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Flora and vegetation of the Banded Iron Formations of the Yilgarn Craton: the Booylgoo Range

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ABSTRACT

A quadrat-based survey was undertaken of the vascular flora and plant communities on the Booylgoo Range, 65km east of Sandstone in the arid Murchison bioregion. The Range is an outcropping of the Booylgoo greenstone belt, which consists of diverse lithologies that includes Archaean banded iron formation (BIF), metabasalt, mafics, and Tertiary laterites. Quadrats were strategically placed to cover these broad geologies and the topographic profile of this range. This survey identified a total of 207 taxa (species, subspecies, varieties and forms) and nine putative hybrids from 47 families of vascular plants. This includes six species of conservation significance, five of these being new records for the area. Range extensions exceeding 100km are reported for nine species, but no endemic taxa were found. Classification analysis of presence/absence data on perennial taxa at 51 sites resolved six floristic community types, one of these with two subtypes. These are described in terms of structure, dominant taxa, indicator species and associated soil and environmental attributes. There is a strong association of community types with edaphic factors (topology, rock substrate and soil chemistry). The greatest floristic dissimilarity among communities is between those on banded iron formation and those on mafic substrates, which is associated with marked differences in soil chemical characteristics. Within BIF sites, the greatest floristic differences are between upland and lowland communities. This is associated with the extremes along a topo-edaphic gradient. The Booylgoo Range is an isolated, arid-zone landform whose different communities are tightly linked to landform element, topography and substrate. Mining and exploration tenements cover all of the survey area and the Booylgoo Range lies on two active pastoral leases. None of the range occurs within the secure conservation estate.

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

INTRODUCTION

The Booylgoo Range is a notable topographical feature in that it is one of very few ranges of significant elevation in the greater Sandstone region, in the northern Yilgarn region of Western Australia. Underlying the range is the Booylgoo greenstone belt, which consists of metamorphosed volcanics and metasedimentary rocks of great antiquity (Tingey 1985; Wyche 2004). It is one of many located within the granitoids of the northern Yilgarn Craton (Cassidy *et al.* 2006; Groenewald & Riganti 2004). This outcropping of bedrock forms a series of rises, hills and ridges that attain elevations of up to 100 m above the surrounding plains of sediments. These and other greenstone belts in the Murchison Mineral Field have been subject to exploitation over the past century for base and precious metals. A significant component of the Booylgoo greenstone belt is banded iron formation (BIF), and a renewed expansion of the iron ore industry in Western Australia has targeted these BIF landforms as highly prospective for iron ore.

Massive outcrops and ranges of ironstones and volcanics provide a challenging environment for plants because of a variety of conditions, including skeletal, acidic, low nutrient and metal-enriched soils with a low water holding capacity and high runoff, hard substrates, excessive UV irradiation, wind exposure and high temperatures (de Castro Vincent & Meguro 2008; Jacobi *et al.* 2007). Nonetheless, these landforms have been found to support diverse floras, distinctive communities and uncommon, endemic or unusual species (Butler & Fensham 2008; van Etten & Fox 2004; Gibson *et al.* 2007; Jacobi *et al.* 2007). Previous surveys have characterised the floristic communities on discrete, isolated greenstone and BIF ranges in the Eastern Goldfields of the Yilgarn Craton (Gibson & Lyons 1998a, 1998b, 2001a, 2001b; Gibson 2004a, 2004b). These floras have been found to be species–rich, have high species turnover among ranges (?-diversity), and can harbour new, rare and poorly known taxa and regional endemics. These studies have also established that the floristic communities are varied both within an individual range and among ranges, and some communities are geographically restricted. Given the deficiency of detailed flora surveys for BIF ranges in the

Northern Yilgarn, this current work is part of an ongoing series of floristic surveys on banded iron formation and greenstone landforms within the northern Murchison geological region of the Yilgarn Craton (Department of Environment 2007; Gibson *et al.* 2007). These surveys aim to provide description of the flora and vegetation communities, which will assist in strategic conservation planning and management for these highly prospective BIF and greenstone ranges (Department of Environment 2007; Department of Industry and Resources 2007). This particular study specifically aims to describe the flora and floristic communities on the Booylgoo Range.

Study Site

The Booylgoo Range is a significant outcropping of Archaean bedrock in the general Sandstone region that is located approximately 65km east of the township of Sandstone and 125km south of Wiluna, in the Murchison region of Western Australia (Fig. 1). It is a north-south trending greenstone belt occurring over a latitudinal range of 27.68 º S – 28.01 º S and a longitudinal range of 119.87 – 119.99 º E, which is c. 40km long and c.4–5km wide along much of its length. It extends over the Booylgoo Spring and Depot Spring Stations, within the shire of Sandstone.

Land Use History

As with much of the Murchison region, pastoralism and mining historically have been the economic mainstays in the greater Sandstone region (Hennig 1998a; Tingey 1985). Although the general Sandstone region is marginal grazing land, pastoral leases were initiated within the first decade of the 20th century, and firmly established by the 1920's (Tingey 1985). Both the Booylgoo Spring and Depot Spring stations are active pastoral leases and currently stock cattle.

Gold deposits were located in the greater Black Range district area of the East Murchison Goldfields in the 1890s, leading to the establishment of Sandstone and Youanmi townships (Hennig 1998a; Tingey 1985). Gold production and the population in the Sandstone township and surrounds peaked around 1912, only to decline after the late 1920s (Hennig 1998a; Tingey 1985). Interest in gold, base metals and iron-ore was renewed in the 1960's and again from late 1970s onwards, such that mining continues on the Sandstone and Gum Creek belts (Tingey 1985; Wyche *et al.* 2004). Owing to little evidence of gold mineralisation, the Booylgoo Range itself has only only been subjected to mineral exploration and has not been subject to the same intensive mining that has occurred on surrounding areas (Wyche *et al.* 2004). Economically viable deposits of iron-ore have been identified in the BIF ridges of the Booylgoo Range (Flint *et al.* 2000).

Climate

Booygloo Spring and Depot Spring stations are on the western border of the north-eastern Goldfields and Sandstone – Paynes Find regions, where the climate is described as arid (Gilligan 1994) or a desert with a limited, bimodal rainfall (Beard 1976, 1990). The closest meteorological centre to the study area is at Booylgoo Spring Station (Fig. 1), which records an average annual mean rainfall of 236mm (Australian Bureau of Meteorology 1908–). The wettest months are February and March, while the driest is September. Sporadic summer rainfall occurs when the remnants of tropical cyclones pass into the Eremaean region, while irregular winter and spring rainfall arrives with moist, south-westerly cold fronts (Leighton 1998). The Booylgoo Range lies within a region with a high drought susceptibility, where annual evaporation range for the region (approaching 3600mm) greatly exceeds the annual rainfall (Gilligan 1994; Leighton 1998). The temperature regime for Booylgoo Spring is for hot summers and cool winters (Australian Bureau of Meteorology 1908–). The average winter (June–August) daily maximum and minimum temperatures are 18.5 °C and 5.2 °C, while the average summer (December–February) daily maximum and minimum temperatures are 35.3 °C and 20.7 °C respectively.

Geology

The geology of the Booylgoo Range and surrounding areas has been described and mapped on the Sandstone 1:250 000 geological sheet (SG/50-16) (Tingey 1985) and Lake Mason 1:100 000 (Sheet 2842) (Wyche 2004). The wider area around the Booylgoo Range, as depicted on the Sandstone sheet, predominately consists of gently undulating plains of Cainozoic sediments. A small proportion of this area of low relief is interrupted by outcropping ranges of Archaean bedrock, which provides the only topographical relief to an otherwise flat landscape. The Booylgoo Range varies in elevation from 470 m above sea level on the lowest slopes and surrounding flats to between 520 and 560 m on the taller ridges. Mt Anderson (576 m) and Mt St Michael (564 m) are the two tallest named peaks for the range (Fig. 1).

The Booylgoo Range is formed by outcropping of the Booylgoo greenstone belt, which consists of a succession of metamorphosed sedimentary deposits and volanic intrusions laid down during the Archaen eon. The metamorphosed igneous rocks include mafic (basalts and gabbro) and ultramafic intrusions, while banded iron formation (BIF) is a significant component of the metasediments (Tingey 1985; Wyche 2004). BIF itself consists of a series of alternating fine layers of shales, silstone, cherts and iron oxide rich sediments, and can host mineral deposits (Page 2001). The Booylgoo greenstone belt occurs within the Southern Cross Domain of the Youanami Terrane (Cassidy *et al.* 2006); previously referred to as the South Cross Granite Greenstone Terrane (Tyler & Hocking 2001a, 2001b). Similar greenstone belts in the Youanmi Terranes have been dated at c. 3.0–2.7 Ga (Cassidy *et al.* 2006). The Booylgoo greenstone belt is a syncline, with the north and south ends dipping towards the centre (Tingey 1985; Wyche 2004). Since the BIF occurs at the lower levels in the sequence, deformations

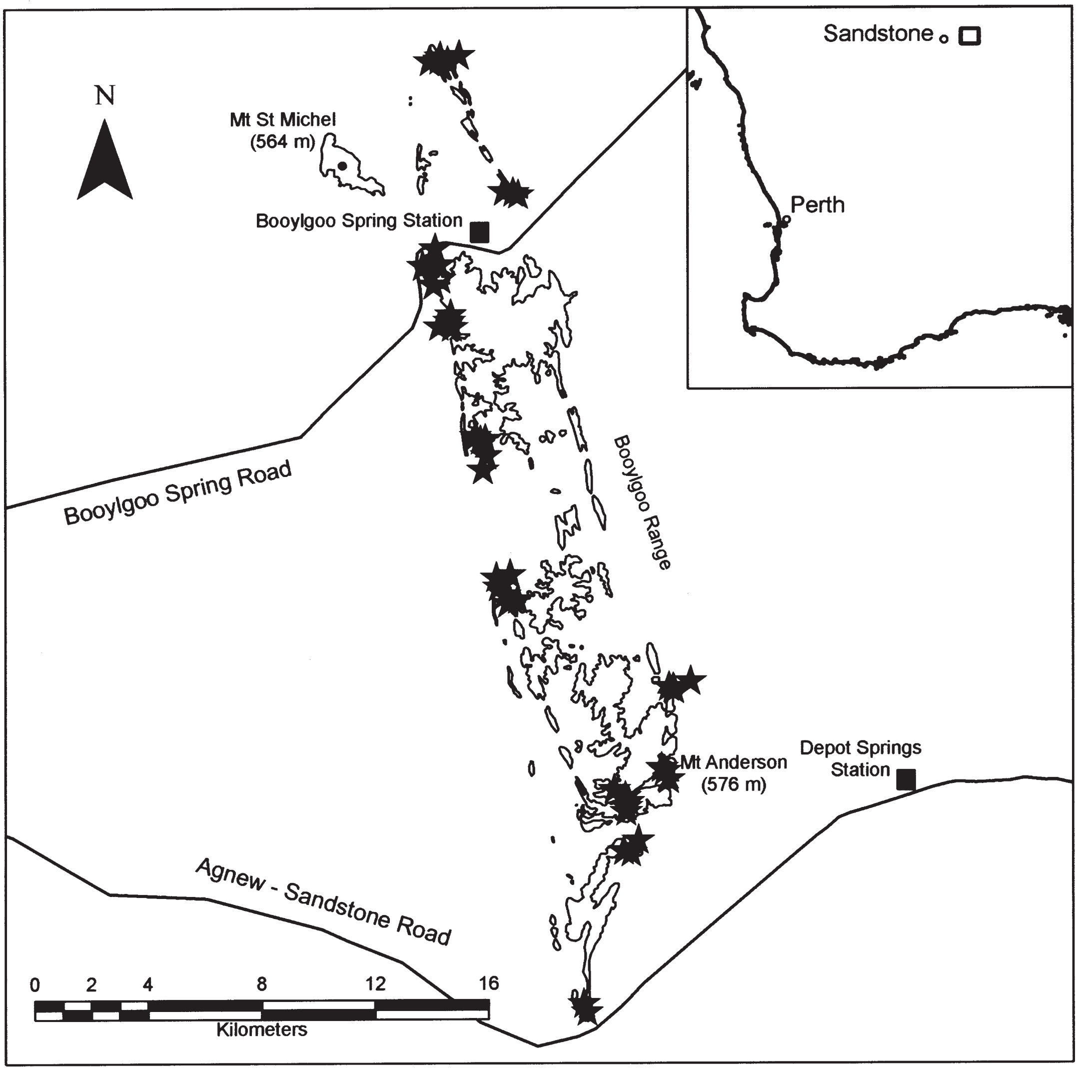

Figure 1. Map depicting the general location of the Booylgoo Range within Western Australia (insert). The major ridges of the range are outlined and associated significant landmarks are labelled. The positions of the 51 floristic quadrats are demarkated by star symbols (★).

have resulted in the protrusion of prominent ridges of BIF on the outer margins of the range. Therefore, this BIF is exposed as two major north-south trending, near parallel ridges that border central ridges of massive to foliate mafic rocks, including metabasalts, komatiitic basalt (metamorphosed), fine-medium grained mafic rock (strongly foliate to schistose), ultramafics (peridotite), tremolite-chlorite-(magnetite) schist and metagabbro (Wyche 2004). The tallest and most extensive outcroppings of BIF occur in the southern half of the range.

There are three main discontinuities within the latitudinal extent of the range, where the bedrock has been extensively dissected by the larger drainage systems and covered by alluvial and colluvial deposits (*cf.* Wyche 2004). The northernmost gap is where the Booylgoo Spring homestead is located and where the Booylgoo Spring Road crosses the range (Fig. 1). In the centre of the range a large area has been eroded by drainage and this partially interrupts the range. The third main discontinuity occurs south of Mt Anderson and the associated east-west oriented band of BIF. South of this point, the range becomes a series of narrow, north-south trending, arcuate ridges of BIF and metabasalt which form a series of low hills of massive BIF that terminate immediately north of the Agnew–Sandstone Road.

