, B, Ca, Cd, Co, Cu, Fe , K, Mg, Mn, Mo, Na, Ni, P, S and Zn) were determined simultaneously using inductively coupled plasma atomic emission spectrometry (ICP AES; Mehlich 1984; Walton & Allen 2004). Soil pH was measured in 0.01 M $CaCl_2$ (method S3, Rayment & Higginson 1992), and electrical conductivity ($EC_{1.5}$) was measured in a 1:5 solution of soil extract:deionised water at 25 ºC (method S2, Rayment & Higginson 1992). Soil organic carbon content (%) was determined using Metson's colorimetric modification of the Walkley and Black wet oxidation method S09 (method 6A1 of Rayment & Higginson 1992). Total soil nitrogen (%) was measured calorimetrically following a modified Kjeldahl digest (method S10, Rayment & Higginson 1992). The effective cation exchange capacity (eCEC) was estimated from the sum of individual charge equivalents per kilogram of Na, Ca, K and Mg, which were calculated from their respective cation concentrations (Rayment & Higginson 1992; Soil and Plant Council 1999).

Classification and ordination analyses were conducted on a data matrix of perennial taxa, with the singleton and annual taxa omitted prior to analysis. This was consistent with the previous surveys in the northern Yilgarn, and justified in that singleton taxa add little additional information, and annuals (desert ephemerals) exhibit high inter-annual variation in distribution and abundance (Mott 1972, 1973). The effect of this omission of taxa on the data matrices was determined from the comparison of resemblance matrices (Bray–Curtis measure of distance) using the '2 Stage' algorithm in Primer (Clark & Gorley 2006) to determine the degree of correlation between datasets. Both classification and ordination analyses were run using resemblance matrices (Bray–Curtis measure of distance) in PATN (V3.03; Belbin 1989). Flexible UPGMA ($\beta = -0.1$) was used to generate a species and site classification (Belbin et al. 1992; Sneath & Sokal 1973). Indicator species analysis (INDVAL) was used to find characteristic taxa of each community type, using the methods of Dufrêne and Legendre (1997) in PC-Ord (McCune & Mefford 1999). A Monte Carlo permutation test (10 000 simulations) was used to test for significant indicator species ($p > 0.05$).

Semi-strong hybrid (SSH) multidimensional scaling was used to generate a site ordination from floristic data (1000 random starts and 50 iterations; Belbin 1991). Principal component correlation (PCC) is essentially a multiple linear regression of extrinsic variables on an ordination (Belbin 1989; Faith & Norris 1989), and was used to correlate the environmental variables with the site ordination. Significant correlations were determined using 1000 interations of a Monte Carlo bootstrapping procedure (MCAO; Belbin 1989). Significant differences in community average values for environmental variables were determined using Kruskal–Wallis nonparametric analysis of variance and Dunns' post-hoc multiple comparisons (Zar 1984).

Geographical distributions of taxa were obtained from online records at the Western Australian Herbarium (1998). The *Acacia aneura* species complex was resolved to several morphological groups, which approximate the varieties described by Pedley (2001; Appendix 1).

RESULTS

Flora

A total of 243 taxa (species, subspecies, varieties and forms) and four putative hybrids were recorded from within or adjacent to the quadrats (Appendix 1). Nine of these were naturalised taxa. Taxa came from 51 families (defined using the Angiopserm Phylogeny Group APG II system), of which the most common were the Asteraceae (33 native taxa and 1 naturalised taxon), Mimosaceae (*Acacia*, 26 taxa and 2 putative hybrids), Chenopodiaceae (23 taxa), Poaceae (18 native and three introduced taxa), Myoporaceae (*Eremophila*, 13 taxa), Caesalpiniaceae (*Senna*, eight taxa and two putative hybrids), Goodeniaceae (nine taxa), Solanaceae (eight taxa), Proteaceae (eight taxa) and Amaranthaceae (*Ptilotus*, seven taxa). *Acacia*, *Eremophila, Ptilotus, Maireana* (ten taxa) and *Rhodanthe* (five taxa) were the most species-rich genera (Appendix 1). Of the 243 taxa, 35% of taxa were annuals, and included 10 annual grasses (4%) and 76 annual/short-term perennials (31%). Half the taxa (122 taxa) were subshrubs, shrubs, tall shrubs and trees. Of the remaining taxa, there were 11 perennial grasses (5%), 16 geophytes (7%), two shoot parasites (including the annual parasite, *Cuscuta epithymum*) and 5 climbers (2%).

Priority taxa

Five taxa of conservation significance—*Calytrix uncinata, Acacia subsessilis, Acacia speckii, Dodonaea amplisemina* and *Calotis* sp. Perrinvale Station (RJ Cranfield 7096)—were collected in the survey, all of which have Priority 3 conservation listing (Smith 2010; priority flora groups are conservation codes for rare or data deficient taxa, compiled by the Western Australian Department of Conservation). All taxa are known from the Yalgoo IBRA bioregion, and no significant range extensions (>100 km) are reported. *C. uncinata, A. subsessilis, A. speckii* are already known from within the bounds of the Yalgoo survey area.

- Almost all records of *A. subsessilis* fall within an area 157 km in diameter, with the exception of two outlying populations. The nearest population to the Woolgah–Wadgingarra Hills is c. 40 km to the southwest on the Edamurta Range. While it is restricted to mafic hills in the Gullewa survey area (Markey & Dillon 2010a), *A. subsessilis* was observed on the Woolgah–Wadgingarra Hills to be associated with both gabbro and mixed mafic/BIF lithologies.
- Isolated individuals of *D. amplisemina* were found on the Woolgah–Wadgingarra Hills and east of Wolla Wolla Hill, which are two new populations for this species and at least 36 km north of the nearest, previously known population.
- *Calotis* sp. Perrinvale Station (RJ Cranfield 7096), formerly known as *C.* aff *cuneifolia* (A Markey & S Dillon 3447), attained priority listing in 2008. It was initially identified as a new taxon in a previous survey of BIF ranges 34 km south of the Gnows Nest Range (Markey & Dillon 2008a). Collections of this species are concentrated around the Gnows Nest Range and Minjar hills, and only three other collections have been recorded from disparate locations within the wider Murchison region. This species is considered to be a near endemic, as the majority of its known distribution is centred on a small area (<40 km) south of the Gnows Nest Range.

Notable taxa

During the course of this survey, two taxa were identified as having affinities to known taxa but were morphologically distinct enough to be considered as potentially new taxa. *Thysanotus* aff. *pyramidalis* (collection number A Markey & S Dillon 5831, sheet PERTH 07828152) is a diminutive perennial geophyte that appears to be different from other species described by Brittan (1987). Of particular note is the branching of the panicle that resembles that of *Thysanotus pyramidalis*, but hairs are lacking on the inflorescence scape, the non-twisted anthers dehisce by an apical pore and the flowers are borne singly on short (2–3 mm) pedicels. Further work is required on *Thysanotus* in the Midwest region since there may be several undescribed entities (M Hislop[1] , pers. comm.).

A putative new variant of *Acacia* was identified, and this was verified by Bruce Maslin[2]. Although it has affinities to *Acacia ulicina*, *Acacia* aff. *ulicina* (collection number A Markey & S Dillon 5553, sheet PERTH 07810253) differs in the following combination of characters: it has shorter peduncles (2–7 mm shorter than *A. ulicina*), and inconspicuous bracteoles and petals that lack a distinct nerve (versus one distinct nerve in *A. ulicina*). The range of *Acacia* aff. *ulicina* (A Markey & S Dillon 5553) is c. 125 km east and greatly disjunct from that of *A. ulicina*.

Range extensions

There was one non-priority listed taxon whose collection within the Yalgoo survey area was a notable range extension (>100 km). The identification of *Hibiscus* cf. *solanifolius* was based on fruit characters. This taxon has been collected from BIF ranges in the Murchison IBRA bioregion (Markey & Dillon 2009, 2010b), the nearest collection being c. 400 km east of the Yalgoo survey area. Most

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collections of this species are from the Central Ranges IBRA bioregion, and the western collections may be a new entity. However, the group of Australian species of *Hibiscus* requires further taxonomic work.

Floristic Communities

For the analyses, taxa were identified to species and subspecies level, with 24 taxa amalgamated into nine species complexes owing to problems differentiating between closely related species or the presence of putative hybrid and intergrades, or when subspecific ranks of infrequently occurring taxa were more informative when combined at the species level. The original site by species dataset comprised 214 taxa from within 55 quadrats, of which 83 were annual/short-lived perennial taxa and 24 perennial singleton taxa. These annuals and singletons were omitted from the matrix, resulting in the final dataset comprised of 108 taxa from 55 quadrats (50% of total taxa). Preliminary classification analyses found little effect on the overall site classification with the omission of singletons and annuals. '2-Stage' comparison (Clark & Gorley 2006) of the original and final data matrices found 88.9% correlation. The average perennial species richness per quadrat was 20.3 ± 0.6 taxa per quadrat, and ranged from 9 to 29 taxa per quadrat.

Five major groups or floristic community types were derived from the site classification analysis of the 55 quadrats (Fig. 2). Nine species groups were selected from the species classification analysis of 108 taxa, which have been presented in a sorted two-way table (Table 1). Community types were identified as uniform and discrete clusters of sites which fused at the five group level of dissimilarity. One community type was further subdivided into two subtypes based on the classification analysis results (Fig. 2). Decisions on the final communities were matched to intuitive classification of the site using patterns in the two-way table (Table 1) and from field observations of site vegetation and physical habitat. Similar decisions were made to define the final species groups presented in Table 1.

At the highest level of fusion, the six communities were clustered into two groups; those associated with rocky crests and upper slopes with outcropping BIF bedrock (community types 1 and 2), and communities on the slopes of BIF ridges, minor BIF crests, pediments and surrounding outwash plains, and slopes of metabasalt and mixed geologies (communities 3a, 3b, 4 and 5).

