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Flora and vegetation of banded iron formations of the Yilgarn Craton: the Lake Mason Zone of the Gum Creek Greenstone Belt

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ABSTRACT

The Lake Mason Zone of the Gum Creek Greenstone Belt is located in the central portion of the Yilgarn Craton, c. 40 km north of the township of Sandstone. Fifty permanent vegetation quadrats were established, with all vascular flora and a series of environmental attributes recorded. A total of 111 taxa were recorded, representing 28 families and 47 genera. Seven taxa of conservation significance were identified, including *Acacia burrowsiana* (P1), *Stenanthemum mediale* (P1), *Calytrix erosipetala* (P3), *Sauropus ramosissimus* (P3) *Baeckea* sp. London Bridge (ME Trudgen 5393; P3), *Baeckea* sp. Melita Station (H Pringle 2738; P3) and *Grevillea inconspicua* (P4). No new taxa or weed species were identified, but the collection of *Acacia* cf. *coolgardiensis* and *Sauropus ramosissimus* represented significant range extensions. Six floristic communities were identified from the survey, which had alliance to topographical position, local geology and edaphic factors. The Lake Mason Zone represents an important repository of significant taxa and floristic communities associated with banded ironstone formations. Any future exploration or development should ensure that the important conservation values and condition of the range are retained.

Keywords: banded ironstone, floristic communities, mulga, Murchison, Yilgarn.

INTRODUCTION

The Lake Mason Zone encompasses the south-western portion of the Gum Creek Greenstone Belt in the Yilgarn Craton. Erosional processes have resulted in a series of distinct ridges, low undulating hills and stony plains that includes the greenstone belt (Tingey 1985). The Lake Mason Zone is also home to an extensive network of salt lakes associated with the present day Lake Mason system (Tingey 1985; Payne et al. 1998). European settlement in the region is linked to pastoral activities and mining; early mineral exploration identified gold deposits associated with mafic rocks (Wyche et al. 2004).

STUDY SITE

The Lake Mason Zone of the Gum Creek belt is located in the centre of the Murchison bioregion (Interim Biogeographic Regionalisation of Australia—IBRA; Thackway & Cresswell 1995), approximately 35 km north of the Sandstone township (Fig. 1). The greenstone belt trends north-west, covering approximately 30 km from north to south and is c. 6–8 km wide. The latitudinal and longitudinal boundaries of the Range are 27° 30" S, 27° 50" S and 119° 20" E and 119° 35" E, respectively. Located entirely within the Sandstone Shire, the land tenure for the Range includes the Barrambie pastoral lease and former Lake Mason pastoral lease, which is now owned by the Department of Environment and Conservation (DEC) and managed as part of the conservation estate.

Land Use History

The Sandstone area within the Murchison has a history of pastoralism and mineral exploration, particularly gold mining (Senior 1995). Early explorers of the region include LA Wells with the 1891–1892 Elder Scientific Exploring Expedition, who passed north of Lake Mason in the vicinity of Montague Range (Tingey 1985). In 1900, the surveyor HGB Mason, for whom the lake is named, travelled through the area (Senior 1995). In 1895, the discovery of gold near the township of Sandstone brought an influx of people into the region (Tingey 1985).

Barrambie and Lake Mason stations primarily ran sheep on the properties, with Lake Mason station initially stocking cattle and horses (Senior 1995). Lake Mason was destocked following the purchase of the property by the Department of Conservation and Land Management (CALM, now DEC) in 2000. Rangeland condition of the former Lake Mason pastoral lease varies, with more than 50% considered in poor to fair condition (Department of Conservation and Land Management