Cainozoic deposits, which are derived from weathering of the exposed bedrock, overlie the lower slopes, flats and outwashes of the Booylgoo Range. Scree of predominately eroded chert and banded iron formation lines the flanks of BIF ridges, while an alluvium of clay, silt and gravel has accumulated in drainage lines. Colluvial deposits and alluvial sheetwash of clay, silt and ferruginous gravels overlie the plains further from the range (*cf.* Wyche 2004). Relatively small areas of ferruginous lateritic duricrust overlie the pediment of BIF ridges along the eastern flanks of the BIF ridges, which often erodes into breakaways. Abutting onto the western flanks of Booylgoo Range is a distinct sandplain of aeolian deposits which overlie weathered regolith.

Soils of greenstone landforms in the eastern Murchison region are derived from weathering of parent rock (mafic metavolcanics and BIF), and as such these soils are typically shallow to skeletal (< 50cm) rudosols (lithosols) or stony red earths becoming progressively shallow stony red earths on the lower slopes, flatsand outwashes (Churchward 1977; Hennig 1998b; van Vreeswyk 1994). Texturally, these soils are fine sandy loam – clay loams, and often contain an abundance of rock fragments. Fine ironstone gravels can be found in weathered soil profiles on pediments, plains and outwashes (Hennig 1998b). The soils are relatively poorly developed, infertile and characteristically acidic (pH 5.0–7.0) (Churchward 1977; Hennig 1998b; van Vreeswyk 1994). Being derived from metalliferous rock, soil concentrations of metal elements are higher than those derived from granitoids (Cole 1973; Churchward 1977; Gray and Murphy 2002).

Vegetation

Using the current Interim Biogeographic Region (IRBA) classification (Environment Australia 2000; Thackway & Creswell 1995), the Booylgoo Range is located within the Murchison IBRA bioregion which has been adopted from the Austin Botanical District and Eremaean Botanical Province of Beard (1976, 1990). The vegetation of this district is dominated by mulga (*Acacia aneura*) low woodlands on plains and mixed *Acacia* stands on rocky outcrops. Beard (1976, 1990) further described the Wiluna subregion of the Austin Botanical District, within which the Booylgoo Range is located, where the vegetation on rocky ranges are described as essentially a shrubby cover of *Acacia aneura*, *Acacia quadrimarginea*, *Acacia grasbyi* and *Hakea suberosus* (= *H. lorea*) over *Cassia* (*Senna*), *Eremophila clarkei* and *Eremophila latrobei* undershrubs, over *Ptilotus obovatus* and annual herbs. This brief description applies to both greenstone and granite hills, as Beard considered the vegetation as similar. Beard (1976) mapped these as uniform physiognomic units on a scale of 1:1 000 000.

To date, there have been no fine scale surveys on the Booylgoo Range per se, and the closest vegetation community descriptions are those by Pringle (1994a, 1998a), which are inclusive in the wider rangeland surveys of the north-eastern goldfields (Pringle & van Vreeswyk (1994) and the Paynes Find – Sandstone region (Payne *et al.* 1998). These surveys have adopted the land system approach, where a land system is a catenary sequence of vegetation communities linked to geological and topographic features. The ridges of BIF and associated metasediments of the Booylgoo Range have been mapped as the Brooking land system (Payne *et al.* 1998; Pringle & van Vreeswyk 1994), which has up to five community types, one to two of these occurring on these uplands (Pringle 1994a, 1998a). Hills of mafic rocks have been mapped as the Gabanintha and Laverton land systems by Payne *et al.* (1998) and Pringle and van Vreeswyk (1994), respectively, and these support five community types, two or three of these occurring on ridges, hill crests and hill slopes. Vegetation communities are common to both land systems, including the main upland stony ironstone mulga shrublands unit and the greenstone hill acacia shrublands (Pringle 1994a, 1998a). Several other mulga shrubland and saltbush communities characteristic of stony plains, lateritic hard pans and drainage tracts occur on the lowlands around these land systems.

METHODS

The methodology employed in this survey follows the standard procedure that has been used in previous vegetation community surveys of other BIF and greenstone ranges in Western Australia (Gibson and Lyons 1998a,1998b, 2001a, 2001b; Gibson 2004a, 2004b; Markey & Dillon 2006a, 2006b; Meissner & Caruso 2008a, 2008b, 2008c). Fifty one 20 x 20 m permanent quadrats were established over the survey area in spring during a two week period of September 2006. Quadrats were established over both the longitudinal and latitudinal extent of the range and placed strategically in vegetation communities on BIF and adjacent geologies to cover the broad toposequence, from hill crests and slopes of exposed bedrock and scree to colluvial deposits on pediments and plains. Only vegetation in good, undisturbed condition was sampled, thereby avoiding burnt, heavily grazed and cleared areas. The vegetation on the adjoining sandplain on the south-western side of the range was not sampled as the substrate was not derived directly from the range bedrock and had been burnt within the past five years.

Quadrats were marked with four steel fence droppers, photographed and both location and altitude recorded with a GPS receiver (Garmin 76, Garmin Ltd). Vegetation structure using dominant taxa was described according to McDonald *et al.* (1998). Cover class estimates of all vascular plant species (spermatophytes and pteridophytes) were recorded, and material was collected for identification at the Western Australian Herbarium. Data on topographical position, aspect, slope, altitude, percentage litter, percentage bare ground, percentage rock cover class of both surface deposits and exposed bedrock, shape of surface rock fragments, soil colour and soil texture were collected according to McDonald *et al.* (1998). Leaf litter and bare ground were visual estimates of percentage cover (bare ground cover including litter and rock cover), and slope readings were obtained from a clinometer. Topographic position (Tp) was coded as semi-quantitative, five point scale (flat / outwash =1, lower slope = 2, mid slope = 3, upper slope or low ridge = 4, crest = 5. Both surface rock fragment (Rock Frag) and exposed bedrock outcrop (% rock) cover classes were scored on seven point cover scale; 0% cover (0); < 2% cover (1); 2–10%, (2); 10–20% (3); 20–50% (4); 50–90% (5); > 90% (6). Maximum rock fragment size (MxR) was classed on a seven point size scale; 2–6mm (1); 6–20mm (2); 20–60mm (3); 60–200mm (4); 200–600mm (5); 600mm–2m (6); > 2m (7).

A bulked topsoil sample (10cm depth) was compiled from 20 subsamples collected over the area of the quadrat. Soil colour was gauged in the field and soil texture was estimated manually according to McDonald *et al.* (1998). Particles over 2mm in size were removed by sieving before soil chemical composition was analysed at the Chemistry Centre of Western Australia. Mineral concentrations were determined by inductively coupled plasma atomic emission spectrometry (ICP AES) for the simultaneous determination of a suite of 16 elements (Al, B, Ca, Cd, Co, Cu , Fe , K, Mg, Mn, Mo, Na, Ni, P, S and Zn), using the Mehlich No. 3 soil test procedure (Mehlich 1984, Walton & Allen 2004). Soil pH was determined in 0.01M $CaCl_2$ (method S3, Rayment & Higginson 1992). The effective Cation Exchange Capacity (eCEC) (cmol(+)/kg) was calculated as the sum total of individual Na, Ca, K and Mg charge equivalents, which were calculated from their respective cation concentrations from ICP AES (Rayment & Higginson 1992; Soil and Plant Council 1999). Electrical conductivity (EC) was determined by method S2 (using a conductivity meter on a 1:5 solution of soil extract:deionised water at 25 ºC (Rayment & Higginson 1992). Soil organic carbon (%) was determined using Metson's colorimetric modification of the Walkley and Black wet oxidation method S09 (Metson 1956, method 6A1 of Rayment & Higginson 1992). Total soil nitrogen (%) was determined by a modified kjeldahl digest (method S10) (Rayment & Higginson 1992).

Floristic communities were determined from simultaneous classification and ordination analyses on dissimilarity matrices (Bray-Curtis coefficient), which had been derived from site by species data matrices, using the PATN (V3.03) (Belbin 1989). For final analyses, annual taxa and perennial singletons (a taxon known from a single quadrat) were omitted, following the protocol employed in previous surveys on Western Australian ironstone and greenstone ranges (e.g. Gibson 2004a, 2004b). This was after the dissimilarity matrixes with sets of taxa were compared using the '2 Stage' algorithm in Primer (Clark & Gorley 2006), and found to be highly correlated. Species and site classifications was undertaken using the flexible 'unweighted pair group method using arithmetic averages' (UPGMA) algorithm, which is agglomerative, hierarchical clustering method (*?* = -0.1) (Belbin 1992; Sneath & Sokal 1973). A two-way table was generated from these site and species classifications. Indicator species analysis (Dufrêne & Legendre (1997) was employed to determine the significant indicator species for each floristic community type, using the INDVAL routine in PC-Ord (McCune & Mefford 1999) and a Monte Carlo permutation test (10 000 simulations) to evaluate the statistical significance of each taxon.

Semi-strong hybrid (SSH) nonmetric multidimensional scaling (MDS) was used to resolve spatial relationships in three dimensions among the sites from the floristic data, using 1000 random starts and 50 iterations (Belbin 1991). Principal Component Correlation (PCC) was used to determine the linear relationship between environmental variables on the site ordination coordinates (Belbin 1989). A Monte-Carlo permutation test (MCAO) was employed to evaluate the significance of the PCC correlation coefficients, using 10000 iterations of this procedure (Belbin 1989). Kruskal-Wallis nonparametric analysis of variance and Dunns' posthoc multiple comparisons were employed to determine differences in environmental variables among the community types (Zar 1984).

Representative specimens of all taxa have been lodged at the Western Australian Herbarium. Collection details and geographical distributions of taxa were obtained from online records (Western Australian Herbarium 1998–). The conservation status of taxa, according to the Western Australian Department of Conservation (DEC) codes, was obtained from Atkins (2008).

RESULTS

Flora

The survey flora list was compiled from the 51 quadrats and opportunistic collections around the Booylgoo Range (Appendix 1). From this, a total of 207 taxa (species, subspecies, varieties and forms) and nine putative hybrids were recorded. Four of the 207 taxa were introduced weeds. No regionally endemic taxa (defined as having a distribution restricted to within a 100km radius) were found during this survey. Taxa were from 47 families, of which the most common were the Poaceae (21 introduced taxa), Asteraceae (19 taxa), Mimosaceae (all taxa of *Acacia*, 17 taxa and 1 hybrid), Myoporaceae (all *Eremophila*, 15 taxa), Chenopodiaceae (15 taxa and 1 hybrid), Caesalpineaceae (all *Senna*, 8 taxa and 6 hybrid entities) Malvaceae (11 taxa, *Sida* 6 taxa), Goodeniaceae (8 taxa), Amaranthaceae (all *Ptilotus*, 8 taxa), Myrtaceae (8 taxa) and Solanaceae (7 taxa) (Appendix 1). Low cover values for herbaceous annuals and geophytes in the quadrats were attributed to dry winter conditions, while summer rains had promoted an abundant cover of annual grasses (*Aristida contorta* and *Eriachne pulchella*).

Priority taxa

Six species of conservation significance were collected in this survey (Table 1), all being recognised under DEC conservation codes (Atkins 2008) as uncommon or data deficient. Five species were new records for the Booylgoo Range, but none of these species can be considered as endemic to the range or wider Sandstone region (Table 1). With the exception of *Grevillea inconspicua* and *Calytrix eriosepetala*, these species were found to be largely restricted to banded iron formation substrates when collected from the Booylgoo Range. *Grevillea inconspicua* tended to be associated with mafic and ultramafic lithologies downslope from exposed BIF seams, and was most common in the central part of the range. *Calytrix erosipetala* was associated with laterites, either on pediments flanking ironstone hills or on laterite breakaways located away from the main range.

For both *Baeckea* sp. Melita Station (H. Pringle 2738) and *Calytrix erosipetala*, the Booylgoo Range populations were a minor range extension of < 50km east of previously known occurrences. *Baeckea* sp. Melita Station (H. Pringle 2738) has a narrow distribution within the eastern Murchison and Yalgoo regions, while *Calytrix erosipetala* is known from approximately 20 locations scattered throughout the wider Murchison bioregion. The ranges of three priority species were extended by over 100km. *Acacia balsamea* has a distribution which extends from north-east Murchison to central and north-west Western Australia, and this latest collection is a range extension of c. 100km west from the nearest known population. The collection of *Homalocalyx echinulatus* at Booylgoo Range extends the southern limit of this species by c. 125km. Although *Calytrix uncinata* is recorded from the Booylgoo Range for the first time, the nearest populations being 100 and 150km north-east and north-west respectively, this new population is within its known range. It was found to be uncommon, being located at a single location on a low ridge of weathered ironstone at the northern end of the range.

Putative new taxa

Two taxa were identified in this survey that have affinities to known taxa but were sufficiently morphologically distinct to consider as putative new entities. *Acacia* aff. *siberica* (PERTH 07556969) belongs to the Juliflora species complex of the Eremaean (flat, multi-nerved phyllodes with cylindrical flowers), and is most closely allied to *A. siberica*, which was also collected from the Booylgoo Range. Although mature pods are lacking from collections, it is suspected that this collection is different enough from *Acacia siberica sensu stricto* to be considered a separate entity (B. Maslin, pers. comm[1].). *Acacia* aff. *siberica* differs from *Acacia siberica* by having adpressed hairs on the phyllodes (versus glabrous phyllodes in *A. siberica*), and united calyx lobes for half their length whilst they are united for less than half their length in *Acacia siberica*.