Community type 1: Gnows Nest Range Acacia aulacophylla – Acacia aneura *upland shrublands*

Substrate and location: On very steep outcrops of BIF bedrock high in the landscape, with correspondingly high runoff scores, exposed bedrock, highest classes of surface rock sizes and skeletal–shallow, strongly acidic soils (Table 3). Soils had relatively high levels of organic C, N, Fe and S, moderately low levels of soil microelements and $EC_{1:5}$, and particularly low concentrations of Co, K and Mn (Table 3).
Distribution: Sites were restricted to BIF ridges on the Gnows Nest Range.
Structural description: Tall shrublands dominated by *Acacia aulacophylla* and/or *Acacia aneura,* over a sparse shrub layer which included *Grevillea extorris*, *Hakea recurva*, *Dodonaea petiolaris*, *Philotheca sericea*, *Eremophila clarkei* and *Sida* sp. dark green fruits (S van Leeuwen 2260). The geophytic rockfern, *Cheilanthes adiantoides*, and perennial herbs, *Ptilotus schwartzii/drummondii* and *Stylidium longibracteatum* were usually encountered growing out of fissured bedrock. Many of these common/dominant taxa were significant indicator species for the community type (Table 2).
Species groups: The majority of taxa in this community were from the species groups B and G, with limited representation from species groups C and E (Table 1). Taxa from species group G characterised community type 1.
Mean perennial species richness: 21.4 ± 1.7 SE taxa per quadrat.

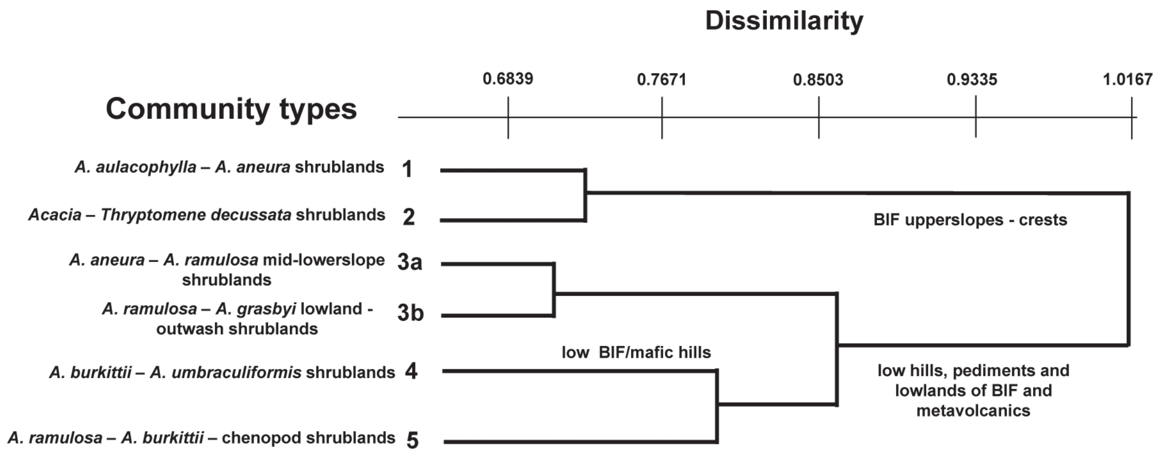

Figure 2. Summary dendrogram of floristic community types and subtypes of the Yalgoo survey region. Groups were resolved from classification analysis of a presence/absence dataset of 214 perennial taxa from 55 quadrats, using flexible UPGMA (dilated using $\beta = -0.1$) and the Bray–Curtis measure of dissimilarity.

Table 1

Two-way table of sites and perennial species, sorted by site and species classification, of the Yalgoo survey area. Community types appear as columns, and species as rows, ordered from the simultaneous classification of 108 taxa from 55 quadrats. Each rectangle represents the record of a species within a quadrat, and quadrats are grouped according to community type.

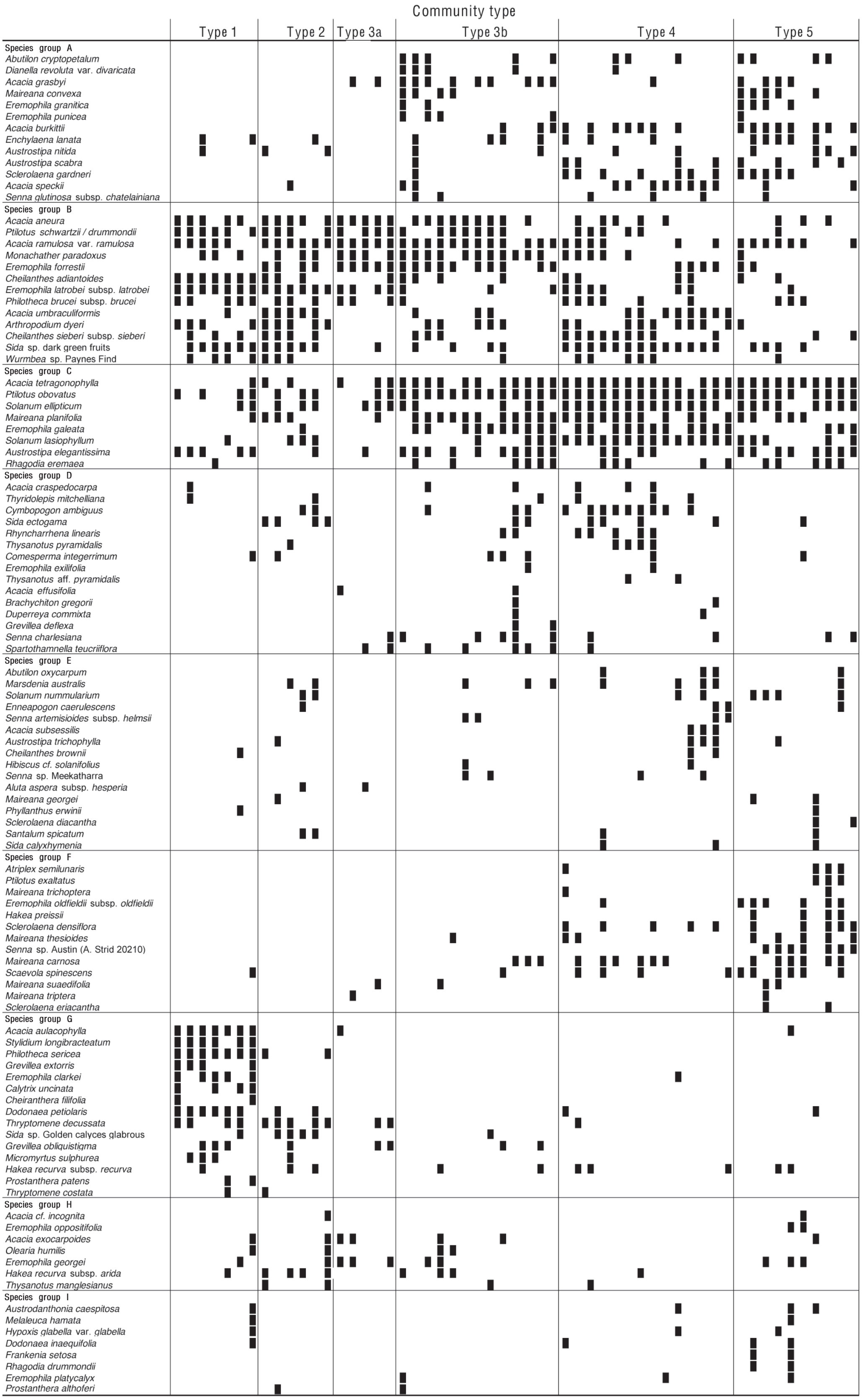

Table 2

Significant indicator taxa of the six community types resolved for the Yalgoo survey area. Indicator values (%) are shown only for taxa which were significant at $p \leq 0.05$ (from Monte Carlo permutation test, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$). The highest indicator values per taxon are indicated by shading.

	Community type					
Indicator taxon	**1**	**2**	**3a**	**3b**	**4**	**5**
Eremophila latrobei subsp. *latrobei**	28	28	18	1	5	0
*Prostanthera patens**	29	0	0	0	0	0
*Cheiranthera filifolia**	29	0	0	0	0	0
*Micromyrtus sulphurea***	31	5	0	0	0	0
*Cheilanthes adiantoides***	40	10	2	4	3	2
*Dodonaea petiolaris****	54	8	0	0	0	1
*Calytrix uncinata****	57	0	0	0	0	0
*Grevillea extorris****	57	0	0	0	0	0
*Eremophila clarkei****	65	0	0	0	1	0
*Philotheca sericea****	75	8	0	0	0	0
*Acacia aulacophylla****	77	0	3	0	0	1
*Stylidium longibracteatum****	86	0	0	0	0	0
*Sida ectogama***	0	37	0	2	7	1
*Acacia umbraculiformis***	1	39	0	3	18	0
Sida sp. golden calyces glabrous***	2	50	0	1	0	0
Hakea recurva subsp. *arida***	2	40	0	5	0	0
*Arthropodium dyeri**	13	27	0	6	16	0
*Thryptomene decussata**	17	37	9	0	0	0
*Eremophila forrestii***	0	15	34	20	3	1
*Acacia grasbyi**	0	0	10	31	0	10
Dianella revoluta var. *divaricata**	0	0	0	25	1	0
*Cymbopogon ambiguus**	0	9	0	4	34	0
*Acacia speckii**	0	3	0	2	30	4
*Eremophila galeata**	0	1	0	29	31	4
*Rhyncharrhena linearis**	0	0	0	5	25	0
*Solanum lasiophyllum****	1	10	0	4	41	10
*Ptilotus obovatus****	7	6	4	23	23	19
Senna sp. Austin***	0	0	0	0	0	70
Eremophila oldfieldii subsp. *oldfieldii***	0	0	0	0	1	54
*Acacia burkittii***	0	0	0	3	16	42
*Hakea preissii***	0	0	0	0	0	40
*Maireana thesioides***	0	0	0	1	3	35
*Maireana convexa**	0	0	0	12	0	31
*Ptilotus exaltatus**	0	0	0	0	0	30
*Sclerolaena densiflora**	0	0	0	0	15	29
*Eremophila granitica**	0	0	0	4	0	29
*Maireana carnosa**	0	0	0	4	15	29
*Acacia tetragonophylla****	1	3	9	19	22	26
*Scaevola spinescens**	2	0	0	1	7	33

Community type 2: Acacia – Thryptomene decussata *upland shrublands*

Substrate and location: On the middle to upper slopes and flattened crests of BIF and laterised BIF ridges, in areas where massive BIF outcrops were absent and where shallow deposits of colluvium and soil overtopped bedrock. Soils were strongly acidic, and concentrations of trace elements and macroelements (N and organic C) were comparatively moderate or low (Table 3).
Distribution: On low BIF ridges at the northern extreme of the Gnows Nest Range, and on the Woolgah–Wadgingarra and Wolla Wolla Hills.
Structural description: Typically tall shrublands of *A. aneura, A. ramulosa* var. *ramulosa*, *A. umbraculiformis* and *Thryptomene decussata,* over a mid-shrub stratum of *Eremophila forrestii* subsp. *forrestii, Eremophila latrobei* subsp. *latrobei, Philotheca brucei* subsp. *brucei, Sida ectogama* and *Thryptomene costata.* The ground stratum usually included the subshrubs *Sida* sp. golden calyces glabrous (HN Foote 32) and *Sida* sp. dark green fruits (S van Leeuwen 2260), and the perennial herbs *P. schwartzii/drummondii* and *Arthropodium dyeri.* Many of these taxa were significant indicator species (Table 2).
Species groups: This community was closely allied to community type 1, but has more substantial representation of taxa from species groups C, D, E, and relatively fewer taxa from species group G.
Mean perennial species richness: 21.5 ± 1.4 SE taxa per quadrat.
Comments: Tended to occur on lower elevations and more moderate slopes than community type 1 (Table 3).