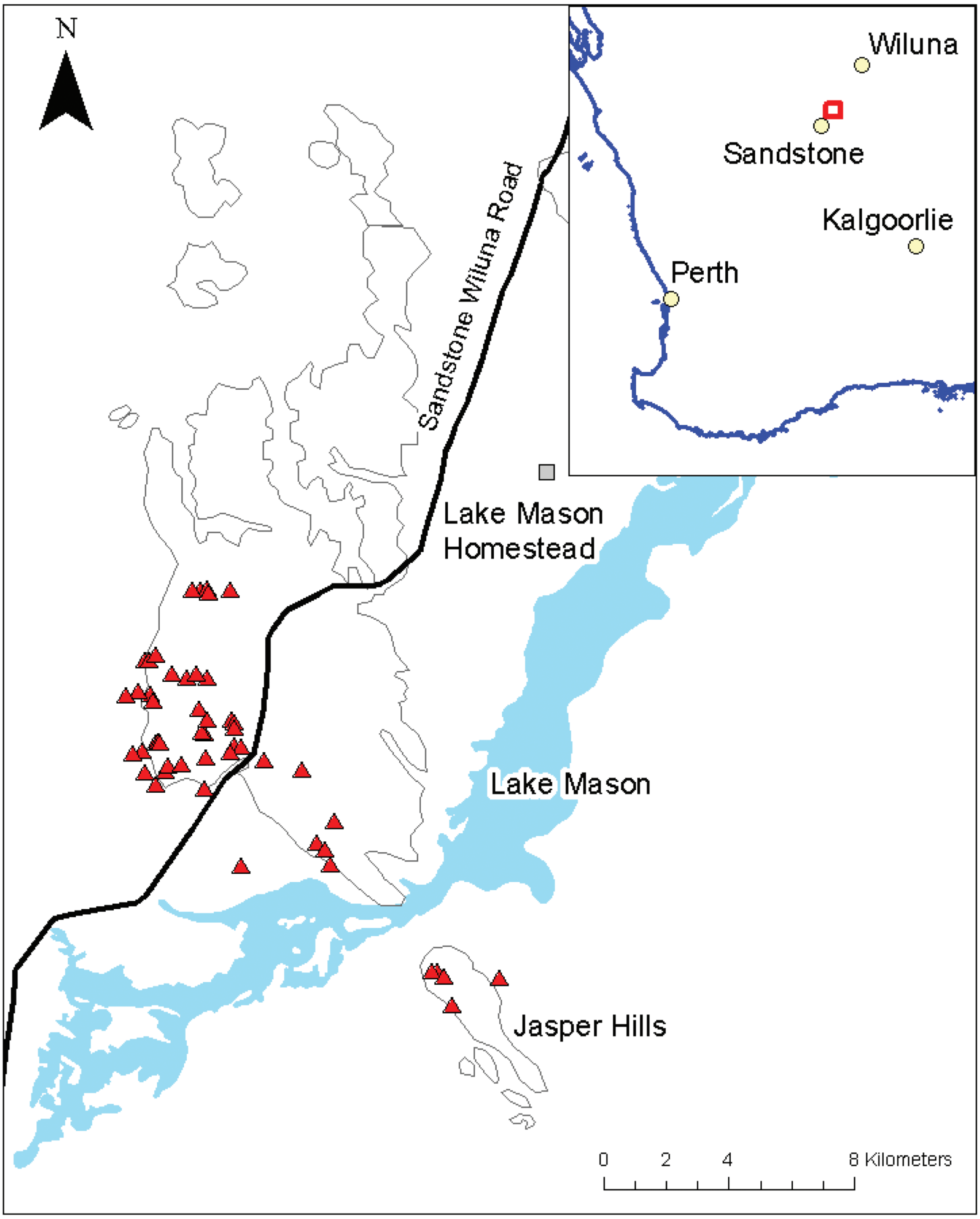


Figure 1. Map showing the location of the Lake Mason Range survey area, with major landforms and landmarks indicated. The locations of the 50 permanent quadrats are marked by triangles (▲).

2001). At the time of purchase, evaluation of the lease suggested that condition on the lease was improving following low stocking rates and limiting water availability (Department of Conservation and Land Management 2001). Fauna surveys were undertaken following destocking between 2004 and 2005, with vegetation quadrats established in conjunction with the fauna sites to represent the majority of the land systems and floristic variation on the former pastoral lease (M Cowan, pers. comm.)[1].

The region that incorporates the greenstone belt has undergone exploration for mineral resources, including gold, uranium (Tingey 1985) and iron ore (Connolly

[1] Mark Cowan, Department of Environment and Conservation, Perth.

1959). The potential for gold deposits in the Gum Creek Belt was identified by government geologists, including T Blatchford in 1898 (Blatchford 1899) and CG Gibson in 1908 (Gibson 1908). Uranium deposits have been identified at Yeelirie (Tingey 1985), north-east of Lake Mason. Analyses of rock samples at Montague Range, north of Lake Mason, identified a metallic iron content of 34% (Connolly 1959).

Climate

The Lake Mason Zone sits in the central portion of the Murchison bioregion, which has an arid climate with hot summers and cool winters. Rainfall is highly variable and occurs sporadically throughout the year (Leighton 1998; Bureau of Meteorology 2009). There is a slight increase in mean rainfall during summer, generally associated with cyclonic activity.

Approximately 40 km east of Lake Mason is the Booygloo Spring weather station. Average annual rainfall at Booygloo is 237.6 mm (based on records from 1922 to 2007), with the months of March (31 mm) and September (5.8 mm) having the highest and lowest mean monthly rainfall, respectively. The highest annual rainfall was recorded in 1975 (607.8 mm) and the lowest rainfall recorded in 1936 (63.5 mm). The single largest rainfall event occurred on 23 February 1975, with 140 mm rain recorded.

Temperatures have been recorded continuously at Booygloo from 1936 to 1975. The average annual maximum is 27.2 °C and average annual minimum is 13 °C. The highest temperatures occur between November and March, with mean maximum temperatures exceeding 30 °C. January is the hottest month, with mean maximum and mean minimum temperatures of 36 °C and 21.5 °C, respectively. The highest daily maximum on record is 43.6 °C on 8 January 1967. The lowest daily minimum temperatures occur between May and October, where mean minimum temperatures are below 10 °C. The coldest month of the year is July, with the average maximum and minimum daily temperature of 17.6 °C and 4.4 °C, respectively. The coldest minimum temperature was recorded 12 July 1969 at –6.7 °C.

Geology

The geology of the Lake Mason Zone within the Gum Creek Greenstone Belt has been mapped and described on the Sandstone 1:250,000 sheet (Tingey 1985) and both the 1:100,000 Lake Mason (Wyche 2004) and Sandstone sheets (Chen & Painter 2005). The Gum Creek Greenstone Belt occurs as a series of low undulating hills. The majority of the Lake Mason Zone is between 500 and 560 m above sea level, with the present-day Lake Mason lake bed at c. 480 m above sea level.

The Gum Creek Belt lies entirely in the northern portion of the Youanmi Terrane in the Southern Cross Domain (SCD) in the Yilgarn Craton (Cassidy et al. 2006). The Yilgarn Craton, situated in the central portion of the Pre-Cambrian Western Shield of Australia, is one of the most well preserved examples of Archaean crust on the planet (Anand & Paine 2002), and is thought to have primarily formed between 3000 Ma and 2600 Ma (Myers 1993; Myers & Swagers 1997). The Yilgarn Craton is largely composed of a series of greenstone belts (Myers & Swagers 1997), which consist of metamorphosed sedimentary and volcanic rocks positioned between vast areas of granitoid rocks (Anand & Paine 2002). The Gum Creek Belt is of similar age to other greenstone belts in the region, c. 2722 Ma (Tingey 1985).

The greenstone belts of the SCD trend predominantly in a north-north-west direction, with evidence of multiple episodes of folding (Griffin 1990). These greenstone belts have been overlain by successions of basalt and banded iron formations (BIF), plus felsic-volcanic and sedimentary rocks (Griffin 1990; Cassidy et al. 2006). As the Gum Creek Greenstone Belt continues north-west it is overlain by additional regolith, eventually linking up with minor greenstone occurrences on the adjacent Glengarry map sheet (Elias et al. 1982). Deeply weathered felsic volcanic rocks are significant components of the Gum Creek Formation and characterize many of the greenstone belts in the northern SCD (Tingey 1985). The central portion of the Gum Creek Greenstone Belt is described as metamorphosed BIF surrounded by fine-grained metabasalts with intermittent pockets of medium and coarse grained metamorphosed ultramafic rock and gneissic granitoids (Tingey 1985).