A previously unrecognised variant of *Acacia xanthocarpa* was collected from this survey. This variant posses flat phyllodes, as opposed to the terete phyllodes of the more typical form. Further investigation may show this to be a new taxon, possibly even a new species (B. Maslin, pers. comm.[1]). Subsequent examination of the herbarium collections has located other specimens from near Booylgoo Springs Station and Lake Mason Station, c. 50km north-west of the Booylgoo Range. Where parent rock type has been noted, this species has been collected mainly from hills of metavolcanics and gabbro.

Putative hybrids

Although interspecific hybrids and intergrades of *Senna*, *Maireana* and *Acacia* were collected, no new putative hybrid combinations were found in this survey. Six putative hybrids of *Senna* taxa were identified, although there was a continuum of intermediate forms (intergrades) between *Senna glaucifolia* and *Senna* sp. Meekatharra (E. Bailey 1–26), and between *Senna glaucifolia* and *Senna artemisioides* subsp. *helmsii* (see Appendix 1). Other *Senna* hybrids were relatively more distinct and discrete entities, including the putative hybrid *Senna glutinosa* subsp. *chatelainiana* x *charlesiana*. This entity matches collections lodged at the Western Australian Herbarium under the name *Senna artemisoides* subsp. *filifolia* x *glutinosa* subsp. *chatelainiana* so the entities are probably synonymous. Preference is given to the former hybrid combination because the *S. artemisoides* complex does not hybridise with the *S. glutinosa* complex, but hybrids can occur within each complex (Randall & Barlow 1998).

Range extensions

Seven other species without a priority conservation listing had their known range limits extended by c. 100–200km from the closest known collection (Western Australian Herbarium 1998–). *Indigofera monophylla* is widespread in northern Western Australia, and the population at Booylgoo Range was a 200km south-east range extension from its southern limit. The range of *Sida* sp. spiciform panicles (E. Leyland s.n. 14/8/90) was extended 350km south-east of its previously known limit. The south-eastern limit of *Cheilanthes brownii* was moved further into the Murchison region,100km south of populations on the Herbert Lukin Ridge, near Wiluna.

Hibiscus solanifolius (*sensu lato*) has a disjunct distribution in the Great Sandy Desert and Coolgardie-Murchison regions. Recent collections from the Booylgoo Range, the Herbert Lukin Ridge (c. 125km north of Booylgoo) (Markey & Dillon, in press), and the Robinson Range (c. 290km northwest) (Meissner *et al*, in press [c]) have extended the range of this entity into the northern Murchison region. It may eventuate that *Hibiscus solanifolius* is a complex of several entities (L. Craven, pers. comm[2]). Similar to *Hibiscus solanifolius*, *Hibiscus sturtii* var. *truncatus* has a disjunct distribution in central and coastal northern Western Australia. The Booylgoo Range collections push the south-western range limit of this latter species west into the central Murchison by c. 200km. The status of *Hibiscus* taxa will be verified during the current revision of the genus (L. Craven, pers. comm[3]).

The perennial sedge, *Cyperus vaginatus*, was located at the southern end of Booylgoo Range, where it was common in a creekline associated with a permanent spring near Mt Anderson. This location pushes its range south-east into central Murchison by c. 225km, which is at the south-eastern limit of a range that extends north into the Pilbara and has disjunctions occurring in the Great Sandy Desert bioregion.

Acacia sp. Peak Hill (R. Gibson 0003) is an informally named entity of which there are seven known populations

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scattered in the Murchison and Gascoyne bioregions (Western Australia Herbarium 1998–). Most occurrences are on the tops and slopes of greenstone and laterite hills. The Booygloo Range population is therefore a significant southern range extension c. 200–280km south of other known populations. Superficially, *Acacia* sp. Peak Hill (R. Gibson 0003) resembles *A. coolgardiensis* or *Acacia ramulosa*, and is part of the Juliflora species complex (flat, multi-nerved phyllodes and cylindrical flowers) (B. Maslin, pers. comm.[4]). This tall shrub (2–3 m) was found only in one small area on BIF at the south-east of the Booylgoo Range, where it was locally common.

Floristic Communities

Twelve taxa were amalgamated into six species complexes for floristic analyses. Among these were hybrid intergrades of *Senna glaucifolia* x sp. Meekatharra (E. Bailey 1–26), which were amalgamated with the one parental taxon to which they were the most morphologically similar. Closely related taxa were amalgamated when this grouping was more informative than when taxa were separate (e.g. four forms of *Haloragis odontocarpa*, and *Eriachne mucronata* and *E. helmsii*), or when they could distinguished due to poor quality of flowering material (e.g. subspecies of *Eremophila forrestii*). The *Acacia aneura* species complex is so variable that it could only be resolved into morphotypes which approximated the varieties described by Pedley (2001), which are consistent with the morphotypes used in previous ironstone surveys (Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c).

For classification and ordination analysis, the site by species matrix consisted of 189 taxa from 51 quadrats within the survey area, of which 62 were annuals and 36 perennial singletons. The average species richness per quadrat was 23.2 ± 1.9 (s.e.) taxa per quadrat, and ranged from 15 to 43 taxa per quadrat. Preliminary analyses verified that singletons and annuals had little overall effect on the classification, and the '2-Stage' comparison of resemblance matrices found 92% correlation between the data matrix with all taxa (singletons and annuals) and the shared perennial dataset used in final analyses. The final shared perennial data matrix consisted of 91 taxa from 51 quadrats, which was 48% of total number of taxa. The average species richness of this final dataset was 16.0 ± 1.3 (s.e) taxa per quadrat, with a range of between 11 and 32 taxa per quadrat.

The floristic classification of the shared perennial dataset simultaneously resolved the sites and species into a hierarchal set of groupings for their respective site and species classifications. From the species classification, the 91 taxa were resolved into nine species groups, which are listed in a sorted two-way table of the site and species classification (Appendix 2). The primary division in the site classification separated floristic communities on mafic-influenced sites (Community types 5 and 6) from those on landforms of banded iron formation (Community types 1–4) (Fig. 2). This split is associated with differences across several species groups (Appendix 2), notably the species groups that contain the more common taxa (A, G and H). Within this latter grouping of banded ironstone sites, there was a further major division which separated sites on lower slopes, pediments and alluvial outwash / colluvial plains from those located generally higher in the landscape, particularly on hill slopes and crests. This division is also discernable on the sorted two-way table, where it is

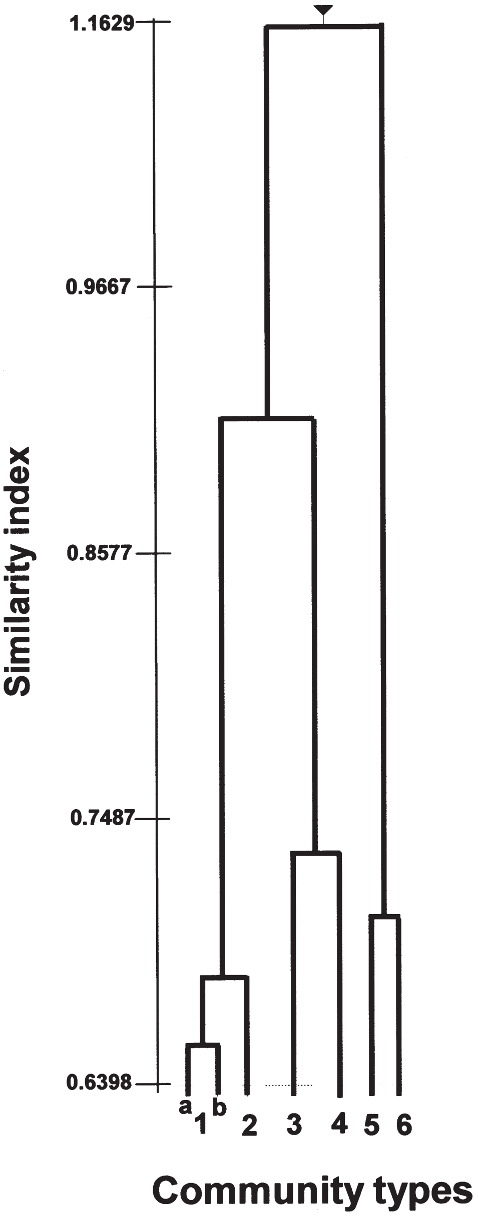

Figure 2. Summary dendrogram of six floristic community types of the Booylgoo Range from classification analysis of a presence / absence dataset of 189 perennial taxa from 51 quadrats, based on UPGMA (flexible) clustering and Bray-Curtis co-efficient of dissimilarity. The dendrogram is resolved to the six group level, with a further two subtypes resolved in Community type 1.

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particularly evident in species groups D–F and G (Appendix 2). At the six group level in the site classification, the 51 quadrats are grouped into six main community types, with one of these communities (Community type 1) further subdivided in two subtypes (Fig. 2).

Community type 1 is a grouping of sites on rocky hill slopes and crests of ridges of banded iron formation. It has good representation in Species group H. Community type 1a is structurally heterogenous unit on gentle to moderately steep hill slopes and crests. Typically this floristic community consists of tall open - sparse *Acacia aneura* shrubland where *Acacia aneura* var cf. *microcarpa* is a significant indicator species, and often with additional *Acacia* species such as *A. quadrimarginea* or *A. thoma.* The sparse mid-stratum consists of various shrubs, including significant indicator species *Eremophila latrobei* subsp. *latrobei*, *Solanum ashbyae* and *Sida* sp. Golden calyces glabrous fruit (H.N. Foote 32) (Table 2). Other common taxa include *Ptilotus schwartzii* and the perennial grasses *Cymbopogon ambiguus* and *Eriachne helmsii*, the latter of which is a significant indicator species. Notable taxa include *Prostanthera campbellii*, *Eriachne helmsii* and *Psydrax suaveolens* on rocky crests, *Homalocalyx echinulatus* and *Eremophila jucunda* subsp. *jucunda*, which form low shrublands on shallow colluvium over sheets of bedrock on mid – lower slopes, and *Senna artemisioides* subsp. *helmsii* and *Eremophila forrestii,* which are also found on mid – lower slopes. Many taxa from Species group I occur in this community type, with limited representation from Species group E–H, otherwise this community type is more poorly represented across the other Species groups A–D, particularly in comparison to Community type 1b (Appendix 2). Species richness is moderately low, with an average number of total taxa of 23.2 ± 1.9 (s.e.) per quadrat (Table 3).

There is some suggestion of further groupings within this heterogenous community type, particularly among crests versus mid-lower slopes. Sites on low ridge crests / hillocks have both clear floristic affinities to Community type 2 and are influenced by adjacent, lower slope communities (see Community type 2 description). More sampling may provide enough floristic information to further subdivide Community type 1a into a upper slope - crest community and a low crests and lower slope community.

Community type 1b is marginally more species rich than Community type 1a (Table 3), with an average total number of taxa being 28.1 ± 1.7 (s.e.) per quadrat (Table 3). Found on gently – moderately inclined mid-upper hill slopes and crests of weathered BIF, this community consists of a more structurally homogenous community than Community type 1a. This community consists of *Acacia aneura* var cf. *microcarpa* and *Thryptomene decussata* tall open - sparse shrubland, with *Acacia ramulosa* var. *ramulosa* as a occasional co-dominant, Common and distinctive mid- stratum shrubs include *Eremophila latrobei* subsp *latrobei*, *Solanum ashbyae*, *Eremophila georgii*, *Dodonaea petiolaris*, *Dodonaea rigida*, *Sida* sp. Golden calyces glabrous fruit (H.N. Foote 32), *Ptilotus obovatus*, *Cheilanthes sieberi*, *Ptilotus schwartzii*, and, less frequently, *Scaevola spinescens* (Table 2). The perennial grass *Thyridolepis multiculmis* is noted as a significant indicator species for the ground layer. Relative to Community type 1a, there is more representation in type 1b from across all species groups, especially A, C and G, but reduced in part of group I.

Community type 2 is the characteristic community type of the steeper, rocky crests and upper slopes of BIF. The majority of sites were located in the southern half of the range, where there are taller and more substantial outcroppings of BIF. It is described as sparse shrublands of *Acacia aneura* and *Thryptomene decussata* over mid-stratum shrubs of *Eremophila latrobei* subsp. *latrobei*, *Prostanthera campbellii*, *Philotheca brucei* subsp. *brucei*, *Eremophila georgei*, *Olearia humilis*, *Sida* sp. Golden calyces glabrous fruit (H.N. Foote 32) and *Dodonaea petiolaris*, over a ground layer that includes *Cheilanthes brownii* and perennial grasses such as *Eragrostis lacunaria* (Table 2). One site of this community consisted of a woodland of *Callitris columellaris* on very steep escarpment near the crest of the range. Taxa from species group I are absent (*Eriachne helmsii, Psydrax* spp. and *Cymbopogon ambiguus*), which distinguishes this community from upland sites in type 1a (Appendix 2). This community has representation in Species groups F and I, and is distinguished from Community type 1a and 1b by good representation in Species group G, whilst there is very limited representation in species group H (Appendix 2). The species richness of this community is on par with Community type 1b, with an average number of total taxa of 27.1 ± 1.4 (s.e.) per quadrat (Table 3).

There is a subset of Community type 1a which shares taxa from Species group G with Community type 2. However, this subtype differs from Community type 2 in that there is an absence of *Thyridolepis multiculmis, Eremophila georgei* and *Cheilanthes sieberi*, the presence of *Eriachne helmsii, Psydrax* spp. and *Cymbopogon ambiguus*, and distinctive representation in Species groups H and I (Appendix 2). This sites occur on exposed seams of BIF bedrock on mid-lower slopes, and which may be too narrow and low to support all taxa associated with Community type 2.