Community type 3: Acacia *mid- to lower-slope shrublands*

Community type 3 was located on the lower half of the topographic profile of BIF ridges, and occurred from middle and lower slopes down to the surrounding flats. This community was further resolved into two subtypes, as was evident in the sorted two-way table (Table 1).

Community type 3a: Gnows Nest Range Acacia aneura – Acacia ramulosa *mid- to lower-slope shrublands*

Substrate and location: On rocky middle to lower slopes on weathered BIF, with minimal outcropping rock cover, smaller classes of surface rocks, moderate slopes and shallow to deep soils (Table 3). Average soil concentrations of Na and Ca were lowest among community types, and values were relatively low to moderate for $EC_{1:5}$, organic C, N, Fe and P (Table 3). Values for most other trace elements tended to be in the middle range among communities.
Distribution: Only located on the Gnows Nest Range.
Structural Description: Characteristically depauperate understorey under a canopy dominated by *Acacia.* Tall shrublands of *A. aneura* and *A. ramulosa* var. *ramulosa*, over a sparse shrub stratum of *E. latrobei* subsp. *latrobei*, *E. forrestii* subsp. *forrestii* and *Eremophila georgei.* The sparse ground layer usually consisted of isolated plants of *P. schwartzii/drummondii and Monachather paradoxa.* Indicator species analysis only found *E. forrestii* subsp. *forrestii* as significant (Table 2).
Species groups: Low representation across the majority of species groups, except for the notable presence of taxa from part of species group B and some representation from species group C (Table 1).
Mean perennial species richness: 13.2 ± 1.6 SE taxa per quadrat.
Comments: This was a comparatively species-poor community type.

Community type 3b: Acacia ramulosa – Acacia grasbyi *lowland to colluvial flat shrublands.*

Substrate and location: On lower slopes, pediments and peneplains (colluvial flats) around BIF ridges, although one site was located on a species-poor basalt hillslope. Sites had low gradients and minimal runoff (Table 3). Being in the depositional areas, this community type had the deepest soils, smallest surficial rocks and nearly no exposed bedrock (Table 3). Concentrations of soil organic C, N, Fe, S and P were comparatively low, and values for most other trace elements tended to be in the middle range (Table 3). However, concentrations of soil Co and K were relatively high compared with other communities.
Distribution: On the Gnows Nest Range and Woolgah–Wadgingarra and Wolla Wolla Hills.
Structural description: Sparse, tall *Acacia* shrublands, co-dominated by combinations of *A. ramulosa* var. *ramulosa*, *Acacia grasbyi*, *Acacia tetragonophylla* and *A. aneura.* The shrub understorey included *Eremophila galeata, Eremophila demissa, E. forrestii* subsp. *forrestii, Maireana planifolia* and *Ptilotus obovatus.* The ground layer included isolated clumps of *Monachather paradoxus* and *Austrostipa elegantissima.* There were relatively few indicator species for this community, including *Dianella revoluta* var. *divaricata* and *Rhyncharrhena linearis* (Table 2).
Species groups: Low representation across the majority of species groups, except for part of species groups B and C (Table 1). Distinguished from type 3a by the higher representation of taxa from species group A. Within community type 3b, there was a subset of sites of depauperate *A. ramulosa* shrublands on flat, stony plains with relatively reduced representation in species group B and increased, moderate representation in species groups C and D (Table 1).
Mean perennial species richness: 19.5 ± 0.8 SE taxa per quadrat.
Comments: Species richness was greater than community type 3a but was still poor relative to the other community types.

Table 3

Summary statistics (average ± SE) of environmental variables for floristic community types of the Yalgoo survey area. Differences were determined using Kruskal–Wallis nonparametric analysis of variance (* indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$), with Dunn's posthoc test (LSD $p < 0.05$, 1: indicates no significant group differences detected in posthoc test). Units for parameters; slope = °, EC = mS/m, eCEC = cmol(±)/kg, elements = mg/kg. Organic C (OrgC) and total N = %. Abbreviations: %Rock Fragment = surface rock fragment cover, Max Rock Size = maximum surface rock size category, % outcrop = exposed bedrock cover. Soil pH values are from a $CaCl_2$ solution, and $EC_{1.5}$ values from a 1:5 soil:water ratio solution.

	Type 1	Type 2	Type 3a	Type 3b	Type 4	Type 5
Slope**	12.4 ± 2.4 ^{b}	5.0 ± 1.7 ^{ab}	5.2 ± 1.8 ^{ab}	1.2 ± 0.4 ^{a}	4.4 ± 1.0 ^{ab}	5.1 ± 2.2 ^{ab}
Topographic position***	4.5 ± 0.2 ^{b}	4.7 ± 0.2 ^{b}	2.5 ± 0.4 ^{ab}	2.1 ± 0.3 ^{a}	3.9 ± 0.3 ^{ab}	2.9 ± 0.3 ^{ab}
Rock fragment ^{NS}	5.0 ± 0.2	4.8 ± 0.4	5 ± 0.3	4.8 ± 0.2	5.1 ± 0.2	4.9 ± 0.3
Max rock size***	5.6 ± 0.3 ^{b}	5.0 ± 0.0 ^{b}	4.0 ± 0.3 ^{ab}	3.5 ± 0.2 ^{a}	4.7 ± 0.2 ^{ab}	4.5 ± 0.3 ^{ab}
Outcrop***	3.9 ± 0.5 ^{bc}	4.2 ± 0.5 ^{c}	0.4 ± 0.2 ^{a}	0.4 ± 0.2 ^{a}	2.1 ± 0.0 ^{abc}	1.2 ± 0.4 ^{ab}
Runoff**	3.9 ± 0.3 ^{b}	3.7 ± 0.2 ^{b}	2.4 ± 0.7 ^{ab}	1.8 ± 0.3 ^{a}	2.9 ± 0.2 ^{ab}	2.6 ± 0.3 ^{ab}
Soil depth***	1.2 ± 0.1 ^{a}	1.4 ± 0.3 ^{ab}	2.7 ± 0.2 ^{bc}	2.8 ± 0.1 ^{c}	1.9 ± 0.2 ^{ab}	2.3 ± 0.2 ^{abc}
% litter ^{NS}	14.6 ± 3.8	11.2 ± 8.1	14.0 ± 2.4	12.7 ± 2.6	11.0 ± 0.6	14.2 ± 2.8
% bare* ^{1}	86.4 ± 2.8	93.3 ± 1.0	85.0 ± 1.6	90.1 ± 2.2	92.5 ± 1.1	88.8 ± 2.2
$EC_{1.5}$**	11.1 ± 1.9 ^{ab}	6.2 ± 1.0 ^{ab}	6.8 ± 1.8 ^{ab}	6.0 ± 0.9 ^{a}	6.5 ± 1.4 ^{a}	27.7 ± 9.9 ^{b}
pH***	4.17 ± 0.06 ^{a}	4.33 ± 0.09 ^{ab}	4.32 ± 0.14 ^{ab}	4.92 ± 0.15 ^{bc}	4.94 ± 0.13 ^{bc}	5.11 ± 0.12 ^{c}
OrgC**	1.380 ± 0.119 ^{b}	0.710 ± 0.076 ^{ab}	0.570 ± 0.039 ^{ab}	0.513 ± 0.056 ^{a}	0.632 ± 0.096 ^{a}	0.777 ± 0.135 ^{ab}
N*	0.092 ± 0.006 ^{b}	0.066 ± 0.005 ^{ab}	0.056 ± 0.003 ^{ab}	0.056 ± 0.005 ^{a}	0.067 ± 0.008 ^{ab}	0.072 ± 0.012 ^{ab}
B ^{NS}	0.24 ± 0.02	0.27 ± 0.08	0.36 ± 0.08	0.35 ± 0.07	0.26 ± 0.04	0.51 ± 0.09
Ca***	190 ± 22.3 ^{ab}	171.7 ± 21.2 ^{a}	145.4 ± 32.2 ^{a}	239.2 ± 29.4 ^{ab}	379.3 ± 46.4 ^{ab}	431 ± 88.9 ^{b}
Co***	0.041 ± 0.006 ^{a}	0.308 ± 0.133 ^{b}	0.23 ± 0.092 ^{b}	1.295 ± 0.29 ^{b}	1.454 ± 0.294 ^{b}	0.88 ± 0.159 ^{b}
Cu ^{NS}	0.67 ± 0.07	0.75 ± 0.07	1.44 ± 0.19	1.16 ± 0.13	1.14 ± 0.21	0.93 ± 0.11
Fe***	105.4 ± 16.4 ^{b}	54.3 ± 5.4 ^{ab}	33.4 ± 2.9 ^{a}	39.8 ± 2.8 ^{a}	59.2 ± 7.3 ^{ab}	65.4 ± 20.7 ^{ab}
K**	102.0 ± 15.3 ^{a}	178.3 ± 21.8 ^{ab}	151.4 ± 20.3 ^{ab}	241.5 ± 27.2 ^{b}	226.4 ± 11.5 ^{b}	240 ± 26.6 ^{b}
Mg***	66.3 ± 8.0 ^{a}	59.5 ± 6.6 ^{a}	40.4 ± 7.5 ^{a}	81.2 ± 9.7 ^{a}	111.8 ± 11.9 ^{ab}	158.4 ± 16.9 ^{b}
Mn***	8.1 ± 1.2 ^{a}	25.2 ± 5.6 ^{ab}	23.2 ± 3.0 ^{ab}	64.4 ± 12.2 ^{b}	67.3 ± 11.3 ^{b}	39.3 ± 8.4 ^{b}
Na**	20.6 ± 5.2 ^{ab}	10.2 ± 2.5 ^{a}	7.1 ± 4.2 ^{a}	13.5 ± 2.3 ^{a}	16.3 ± 2.7 ^{a}	95.9 ± 41.6 ^{b}
Ni* ^{1}	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	0.5 ± 0.1
P ^{NS}	17 ± 5.8	14.5 ± 2.9	7.2 ± 0.8	8.5 ± 1.2	10.7 ± 2.2	21.9 ± 13.2
S ***	23.6 ± 5.2 ^{b}	11.2 ± 1.1 ^{ab}	19.8 ± 3.7 ^{b}	9.5 ± 1.2 ^{ab}	6.7 ± 1.1 ^{a}	35.3 ± 14.3 ^{b}
Zn ^{NS}	1.39 ± 0.11	1.45 ± 0.14	1.4 ± 0.24	2.14 ± 0.3	2.07 ± 0.24	2.36 ± 0.36
eCEC ***	1.844 ± 0.209 ^{a}	1.847 ± 0.212 ^{a}	1.477 ± 0.283 ^{a}	2.54 ± 0.293 ^{a}	3.463 ± 0.292 ^{ab}	4.486 ± 0.52 ^{b}
Latitude ^{NS}	28.5414 ± 0.0239	28.3521 ± 0.0315	28.5124 ± 0.0202	28.3618 ± 0.0365	28.3208 ± 0.0266	28.4463 ± 0.049
Longitude ^{NS}	116.8321 ± 0.0178	116.6353 ± 0.0621	116.8079 ± 0.0143	116.7691 ± 0.0333	116.7844 ± 0.0249	116.8263 ± 0.0159
Elevation ^{NS}	378.7 ± 4.5	353.7 ± 9.3	355.4 ± 8.0	347.1 ± 5.4	373.6 ± 6.3	365.0 ± 4.0
Total species / quadrat	34.7 ± 2.6	36.8 ± 4.2	14.2 ± 1.7	26.7 ± 2.1	36.3 ± 2.5	33.2 ± 3.2
Perennial species/quadrat	21.4 ± 1.7	21.5 ± 1.4	13.2 ± 1.6	19.5 ± 0.8	22.2 ± 1.3	22.8 ± 1.3
Number of quadrats	7	6	5	13	14	10