Typical of many of the greenstone belts in the region, there is a lack of surface exposure of the underlying geology (Tingey 1985). The majority of the Gum Creek Belt appears as low undulating hills with varying amount of bedrock exposed at the surface. Significant outcrops, including a prominent ridge of BIF, occur in the south-western portion of the belt and at Jasper Hill (Tingey 1985). Jasper Hill is separated from the main outcrop segment by quaternary alluvial deposits associated with Lake Mason. The majority of the greenstone belt is surrounded by quaternary deposits of colluvial and alluvial origins with aeolian sands of granitoid origin adjacent to the outcrops (Tingey 1985). Lake Mason trends north-east through the southern portion of the Gum Creek belt, which is derived from quaternary deposits linked to a Cenozoic drainage system (Tingey 1985).

The soils of the Murchison region are characteristically red brown hard pans overlain by shallow earthy loams, with shallow stony loams typically associated with the uplands (Beard 1990). The soils of the greenstone belts of the Sandstone region are derived from weathering and erosional processes, and are characteristically skeletal to shallow (<50 cm depth), poorly developed and acidic in nature (Churchward 1977; Hennig 1998). The Lake Mason Zone is principally composed of stony soils and stony red earths on the hills and ridges, including Jasper Hill, with shallow red earths and shallow hard pan loams more prevalent on the footslopes and pediments (Hennig 1998; Payne et al. 1998). The extensive quaternary sandplains, adjacent to the uplands and stony plains, are typically deep red, clayey sands with shallow clays and highly saline soils associated with Lake Mason and allied drainage zones (Hennig 1998).

Vegetation

The Lake Mason Zone is part of the Wiluna sub-region of the Austin Botanical District in the Eremaean Province (Beard 1990) in the central part of the Murchison bioregion (Thackway & Cresswell 1995). Beard (1976) described the vegetation of the Range as part of the regional survey of the Murchison 1:1,000,000 map sheet. This area is the dominant *Acacia aneura* (mulga) region in the state (Beard 1990).

Beard (1976) mapped the uplands as mulga shrubland, with adjacent areas of mulga low woodland. Mulga and saltbush vegetation is allied with Lake Mason and the surrounding salt flats that occur in the southern portion of the Range. Community structure is predominantly tall shrubs (>3 m), principally *Acacia aneura*, with sparse cover of low shrubs (1–2 m) and ephemerals present under favourable conditions (Beard 1990). Other than *A. aneura*, other species are primarily considered isolated or localised when defining community composition (Beard 1990).

The vegetation communities of the rocky slopes and uplands largely consist of tall shrubs of *A. aneura*, *A. quadrimarginea*, *A. grasbyi* and *Hakea lorea* with additional mid-stratum shrubs of *Senna* sp. (formerly *Cassia*), *Eremophila clarkei*, *E. latrobei* and *Ptilotus obovatus* with annuals (Beard 1976). Beard (1976) did not differentiate between the vegetation communities growing on granites and greenstones. The vegetation on the quaternary sandplains abutting the uplands and pediments is predominantly scattered trees, typically *Eucalyptus kingsmillii*, *E. lucasii* and *E. ebbanoensis*; and shrubs over hummock grasslands of *Triodia basedowii*, *T. pungens*, and *T. melvillei* (Beard 1976).

There are no detailed vegetation surveys associated with the Lake Mason Zone. There are 281 taxa from the greenstone belt and adjacent sandplains held in the Western Australia Herbarium records. Land system mapping undertaken by the then Agriculture Western Australia (now Department of Agriculture and Food) produced broad vegetation associations allied to geology and geomorphology for portions of the Murchison (see Payne et al. 1998). The Lake Mason Zone is predominantly composed of those land systems associated with uplands of *Acacia* shrubs, including the Wiluna, Gabinantha and Bevon land systems. Jasper Hill, the southern portion of Lake Mason BIF, has been mapped as Brooking and Gabinantha land systems (Payne et al. 1998). Other land system classifications located on and adjacent to the greenstone belt include Violet (low rises and undulating plains of colluvium) in the central portion of the greenstone belt, the Sherwood (breakaways associated with granites and stony plains; Mabbutt et al. 1963) in the north and Tango (ironstone gravels with saline hardpan and stony plains) associated with the margins of Lake Mason (Payne et al. 1998). The extensive quaternary sandplains prevalent to the north-west and south-east of Lake Mason are part of the Bullimore land system (Payne et al. 1998).

The predominant vegetation associations allied with the stony uplands and rises are *Acacia* shrublands on stony ironstones and greenstones (Payne et al. 1998; Pringle 1998a, 1998b). Common tall shrubs include *A. burkittii*, *A. quadrimarginea*, *A. ramulosa* and *A. tetragonophylla* (Pringle 1998a, 1998b). Other widespread taxa found in the *Acacia* shrublands are *Eremophila* spp. (e.g. *E. forrestii* and *E. latrobei*), *Scaevola spinescens*, *Ptilotus obovatus*, *Senna* spp., *Sida* spp. and *Solanum lasiophyllum* (Pringle 1998a, 1998b). Chenopod shrubs, such as *Maireana* spp., are found in the understorey in the saline environments, with *Acacia* remaining the dominant tall shrub component (Pringle 1994, 1998a, 1998b).

The land system mapping (i.e. Payne et al. 1998) and broad scale vegetation mapping (i.e. Beard 1976) have provided general structure and composition of the vegetation found on greenstone belts and granitiods of the Yilgarn Craton. However, recent surveys on greenstone belts and associated BIF in the Yilgarn Craton have found that distinct vegetation communities occur within (see Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c) and among these landscapes (Gibson et al. 2007). This study aims to record the floristic diversity, describe vegetation patterns and examine environmental correlates associated with the Lake Mason Zone of the Gum Creek Greenstone belt.

METHODS

Fifty 20 x 20 m permanent quadrats were established across the range in late August 2008. The quadrats encompassed the topographical, geological and geomorphological variation found across the length and breadth of the range, including Jasper Hill located to the south of the main portion of the range. The quadrats were located to capture the vegetation communities associated with the greenstone belt, particularly the occurrence of BIF and adjacent geologies, and were placed across a broad topographical sequence from hill crests down slope to the colluvial deposits off the range. Survey methods followed those of previous surveys of greenstone belts in the Yilgarn Craton (e.g. Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c). Vegetation communities were selected to represent areas of minimal disturbance or modification found on the range, which has previously been the focus of mineral exploration and pastoral activities. Thus, we avoided localities with heavy grazing, evidence of clearing, or disturbance related to mineral exploration.