Community type 3 is closely allied to Community type 4 (Fig. 2), both having generally poor representation in Species groups E–G (Fig. 2, Appendix 2). Sites grouped in this community type are typically shrublands on lower slopes, pediments, valley flats or plains adjacent to BIF landforms. These are shrublands of *Acacia aneura* (var. cf. *microcarpa*.and var. cf. *tenuis*), often with *Acacia ramulosa* var. *ramulosa* as co-dominant, over a shrub stratum over *Senna* spp. (particularly *Senna glaucifolia*), *Eremophila jucunda* subsp. *jucunda*, *Solanum lasiophyllum, Eremophila latrobei* subsp. *latrobei*, *Eremophila galeata, Ptilotus obovatus* and *Ptilotus schwartzii.* Most of these listed taxa are significant indicator species for this community, and other taxa have relatively high indicator values (Table 2). This is a comparatively more speciose community, with an average number of total taxa of 31.1 ± 2.5 (s.e.) per quadrat (Table 3). There is some representation from across Species groups A to G, with most taxa in the community occurring in Species groups H and I, whilst there is poor representation from Species groups E, F, and G. There are some floristic similarities between Community type 1b and 3, although the latter community has a notably reduced representation in group I and a far more constant and wider representation from group H (Appendix 2).

Community type 4 is the community typical of pediments and valley flats at the base of the Booylgoo Range, which consists typically of tall, sparse – open shrublands of *Acacia aneura*, *Acacia ramulosa* var. *ramulosa* and *Acacia craspedocarpa*, with isolated trees of *Brachychiton gregorii*, over a sparse or open shrubland of *Solanum lasiophyllum*, *Senna glaucifolia*, *Senna* sp. Meekatharra (E. Bailey 1–26), *Senna artemisioides* subsp. *helmsii*, *Eremophila galeata* and *Ptilotus obovatus*, over perennial grasses such as *Enneapogon caerulescens* and *Monachather paradoxa*. The main indicator species are *Brachychiton gregorii*, *Senna glaucifolia*, *Acacia craspedocarpa*, *Eremophila galeata*, and the hybrid, *Senna artemisioides* subsp. *helmsii* x *glaucifolia* (Table 2). There was also an unusual variant of *Eremophila latrobei* subsp. *latrobei* which has a distinctive lax, open branched, taller growth form and more densely hirsute, white-coloured leaves. Community type 4 is allied to type 3, but has relatively little representation in Species groups B–G and far more restricted representation in group I. There is good presentation in Species group H, which has high constancy across the sites in Community type 4 and differential representation of taxa within this group relative to Community type 3 (Appendix 2). The average number of total taxa is 31.5 ± 3.9 (s.e.) per quadrat, which is similar to that of Community type 3 (Table 3).

As previously mentioned, **Community types 5 and 6** were the first communities to be separated by the classification analyses. **Community type 5** consists entirely of sites located on mafic bedrock and colluvium in the basalt hills adjacent to the BIF ridges. Sampling of mafic sites was limited and these sites were somewhat heterogeneous as they were spread over the toposequence of the basalt hills. This general basalt community consisted of tall, sparse – open shrublands of *Acacia xanthocarpa* and *Acacia ramulosa* subsp. *ramulosa*, over a sparse shrub layer which included to varying degrees the indicator species *Dodonaea rigida*, *Eremophila exilifolia*, *Senna manicula*, *Eremophila granitica*, *Eremophila forrestii*, *Grevillea inconspicua, Solanum ashbyae* and *Cheilanthes lasiophylla* (Table 2). Other common components include *Acacia tetragonophylla*, *Ptilotus obovatus* and *Scaevola spinescens*. The average species richness is 32.0 ± 1.9 (s.e.) taxa per quadrat (Table 3). Taxa which are common within and constant to Community type 5 are Species group A, and a central portion of Species group H (Appendix 2). Otherwise, there is poor representation in Species groups B–G and I. This combination of representation among the Species groups highlights the distinctiveness of this community type from those on adjacent BIF substrates.

Community type 6 is a heterogenous grouping of only three sites which were allied most closely to Community type 5 and still had some floristic affinities to Community type 3 (*Solanum lasiophyllum*, *Senna* sp. Meekatharra (E. Bailey 1–26) and *Acacia aneura* var cf. *aneura* from Species group H) (Appendix 2). These sites were located downslope from outcropping ridges of BIF, in shallow gullies and where there was some influence of associated ultramafics, mafics, cherts, shale and other metasediments. The general community consisted of tall shrublands of *Acacia aneura* and *Acacia ramulosa* var. *ramulosa*, over various shrubs, including *Grevillea inconspicua*, *Senna manicula*, and *Eremophila platycalyx* subsp. *platycalyx*. The main indicator species are *Senna* sp. Meekatharra (E. Bailey 1–26), *Austrostipa trichophylla*, *Eremophila oldfieldii* subsp. *angustifolia*, *Dodonaea petiolaris* and *Ptilotus exaltatus*. These sites had an average species richness of 33.3 ± 3.5 (s.e.) taxa per quadrat.

Communities not in classification

An interesting spring community was observed which was not sampled in this survey. Located near Mt Anderson, the valley flat had been impacted from historical use as a stockyard, but there was a distinct community associated with the permanent spring and associated creekline. The surrounding creekline and valley vegetation consisted of a tall shrubland of *Hakea lorea* subsp. *lorea*, *Acacia aneura* and *A. craspedocarpa* over a sparse shrub layer of *Eremophila serrulata*, *Solanum lasiophyllum* and occasional saplings of *Santalum lanceolatum*. The herb layer consisted of subshrubs and tall herbs of *Trichodesma zeylanicum*, *Pluchea dentax*, *Haloragis trigonocarpa, Nicotiana occidentalis* and a dense cover of *Cymbopogon ambiguus*. *Cyperus vaginatus* and *Typha domingensis* were the dominant aquatic plants growing in the spring. Elements of this community occur in ephemeral creeklines, but the spring community itself would be expected to be uncommon on the range as there are only three permanent springs.

SSH MDS Ordination

Semi-strong hybrid multidimensional scaling of the floristic data was used to reduce floristic relationships among sites into a three dimensional solution (Fig. 3). At a value of 0.20, the ordination procedure was not at a satisfactory level (Seber 1984) but indicates moderate distortion in solving the ordination in three dimensions. Nonetheless, the SSH MDS ordination was informative, and is presented in Fig. 3. The two groups identified from the primary division in the classification were evident in ordination, with a BIF associated group (Community types 1a, 1b, 2, 3, 4) distinct from a group of mafic sites (Community types 5 and 6). At the seven group level, sites are generally clustered by community type, although some of these are relatively dispersed clusters and there is some overlap of different community types. This overlap is most noticeable among the subtypes, 1a and 1b. The greatest floristic dissimilarity is between the Community

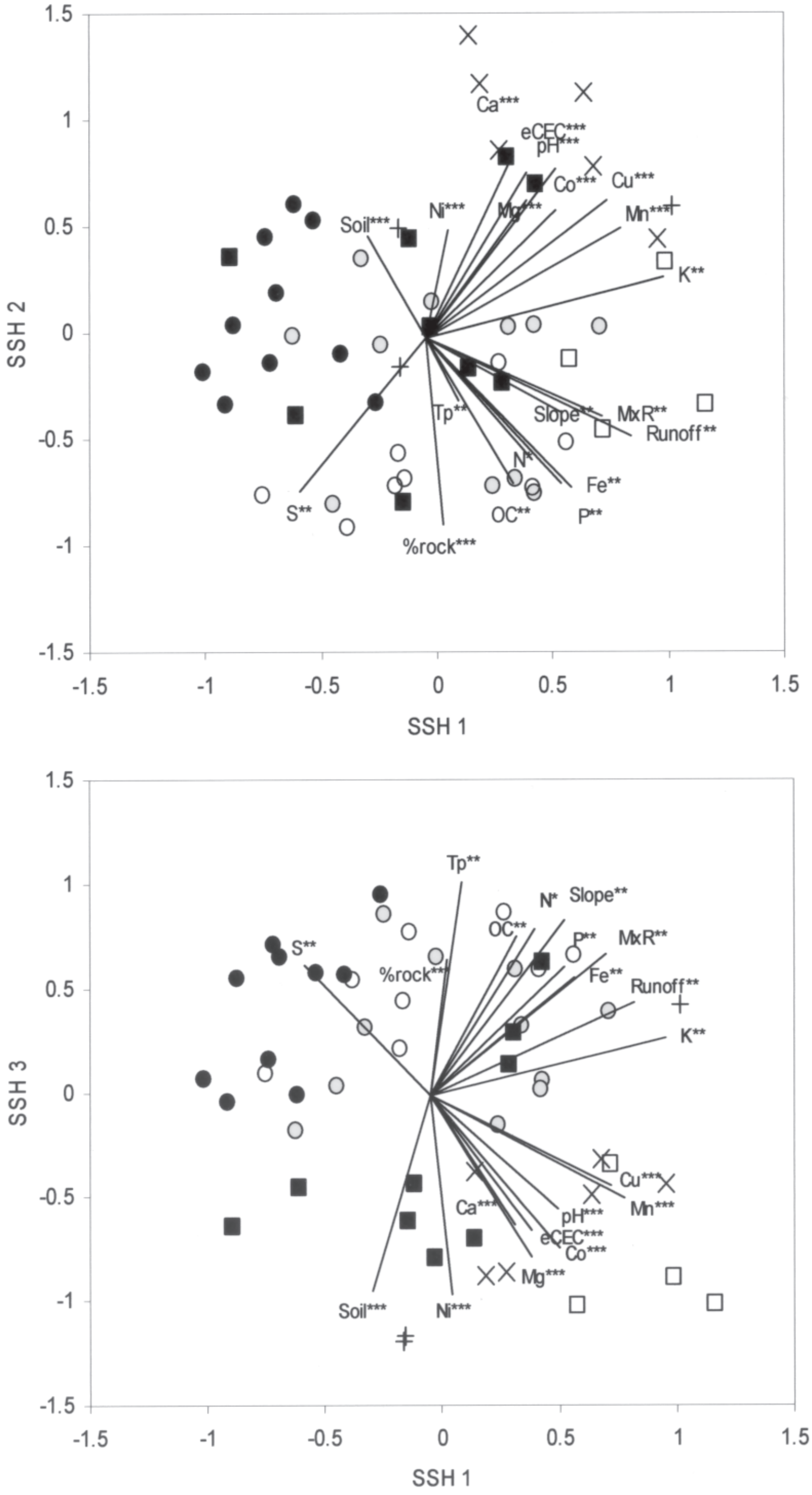

Figure 3. Ordination diagrams from three dimensional ordination (SSH MDS) using Bray-Curtis dissimilarities in Booylgoo Range floristic data (stress value = 0.20). Sites are labelled by Community type (1a ○, 1b ◍, 2 ●, 3 ■, 4 □, 5 ×, 6 +). Vectors of best linear fit are drawn in positive direction for each significant environmental variable. Levels of significant correlations (from MCAO) are indicated by asterisks (= $p < 0.05$, ** $= p < 0.01$, *** $= p < 0.001$). Abbreviations for environmental variable are given in the methods section.*

types 2 and 5. The sites classified as Group 6 are a loose, floristically heterogenous cluster.

Environmental Correlates

The topsoils from the Booylgoo Range sites were found to be strongly acidic, averaging pH 4.7. Soil acidity ranged from pH 3.9 to pH 6.6, which is can be described as ranging from strongly to slightly acidic (*cf.* Slattery *et al.* 1999). Soils were generally classed as shallow (5–50cm), red, stoney silty clay loams or silty clay sands, and observed to be firm-setting or forming a crust over loose soil. For most sites the ground was usually bare of vegetation (86.5% ± 1.1 (s.e.)), had only a very sparse cover of leaf litter (13.5% ± 1.2 (s.e.)) and an extensive mantle of loose rock fragments (> 90%). Surface fragments derived from BIF outcrops were typically angular platy or tabular in shape, while mafic colluvium was more angular – subangular. Surface rock sizes ranged from 2mm to 2 m, but the average maximum size class was 4.7 (which equates to a size range of 20–60cm). These general soil characters close match descriptions for lithosols on greenstone hills and rises through the Mid West region (Hennig 1998b; van Vreeswyk 1994).

Four elements B, Cd, Mo and Na were undetected in over half of the samples and omitted from analysis. The remaining soil chemical and site physical parameters were compared for inter-correlation (Table 4). Among the soil parameters, there was one highly inter-correlated set of trace elements (Ca, Ni, Co, Mg, Mn, eCEC and pH). Another set consisted of Fe, organic C, P and N. Among the geomorphological variables, there was one main set of inter-correlated variables (topographic position, slope, maximum rock fragment size, outcrop cover, runoff, altitude and soil depth), where soil depth was negatively correlated with the others. These parameters (especially slope) are all positively correlated with the set of Fe, P, organic C, and N (Table 4).

There were too few samples from Community types 4 and 6 to permit statistical comparison with the other community types. However, non-parametric analysis of variance found significant differences in average soil and site physical parameters among the remaining community types (Kruskal-Wallis non-parametric ANOVA) (Table 3). Among the inter-correlated suite of trace elements (Ca, Co, Cu, Mg, Mn and Ni) and eCEC, significantly highest values were associated with Community type 5. These were sites on mafic bedrock substrates, which suggests the metalliferous bedrock is having a strong influence on soil composition. Conversely, values were relatively lower in the communities were associated with massive banded iron formation. Trace element values were relatively moderate in Community type 3, while generally lowest among Community types 1a, 1b and, in particular, Community type 2. The trace element concentrations in Community type 4 were comparable to type 3 (Table 3), which suggests that both these communities are on lowland sites which are receiving trace element enrichment. Levels of exchangeable cations were of intermediate levels in Community types 1b and 3, and lowest in types 1a and 2. Although not tested, soils from Community type 6 tended to have a moderately high but variable eCEC, and trace elements were within the ranges of values for Community types 1, 2 and 3. Despite differences in eCEC and trace elements concentrations, soil salinity (as estimated by EC) was not significantly different among the community types (Table 3).