Classes for site physical variables (from McDonald et al. 1998)

Topographic position: 1 = outwash; 2 = lower slope; 3 = mid slope; 4 = upper slope or low, isolated ridge/hillock; 5 = crest.
Surface rock fragment and exposed bedrock cover: 0 = 0 %; 1 = <2 %; 2 = 2–10%, 3 = 10–20%; 4 = 20–50%; 5 = 50–90; 6 = >90%.
Maximum rock fragment size: 1 = 2–6 mm; 2 = 6–20 mm; 3 = 20–60 mm; 4 = 60–200 mm; 5 = 200–600 mm; 6 = 600 mm – 2 m.
Runoff: 0 = no runoff; 1 = very slow; 2 = slow; 3 = moderately rapid; 4 = rapid; 5 = very rapid
Soil depth: 1 = 0–5 cm; 2 = 5–50 cm; 3 = >50 cm

Community type 4: Acacia burkittii – Acacia umbraculiformis *shrublands on low BIF/mafic hills.*

Substrate and location: On varying geologies, including BIF, basalt and gabbro on low crests and low, gently undulating hills and pediments. Usually on middle to upper hillslopes with moderate gradients, shallow soils, moderate runoff scores and moderate cover of exposed bedrock (Table 3). The soils for community type 4 were moderately acidic, and had moderately high concentrations of Ca, K, Mg, Co and soil eCEC and low concentrations of S (Table 3).
Distribution: Located primarily on the uplands of the Woolgah–Wadgingarra Hills (on hillock crests), with two sites on the Gnows Nest Range.
Structural description: Tall, open shrublands co-dominated to varying degrees by *Acacia burkittii*, *A. aneura* and *A. umbraculiformis*. Other common or typical taxa included *A. tetragonophylla, Sida ectogama*, *Solanum ellipticum*, *M. planifolia* and *Sida* sp. dark green fruit (S van Leeuwen 2260). The ground layer included isolated clumps *Austrostipa elegantissima*. Best indicator species for this community included *Acacia speckii, Solanum lasiophyllum, P. obovatus* and *Eremophila galeata* (Table 2).
Species groups: The majority of taxa within this community type were from species groups A, B, D and, in particular, group C. There was some suggestion of a community 4 subtype with taxa from species group E and fewer taxa from species group D (Table 1). This was a sparse shrubland of *Acacia umbraculiformis* and *Acacia subsessilis* over *Eremophila galeata, Acacia speckii* and *Ptilotus obovatus* which occur on basalt hillslopes.
Mean perennial species richness: 22.2 ± 1.3 SE taxa per quadrat.
Comments: A number of sites were species-poor and heavily grazed basalt/gabbro hillslopes.

Community type 5: Acacia ramulosa – Acacia burkittii – *chenopod shrublands.*

Substrate and location: Typically located on moderately inclined mid-slopes of hills and low, weathered, stony rises and laterised breakaways. Rocks types were variable, and included BIF and laterised BIF, basalt, gabbro, calcrete, banded chert and metasedimentary influences. Even sites on ridges of outcropping metasediments also had mafics and calcretes. Soils from Community type 5 were of low acidity or neutral, and had comparatively high levels of K, Ca, Mg, Na (and a correspondingly high eCEC), and moderately high concentrations of Mn, Ni, Zn and P. These soils also were more saline, with relatively high Na and $EC_{1.5}$ values (Table 3).
Distribution: On the Gnows Nest Range and Woolgah–Wadgingarra Hills.
Structural description: A heterogeneous assemblage of sites, with a suggestion of two variants within the community. One variant consisted of shrublands on rocky pediments and mid-slopes, dominated to varying degrees by *A. ramulosa, A. burkittii, A. tetragonophylla* and *Eremophila oldfieldii* over *Eremophila granitica, Rhagodia eremaea* and chenopod subshrubs (*Maireana, Sclerolaena* and *Enchylaena*) and *Austrostipa* spp. The second group consisted of more sparse, open shrublands of *A. burkittii, Eremophila oldfieldii* over *Hakea preissii, Rhagodia eremaea, Senna* sp. Austin and chenopod subshrubs, including *Maireana trichoptera* and *Atriplex semilunaris.* Many of these dominant taxa are significant indicator species, including several species of chenopods subshrubs (Table 2).
Species groups: Moderate to high representation of taxa from species groups A, C and F, and few taxa from species groups H and I (Table 1).
Mean perennial species richness: 22.8 ± 1.3 SE taxa per quadrat.
Comments: Community type 5 tended to occur on flatter and lower topographic positions than community type 4, although these differences were not statistically significant (Table 3).

Physical Environment

Quadrats were located over an elevational range of 309 to 410 m. The soils were, on average, acidic (pH 4.75 ± 0.07 SE), shallow (<50 cm depth), lacking in nitrogen and organic carbon (<2%), and with >50% cover in a mantle of surficial rocks. The ground was predominately bare (90.1 ± 0.9%) and with only a sparse cover of litter (12.7 ± 1.0%).

The elements Al, Cd and Mo were at undetectable levels, and excluded from the soil dataset. Many of the soil and physical parameters were inter-correlated (Table 4). Among the soil chemical parameters, relationships among many of the elements ranged from weak to strong; notably within a set of trace elements (Co, Ca, Cu, K, Mg, Mn, Na, Ni and Zn) and within a set of macronutrients and elements (Fe, organic C, N and P). Relationships between a few elements were very strong (e.g. organic C and N, Co and Mn; Table 4). Many of the site physical parameters were inter-correlated (e.g. altitude, slope, rock exposure and runoff). Relationships between soil depth and the set of altitude, slope, rock exposure and runoff were moderately to strongly negative. The relationship between soil depth and Fe, N and organic C was weakly to moderately positive. Autocorrelation is expected for site physical parameters (such as runoff and slope), and for eCEC and Ca and Mg, as eCEC is partially derived from these two element concentrations.

Univariate analyses

Univariate analyses (non-parametric ANOVA) found significant differences in most environmental parameters among the six community types and subtypes (Table 3). Significant differences in site physical parameters were only found between communities at topographic extremes in the landscape. Sites associated with community types 1 and 2 were generally significantly steeper and at higher topographic positions than community types 3b and (less often) 3a (Table 3). For community types 1 and 2, soils were significantly shallower, runoff was significantly greater, and there was more exposed rock outcrop cover and larger surface rocks than community type 3b. Elevation did not differ statistically among communities probably because there was only a small (30 m) difference between the minimum and maximum average elevations (Table 3).

There were some significant differences in soil chemical parameters between the community types (Table 3). Community type 1 had the lowest average soil pH and significantly lower soil pH and Mn and K concentrations than community types 3b, 4 and 5. Soil organic C was significantly higher in community type 1 than in community types 3b and 4, and there were significantly higher concentrations of soil N in community type 1 than in community type 3b. Community type 1 had high concentrations of Fe that were significantly higher than those found in soils from community types 3a and 3b. Concentrations of Co were significantly lower in community type 1 than the other community types, but Co was not significantly different between community types 2 to 5. Community type 4 had a low concentration of S, which was significantly lower than found in community types 1, 3a and 5. Community type 5 had significantly higher soil pH than in community types 1, 2 and 3a. Mg and eCEC values were also significantly higher in community type 5 than in community types 1, 2, 3a and 3b. Average soil Na concentrations were greatest in community type 5 and were significantly higher than for community types 2, 3a, 3b and 4. Soil $EC_{1:5}$ was also high in this community, and significantly higher than community types 3b and 4. This indicated that community type 5 had comparatively more saline soils. Low Ca concentrations were found in community types 2 and 3a, which were significantly lower than those in community type 5.