The quadrats were marked by four steel fence droppers, and their locations recorded with a Garmin Map76 GPS. Photographs were taken at a set distance of 5 m from each corner. Site physical characteristics (landform, slope, aspect, litter and bare ground cover, size of coarse fragments, cover of surface rock fragments and bedrock, soil colour and texture) were recorded as a series of descriptive attributes and semi-quantitative scales as defined by McDonald et al. (1998). Landform description was based on topographical position (crest, upper slope, mid-slope, lower slope or flat) and landform element type (e.g. hillcrest, hillslope, breakaway; McDonald et al. 1998).

Coarse fragments and rock outcrop data were recorded as rock type present and as per cent (%) cover. The seven cover classes were: 0% cover (0); <2% cover (1); 2–10% (2); 10–20% (3); 20–50% (4); 50–90% (5); >90% (6). Site disturbance was ranked between zero and three, with zero (0) representing no effective disturbance and three (3) being extensively cleared. Runoff was assigned to one of six classes (0 = no runoff, 1 = very slow, 2 = slow, 3 = moderately rapid, 4 = rapid, 5 = very rapid; McDonald et al. 1998).

Vegetation structure was determined by recording the dominant taxa in each stratum, noting emergent taxa where appropriate (McDonald et al. 1998). All vascular plants within the quadrat were recorded and assigned to a cover class (D >70%, M 30–70%, S 10–30%, V <10%, I isolated plants, or L isolated clumps); material was collected for verification and vouchering at the WA Herbarium. Additional specimens were collected adjacent to the plots, contributing to the overall species list for the range. Where sufficient representative plant material was available, it was lodged at the WA Herbarium. Nomenclature generally follows Paczkowska and Chapman (2000).

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

The classification and ordination analyses were undertaken on a presence–absence data matrix of the 77 perennial species that occurred in more than a single quadrat, which is consistent with previous greenstone belt studies (Gibson 2004a, 2004b). All annuals, singletons and specimens unidentifiable beyond genera (i.e. sp. in det.) were removed from the original species matrix. The dissimilarity between quadrats was determined using the Bray–Curtis measure and the Resemblance routine in PRIMER v6 (Clarke & Gorley 2006). The Bray–Curtis measure is a widely-used assessment of ecological distance, which reflects compositional change (Legendre & Legendre 1998; Anderson & Robinson 2003), thus providing quantitative output for similarity between samples (Faith et al. 1987). The species by site matrix was used in a classification based on flexible unweighted pair-group mean average (UPGMA, $\beta = -0.1$) using PATN v3.11 (Belbin 1989). The similarity profile (SIMPROF) routine in PRIMER v6 (Clarke & Gorley 2006) was used to determine, a priori, similarities in the structure of communities between samples. Non-metric Multi-Dimensional Scaling (MDS) was then used to highlight groups determined through the SIMPROF procedure.

The degree of association of individual species within each community group, as determined by SIMPROF, was measured using indicator species analysis (Dufrêne & Legendre 1997). Indicator values examine information on consistency and fidelity of each species between groups. Statistical significance of the indicator values was determined by the Monte Carlo randomization procedure performed with 1000 iterations using PC-ORD (McCune & Mefford 1999). The similarity percentages (SIMPER) analyses provided information on those species typically found within each community. The SIMPER routine in PRIMER determines those taxa contributing the greatest similarity within a community and dissimilarity amongst communities (Clarke & Warwick 2001). Those taxa contributing 10% or greater to the similarity within each community type are reported.

Relationships between environmental variables were examined using the nonparametric Spearman rank correlation routine in Statistix 7.1 (Analytical Software, Tallahassee, Florida). The environmental variables were analysed using Kruskal–Wallis nonparametric analysis of variance and post-hoc significance testing of means $\alpha = 0.05$ (Sokal & Rolf 1995), based on the groups determined by the SIMPROF routine. An environmental data matrix, which included soil chemical properties and site physical characteristics, was created. The BIO-ENV routine in PRIMER v6 (Clarke & Gorley 2006) was used to determine the environmental variables most highly correlated with the site resemblance matrix. The environmental variables were transformed [log(1+x)] and normalised prior to analyses.

RESULTS

Summary information

A total of 111 taxa, representing 28 families and 47 genera, were identified from the quadrats in the Lake Mason Zone (Fig. 1). A further 13 taxa were collected from areas adjacent to the quadrats. The families with the greatest number of representative taxa were Mimosaceae (21 *Acacia* taxa), Myoporaceae (12 *Eremophila* taxa), Chenopodiaceae (11 taxa), Malvaceae (11 taxa) and Poaceae (10 taxa). At the level of genus, *Senna* had the greatest number of species present (6 taxa) after *Acacia* and *Eremophila*. No new taxa or weed species were recorded during the survey.

Survey sites occurred between 485 m and 556 m above sea level (mean 521 ± 17 SD). Species richness varied between seven and 26 taxa per quadrat, with an average richness per quadrat of 14.6 ± 4.5 SD. Ten taxa were amalgamated into four species complexes during analysis. The majority of taxa recorded on the range were perennials and shrubs, with only eight annual and two geophyte taxa identified from the range.

Priority Taxa

Seven taxa of conservation significance were recorded from the range (Table 1). Only two of the species, *Acacia*

Table 1

Priority taxa collected during the survey of the Lake Mason area. Bioregion abbreviations: Mur = Murchison, Gas = Gascoyne, Yal = Yalgoo, GD = Gibson Desert, GVD = Great Victoria Desert.