Soils were most acidic in the upland BIF communities, types 1a and 2, while weakly acidic in Community type 5 (Table 3). Organic C, N, P and Fe were also significantly the highest within Community type 2 and, to a lesser degree, among types 1a and 1b. These values were generally lower for Community type 5 and the lowest for sites associated with Community type 3. Although not tested, Community type 4 tended to have relatively low N, organic C, higher pH, higher trace elements on par with Community type 3 and 5. Leaf litter was observed to accumulate in rocky crevices in upland BIF outcrops, which may account for the elevated soil N and organic C observed in upland BIF communities. Both P and S were also significantly lower in Type 5 than in the other communities, which suggest that soils derived from banded iron formation have higher P and S levels than those associated with mafic bedrock.

With the exception of runoff, bare ground and litter cover, there were significant differences in site physical attributes among the community types (Table 3). There was a tendency for Community type 2 to occupy the highest topographic positions in the landscape, while type 3 occurred at the lowest altitudes and types 1 and 5 were variable (although this was not significant in multiple range tests) (Table 3). In conjunction with occupying the highest upland positions, sites from Community type 2 had the steepest slopes, greatest cover of massive outcrop, the largest surface rock fragments (corresponding to a size range from 60cm to 2m), lowest cover of surface rock fragments and the shallowest soil depths (being skeletal (> 5cm) on average). Community types 1a, 1b and 5 had middle range values for slope angle, outcrop and rock fragment sizes, and generally shallow (5–50cm) soil depths. At the other extreme, Community type 3 occupied sites at the lowest topographic positions, with the lowest gradients, lowest outcrop cover (no outcrop), deepest average soil depth class (>50cm) and smallest surface rock fragments (Table 3). Although not verified statistically, slope angles tended to be also very low in Community type 4, where sites also had relatively small surface rock fragments and minimal or no outcropping bedrock. Community type 6 was comprised of only three sites, all which generally occupied steep, rocky mid-slopes of BIF colluvium and with a moderate amount of BIF outcrop and mafic and ultramafic influence.

There is some suggestion of a geographical segregation of floristic community types, notably where sites of Community type 2 were concentrated towards the southern end of the range among the relatively tall ridges (Table 3). There is also a trend for a more northern distribution of Community type 3, but recent fires and accessibility precluded sampling at the southern sites which may be suitable terrain for this community. Differences in longitude are minor (Table 3) because the range is narrow and the central-eastern margin of the range was inaccessible (Fig. 1).

Principal Component Correlation (PCC)

Principal component correlation (PCC) of environmental variables with the ordination coordinates found significant linear relationships for most environmental parameters, and the fitted linear vectors are shown in Fig. 3. There are two major enviro-florisitic gradients, and the observed trends mirror results from the univariate analyses. One main gradient consists of collinear vectors for a set soil variables (Ni, Ca, eCEC, Mg, Co, Cu, Mn and pH). Sulphur runs parallel but negative in direction to this first main gradient. This gradient is linked to geological substrate, with the main separation of the mafic-associated Community type 5 at the high extreme of this gradient from the BIF ridge-associated Community types 1a, 1b and 2 at the low extremes. This reinforces previous findings that Community 5 is associated with relatively high soil concentrations of trace elements, soil pH and eCEC, while Community types 2 and 1b, and 1a (to lesser extent), are associated with low soil pH and trace element concentrations. Community types 3 and 4 coincide with the middle range of this gradient, again suggesting elemental enrichment in lowland soils.

Orthoganol to this first main gradient are two near-collinear gradients, one of gradient of mainly soil trace elements and macronutrients (Fe, N, P, organic C, runoff) and another gradient of geomorphology (topographic position, maximum surface rock size, and slope). Soil depth is nearly parallel but opposite in direction to this gradient. This gradient is associated with the separation of Community types 2, 1b and 1a from types 3 , 4 and 5, which corresponds to the segregation of BIF lowland and outwash sites on deeper soils from sites on hill slopes and crests with skeletal soils, massive exposed rock outcrops and large rock fragments. Community type 2 is at the highest extreme of this gradient, while Community types 1a and 1b are closely adjacent. The vector for outcrop cover is somewhat distant from these other two main gradients, but the pattern is similar; Community type 2 is at the high extreme of rock outcrop cover, whilst types 3, 4 and 5 are at the low end of rock outcrop cover.

DISCUSSION

Flora

A total 207 taxa were recorded from this survey, which is in excess of double the number of taxa (84) previously known from herbarium records for the the range and surrounding plains (Western Australian Herbarium 1998–). The spring survey had been preceded by a good summer rainfall and a poor winter, which had promoted the abundant growth of annual grasses (*Eriachne pulchella*, *Aristida contorta*) but herbaceous winter annuals and geophytes were largely absent from sites. It is likely that numbers of these lifeforms have been underestimated, and it is assumed further sampling during a relatively wet winter will increase the total species count for the range.

Similar ironstone surveys conducted during the same field season in 2006 recorded 191 taxa for the Herbert Lukin Ridge (c. 125km north of Booylgoo Range) (Markey & Dillon 2009), and 144 and 116 taxa for the Cashmere Downs and Mt Forrest – Mt Richardson Ranges, respectively (c. 100km south) (Meissner *et al.* 2009c). This suggests that the Booylgoo Range supports a relatively rich flora for an arid-zone greenstone range in the Murchison region. A variety of habitats associated with tall peaks, steep escarpments and permanent springs may account, in part, for this species richness. Had the survey been extended to the sandplains at the base of the range, this number of taxa would have been considerably larger. However, these counts for Booylgoo Range are markedly lower than for similar surveys in the more southern greenstone ranges, such as the Bremer Range (267 taxa) (Gibson & Lyons 1998a) and Forrestiana greenstone belt (342 taxa) (Gibson 2004b). This regional decrease in species richness with increasing distance inland appears to be associated with a gradient of increasing aridity (Beard 1976, 1990; Hopper *et al.* 1997).

Significant numbers of rare and endemic taxa have been recorded for greenstone outcrops in the Yilgarn Craton (Gibson *et al.* 2007). Six priority taxa were recorded for Booylgoo Range during this survey, of which five were new records for the landform. This is the current total number of priority taxa known for the range (Western Australian Herbarium 1998–). In addition to rare and poorly known taxa, several unusual variants of described taxa were found, notably a flat phyllode variant of *Acacia xanthocarpa* and *Acacia* aff. *siberica*. However, no taxa were found which could be considered endemic to the Booylgoo Range. This lack of endemic taxa has been reported for other greenstone ranges, such as Mt Manning Range (Gibson 2004a), Weld Range (Markey and Dillon 2008a) and the Highclere Hills (Gibson & Lyons 2001b), and only one endemic taxon was located at the Herbert Lukin Ridge (Markey, & Dillon in press). Species diversity and endemism of Western Australiam granite outcrops decline with increasing aridity (Hopper *et al.* 1997), and the same trend is becoming evident for BIF ranges on the Yilgarn Craton (Gibson *et al.* 2007).

The representation of genera and families for the Booylgoo Range is typical for the general flora of the Murchison – eastern Goldfields regions (Beard 1976, 1990; Pringle 1994b), and for other ironstone surveys in the eastern Goldfields (e.g. Gibson & Lyons 1998a, 1998b; Gibson 2004a, 2004b). The dominant genera (*Acacia*, *Ptilotus*, *Eremophila*, *Senna* and *Sida*) are characteristically Eremaean (Beard 1976, 1990; Pringle 1994b, 1998b), and many other taxa reported for Booylgoo Range occur in the Gascoyne, Ashburton, Pilbara and Central Desert regions. Genera reported for ranges in the Coolgardie and Yalgoo interzone bioregions are absent or poorly represented on the Booylgoo Range, including *Melaleuca*, *Eucalyptus*, *Banksia*, *Persoonia*, *Hibbertia* and *Mirbelia* (Gibson & Lyons 1998a, 2001a, 2001b; Gibson 2004a, 2004b; Markey & Dillon, 2008b). Of the range extensions of over 100km reported by this survey, all were southern or western range extensions for otherwise more northern or eastern taxa, which further suggest a significant floristic affinity of the Booylgoo Range to other arid regions.

Floristic Communities:

The broad-scale surveys of Beard (1976a), Payne *et al.* (1998) and Pringle and van Vreeswyk (1994) do not readily distinguish floristic differences among different ironstone and greenstone ranges in the Murchison and north-eastern Goldfields. This survey is the first of which has specifically addressed the floristic communities on the Booylgoo Range at a fine scale, and reports seven floristic Community types and subtypes. The primary split in the classification distinguishes those community types on BIF substrates (types 1, 2, 3 and 4) from communities associated with mafic substrates (types 5 and 6). Community type 5 was the most characteristic community of the metabasalt and mafic lithologies which dominate the central portion of the range. In contrast, Pringle (1994a, 1998a) reported that greenstone and ironstone hills shared the same stony ironstone mulga shrublands as a dominant community. However, these units were broadly circumscribed, and the greenstone hill acacia shrublands unit described by Pringle (1994a, 1998a) does not bare a close a resemblance to Community type 5. Marked differences between mafic and BIF communities have been found within some other ranges of mixed mafic and BIF geologies on the Yilgarn Craton (Gibson 2004a; Markey & Dillon 2008a; Meissner *et al.*2009 a, b).

It is interesting to note that the basalt community is composed of taxa that are commonly but not exclusively found on mafic substrates in the wider region. The dominant or significant indicator species (*Acacia xanthocarpa*, *Dodonaea rigida, Senna manicula, Eremophila granitica, Cheilanthes lasiophylla*, *Eremophila exilifolia, Eremophila forrestii* and *Grevillea inconspicua*) are most often recorded from mafic hills and rises, but can also be found on other lithologies; usually granite and (to a lesser extent) BIF, other metasediments and sandstone (Western Australian Herbarium 1998–). Within BIF-associated communities, dominant or indicator species (e.g. *Thyptomene decussata, Philotheca brucei* subsp. *brucei* and *Prostanthera campbellii*) are not entirely restricted to massive BIF outcrops, but have also been been recorded on laterites and occasionally on sandstone, sandplains and hard pans. However, these taxa characteristic of the BIF communities are not often recorded from mafic lithologies. This suggests that the BIF and mafic communities on the Booylgoo Range are being defined by taxa with substrate preferences. The intensive biogeochemical survey in the eastern Goldfields by Cole (1973) demonstrated clear associations of species with mafic/ultramafic substrates, and indicated some physiological responses to metalliferous soils.

Within BIF landforms on the Booylgoo Range, the greatest floristic differences among communities were between the upland and lowland communities, despite the maximum elevation of only 100 m. This mirrors the general trends found in semi-arid and arid ranges in Australia (Butler & Fensham 2008; van Etten & Fox 2004) and the Yilgarn and eastern Goldfields (Gibson & Lyons 1998a, 2001a, 2001b; Gibson 2004a, 2004b; Markey & Dillon, 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c) , where the upper slopes and crest communities are markedly different to the vegetation matrix on the surrounding plains. Three communities (types and subtypes) were resolved for the hill crests and hill slopes (uplands), but one of these was a heterogenous community (Community type 1b) which occurred from lower slopes to low ridge crests / hillocks (*c.* 20 m), which may be further subdivided with more sampling . Heterogeneity within this community subtype and overlap in floristic composition among subtypesof Community type 1 may be indicative of broad transitional zones (cf. van Etten & Fox 2004).

Environmental correlates

There was a strong association between site soil chemical and physical parameters with floristic community type, the greatest difference being associated with parent rock type. Soils on mafic substrates are comparatively rich in trace metals, these soils being ultimately derived from a parent bedrock that has high levels of Mg, Mn, Cr, Cu, Co, Ni and Zn (Cole 1973; Cornelius *et al.* 2007; de Castro Vincent & Meguro 2008; Gray & Murphy 2002). These soils were also found to have a comparatively higher eCEC (presumably from the higher Mg concentrations) and be less acidic, presumably because of the buffering capacity of exchangeable cations (Gray & Murphy 2002). The presence of calcrete deposits may also account for the neutral – basic pH reported for soils derived from weathered mafics (Anand *et al.* 1997; Gibson & Lyons 1998a, 2001b). Although there is a clear association between the mafic community and substrate, the degree to which soil heavy metals are biologically available (see Cole 1973; Robinson *et al* 1996) and how they influence species distributions and community composition is largely unknown for greenstones in Western Australia, It is speculated that an ability to resist metal uptake or a relatively higher level of tolerance to elevated levels of soil metals would be expected among some species in the mafic community, as these strategies have been found among mafic/ultramafic species in the eastern Goldfields (Cole 1973).

Within the more intensively sampled BIF landforms of the Booylgoo Range, a catena of community types was found to be associated with a topo-edaphic gradient. Similar enviro-floristic gradients have been studies in detail in other semi-arid and arid ranges in Australia, including in the Hamersley Ranges of the Pilbara (van Etten & Fox 2004) and among greenstone ranges in the goldfields (Chalwell 2003; Gibson & Lyons 1998b, 2001a; Gibson 2004a) and in the Yalgoo and Murchsion regions (Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c). These sites exhibit the same general topographical sequence over the landform, and similar general trends in soil development.