SSH MDS ordination

Nonmetric multidimensional scaling ordination showed floristic relationships among the five community types (Fig. 3a and 3b), which was reduced to three dimensions with a level of stress of 0.2. The greatest separation in ordination space was between community types 1 and 2, and community types 3, 4 and 5, but there was spatial overlap of some communities as the groups did not form tight, discrete clusters. From principle component correlation (PCC) analysis, many of the site physical and soil chemical parameters were significantly correlated with the site ordination (Fig. 3c and 3d). There were several major gradients composed of approximately co-linear vectors. One of these consisted of site physical parameters (topographic position, bedrock exposure, maximum rock size, slope, elevation and runoff). Soil depth was co-linear but negatively aligned with this major gradient, and the two vectors of soil N and organic C were roughly co-linear and positively aligned with this gradient. A second major gradient, comprised of approximately co-linear vectors of Zn, eCEC, Mg, Ca, Ni, K and pH, was orthogonal to this first major gradient. The remaining vectors of soil variables were not closely co-linear to one another in ordination space.

Quadrats classified as community types 1 and 2 coincided with the higher ends of gradients for topography and both soil N and organic C concentrations, indicating a postitive association with rocky, upland sites with skeletal soils rich in N and organic C. Community type 1, in particular, coincided with the higher extremes of these topographic and soil gradients. This community type also was associated with relatively higher latitudes, which related to the restriction of these sites to the Gnows Nest Range in the south of the survey area. Community types 4 and 5 coincided with higher values along the second major soil chemical gradient, with these sites associated with higher values for pH, eCEC, K, Ni, Mg, Ca. These two communities were also associated with higher values of bare ground cover. Community type 3b coincided at the lower extreme of the site physical parameter gradient, and together with community type 3a, was associated with low values of soil P.

DISCUSSION

Flora

This is the fifth in a series of floristic surveys of BIF ranges within the wider northern Yalgoo IBRA bioregion, within a triangular area bounded approximately by the townships of Perenjori, Paynes Find and Yalgoo (Markey & Dillon 2008a, 2010a; Meissner & Caruso 2008a, 2008b). The representation of genera and families in the flora from the Yalgoo survey area was similar to those from previous surveys on neighbouring BIF landforms, and characteristic of the Yalgoo region (Beard 1976a; Pringle 1998b). There is high representation of characteristic Eremaean groups, such as *Acacia*, *Eremophila*, *Ptilotus*, *Senna* and the Chenopodiaceae (Beard 1976a, 1990; Pringle 1998b). At the time of the survey the Yalgoo area was still undergoing a long-term drought, and only 10 mm of rain had fallen in the prior 18 months (R Pitman pers. comm.[3]). This reduced the proportion of annual species (76 taxa, 31% of total), many of which were common and widespread species, relative to the adjacent central Tallering region (185 taxa, 45% of total; Markey & Dillon 2008a). The latter region was sampled in year of high winter rainfall. A low proportion of annual herbs (28% of total taxa) was recorded for the Gullewa region after summer rains and a particularly dry winter (Markey & Dillon 2010a).

The total number of taxa for the Yalgoo survey was roughly similar to counts from other BIF surveys in the northern Yalgoo IBRA bioregion (Table 5), although geologies, area and sampling density was not uniform among surveys and the Gullewa, Yalgoo and central Tallering surveys covered relatively large areas. Counts for

[3] Roger Pitman, Station Manager. Badja Station, Yalgoo.

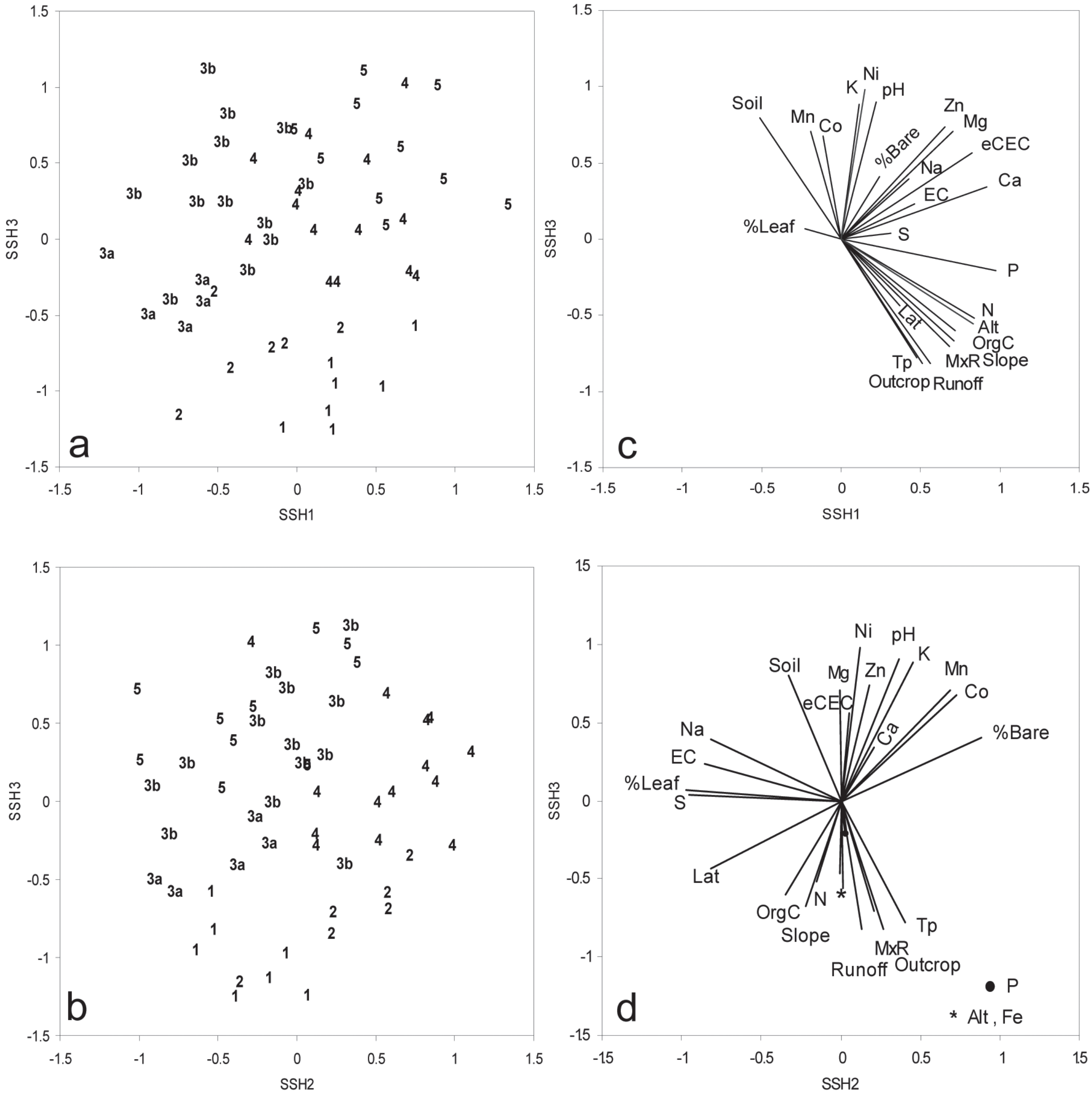

Figure 3. 3D SSH MDS ordination of sites for the Yalgoo survey area, based on dissimilarities in floristic composition from a presence/absence data matrix of 108 perennial taxa from 55 quadrats: (a) SSH axis 1 vs 3; and (b) SSH axis 2 vs 3 (both from three dimensional solution). Stress = 0.20. Sites are numbered by their respective floristic community types. Vectors of best fit linear correlations of site physical parameters and site ordination coordinates are presented in adjoining panels to the ordination: (c) vectors for axis 1 vs 3; and (d) vectors for axis 2 vs 3. Vectors are presented in a positive direction and only significant vectors ($p < 0.05$) are displayed, as determined from Monte Carlo permutation tests. All vectors are significant at $p < 0.001$, except for %Leaf, P, Alt and %Bare ($p < 0.01$), and Ni ($p < 0.05$).

perennial taxa and average perennial species richness among the three closest survey areas to Yalgoo are broadly comparable (Table 5). Beard (1976a) noted a decline in species along a north-east gradient across the Yalgoo bioregion, which was attributed to increasing aridity. Apart from the southern half of the central Tallering area being notably species-rich (335 taxa recorded from 52 quadrats; Markey & Dillon 2008a), this trend was not evident from the figures from the surveys of the BIF ranges.

Taxa of conservation significance

Seven priority taxa are known from the Yalgoo survey area (*Rhodanthe collina*, *Labichea obtrullata*, *Triglochin protuberans*, *Enekbatus roseus*, *Grevillea globosa*, *Goodenia neogoodenia* and *Balaustion microphyllum*), but none were located during this survey. Only *Grevillea globosa*, *Labichea obtrullata* and *Rhodanthe collina* are associated with BIF landforms (Western Australian

Table 4

Matrix of Spearman rank correlation coefficients for environmental variables collated from 55 quadrats established on the Yalgoo survey area. Only correlations significant at $p < 0.01$ are shown. Parameter codes are as follows: topographical position (Tp), litter ground cover (%litter), bare ground cover (%bare), maximum surface rock fragment size (MxR), and surface rock cover (%RF), exposed rock cover (outcrop). Full details of other environmental parameter codes are given in the methods section.