Family	Taxon	Status for Lake Mason	Priority	Bioregion
Mimosaceae	*Acacia burrowsiana*		P1	Mur, Gas
Rhamnaceae	*Stenanthemum mediale*	New record	P1	Mur
Myrtaceae	*Baeckea* sp. London Bridge (ME Trudgen 5393)	New record	P3	Mur
Myrtaceae	*Baeckea* sp. Melita Station (H Pringle 2738)	New record	P3	Mur, Gas, Yal
Myrtaceae	*Calytrix erosipetala*	New record	P3	Mur, Yal
Euphorbiaceae	*Sauropus ramosissimus*	New record	P3	Mur, Gas, GD, GVD
Proteaceae	*Grevillea inconspicua*		P4	Mur

burrowsiana (P1) and *Grevillea inconspicua* (P4), had been recorded in the vicinity of the range prior to this survey. Three new populations of *A. burrowsiana* were recorded from the mid- to upper slopes of banded ironstone formations. *Stenanthemum mediale* (P1), *Sauropus ramosissimus* (P3) and *Baeckea* sp. London Bridge (ME Trudgen 5393; P3) were identified from single populations at different localities on upper slopes and breakaways on the range. Furthermore, the record for *Sauropus ramosissimus* is a range extension of c. 120 km east from the closest population near Leinster. *Baeckea* sp. Melita Station (H Pringle 2738; P3) and *Calytrix erosipetala* (P3) were recorded from five and two new localities, respectively, ranging from the mid-slopes to crests.

Range Extensions

In addition to the range extension for the priority taxon *Sauropus ramosissimus* (P3), the record of *Acacia* aff. *coolgardiensis* represented a potential range extension of c. 350 km, however, there was insufficient material to confirm identification. Additional material from the area is required.

Hybrids/Integrades

Two interspecific hybrids and a single hybrid were collected. All specimens were synonymous with collections held at the WA Herbarium and typical of the Murchison region. The hybrid recorded during the survey was *Maireana georgei* x *Enchylaena tomentosa* and the two interspecific hybrids were: *Prostanthera althoferi* x *campbellii* and *Senna glaucifolia* x sp. Meekathera (E Bailey 1–26).

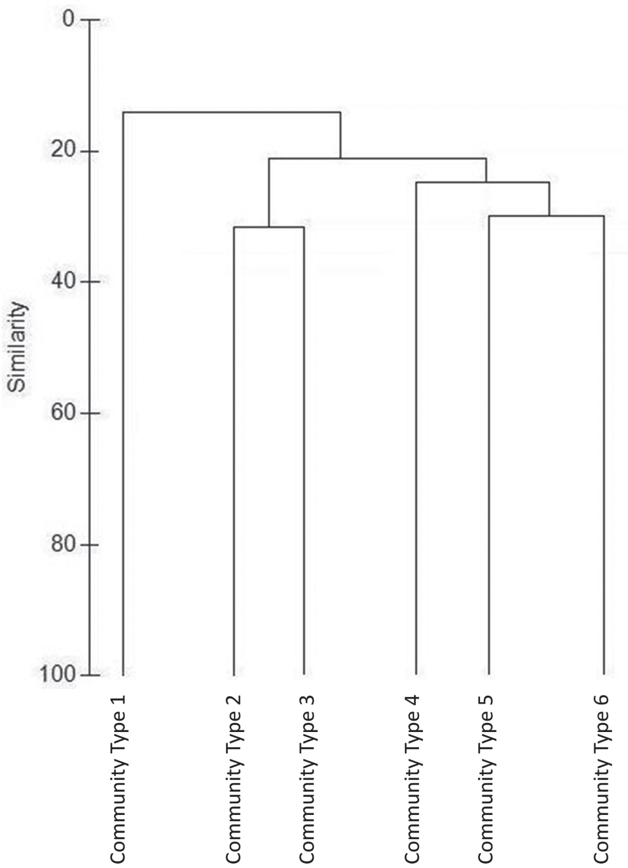


Figure 2. Summary dendrogram of community types for the Lake Mason Zone of the Gum Creek Greenstone Belt. The six community types displayed in the dendrogram are derived from the classification analyses of the 77 perennial species found in 50 quadrats.

Floristic Communities

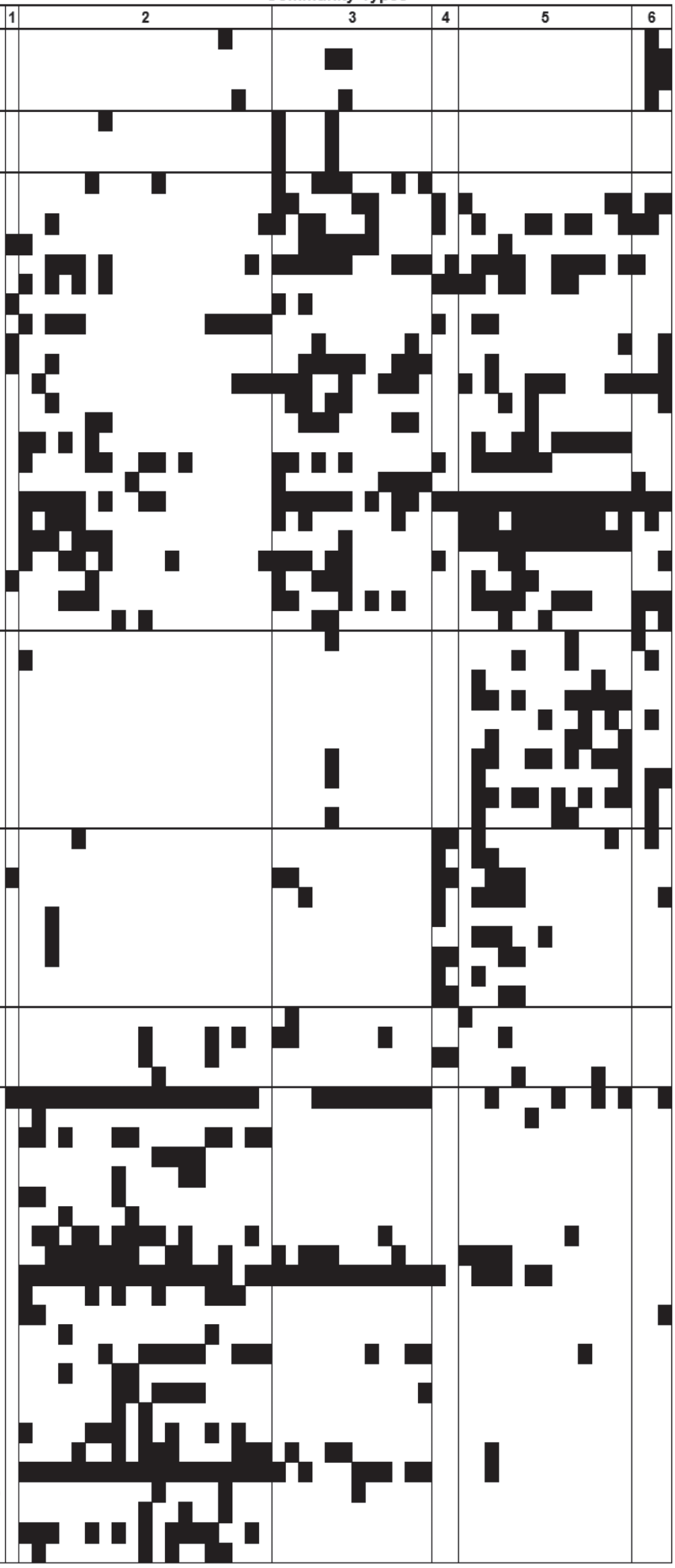
Based on the clustering of samples and the SIMPROF routine, six community types (1–6) were identified during the analyses (Fig. 2). Three of the vegetation communities recognized had representation in three or fewer quadrats. The hierarchical clustering routine identified seven species groups (A–G). Species group C was composed of widespread taxa, with affinities to all community types. The relationship between species groups and community types are discussed below. The two-way table displays the relationship between the seven species groups and the six community types (Table 2). The MDS routine displays the relationship between the sites, based on the resemblance matrix. Quadrats with similar floristic composition clustered together, which corresponded to community type; represented on the 3D graph as the least distance between points. The resulting stress value was 0.14 (Fig. 3).