The association of floristic community types with topography and soil depth on outcrops has been inferred to be a response (at least in part) to a soil moisture gradient (Gibson & Lyons 1998b, 2001a; Gibson 2004a), where skeletal soils on crests and steep terrain will retain little water in comparison to deeper soils, and where a mantle of surface gravels will impede water runoff and reduce water loss (Specht *et al.* 2006; van Vreeswyk 1994). Deeper soils on the lower slopes and outwashes would be expected to not only received runoff and retain soil moisture, but also overlie groundwater sources (Chalwell 2003; Conn & Snyder-Conn 1981; Specht *et al.* 2006; van Vreeswyk 1994). The amount of runoff from the Booylgoo Range is sufficient to form permanent springs which support a *Typha-Cyperus* wetland community. Even within upland sites, presumably the entrapment of water in rock crevices and as temporary pools on impermeable surfaces supports other species such as *Cheilanthes brownie* and *Cymbopogon ambiguus*.

Soil depth is also a limiting factor for root development, and communities on rocky uplands were characterised by taxa which could tolerate skeletal, rocky soils by a number of strategies, including being shallow-rooted (e.g. *Sida* sp. Excedentifolia (J.L. Egan 1925); *Cymbopogon ambiguus*; *Ptilotus schwartzii*), rooting into rock fissures (e.g. *Prostanthera campbellii*, *Micromyrtus sulphurea*) and / or growing through loose scree (e.g. *Dodonaea petiolaris*). Some of the large shrubs and trees, such as *Callitris columellaris*, would be expected to be very deep-rooted, and it is this strategy can allow for larger shrubs and trees on rock outcrops to access deeper water sources within the rocks (Chalwell 2003; da Silva & Dillenberg 2007).

Within BIF landforms, soil fertility was found to be strongly associated with topography, such so that the highest values of trace element concentrations, eCEC and soil pH were found in soils on lower slopes, flats and outwashes. It is presumed that upland soils are heavily leached, particularly of the more readily mobilised elements such as Mg, Na and Ca (Britt *et al.* 2001; Cornelius *et al.* 2007). Conversely, soils in depositional areas tend to be enriched by leachates as well as washdown of soil and colluvium, which leads to a higher eCEC and levels of mobile ions such as Ca and Mg (as carbonates) (Cole 1973; Gray & Murphy 2002; Hennig 1998; van Vreeswyk 1994). These weakly acidic to basic soils may be buffered by the higher eCEC and mobile ions (Gray & Murphy 2002). These general trends in soil composition over a topographic gradient have been reported for other ironstone and greenstone ranges in the Murchison and Eastern Goldfields (Cole 1973; Hennig 1998; Gibson & Lyons 2001a, 2001b; Gibson 2004a, 2004b). Saline soils have also been reported from lowland sites under weathered mafics (Gibson & Lyons 1998), exposed pallid zones under laterites (Gibson & Lyons 2001a), and alluvial outwash / colluvial plains (Markey & Dillon in press), but saline soils and their associated communities were not evident on the Booylgoo Range.

The opposite trend was observed for soil pH, N, P, organic C and Fe, where concentrations were greatest and soil most acidic at the highest topographic positions in landscape; these being on rocky outcrops of massive BIF. In these rocky, upland sites, soil development is presumably from *in situ* weathering of parent bedrock (Litchfield 1963; Gray & Murphy 2002), which may account for higher acidity and relatively higher levels of iron and phosphorus. It is presumed that the high levels of organic carbon and nitrogen in these soils were derived from the leaf litter collecting in rock fissures, crevices and among cobbles and boulders. Coincidentally, these areas were where the only substantial deposits of soil were to be found. Relatively higher soil N concentrations in upland BIF communities have been reported for some Yilgarn BIF ranges (Gibson 2004a; Markey & Dillon 2008a, 2008b). Other ironstone surveys have found the opposite trend, where relatively higher N concentrations are found in soils from lowland sites supporting *Eucalyptus* woodlands. This was associated with a greater cover of leaf litter in the Hunt Range and adjacent hills in the eastern Goldfields (Gibson & Lyons 2001a) and in a saline lake edge community in the Bremer Range (Gibson & Lyons 1998a).

It would appear that microhabitats among the rocky, fissured terrain of the Booylgoo Range can intercept rainwater and trap organic material. Steep escarpments of massive BIF also support tall stands of *Callitris collumelaris*, which is a well known, fire sensitive species often recorded on steep valley slopes and escarpments of arid zone ranges (Bowman & Latz 1993). It is a common feature of rock outcrops and ranges to posses a heterogenous array of habitats, including sheltered sites for fire sensitive species and communities, and microhabitats which support less xeric species, and provide sites for effective seed burial and germination (Butler & Fensham 2008; Conn & Snyder-Conn 1981; Jacobi *et al.* 2007; Hopper *et al.* 1997).

Regional Significance

The nearest ironstone and greenstone ranges to the Booylgoo Range which have been adequately surveyed to date are the Herbert Lukin Ridge (on the Joyners Find greenstone belt), Cashmere Downs and Mt Richardson - Mt Forrest. There are notable differences in the flora even among these relatively close ranges. Only 45% of 273 native taxa (species and subspecies) are common to both the Herbert Lukin Ridge and the Booylgoo Range (from Markey & Dillon, 2009 a b). These values are even less for the southern ranges, with 31% and 45% of taxa in common between Booylgoo Range and Cashmere Downs and Mt Richardson – Mt Forrest, respectively (data from Meissner *et al.* in press [a, b]). Dominant taxa on the Herbert Lukin Ridge are absent from Booylgoo Range, including *Acacia pruinocarpa*, *Triodia melvillei*, *Tribulus suberosus* and *Stenathemum petraeum* (Markey & Dillon, 2009). Conversely, species dominant or common on Booylgoo Range (e.g. *Acacia ramulosa* var. *ramulosa*, *Grevillea inconspicua*, *Thryptomene decussata*, *Philotheca brucei*, *Cymbopogon ambiguus* and *Acacia xanthocarpa*) are notably absent from the Herbert Lukin Ridge. Similarly, while *Eucalyptus kingsmillii* subsp. *kingsmillii, Eucalyptus lucasii, Acacia cockertoniana, Aluta aspera* subsp. *hesperia* and *Eremophila conglomerata* are rarely encountered on Booygloo Range, these species are common taxa on Cashmere Downs and Mt Richardson - Mt Forrest (Meissner *et al* 2009 a, b).

In addition to differences in dominant or characteristic taxa, the communities described for the Booylgoo Range bare little similarity with those found on the Herbert Lukin Ridge, Cashmere Downs or Mt Richardson - Mt Forrest. Both the upland *Acacia-Triodia melvillei* shrublands, and saline flat *Acacia aneura*, *A. pruinocarpa* – chenopod communities of the Herbert Lukin Ridge are absent from the Booylgoo Range (Markey & Dillon, 2009). Similarly, fundamentally different communities have been described for ironstone communities on Mt Richardson, Mt Forrest and Cashmere Downs, many of which are dominated by *Eucalyptus* spp, *Acacia cockertoniana* and *Callitris columellaris* (Meissner *et al.* 2009 a b).

The Sandstone and Gum Creek belts are the closest greenstone belts to the Booylgoo Range, the latter of which forms the Black and Montague ranges at least 40km west and 60km north-west, respectively (Tingey 1985; Wyche *et al.* 2004). These ranges have only been recently surveyed, and preliminary results suggest that they are floristically more similar to the Booylgoo Range than the previously discussed ranges, although surveys were conducted during a dry season and species counts for these ranges are low (111 and 91 taxa respectively) (W. Thompson[1], unpublished data). All three ranges share common, widespread species such as *Eremophila latrobei, Eremophila jucunda, Grevillea inconspicua, Grevillea berryana, Ptilotus schwartzii* and *Acacia xanthocarpa,* and there are some general similarities among some of the communities. However, when perennial taxa are compared in a combined dataset, the Black and Montague Range have approximately 50% and 40% taxa, respectively, in common with the Booylgoo Range. This suggests that even these close ranges may have floristically dissimilar communities, although this can only be verified by an analysis of combined datasets.

On a regional scale, the flora and floristic communities have been found to vary significantly among adjacent ranges in the Yilgarn Craton (Gibson *et al.* 2007; Department of Environment and Conservation 2007). This has been attributed, to, in part, a gradient of increasing aridity over the wider region, leading to a regional turnover of flora (Beard 1990; Gibson & Lyons 2001b, Gibson 2004a; Gibson *et al.* 2007). Other factors which may also account for such a regional pattern are range-specific differences in edaphic features, geology and topography. It is speculated that floristic composition may also reflect the unique evolutionary history of each range, including their role as refugia during the oscillating climate of the Pleistocene. (Byrne 2008; Gibson & Lyons 1998a,b; 2001a, 2001b, Gibson 2004a; Gibson *et al.* 2007; Hopper and Gioia 2004). The BIF ranges of the northern Yilgarn also lie at the margins of the semi-arid to arid climatic zones, where significant regional shifts in species distributions are postulated to have occurred during climatic oscillations in the Pleistocene (Byrne 2008; Hopper and Gioia 2004). Both this and also be other historical factors may have influenced community assembly among isolated ranges in the arid zone.

Conservation

Within the wider Sandstone region, only a small proportion of the land surface area consists of outcropping greenstone landforms. The Booylgoo Range is significant in this respect. It is an isolated series of extensive, tall ridges and hills, where vegetation communities are tightly linked to topography and substrate. There is even some evidence for two floristic communities being geographically restricted to parts of the Booylgoo Range. The steep ridges and the heterogeneous topography provide a diversity of microhabitats and acts as a refuge for fire-sensitive species. It harbours taxa of conservation significance, has floristic dissimilarities to adjacent ranges and possibly some range-specific communities. These attributes of the Booylgoo Range contribute to conservation values of this arid zone landform.

The vegetation of the Booylgoo Range was found to be in reasonable condition and relatively free of naturalised weeds. There was clear evidence of goat browsing, but this was not considered to be too significant at the time of survey. It was most severe in the southern extent of the range where free water was readily available from operating wells and natural springs. Goats are serious problem in the Sandstone – Yalgoo region (Dowd 1998), and their control or eradication requires a concerted regional effort by a number of pastoral leaseholders and government agencies.

Mining and mineral exploration are a potential threat to the flora and communities of the Booylgoo Range. Greenstone belts of the Yilgarn Craton are highly prospective for mineral resources, and many have been exploited in the Murchison Mineral Field (Department of Industry and Resources 2007; Tingey 1985; Wyche *et al.*. 2004). Apart from old exploration tracks and small clearings, there are relatively few signs of past mineral exploration and mining activities on Booylgoo Range. This lack of significant historical activity was due to little evidence for gold mineralisation (Wyche *et al.* 2004). However, iron-ore deposits with economic potential have now been identified for the range (Flint *et al.* 2000). To date, the entire area is covered by tenements and no communities described for the Booylgoo Range are reserved within the secure Conservation Estate. These communities are vulnerable to disturbance, and future activities on the range must follow best practices to protect both geographically restricted communities, and rare and poorly known taxa.

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APPENDIX 1

Flora List for Booylgoo Range. Nomenclature follows Packowska and Chapman (2000), except where recent changes have been incorporated from the Census of Western Australian Plants database (Western Australian Herbarium 1998–). Introduced taxa are indicated by an asterisk, informal (phrase) names have a type collection number in parenthesis and new (unnamed) taxa have accession number in parenthsis.

Acanthaceae
Harnieria kempeana subsp. *muelleri*

Adiantaceae
Cheilanthes brownii
Cheilanthes lasiophylla
Cheilanthes sieberi subsp. *sieberi*

Amaranthaceae
Ptilotus aervoides
Ptilotus chamaecladus
Ptilotus exaltatus
Ptilotus helipteroides
Ptilotus obovatus
Ptilotus polystachyus var. *polystachyus*
Ptilotus roei
Ptilotus schwartzii

Anthericaceae
Thysanotus manglesianus

Asclepiadaceae
Marsdenia australis
Rhyncharrhena linearis

Asteraceae
Brachyscome ciliocarpa
Calocephalus multiflorus
Calotis hispidula
Chrysocephalum puteale
Erymophyllum ramosum subsp. *ramosum*
Gnephosis eriocephala
Gnephosis tenuissima
Helipterum craspedioides
Isoetopsis graminifolia
Lemooria burkittii
Myriocephalus guerinae
Olearia humilis
Pluchea dentex
Podolepis capillaris
Rhodanthe battii
Rhodanthe maryonii
Schoenia ayersii
Taplinia saxatilis
Waitzia acuminata var. *acuminata*

Boraginaceae
Heliotropium inexplicitum
Trichodesma zeylanicum

Brassicaceae
Lepidium oxytrichum
Lepidium platypetalum
Stenopetalum anfractum

Caesalpiniaceae
Senna aff. *glutinosa* (PERTH 07557132)
Senna artemisioides subsp.x *artemisioides* x subsp. x *sturtii*
Senna artemisioides subsp. x *sturtii*
Senna artemisioides subsp.*helmsii* x *glaucifolia*
Senna artemisioides subsp.*helmsii* x *glaucifolia* x *oligophylla*
Senna artemisioides subsp. aff. *helmsii* (PERTH 07723113)
Senna artemisioides subsp. *filifolia*
Senna artemisioides subsp. *helmsii*
Senna artemisioides subsp. x *artemisioides*
Senna glaucifolia
Senna glaucifolia x sp. *Meekatharra* (E. Bailey 1-26)
Senna glutinosa subsp.*chatelainiana* x *charlesiana*
Senna manicula
Senna sp. Meekatharra (E. Bailey 1-26)

Casuarinaceae
Casuarina pauper

Chenopodiaceae
Atriplex codonocarpa
Chenopodium melanocarpum forma *melanocarpum*
Chenopodium saxatile
Dysphania kalpari
Dysphania rhadinostachya subsp. *rhadinostachya*
Enchylaena tomentosa var. *tomentosa*
Maireana carnosa
Maireana convexa
Maireana georgei
Maireana planifolia x *villosa*
Maireana triptera
Rhagodia drummondii
Rhagodia eremaea
Sclerolaena densiflora
Sclerolaena eriacantha
Sclerolaena gardneri