	EC	pH	OrgC	N	B	Ca	Co	Cu	Fe	K	Mg	Mn	Na	Ni	P	S	Zn	eCEC	Slope	Tp	%RF	MxR	Outcrop	Runoff	Soil	%litter	%bare	Lat	Long
Soil Chemical Parameters																													
EC																													
pH	.																												
OrgC	0.580	-0.379																											
N	0.534	.	0.942																										
B	0.414	.	.	.																									
Ca	.	0.771	.	.	.																								
Co	.	0.785	-0.528	.	.	0.618																							
Cu	.	.	.	.	.	.	0.429																						
Fe	.	.	0.479	0.490	.	.	.	.																					
K	.	0.641	.	.	0.451	0.658	0.637	.	.																				
Mg	.	0.709	.	.	.	0.825	0.634	.	.	0.539																			
Mn	-0.414	0.721	-0.530	.	.	0.517	0.935	0.404	.	0.589	0.477																		
Na	0.757	0.381	.	.	0.525	0.600	.	.	.	0.368	0.716	.																	
Ni	.	0.392	.	.	.	0.376	0.565	0.382	.	.	0.560	0.403	0.355																
P	.	.	0.429	0.463	.	.	.	.	0.521	.	.	.	.	.															
S	0.734	-0.380	0.583	0.419	.	.	-0.649	.	.	-0.371	.	-0.699	.	.	.														
Zn	.	0.600	.	.	0.465	0.707	0.519	0.475	.	0.684	0.522	0.496	0.418	.	0.367	.													
eCEC	0.357	0.775	.	.	0.361	0.941	0.631	.	.	0.644	0.931	0.491	0.693	0.501	.	.	0.664												
Physical Parameters																													
Slope	.	-0.355	0.463	0.377	.	.	-0.395	.	0.544	-0.450	.	-0.351	.	.	.	.	.	.											
Tp	.	.	0.372	0.360	.	.	-0.347	.	0.530	.	.	.	.	.	.	.	.	.	0.601										
%RF	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-0.400	.	.	.									
MxR	.	.	0.481	0.444	.	.	.	.	0.592	.	.	.	.	.	0.410	.	.	.	0.784	0.787	.								
Outcrop	.	.	0.471	0.424	.	.	-0.383	.	0.667	-0.383	.	.	.	.	0.417	.	.	.	0.692	0.848	.	0.850							
Runoff	.	-0.401	0.400	0.366	.	.	-0.373	.	0.551	-0.418	.	.	.	.	.	.	.	.	0.747	0.760	.	0.807	0.814						
Soil	.	.	-0.361	.	0.379	.	.	.	-0.607	0.416	.	.	.	.	.	.	.	.	-0.598	-0.765	.	-0.759	-0.859	-0.714					
%litter	.	.	.	.	.	.	.	0.389	.	.	.	.	.	.	.	.	.	.	.	-0.398	-0.370	.	.	.	0.369				
%bare	.	.	-0.486	-0.419	.	.	.	.	.	.	.	.	.	.	.	-0.405	.	.	.	.	0.431	.	.	.	.	-0.519			
Lat	0.403	.	0.497	0.388	0.386	.	-0.480	.	.	.	.	-0.548	.	.	.	0.552	.	.	.	.	.	.	.	.	.	.	-0.523		
Long	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.470	
Altitude	.	.	.	.	.	.	.	.	0.421	.	.	.	.	.	.	.	.	.	0.521	0.437	.	0.491	0.436	0.474	-0.512	.	.	.	.

Herbarium 1998–). *Rhodanthe collina* is a winter annual herb which was last collected in 2005, and has not been collected north of Minjar Hill (c. 40 km south; Markey & Dillon 2008a; Western Australian Herbarium 1998–). More intensive survey following favourable winter rainfall may locate these species within the survey area.

Previous studies on the Yilgarn BIF ranges have identified rare or uncommon taxa, regional endemics, range endemics (restricted to one or several BIF ranges) and BIF endemics (distributions centered on BIF), and that some ranges harbour a disproportionately high number of endemics or taxa of conservation significance (Gibson et al. 2007). The number of significant taxa found in the Yalgoo survey area was similar to that recorded for the Gullewa survey area, and both areas have considerably fewer significant taxa than the other, more southern BIF ranges (Table 5). More comprehensive investigations have further verified that the Karara–Windaning, Mount Gibson and Koolanooka–Perenjori BIF hills do have relatively high numbers of priority taxa (Department of Environment and Conservation 2007; Gibson et al. 2007). Counts of endemic taxa are also relatively high for the central Tallering and Koolanooka – Perenjori Hills surveys, which contrasts with very low counts of regional endemics or near-endemics recorded for the Gullewa and Yalgoo survey areas (Table 5).

It is unclear as to what accounts for the patterns of endemism observed among BIF ranges (Gibson et al. 2007), but the lower number of taxa of conservation significance may be a consequence of less taxa overall being recorded from the Yalgoo and Gullewa landforms, since the two are correlated (Gibson et al. 2007). Both lower counts of endemics and uncommon taxa could also be a function of reduced diversity of BIF habitats among the relatively more subdued BIF landforms in the Gullewa and Yalgoo survey areas. These lower counts could also be a consequence of the Yalgoo survey area being located within a region of reduced endemism, species richness and relatively intact vegetation. It is the northernmost of all BIF survey areas listed in Table 5. This places the Yalgoo survey area as relatively distant from the South West Botanical District, which is a floristic region of high species richness and endemism (Hopper & Gioia 2004), and where extensive clearing for agriculture has contributed to high numbers of threatened species.

Vegetation Communities

There is some general correspondence between the communities described by Pringle (1998a) and those described in this study, i.e. stony ironstone acacia (SIAS) encompassing the Yalgoo community types 1 and 2. However, these communities of Pringle (1998a) were very broadly defined for a large region of the Midwest (Payne et al. 1998) and based on dominant taxa and structure, which limits comparisons between Pringle (1998a) and the recent series of BIF and greenstone surveys. Fine-scale surveys using total perennial floristic composition, similar methodology and recent taxonomic treatments do enable closer comparisons of communities among ranges within the Mt Gibson – Paynes Find – Perenjori area (Markey & Dillon 2008a; Meissner & Caruso 2008a, 2008b; Woodman Environmental Consulting 2007).

There were some general similarities between some Yalgoo communities to those on similar geologies described for the Gullewa area and around the Minjar and Warrieder Hills (Markey & Dillon 2008a, 2010a). Gullewa community type 6, which was associated with metavolcanics, has some similaritities to sites of Yalgoo community type 4 on basalt and gabbro hillslopes. Gullewa community type 1 is a BIF crest community that shares some common elements with Yalgoo community types 1 and 2. The lower slope – pediment community, Gullewa community type 3, is similar to Yalgoo community type 3. An upland community described for BIF ridges south of the Gnows Nest Range (central Tallering community type 3 is) has some floristic affinities to the Yalgoo community type 1, but many characteristic taxa (such as *Drummondita fulva*, *Astroloma serratifolium* and *Mirbelia bursarioides*) were absent or rarely encounterd in the Yalgoo community.

There are communities described in other surveys which were not located in the Yalgoo survey area. This includes the lowland woodlands and saline depression communities of the Gullewa survey area and lower slope communities of the hills south of Gnows Nest Range (Markey & Dillon 2008a, 2010a). Although the vegetation of the lower slopes of the hills south of Gnows Nest Range (central Tallering community type 1a) was suggested to be more widespread in the Yalgoo region (Woodman Environmental Consulting 2007), woodlands

Table 5

Species richness of floras from BIF ranges in the northern Yalgoo IBRA. Data from quadrat-based BIF range surveys only ([1] Markey & Dillon 2008a, [2] 2010a, [3] this survey; [4] Meissner & Caruso 2008a, [5] 2008b).

BIF Survey area	Total taxa (native)	No. quadrats	Perennial taxa	Perennial taxa/quadrat	Taxa of conservation significance	Endemic taxa
Yalgoo [3]	243 (234)	55	159	22.7 ± 0.6	5 priority	2 near endemic
Gullewa [2]	235 (220)	50	153	24.6 ± 0.8	6 priority	1 near endemic
Central Tallering [1]	414 (388)	103	223	23.7 ± 0.5	1DRF, 15 priority	10 endemic or near endemic
Mt Gibson [4]	243 (233)	50	–	17.7 ± 0.7	2 DRF, 7 priority	3 endemic
Koolanooka and Perenjori Hills [5]	238 (215)	50	–	21.3 ± 0.5	13 priority taxa	6 endemic or near endemic

Table 6

Comparison of flora and shared perennial taxa among three BIF range surveys within the Yalgoo region. Counts of perennial taxa or the combined total number of taxa between pairs of ranges are given in parentheses. Distance = min – max distances between survey areas, and midpoint distance in parentheses. Results from analysis of similarity (ANOSIM) of perennial data matrices are given as pairwise and global R values (R statistic) and their respective levels of significance. Data from Markey & Dillon 2008a, 2010b; this survey.

Pairwise comparison	Distance (km)	% shared perennial taxa (total taxa)	R statistic	p value %
Central Tallering, Gullewa	40–122 (70)	46% (254)	0.518	0.01
Central Tallering, Yalgoo	8–113 (70)	43% (263)	0.358	0.01
Gullewa, Yalgoo	10–80 (40)	58% (189)	0.231	0.01
Total comparison				
Central Tallering, Gullewa,Yalgoo	–	55% (276)	0.383	0.01

and shrublands of *Acacia ramulosa* var. *ramulosa*, *Callitris collumelaris*, *Eucalyptus* ssp. and *Acacia coolgardiensis* subsp. *latior* were not located in the Yalgoo survey. Finally, the floristic communities described for the Mt Gibson and Koolanooka Hills and the southern part of the central Tallering Land System survey areas are fundamentally different to those described for the Yalgoo survey area, as discussed below (Markey & Dillon 2008a; Meissner & Caruso 2008a, 2008b).

Preliminary analysis of similarity (ANOSIM; Clarke 1993; Clarke & Warwick 2001) of matrices showed that the perennial vegetation units found in the three survey areas were significantly different in terms of species composition (ANOSIM global R = 0.383, p = 0.01%; Table 6). On a larger scale, meta-analyses of the combined data sets for the Yilgarn craton have found regional differences in floristic communities among BIF ranges (N Gibson[4], pers. comm.). This regional turnover in community composition over distances of 120 km has been speculated to result from a combination of climate, soils, geology, topography and the individual history of speciation within each range (Butcher et al. 2007; Gibson et al. 2007).

Species Turnover among Ranges

The southern part of the Yalgoo survey area was only 30 km north (mid-point distance) of the northern part of the central Tallering survey area, and yet many taxa characteristic of the central Tallering region were absent (Markey & Dillon 2008a). Many of these were expected to occur at least on the northern Gnows Nest Range, given that they are common on the adjacent Minjar and Gossan Hills (e.g. *Drummondita fulva*, *Micromyrtus trudgenii*, *Polianthion collinum*, *Hemigenia benthamii*, *Prostanthera magnifica*, *Calycopeplus paucifolius* and *Astroloma serratifolium*; this study; Markey & Dillon 2008a). Other taxa common and characteristic to the central Tallering floristic communities were rarely encountered within the Gullewa and Yalgoo survey areas (e.g. *Allocasuarina acutivalvis* subsp. *acutivalvis*, *Mirbelia bursarioides*, *Persoonia manotricha*, *Eremophila glutinosa* and *Prostanthera patens*; this study; Markey & Dillon 2010a). There was a notable absence of *Eucalyptus* and *Callitris* woodlands in the Yalgoo survey area, whereas they dominated the valleys and lowerslopes in southern Gullewa, and from the southern extent of the Gnows Nest Range southwards into the south-west of the central Tallering area (Markey & Dillon 2008a, 2010a). The Myrtaceae were poorly represented in the Yalgoo survey area (4% of perennial taxa), whereas the central Tallering survey (Markey & Dillon 2008a) found this to be higher (11% of perennial taxa). Even on a smaller scale within the Yalgoo survey area, a replacement series from south-west to north-east was noticed, such as the replacement of *Acacia assimilis* subsp. *assimilis* with *Acacia aulacophylla*, and *Ptilotus drummondii* subsp. *drummondii* with *Ptilotus schwartzii*. These findings from the BIF surveys in the Paynes Find – Yalgoo region concur with Beard's (1976a, 1976b) delineation of the Yalgoo bioregion as marking the transition from interzone eucalypt woodlands to the mulga-dominated communities of the Eremaean.