Table 2

Two-way table of community types (columns) and species groups (rows) for the Lake Mason Zone. Taxa are sorted within species groups. The squares represent the presence of the specific taxon in the corresponding quadrat.

Community Types: 1, 2, 3, 4, 5, 6

Species Groups	Species
A	*Abutilon otocarpum*
A	*Eremophila longifolia*
A	*Sclerolaena convexula*
A	*Senna glaucifolia*
B	*Acacia pruinocarpa*
B	*Enchylaena tomentosa*
B	*Exocarpos aphyllus*
C	*Acacia aneura* var. *argentea*
C	*Acacia aneura* var. *conifera*
C	*Acacia aneura* var. *tenuis*
C	*Acacia ramulosa* var. *ramulosa*
C	*Acacia tetragonophylla*
C	*Acacia xanthocarpa*
C	*Dianella revoluta* var. *divaricata*
C	*Dodonaea rigida*
C	*Eragrostis eriopoda* complex
C	*Eremophila forrestii*
C	*Eremophila galeata*
C	*Eremophila granitica*
C	*Maireana convexa*
C	*Maireana georgei* x *Enchylaena tomentosa*
C	*Marsdenia australis*
C	*Psydrax rigidula*
C	*Ptilotus obovatus*
C	*Scaevola spinescens*
C	*Senna* sp. Meekatharra (E. Bailey 1-26)
C	*Sida ectogama*
C	*Sida* sp. dark green fruits (S. van Leeuwen 2260)
C	*Solanum lasiophyllum*
C	*Spartothamnella teucriiflora*
D	*Acacia craspedocarpa*
D	*Enneapogon caerulescens*
D	*Eremophila oppositifolia* subsp. *angustifolia*
D	*Eremophila pantonii*
D	*Hakea preissii*
D	*Lepidium platypetalum*
D	*Maireana triptera*
D	*Rhagodia drummondii*
D	*Sclerolaena eriacantha*
D	*Senna artemisioides* subsp. *filifolia*
E	*Acacia burkittii*
E	*Acacia burrowsiana*
E	*Austrostipa elegantissima*
E	*Duperreya sericea*
E	*Eremophila exilifolia*
E	*Eremophila oldfieldii* subsp. *angustifolia*
E	*Grevillea inconspicua*
E	*Hibiscus* aff. *solanifolius*
E	*Senna artemisioides* subsp. x *artemisioides*
F	*Brachychiton gregorii*
F	*Cheilanthes sieberi* subsp. *sieberi*
F	*Prostanthera althoferi*
F	*Santalum spicatum*
G	*Acacia aneura* var. *microcarpa*
G	*Acacia paraneura*
G	*Acacia quadrimarginea*
G	*Acacia rhodophloia*
G	*Baeckea* sp. Melita Station (H. Pringle 2738)
G	*Cheilanthes brownii*
G	*Dodonaea adenophora*
G	*Dodonaea petiolaris*
G	*Eremophila jucunda*
G	*Eremophila latrobei* subsp. *latrobei*
G	*Eremophila punctata*
G	*Eriachne helmsii*
G	*Eriachne mucronata*
G	*Grevillea berryana*
G	*Micromyrtus sulphurea*
G	*Olearia humilis*
G	*Philotheca brucei* subsp. *brucei*
G	*Prostanthera campbellii*
G	*Psydrax latifolia*
G	*Ptilotus schwartzii*
G	*Senna glaucifolia* x sp. Meekatharra (E. Bailey 1-26)
G	*Sida* sp. Excedentifolia (J.L. Egan 1925)
G	*Sida* sp. Golden calyces glabrous (H.N. Foote 32)
G	*Thryptomene decussata*