Convolvulaceae
Duperreya commixta

Crassulaceae
Crassula colorata var. *acuminata*

Cucurbitaceae
*Citrullus lanatus**

Cupressaceae
Callitris columellaris

Cuscutaceae
*Cuscuta epithymum**

Cyperaceae
Bulbostylis barbata
Cyperus vaginatus

Euphorbiaceae
Euphorbia australis
Euphorbia boophthona
Euphorbia drummondii subsp. *drummondii*
Phyllanthus erwinii

Geraniaceae
Erodium cygnorum

Goodeniaceae
Brunonia australis
Goodenia havilandii
Goodenia macroplectra
Goodenia mimuloides
Scaevola spinescens
Velleia glabrata
Velleia hispida
Velleia rosea

Haloragaceae
Haloragis odontocarpa forma *octoforma*
Haloragis odontocarpa forma *pterocarpa*
Haloragis odontocarpa forma aff. *octoforma*
Haloragis odontocarpa forma *rugosa*
Haloragis trigonocarpa

Lamiaceae
Prostanthera albiflora
Prostanthera althoferi subsp. *althoferi*
Prostanthera althoferi subsp. *althoferi x campbellii*
Prostanthera campbellii
Spartothamnella teucriiflora

Lobeliaceae
Isotoma petraea

Loranthaceae
Lysiana murrayi

Malvaceae
Abutilon cryptopetalum
Abutilon oxycarpum subsp. *prostratum*
Hibiscus gardneri
Hibiscus solanifolius
Hibiscus sturtii var. *truncatus*
Sida aff. *intricata* (PERTH 07557396)
Sida ectogama
Sida sp. dark green fruits (S. van Leeuwen 2260)
Sida sp. Golden calyces glabrous fruit (H.N. Foote 32)
Sida sp. *Excedentifolia* (J.L. Egan 1925)
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)

Mimosaceae
Acacia aff. *siberica* (PERTH 07556969)
Acacia aneura var. cf. *aneura*
Acacia aneura var. cf. *microcarpa*
Acacia aneura var. cf. *tenuis*
Acacia aneura var. cf. *argentea*
Acacia aneura x *craspedocarpa*
Acacia balsamea
Acacia burkittii
Acacia craspedocarpa
Acacia minyura
Acacia quadrimarginea
Acacia ramulosa var. *ramulosa*
Acacia rhodophloia
Acacia sibirica
Acacia thoma
Acacia tetragonophylla
Acacia xanthocarpa

Myoporaceae
Eremophila exilifolia
Eremophila foliosissima
Eremophila forrestii subsp. *forrestii*
Eremophila forrestii subsp. *hastieana*
Eremophila galeata
Eremophila georgei
Eremophila granitica
Eremophila jucunda subsp. *jucunda*
Eremophila latrobei subsp. *latrobei*
Eremophila longifolia
Eremophila oldfieldii subsp. *angustifolia*
Eremophila oppositifolia subsp. *angustifolia*
Eremophila platycalyx subsp. *platycalyx*
Eremophila serrulata
Eremophila spectabilis subsp. *brevis*

Myrtaceae
Baeckea sp. Melita Station (H. Pringle 2738)
Calytrix desolata
Calytrix erosipetala
Calytrix uncinata
Eucalyptus kingsmillii subsp. *kingsmillii*
Homalocalyx echinulatus
Micromyrtus sulphurea
Thryptomene decussata

Nyctaginaceae
Boerhavia coccinea

Papilionaceae
Indigofera monophylla
Swainsona incei
Swainsona kingii

Phormiaceae
Dianella revoluta

Pittosporaceae
Pittosporum angustifolium

Poaceae
Aristida contorta
Austrostipa elegantissima
Austrostipa scabra subsp. *scabra*
Austrostipa trichophylla
Cymbopogon ambiguus
Cymbopogon obtectus
Digitaria brownii
Enneapogon caerulescens
Eragrostis dielsii
Eragrostis eriopoda
Eragrostis lacunaria
Eragrostis pergracilis
Eriachne helmsii
Eriachne mucronata
Eriachne pulchella subsp. *dominii*
Monachather paradoxus
Neurachne minor
Paspalidium basicladum
Thyridolepis mitchelliana
Thyridolepis multiculmis
Tripogon loliiformis

Polygalaceae
Polygala isingii

Portulacaceae
Calandrinia creethae
Calandrinia eremaea
Calandrinia monosperma
*Portulaca oleracea**

Primulaceae
Anagallis arvensis var. *caerulea**

Proteaceae
Grevillea berryana
Grevillea inconspicua
Hakea lorea subsp. *lorea*
Hakea preissii

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

Rutaceae
Philotheca brucei subsp. *brucei*

Santalaceae
Santalum lanceolatum
Santalum spicatum

Sapindaceae
Dodonaea lobulata
Dodonaea microzyga var. *acrolobata*
Dodonaea petiolaris
Dodonaea rigida

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

Stackhousiaceae
Stackhousia muricata

Sterculiaceae
Brachychiton gregorii

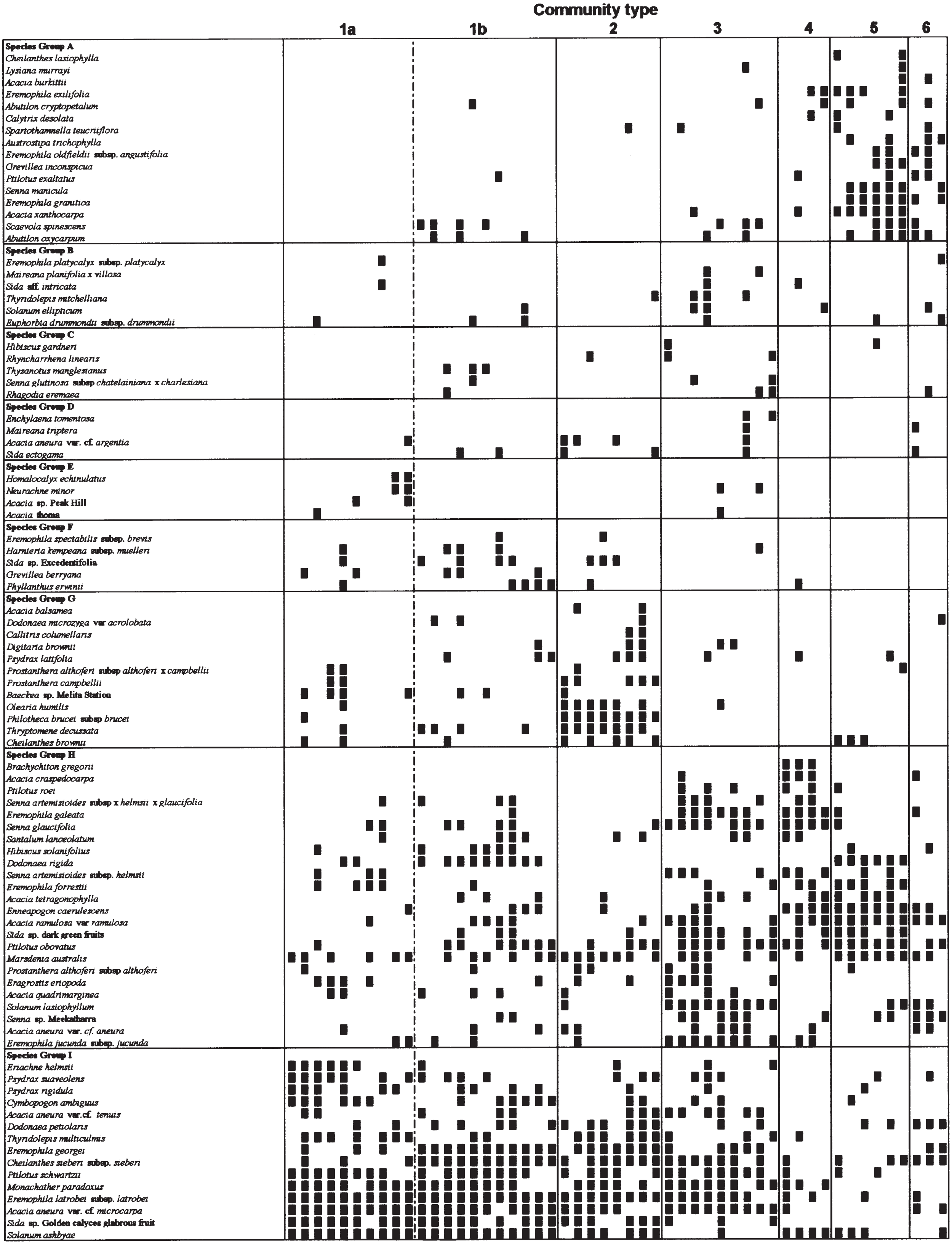
Stylidiaceae
Stylidium induratum

Typhaceae
Typha domingensis

Zygophyllaceae
Tribulus adelacanthus
Tribulus astrocarpus
Zygophyllum eichleri

APPENDIX 2

Sorted two-way table of sites and perennial species occurrences for the Booylgoo Range, showing species occurrence by community type. Sites appear as columns and species as rows, and are sorted according to groupings determined by classification analyses.



Community type

1a 1b 2 3 4 5 6

Species Group A
Cheilanthes lasiophylla
Lysiana murrayi
Acacia burkittii
Eremophila exilifolia
Abutilon cryptopetalum
Calytrix desolata
Spartothamnella teucriiflora
Austrostipa trichophylla
Eremophila oldfieldii **subsp.** *angustifolia*
Grevillea inconspicua
Ptilotus exaltatus
Senna manicula
Eremophila granitica
Acacia xanthocarpa
Scaevola spinescens
Abutilon oxycarpum

Species Group B
Eremophila platycalyx **subsp.** *platycalyx*
Maireana planifolia x villosa
Sida **aff.** *intricata*
Thyridolepis mitchelliana
Solanum ellipticum
Euphorbia drummondii **subsp.** *drummondii*

Species Group C
Hibiscus gardneri
Rhyncharrhena linearis
Thysanotus manglesianus
Senna glutinosa **subsp** *chatelainiana* **x** *charlesiana*
Rhagodia eremaea

Species Group D
Enchylaena tomentosa
Maireana triptera
Acacia aneura **var. cf.** *argentia*
Sida ectogama

Species Group E
Homalocalyx echinulatus
Neurachne minor
Acacia **sp. Peak Hill**
Acacia **thoma**

Species Group F
Eremophila spectabilis **subsp.** *brevis*
Harnieria kempeana **subsp.** *muelleri*
Sida **sp. Excedentifolia**
Grevillea berryana
Phyllanthus erwinii

Species Group G
Acacia balsamea
Dodonaea microzyga **var** *acrolobata*
Callitris columellaris
Digitaria brownii
Psydrax latifolia
Prostanthera althoferi **subsp** *althoferi* **x** *campbellii*
Prostanthera campbellii
Baeckea **sp. Melita Station**
Olearia humilis
Philotheca brucei **subsp** *brucei*
Thryptomene decussata
Cheilanthes brownii

Species Group H
Brachychiton gregorii
Acacia craspedocarpa
Ptilotus roei
Senna artemisioides **subsp x** *helmsii* **x** *glaucifolia*
Eremophila galeata
Senna glaucifolia
Santalum lanceolatum
Hibiscus solanifolius
Dodonaea rigida
Senna artemisioides **subsp.** *helmsii*
Eremophila forrestii
Acacia tetragonophylla
Enneapogon caerulescens
Acacia ramulosa **var** *ramulosa*
Sida **sp. dark green fruits**
Ptilotus obovatus
Marsdenia australis
Prostanthera althoferi **subsp** *althoferi*
Eragrostis eriopoda
Acacia quadrimarginea
Solanum lasiophyllum
Senna **sp. Meekatharra**
Acacia aneura **var.** *cf. aneura*
Eremophila jucunda **subsp.** *jucunda*

Species Group I
Eriachne helmsii
Psydrax suaveolens
Psydrax rigidula
Cymbopogon ambiguus
Acacia aneura **var.cf.** *tenuis*
Dodonaea petiolaris
Thyridolepis multiculmis
Eremophila georgei
Cheilanthes sieberi **subsp.** *sieberi*
Ptilotus schwartzii
Monachather paradoxus
Eremophila latrobei **subsp.** *latrobei*
Acacia aneura **var. cf.** *microcarpa*
Sida **sp. Golden calyces glabrous fruit**
Solanum ashbyae

Table 1

Taxa of conservation significance collected within the Booylgoo Range. Priority status is listed under DEC conservation codes for Western Australia (Atkins 2008). Endemic taxa are defined as those restricted to hills within 100km radius. IBRA Regions are denoted as: Yal = Yalgoo, Mur = Murchison, GD = Gibson Desert, LSD = Little Sandy Desert, Pil = Pilbara, Gas = Gascoyne, GS = Geraldton Sandplains (Thackway & Cresswell 1995; Environment Australia 2000).