The β-diversity (species turnover between ranges) of BIF ranges in the Yilgarn has been reported to be high, such that even relatively close (<100 km) BIF ranges have been found to harbour notably different suites of taxa (Gibson 2004a, 2004b; Gibson & Lyons 2001a, 2001b; Gibson et al. 2007; Markey & Dillon 2008a, 2008b, 2010a; Meissner & Caruso 2008a, 2008b). When compared, 55% of 276 perennial taxa were shared among the Gullewa, Yalgoo and central Tallering combined floras, with Gullewa and Yalgoo having the most similar floras (Table 6). When the central Tallering area was separated into the northern and southern halves, the northernmost Minjar area has 45% of perennial taxa in common with Yalgoo (205 taxa), which declines to 33% when compared with the southernmost Mt Karara – Windaning Hills (233 taxa; Markey & Dillon 2008a). Such high β-diversity among rock outcrops could be attributed to range specific differences in soils and geomorphology, aridity and current climate (Gibson et al. 2007; Harrison 1997; Jacobi et al. 2007). Historical factors include climatic instability during the Pleistocene that affected the southern western

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interzone, and the stochastic processes of colonisation and extinction among individual ranges (Hopper & Gioia 2004; Hopper et al. 1997; Porembski 1998).

Physical Environment and Community Associations

The Yalgoo floristic communities were found to be associated with geological substrate, topography and edaphic factors, with the most floristically dissimilar communities at opposite extremes of this edapho-topographic gradient. Pringle (1998a) noted that it was only on greenstone and BIF landforms that there was there such a close association of substrate with vegetation in the wider Yalgoo–Sandstone region. Associations between floristic communities and both substrate and edapho-topographic gradients have been reported for other Yilgarn and Pilbara BIF landforms (van Etten & Fox 2004; Gibson 2004a, 2004b; Gibson & Lyons 2001a, 2001b; Markey & Dillon 2008a, 2008b, 2009, 2010a, 2010b; Meissner & Caruso 2008a, 2008b, 2008c; Meissner et al. 2010a, 2010b, 2010c). Within the Yalgoo survey area, the greatest diversity of both habitats and floristic communities occurred on the Gnows Nest Range. This included a BIF crest/upper slope community (community type 1) and a midslope community (type 3a) which were only located on the range. The greater number of communities may be attributed to both the wider elevational range and more varied geology (BIF, mafics and laterite breakaways) on Gnows Nest Range.

Previous Yilgarn BIF surveys have found distinct communities exclusively associated with mafic substrates (Markey & Dillon 2008b), including in the adjacent Gullewa survey area (Markey & Dillon 2010a). A distinct mafic community was not identified for the Yalgoo survey area, possibly because mafics were often closely intermingled with BIF geologies. Community types 4 and 5 were found on a range of substrates that included mafics, and this perhaps is reflected in the compositional heterogeneity of these communities. Increased sampling on basalt and gabbro hills in the region may resolve a mafic–specific community in community type 4.

The attributes of topsoils from the Yalgoo survey area were typical of topsoils in the wider Yalgoo–Sandstone region (Hennig 1998b; Markey & Dillon 2008a; 2010a). We acknowledge that analyses were only conducted on the upper 10 cm of soil, and soil composition at depths relevant to the more deeply-rooted species has not been addressed. Significant differences were, however, found in topsoil attributes between communities. Communities of the upper slopes (community types 1 and 2, but particularly so in community type 1) had relatively shallow, rocky, strongly acidic and infertile topsoils as opposed to the deep, fertile lowland soils of community type 3b and the more mineral-enriched soils of community types 4 and 5. Relatively low levels of soil elements in the upland communities (particularly community type 1) indicated prolonged leaching of mobile elements (Britt et al. 2001; Edwards 1955; Gray & Murphy 2002; Tiller 1962). Soils on lower slopes, pediments and colluvial flats tend to accrue leachates, and these elements (notably Ca, Mg, K and Mg) increase soil eCEC and soil pH buffering (Gray & Murphy 2002; Ben-Shahar 1990). The soils of lowland community types 3b and 5 were less acidic and more mineral-rich than community type 1, but higher eCEC was only evident in community type 5 (which was attributed to high Mg and Ca concentrations). The reduced buffering capacity of leached soils can lead to increased acidity (Gray & Murphy 2002), and strongly acidic soils (as found in community type 1) could reduce soil trace element solubility and uptake by ironstone plants (Foulds 1993; Slattery et al. 1999). The relatively higher soil organic C and N levels in upland communities (especially community type 1) was attributed to the accumulation of leaf litter in rock crevices, which enrich these small pockets of soil (Foulds 1993; Facelli & Brock 2004). Elevated soil Fe concentrations in the soils from community type 1 relative to lowland community types 3a and 3b reflected soil development from in situ weathering of BIF, resulting in a precipitation of iron oxides (Foulds 1993).

Community types 4 and 5 were located on a variety of geological substrates that all included an amount of mafic metavolcanics and calcretes. Community type 4 was located on low crests, middle slopes and pediments of basalt or interbedded BIF and basalt, with shallow, weakly acidic soils. Community type 5 was located on low stony rises, low hillslopes of mixed mafic/BIF geologies and occasionally around laterised breakaways. Soils in these two communities tended to have relatively higher soil trace element concentrations and higher eCEC than community types 1, 2 and 3a. These substrates probably contributed to the enriched, weakly acidic to neutral soils found in these communities, since soils derived from metavolcanics have high levels of trace elements and heavy metals, a higher eCEC and a more neutral to alkaline pH (Cole 1973; Cornellius et al. 2007, Gray & Murphy 2002; Gray & Humphreys 2004; Hennig 1998; Tiller 1962). Low concentrations of S may reflect parent rock composition in community type 4.

In situ weathering of metavolcanics also produces calcrete deposits on hillslopes and valleys (Anand et al. 1997). Other greenstone vegetation surveys have reported alkaline soils (pH >8), calcretes and calcareous soils in outwash locations in association with distinct vegetation communities (e.g. Cole 1973; Gibson & Lyons 1998, 2001b; Hennig 1998). Alkaline soils were not found in soils from the Yalgoo survey, but small deposits of calcretes were associated with community type 5. Soils in this community also had relatively high Na and $EC_{1:5}$ values, indicating elevated soil salinity, although these soils could not be considered saline (Shaw 1999). Salts can be derived from laterite breakaway clays (Gibson & Lyons 2001a), as well as from weathered mafics and BIF. Distinctive taxa in community type 5 commonly occur on saline, calcareous soils, including chenopod shrub taxa, *Hakea preissii*, *Senna* sp Austin (A Strid 20210), *Eremophila oldfieldii*, *Eremophila oppositifolia* and *Frankenia setosa* (Western Australian Herbarium 1998–). These species are characteristic of communities on similar or more saline soils and substrates in the Gullewa region (Gullewa community types 4b and 5; Markey & Dillon 2010a) and the central Tallering land system (central Tallering Community type 5a; Markey & Dillon 2008a).

The general association of a vegetation catena with a transition from leached, infertile skeletal upland soils to fertile, deep, lower slope and colluvial flats and mineral-rich metavolcanic soils have been reported for other ranges in the Yalgoo bioregion (Markey & Dillon 2008a, 2010a; Meissner & Caruso 2008a, 2008b) and among other greenstone communities in the wider Yilgarn (Gibson 2004a, 2004b; Gibson & Lyons 2001a, 2001b), the Pilbara region (van Etten & Fox 2004) and ironstone mountains in Brazil (Jacobi et al. 2007). Although not assessed, there is likely to be a soil moisture gradient over the BIF and greenstone landforms, where there is minimal infiltration and substantial run-off of rainfall from steep uplands to the lower slopes and colluvial flats (Chalwell 2003; Cole 1973; Conn & Snyder-Conn 1981; Payne & Pringle 1998; Specht et al. 2006). This may also influence the distribution of species and assemblages over the landforms. Fissured bedrock and loose rock piles trap soil and water and therefore provide moist microhabitats, and it is not surprising that significant indicator species of community types 1 and 2 included fissure exploiting geophytes, such as *Cheilanthes adiantoides* and *Stylidum longibracteatum*, and shrubs, such as *Thyrptomene decussatu, Micromyrtus sulphurea, Grevillea extorris* and *Sida* sp. golden calyces glabrous (HN Foote 32). Groundwater sources around ranges in the Yalgoo survey area are 13–21 m below ground (Department of Water 2010), therefore rainfall run-off is of primary importance for the surrounding lowland *Acacia* shrublands (Pringle 1998a).

Conservation

BIF ranges in the Yilgarn can be highly floristically diverse (Gibson et al. 2007), and although the Yalgoo survey area did not have as many restricted communities and endemic and uncommon taxa as the central Tallering Land System (Markey & Dillon 2008a), these BIF ranges still harbour taxa of conservation significance and distinctive floristic communities. The Yalgoo survey area has been affected by long-term drought and both this and a century of grazing from livestock and feral goats has affected the condition of vegetation on the upland areas. Goats are a serious problem within the wider Sandstone–Yalgoo region, particularly on hills and breakaways (Pringle 1998b). Naturalised plants do not appear to be a significant issue on the ranges (at least during drought conditions), since weed taxa were few in number and typically small annual grass taxa (Appendix 1).

Mineral exploration tracks, drill holes and even the remains of mining centres can be found over most of the survey area from a century of activity. Many of these old excavations remain open and unsecured, and few areas appeared to have undergone any degree of restoration. None of the survey area is reserved within the conservation estate, and exploration and mining tenements cover all BIF and metavolcanic landforms within the Yalgoo survey area. Extensive drilling operations have recently commenced on the Woolgah–Wadgingarra and Wolla Wolla Hills and on the Gnows Nest Range. Given the potential for permanent and high level impacts with extensive open-cast mining operations, further exploration and mining activities need assessment and management to minimise threats to floristic communities and taxa of conservation significance. Given the high β-diversity among ranges, the reservation of representative areas with the CAR system (CALM 2004) will be a difficult objective to meet.