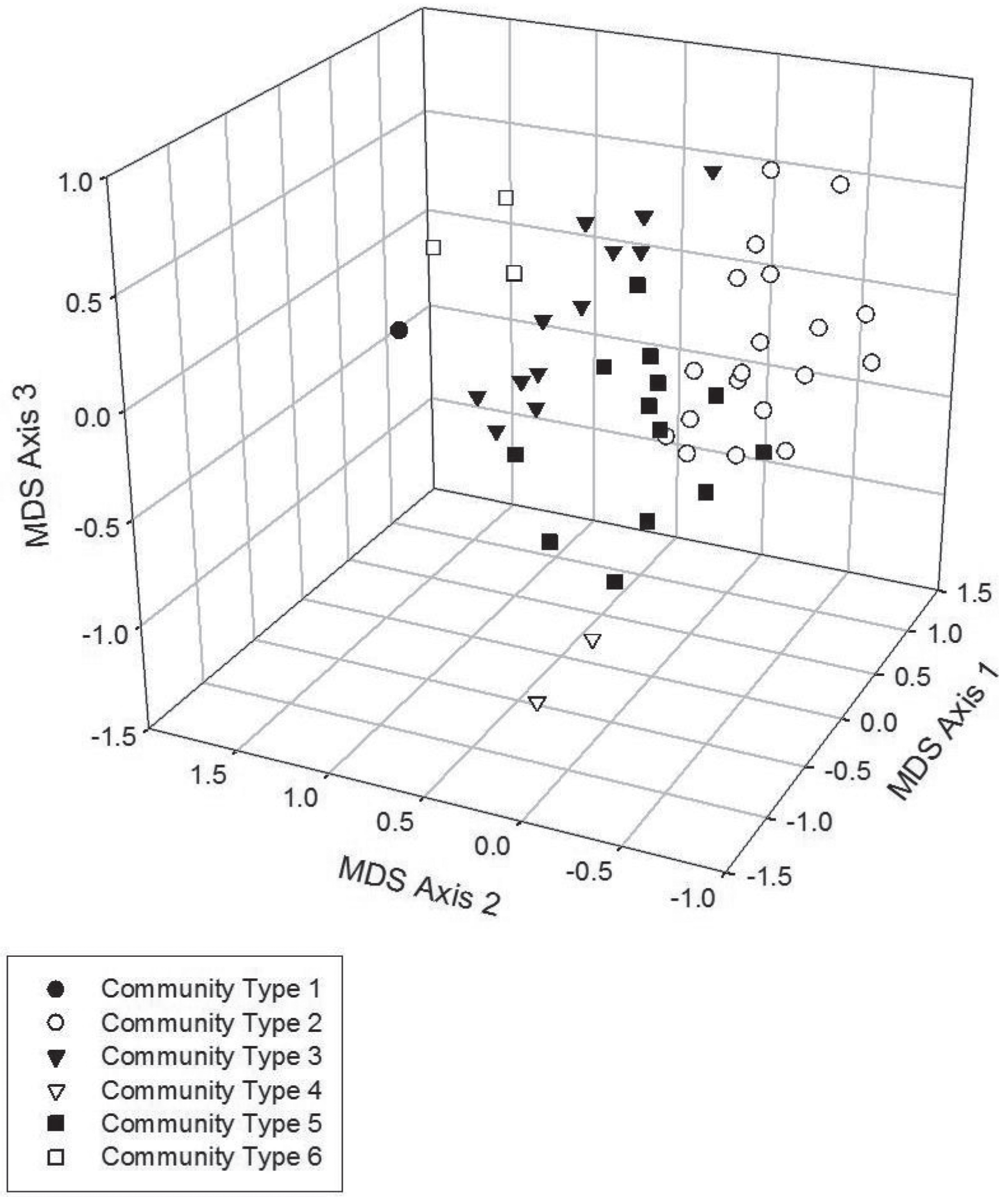


Figure 3. 3D graph (stress level = 0.14) of the first three axes of the MDS ordination of survey plots on the Lake Mason Zone of the Gum Creek Greenstone Belt. Data is a matrix of 77 species x 50 survey sites; taxa are perennial species occurring at more than a single plot.

Community type 1 was identified from a single quadrat (MASN 20), found on the outwash plains away from the footslopes. The community was composed of sparse tall shrubland of *Acacia aneura* var. *microcarpa* with an open mid-stratum of *Eremophila forrestii* and *A. ramulosa* var. *ramulosa* over a sparse cover of grasses, including *Austrostipa elegantissima*, *Aristida* sp. and *Eragrostis eriopoda* complex (Table 2). The site was acidic (pH = 5.1) with a minimal cover of weathered ironstone coarse fragments up to medium pebble size (Table 3). This community type was closely allied with species group C. The separation of this community type was attributed to the poor species richness, with only 10 taxa recorded from the quadrat.

Community type 2 was characteristic of the upper slopes and rocky crests, and was identified from 19 quadrats. Typical vegetation structure was tall shrubs of *Acacia aneura* var. *microcarpa* over a mid-stratum of *Eremophila latrobei* subsp. *latrobei*, with sparse cover of *Ptilotus schwartzii* (Table 2). Other species common to this community include the mid-stratum shrubs *E. jucunda* and *Dodonaea petiolaris* and the low shrub species *Sida* sp. golden calyces glabrous (HN Foote 32). Indicator species analyses (Table 4) suggested that key taxa in this community were *A. aneura* var. *microcarpa*, *A. quadrimarginea*, *Dodonaea petiolaris*, *E. latrobei* subsp. *latrobei*, *E. punctata*, *Grevillea berryana*, *Olearia humilis*, *Prostanthera campbellii*, *Ptilotus schwartzii*, *Sida* sp.

golden calyces glabrous (HN Foote 32) and *Thryptomene decussata*. This community type was strongly allied with species group C and G, with almost a complete absence of taxa belonging to the other species groups (Table 2).

Mean species richness was 14.0 ± 3.2 SD in this community type, with between eight and 20 taxa recorded per quadrat. This community was associated with strongly acidic (mean pH 4.5 ± 0.3 SD) sandy loam soils and below average potassium content (mean K 84.0 mg kg^{-1} ± 31.9 SD; Table 3). Survey sites generally had abundant to extremely abundant cover of coarse fragments, typically composed of BIF and weathered BIF with some quartz and metasediments present. The majority of survey locations had exposed bedrock present (2–50%), predominantly BIF and weathered BIF (Table 3).

Community type 3 was typical of the mid- to lower slopes with more gentle gradients, and was recorded in 12 quadrats. Community structure was defined by tall shrubs of *A. aneura* var. *microcarpa* and the ubiquitous shrub species *Eremophila latrobei* subsp. *latrobei* in the mid-stratum. These two species contributed 30% of the similarity within the community type. Composition was most closely allied to species group C, with minimal representation of taxa associated with the remaining species groups (Table 2). The indicator values (IV) identified five taxa that typify this community: *A. aneura* var. *argentea*, *A. ramulosa*, *E. forrestii*, *E. latrobei* subsp. *latrobei*, and *Maireana convexa* (Table 4).

This community type occured on strongly acidic (pH 4.1–5) sandy loams and sandy clay loams (Table 3). Coarse fragments of BIF, weathered BIF, iron-enriched rock, quartz and associated metasediments were prevalent, with almost no exposed bedrock found in the quadrats. Bare ground with sparse litter cover (mean 18.08 % ± 11.7 SD) was typical. Mean species richness was 14.6 ± 5.4 SD and ranged from seven to 23 taxa per quadrat (Table 3).