Family	Taxon	Record for Booylgoo	Priority Code	IBRA Bioregion Distribution
Mimosaceae	*Acacia balsamea*	new record	4	Mur, Gas, GD, LSD, Pil
Myrtaceae	*Baeckea* sp. Melita Station	new record	4	Yal, Mur
Myrtaceae	*Calytrix erosipetala*	new record	3	Yal, Mur
Myrtaceae	*Calytrix uncinata*	new record	3	Yal, Mur
Proteaceae	*Grevillea inconspicua*	–	4	Mur
Myrtaceae	*Homalocalyx echinulatus*	new record	3	Mur, Gas, GS

Table 2

Significant indicator taxa of the eight group classification of BIF landforms within the Booylgoo Range. 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	**1a**	**1b**	**2**	**3**	**4**	**5**	**6**
Eremophila latrobei subsp. *latrobei****	21	21	21	13	5	1	2
Acacia aneura var *cf microcarpa***	22	19	9	22	1	0	10
Sida sp. Golden calyces glabrous fruit **	29	24	20	4	0	0	0
*Eriachne helmsii**	35	1	2	5	0	0	0
*Solanum ashbyae**	21	21	12	0	21	5	2
*Eremophila georgei****	3	29	23	9	0	0	13
*Thyridolepis multiculmis**	0	27	0	0	0	0	0
Philotheca brucei subsp *brucei****	1	0	91	0	0	0	0
*Thryptomene decussata****	1	10	57	0	0	0	0
*Olearia humilis***	1	0	59	1	0	0	0
*Prostanthera campbellii***	5	0	47	0	0	0	0
*Solanum lasiophyllum***	0	0	1	47	0	5	21
Eremophila jucunda subsp. *jacunda***	2	2	1	42	13	0	0
Acacia aneura var. cf. *tenuis**	3	5	9	29	0	0	0
*Brachychiton gregorii****	0	0	0	0	75	0	0
*Senna glaucifolia***	2	5	1	23	38	1	0
*Acacia craspedocarpa***	0	0	0	1	47	0	9
*Eremophila galeata***	0	0	0	20	44	1	5
Senna artemisioides subsp. *helmsii* x *glaucifolia**	5	0	0	11	31	6	0
*Acacia xanthocarpa****	0	0	0	1	5	73	0
*Dodonaea rigida****	2	33	0	0	0	50	0
*Senna manicula***	0	0	0	0	0	60	10
*Eremophila granitica***	0	0	0	0	0	46	30
*Cheilanthes lasiophylla**	0	0	0	0	0	33	0
*Eremophila exilifolia**	0	0	0	0	21	38	0
*Eremophila forrestii**	8	0	0	2	12	34	0
*Grevillea inconspicua**	0	0	0	0	0	30	13
Senna sp. Meekatharra *	0	1	0	13	3	5	43
*Austrostipa trichophylla**	0	0	0	0	0	11	44
Eremophila oldfieldii subsp. *angustifolia**	0	0	0	0	0	11	44
*Dodonaea petiolaris**	1	7	19	2	0	4	34
*Ptilotus exaltatus**	0	1	0	0	5	2	38
Number of quadrats	10	11	8	9	4	6	3

Table 3

Summary statistics (average ± s.e.) of environmental variables for floristic community types of the Booylgoo Range. Differences among groups were determined using Kruskal – Wallis nonparametric analysis of variance, and groups tested are in bold text. (*= $p < 0.05$,** = $p < 0.01$,*** = $p < 0.001$), with significant Dunn's posthoc test (LSD $p < 0.05$) results indicated by letters in superscript. Parameter codes are explained in the methods section. Units for parameters; EC =mS/m, eCEC = cmol(+)/kg, minerals = mg/kg, organic C and N = %. Abbreviations: Rock Frag = surface rock fragment cover, Rock Max Size = maximum surface rock size category. Aspect is expressed as sine (east-west) or cosine (north-south) of value in radians.

Variable				**Community Type**			
	type 1a	**type 1b**	**type 2**	**type 3**	**type 4**	**type 5**	**type 6**
Soil parameters							
EC NS	2.4 ± 0.3	3.6 ± 0.4	3.0 ± 0.5	5.7 ± 2.0	2.5 ± 0.5	4.5 ± 1.1	5.3 ± 1.3
pH***	4.22 ± 0.06 a	4.46 ± 0.09 ab	4.25 ± 0.08 a	4.42 ± 0.06 ab	5.1 ± 0.24	5.97 ± 0.2 b	5.23 ± 0.32
OrgC***	0.89 ± 0.11 b	1.00 ± 0.20 b	1.44 ± 0.32 b	0.43 ± 0.03 a	0.31 ± 0.05	0.58 ± 0.06 ab	1.14 ± 0.13
N***	0.07 ± 0.01 b	0.07 ± 0.01 b	0.10 ± 0.02 b	0.04 ± 0.00 a	0.03 ± 0.00	0.05 ± 0.00 ab	0.09 ± 0.01
Al NS	442.0 ± 21.7	401.8 ± 31.6	436.3 ± 26.3	357.8 ± 19.7	407.5 ± 42.7	448.3 ± 41.2	313.3 ± 17.6
Ca***	123.2 ± 15.8 a	215.5 ± 19 ab	212.3 ± 50.6 a	184.4 ± 19.9 a	282.5 ± 74.9	935.0 ± 152.5 b	773.3 ± 413.5
Co***	0.16 ± 0.08 ab	0.30 ± 0.08 abc	0.05 ± 0.01 a	0.64 ± 0.23 bc	2.39 ± 0.37	3.09 ± 0.443 c	2.01 ± 1.20
Cu*	0.75 ± 0.05 ab	0.79 ± 0.07 ab	0.65 ± 0.05 a	0.73 ± 0.11 a	1.83 ± 0.5	2.07 ± 0.42 b	0.73 ± 0.2
Fe**	50.5 ± 8.6 ab	84.5 ± 25.1 b	109.3 ± 36.3 b	31.0 ± 1.4 a	38.3 ± 2.1	42.8 ± 3.4 ab	56.3 ± 3.8
K*	147.6 ± 12.3	205.8 ± 18.5	142 ± 18.5	189.4 ± 15.9	167.5 ± 17.5	171.7 ± 15.4	193.3 ± 3.3
Mg***	29.3 ± 3.8 a	51.6 ± 3.8 abc	42.3 ± 6.3 ab	60.7 ± 8.8 cb	135 ± 13.2	256.7 ± 63.5 c	270.7 ± 146.0
Mn**	24.4 ± 3.3 a	39.8 ± 9.0 ab	21.4 ± 3.7 a	38 ± 9.4 ab	115.5 ± 21.8	112.3 ± 18.1 b	64.0 ± 18.1
Ni***	0.14 ± 0.02 a	0.35 ± 0.07 ab	0.16 ± 0.03 a	0.4 ± 0.1 ab	1.03 ± 0.3	1.25 ± 0.42 b	2.53 ± 2.08
P**	13.9 ± 2.7 ab	27.8 ± 10.8 ab	44.4 ± 17.9 b	6.3 ± 0.7 a	5.5 ± 0.6	6.8 ± 0.6 a	10.7 ± 3.2
S**	10.1 ± 1.0 b	12.1 ± 1.4 b	10.3 ± 0.4 b	11.4 ± 1.9 b	5.3 ± 1.1	4.8 ± 0.4 a	9.7 ± 4.2
Zn NS	3.75 ± 1.56	4.19 ± 0.95	2.15 ± 0.25	5.12 ± 2.23	2.85 ± 0.5	3.65 ± 0.73	3.73 ± 1.39
ECEC***	1.24 ± 0.13 a	2.04 ± 0.156 ab	1.79 ± 0.34 a	1.97 ± 0.20 ab	2.97 ± 0.45	7.23 ± 1.23 b	6.62 ± 3.24
Ca:Mg	4.3 ± 0.2	4.2 ± 0.2	4.7 ± 0.5	3.3 ± 0.3	2.0 ± 0.3	4.0 ± 0.6	3.0 ± 0.4
Physical Site Parameters							
CosAspect NS NS	0.22 ± 0.20	0.10 ± 0.23	0.11 ± 0.16	0.34 ± 0.26	0.04 ± 0.51	-0.07 ± 0.34	-0.10 ± 0.34
SinAspect EW NS	-0.18 ± 0.25	-0.44 ± 0.16	0.24 ± 0.33	-0.07 ± 0.21	0.44 ± 0.07	-0.26 ± 0.26	0.22 ± 0.59
Topography***	3.2 ± 0.4b	3.5 ± 0.3 b	4.3 ± 0.3 b	1.4 ± 0.2 a	1.4 ± 0.1	3.5 ± 0.4 b	3.2 ± 0.2
Slope**	8.6 ± 1.3 ab	14.4 ± 2.4 b	17.6 ± 4.2 b	3.3 ± 1.0 a	3.0 ± 0.9	8.7 ± 1.1 ab	14.7 ± 4.3
Rock Frag*	5.1 ± 0.1	5.2 ± 0.2	4.4 ± 0.3	4.3 ± 0.5	5.0 ± 0	5.3 ± 0.2	5.0 ± 0
MxR**	4.5 ± 0.2 ab	5.0 ± 0.3 ab	5.6 ± 0.2 b	3.7 ± 0.4 a	4.0 ± 0	5.0 ± 0.3 ab	5.7 ± 0.3
Outcrop**	1.8 ± 0.7 ab	2.4 ± 0.6 ab	4.3 ± 0.3 b	0.1 ± 0.1 a	0.5 ± 0.3	1.2 ± 0.2 ab	2.0 ± 1.0
Runoff NS	2.4 ± 0.2	2.9 ± 0.1	2.8 ± 0.3	2.1 ± 0.3	2.5 ± 0.3	2.7 ± 0.2	3.0 ± 0.0
Soil depth**	1.9 ± 0.3 ab	1.4 ± 0.2 a	1.3 ± 0.1 a	2.9 ± 0.1 b	2.9 ± 0.1	2.2 ± 0.3 ab	2.0 ± 0.6
%Leaf	13.3 ± 2.7	13.6 ± 2.5	14.4 ± 4.3	14.1 ± 2.9	8.0 ± 2.9	12.7 ± 3.5	18.3 ± 7.3
%Bare	87.5 ± 2.4	85 ± 2.1	86.3 ± 2.5	89 ± 2.6	88.8 ± 3.1	84.2 ± 3	83.3 ± 6
Altitude*	518.9 ± 8	540.2 ± 9.3	548.3 ± 13.4	519.2 ± 7.1	522.3 ± 10	547.9 ± 5.7	542.3 ± 6.4
Latitude*	-27.88 ± 0.026ab	-27.844 ± 0.027 ab	-27.916 ± 0.032 a	-27.797 ± 0.024 b	-27.844 ± 0.033	-27.814 ± 0.034 ab	-27.803 ± 0.072
Longitude**	119.947 ± 0.009	119.926 ± 0.009	119.955 ± 0.009	119.91 ± 0.01	119.918 ± 0.014	119.91 ± 0.01	119.913 ± 0.023
Number of species / quadrat							
All taxa 1	23.2 ± 1.9	28.1 ± 1.7	27.1 ± 1.4	31.1 ± 2.5	31.5 ± 3.9	32.0 ± 1.9	33.3 ± 3.5
Annuals only	7.4 ± 1.0	9.3 ± 0.8	9.6 ± 1.5	8.9 ± 1.5	10 ± 3.6	9.7 ± 1.3	7 ± 2
Number of quadrats	10	11	8	9	4	6	3

[1:] including singleton taxa

Table 4: Matrix of Spearmann rank correlation coefficients for environmental variables collated from 51 quadrats established on the Booylgoo Range. Only correlations significant at $p < 0.01$ are shown. Full details of environmental parameter codes are given in the methods section.

	EC	pH	OrgC	N	Al	Ca	Co	Cu	Fe	K	Mg	Mn	Ni	P	S	Zn	eCEC	NS	EW	Tp	Slope	Rock Frag	MxR	Outcrop	Runoff	I Depth D	%Leaf	%Bare	Altitude	Latitude
Soil chemical paramters																														
EC																														
pH	.																													
OrgC	.	.																												
N	.	.	0.99																											
Al	-0.42	.	.	.																										
Ca	.	0.86	.	.	.																									
Co	.	0.82	.	.	.	0.74																								
Cu	.	0.57	.	.	.	0.36	0.78																							
Fe	.	.	0.84	0.83	.	.	.	.																						
K	.	.	.	.	.	.	.	.	.																					
Mg	.	0.81	.	.	.	0.93	0.75	.	.	.																				
Mn	.	0.71	.	.	.	0.47	0.86	0.89	.	.	0.48																			
Ni	.	0.62	.	.	.	0.81	0.65	.	.	.	0.87	.																		
P	.	.	0.81	0.79	.	.	.	.	0.97	.	.	.	.																	
S	0.52	-0.51	.	.	.	-0.42	-0.55	-0.48	.	.	-0.41	.	.	.																
Zn	.	.	.	.	0.38	.	.	.	.	.	.	.	.	.	.															
eCEC	.	0.85	.	.	.	0.99	0.76	.	.	.	0.97	0.48	0.84	.	-0.41	.														
Physical paramters																														
Aspect NS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.													
Aspect EW	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.												
Topography	.	.	0.55	0.56	0.46	.	.	.	0.44	.	.	.	.	0.43	.	.	.	.	.											
Slope	.	.	0.70	0.71	.	.	.	.	0.63	.	.	.	.	0.60	.	.	.	.	.	0.49										
Rock Frag	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.									
MxR	.	.	0.59	0.64	.	.	.	.	0.51	.	.	.	.	0.48	.	.	.	.	.	0.70	0.64	.								
Outcrop	.	.	0.68	0.65	0.37	.	.	.	0.58	.	.	.	.	0.57	.	.	.	.	.	0.79	0.68	.	0.66							
Runoff	.	.	0.42	0.44	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.46	0.58	.	0.69	0.44						
Soil	.	.	-0.56	-0.55	-0.36	.	.	.	-0.47	.	.	.	.	.	.	.	.	.	.	-0.72	-0.69	.	-0.68	-0.76	-0.51					
%Leaf	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.				
%Bare	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-0.57			
Altitude	.	.	0.45	0.45	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.55	0.37	.	0.52	0.50	0.36	-0.45	.	.		
Latitude	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	
Longitude	.	.	.	.	.	-0.36	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-0.84