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APPENDIX 1

Flora list for BIF and metavolcanic landforms of the Yalgoo survey area. Nomenclature follows Packowska & Chapman (2000), except when updated from the Census of Western Australian Plants database (Western Australian Herbarium 1998–). Naturalised species are denoted by an asterisk. Informal (phrase) names and entities of uncertain taxonomic status (i.e. *affinis.*) are followed by a collection number. Family taxonomy follows the APG II system (Angiosperm Phylogeny Group 2003), which was current at time of flora list compilation

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

Aizoaceae
- *Cleretum papulosum* subsp. *papulosum**
- *Mesembryanthemum nodiflorum**
- *Tetragonia cristata*
- *Tetragonia diptera*

Amaranthaceae
- *Ptilotus aervoides*
- *Ptilotus drummondii*
- *Ptilotus exaltatus*
- *Ptilotus gaudichaudii* var. *parviflorus*
- *Ptilotus helipteroides*
- *Ptilotus obovatus*
- *Ptilotus schwartzii*

Anthericaceae
- *Arthropodium curvipes*
- *Arthropodium dyeri*
- *Thysanotus manglesianus*
- *Thysanotus pyramidalis*
- *Thysanotus* aff. *pyramidalis* (A Markey & S Dillon 5831)
- *Thysanotus speckii*

Apiaceae
- *Daucus glochidiatus*
- *Hydrocotyle pilifera* var. *glabrata*
- *Trachymene ceratocarpa*
- *Trachymene cyanopetala*
- *Trachymene ornata*
- *Trachymene pilosa*

Apocynaceae
- *Alyxia buxifolia*

Asclepiadaceae
- *Marsdenia australis*
- *Marsdenia graniticola*
- *Rhyncharrhena linearis*

Asteraceae
- *Actinobole uliginosum*
- *Bellida graminea*
- *Blennospora drummondii*
- *Brachyscome ciliocarpa*
- *Calocephalus multiflorus*
- *Calotis* sp. Perrinvale Station (RJ Cranfield 7096)
- *Calotis hispidula*
- *Calotis multicaulis*
- *Cephalipterum drummondii*
- *Chthonocephalus pseudevax*
- *Dielitzia tysonii*
- *Gilruthia osbornei*
- *Helipterum craspedioides*
- *Hyalosperma glutinosum* subsp. *glutinosum*
- *Hypochaeris glabra**
- *Isoetopsis graminifolia*
- *Lawrencella rosea*
- *Lemooria burkittii*
- *Millotia myosotidifolia*
- *Olearia humilis*
- *Olearia pimeleoides*
- *Olearia stuartii*
- *Podolepis canescens*
- *Podolepis capillaris*
- *Podolepis lessonii*
- *Pogonolepis stricta*
- *Rhodanthe battii*
- *Rhodanthe citrina*
- *Rhodanthe laevis*
- *Rhodanthe maryonii*
- *Rhodanthe stricta*
- *Schoenia cassiniana*
- *Senecio glossanthus*
- *Waitzia acuminata* var. *acuminata*

Boraginaceae
- *Omphalolappula concava*

Boryaceae
- *Borya sphaerocephala*

Brassicaceae
- *Lepidium oxytrichum*
- *Stenopetalum anfractum*

Caesalpiniaceae
- *Senna artemisioides* subsp. *filifolia*
- *Senna artemisioides* subsp. *helmsii*
- *Senna artemisioides* subsp. *helmsii* x *glaucifolia*
- *Senna artemisioides* subsp. *petiolaris*
- *Senna charlesiana*
- *Senna glaucifolia*
- *Senna glaucifolia* x subsp. Meekatharra (E Bailey 1–26)
- *Senna glutinosa* subsp. *chatelainiana*
- *Senna* sp. Austin (A Strid 20210)
- *Senna* sp. Meekatharra (E Bailey 1–26)

Casuarinaceae
- *Allocasuarina acutivalvis*

Chenopodiaceae
- *Atriplex bunburyana*
- *Atriplex semilunaris*
- *Dysphania melanocarpum* forma *melanocarpum*
- *Dysphania saxatile*
- *Enchylaena lanata*
- *Enchylaena tomentosa* var. *tomentosa*
- *Maireana carnosa*
- *Maireana convexa*
- *Maireana georgei*
- *Maireana glomerifolia*
- *Maireana planifolia*
- *Maireana suaedifolia*
- *Maireana thesioides*
- *Maireana tomentosa* subsp. *tomentosa*
- *Maireana trichoptera*
- *Maireana triptera*
- *Rhagodia drummondii*
- *Rhagodia eremaea*
- *Salsola tragus*

Sclerolaena densiflora
Sclerolaena diacantha
Sclerolaena eriacantha
Sclerolaena gardneri

Colchicaceae
Wurmbea sp. Paynes Find (CJ French 1237)

Convolvulaceae
Duperreya commixta

Crassulaceae
Crassula colorata var. *acuminata*
Crassula colorata var. *colorata*

Cuscutaceae
*Cuscuta epithymum**

Droseraceae
Drosera bulbosa subsp. *major*

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

Frankeniaceae
Frankenia setosa

Geraniaceae
*Erodium aureum**
Erodium cygnorum

Goodeniaceae
Goodenia berardiana
Goodenia havilandii
Goodenia mimuloides
Goodenia occidentalis
Scaevola spinescens
Scaevola tomentosa
Velleia cycnopotamica
Velleia hispida
Velleia rosea

Hypoxidaceae
Hypoxis glabella var. *glabella*

Juncaginaceae
Triglochin isingiana

Lamiaceae
Hemigenia botryphylla
Prostanthera althoferi subsp. *althoferi*
Prostanthera patens
Spartothamnella teucriiflora

Loranthaceae
Amyema fitzgeraldii

Malvaceae
Abutilon cryptopetalum
Abutilon oxycarpum
Hibiscus cf. *solanifolius*
Sida calyxhymenia
Sida ectogama
Sida sp. dark green fruits (S van Leeuwen 2260)
Sida sp. golden calyces glabrous (HN Foote 32)

Mimosaceae
Acacia aff *ulicina* (A Markey & S Dillon 5553)
Acacia andrewsii
Acacia aneura var. cf. *alata*
Acacia aneura var. cf. *aneura*
Acacia aneura var. cf. *argentia*
Acacia aneura var. cf. *intermedia*
Acacia aneura var. cf. *macrocarpa*
Acacia aneura var. cf. *microcarpa*
Acacia aneura var. cf. *tenuis*
Acacia aneura var. cf. *tenuis/aneura* intergrade
Acacia aneura x *craspedocarpa*
Acacia assimilis subsp. *assimilis*
Acacia aulacophylla
Acacia burkittii
Acacia cf. *incognita*
Acacia effusifolia
Acacia craspedocarpa
Acacia eremaea
Acacia exocarpoides
Acacia grasbyi
Acacia ramulosa var. *ramulosa*
Acacia sclerosperma subsp. *sclerosperma*
Acacia speckii
Acacia subsessilis
Acacia tetragonophylla
Acacia tysonii
Acacia umbraculiformis
Acacia victoriae

Myoporaceae
Eremophila clarkei
Eremophila exilifolia
Eremophila forrestii subsp. *forrestii*
Eremophila galeata
Eremophila georgei
Eremophila glutinosa
Eremophila granitica
Eremophila latrobei subsp. *latrobei*
Eremophila oldfieldii subsp. *oldfieldii*
Eremophila oppositifolia subsp. *angustifolia*
Eremophila pantonii
Eremophila platycalyx subsp. *platycalyx*
Eremophila punicea

Myrtaceae
Aluta aspera subsp. *hesperia*
Calytrix uncinata
Melaleuca hamata
Micromyrtus sulphurea
Thryptomene costata
Thryptomene decussata

Papilionaceae
Mirbelia bursarioides
Swainsona oliveri

Phormiaceae
Dianella revoluta var. *divaricata*

Pittosporaceae
Cheiranthera filifolia var. *simplicifolia*

Plantaginaceae
Plantago debilis

Poaceae
Aristida contorta
Austrodanthonia caespitosa
Austrostipa elegantissima
Austrostipa nitida
Austrostipa scabra s. l.
Austrostipa trichophylla
Bromus arenarius
Cymbopogon ambiguus
Elymus scaber
Enneapogon caerulescens
Eragrostis dielsii
Eragrostis eriopoda

Appendix 1 (cont.)

Eriachne pulchella subsp. *dominii*
*Lamarckia aurea**
Monachather paradoxus
Paspalidium basicladum
*Pentaschistis airoides**
*Rostraria pumila**
Thyridolepis mitchelliana
Thyridolepis multiculmis
Tripogon loliiformis

Polygalaceae
Comesperma integerrimum

Polygonaceae
*Emex australis**

Portulacaceae
Calandrinia cf. *creethae*
Calandrinia eremaea s. l.
Calandrinia sp. truncate capsules (A Markey & S Dillon 3474)

Proteaceae
Grevillea deflexa
Grevillea extorris
Grevillea obliquistigma subsp. *obliquistigma*
Grevillea pityophylla
Hakea preissii
Hakea recurva subsp. *arida*
Hakea recurva subsp. *recurva*
Persoonia manotricha

Rubiaceae
Psydrax latifolia
Psydrax suaveolens

Rutaceae
Philotheca brucei subsp. *brucei*
Philotheca sericea

Santalaceae
Exocarpos aphyllus
Santalum spicatum

Sapindaceae
Alectryon oleifolius subsp. *oleifolius*
Dodonaea amplisemina
Dodonaea inaequifolia
Dodonaea petiolaris
Dodonaea rigida

Solanaceae
Nicotiana cavicola
Nicotiana occidentalis subsp. *occidentalis*
Nicotiana rosulata subsp. *rosulata*
Solanum ellipticum
Solanum lasiophyllum
Solanum nummularium
Solanum orbiculatum subsp. *orbiculatum*

Sterculiaceae
Brachychiton gregorii
Rulingia luteiflora

Stylidiaceae
Stylidium longibracteatum

Thymelaeaceae
Pimelea forrestiana

Urticaceae
Parietaria cardiostegia

Zygophyllaceae
Zygophyllum lobulatum