Community type 4 was another floristic grouping likely to have been segregated during the classification due to a combination of low species richness and associated geology. This community type was recorded in two quadrats, MASN 06 and MASN 33, located on the mid-slopes and pediments. Both quadrats were located on basalts with quartz and hematite present. Soils were relatively neutral to alkaline (pH 6.2 and 7.7) sandy loams, associated with the high Ca^{2+} content in the soil profile (960 and 5500 mg kg^{-1}, respectively; Table 3). The two quadrats had 20 and eight taxa, respectively.

The community consisted of open shrubland of *Acacia burkittii* and *A. xanthocarpa* over sparse shrubland of *Grevillea inconspicua*, *Prostanthera althoferi*, *Ptilotus obovatus* and *Senna artemisioides* subsp. x *artemisioides*, with isolated cover of the perennial grass *Austrostipa elegantissima*. Indicator values identified *Acacia burkitti*, *Eremophila exilifolia*, *G. inconspicua*, *Prostanthera althoferi* and *S. artemisioides* subsp. x *artemisioides* as typical species within the community (Table 4). Species groups C and E were strongly represented in this community type, with an absence of taxa from groups A, B and D (Table 2).

Community type 5 had no particular affinity with landscape position, as it occured in 13 quadrats that varied topographically from the crests to the colluvial outwash plains. Community structure was typically open shrubland of *Senna* sp. Meekatharra over isolated shrubs of *Scaevola spinescens* and *Ptilotus obovatus*. Other species associated with this community type were tall shrubs of *A. aneura* and *A. xanthocarpa*, mid-stratum shrubs *A. tetragonophylla*, *E. pantonii*, *E. galetea*, and low chenopod shrubs of *Maireana georgei* x *Enchylaena tomentosa* and *M. triptera* (Table 2). Indicator values suggested that *S.* sp. Meekatharra, *Eremophila pantonii*, *M. triptera* and *Sclerolaena eriacantha* were typical species for this community (Table 4). Species richness ranged from nine to 26 taxa per quadrat, with a mean of 15.8 ± 4.9 SD. Taxa within the community were closely allied with species groups C, D and E, with no representatives from groups A and B (Table 2).

The community was found on soils that varied widely in pH (range 4.3 to 7.3; mean 5.9 ± 1 SD) and Ca content (range 150 to 5500 mg kg^{-1}; mean 1413 mg kg^{-1}; Table 3). Two quadrats had extremely high Ca concentrations, therefore the median value of 670 mg kg^{-1} is more representative of soil Ca values. Sites typically had an abundance of coarse fragments primarily composed of weathered BIF, iron-enriched rock and quartz, with weathered BIF predominant in those sites with exposed bedrock. Those locations with higher soil pH values concomitantly were characterised by the highest Ca content, indicating the presence of calcareous soils.

Community type 6 was recorded in three quadrats, all located on the lower slopes to outwash plains. The community structure was sparse to open shrubland of *A. aneura* over sparse to open shrubs of *E. galetea*, *Ptilotus obovatus* and *Solanum lasiophyllum*. Indicator species were: *Abutilon otocarpum*, *Acacia aneura* var. *conifera*, *E. galatea*, *E. longifolia*, *Eriachne mucronata*, *Rhagodia drummondii*, *Scleroleana convexa*, *Solanum lasiophyllum* and *Spartothamnella teucriiflora* (Table 4). Species richness ranged from 10 to 21 taxa (mean 16.0 ± 5.6 SD) per quadrat. Taxa from this community type were strongly associated with species groups A, C and D, with no representatives from groups B and F (Table 2).

This community type was recorded in quadrats in the southern portion of the greenstone belt, including Jasper Hill. Sites typically had slight to moderate covering of coarse fragments, predominantly weathered BIF, ironstones, quartz and associated metasediments over gentle to non-existent gradients. There was only a very slight presence of exposed bedrock of weathered BIF. Soils were generally acidic (mean pH 6 ± 1.2 SD), but approached neutral at some sites, with pH ranging from 5.2 to 7.3. Soils that were neutral were associated with high Ca concentrations (Table 3).

Environmental Variables

Environmental parameters, including both site physical and soil chemical properties, are addressed within each community type (Table 3). Community type 2 occurred

Table 3

Summary statistics of environmental variables for each community type for the Lake Mason Zone of the Gum Creek Greenstone Belt. Mean values with standard deviation are listed for community types recorded in more than one quadrat. Differences were determined using Kruskal–Wallis non-parametric analysis of variance; only community types with >2 representative sites were included in the analyses (community types 1 and 4 were excluded). Significance values are indicated by * ($p < 0.05$ = *, $p < 0.01$ = **, $p < 0.001$ = ***, $p < 0.0001$ = ****); post-hoc differences were set at $\alpha = 0.05$. No significant differences of mean is indicated by $^{+}$. Units of measurements for the parameters are: soil chemicals = mg/kg; abundance of fragments and outcrop abundance = categorical maximum (0 = 0%, 1 = <2%, 2 = 2–10%, 3 = >10–20%, 4 = >20–50 %, 5 = >50–90%, 6 = >90%); topographical position: 1 = crest, 2 = upper slope, 3 = mid-slope, 4 = lower slope, 5 = flat; species richness = number of taxa per quadrat.

	Community Types										
	1	2		3		4		5		6	
Soil Parameters	**Value**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**
B*	0.05	0.07	± 0.02 ^{a}	0.10	± 0.06 ^{ab}	0.15	± 0.07	0.12	± 0.06 ^{b}	0.07	± 0.03 ^{ab}
Ca****	240	149.9	± 94.5 ^{a}	192.3	± 90.1 ^{a}	3230	± 3210	1413.1	± 1744 ^{b}	763.3	± 898.9 ^{ab}
Cd $^{+}$**	5.00E-03	5.00E-03	± 0.0	5.00E-03	± 0.0	5.00E-03	± 0.0	5.00E-03	± 0	6.67E-03	± 0.0
Co****	1.58	0.24	± 0.35 ^{a}	0.60	± 0.71 ^{ab}	2.65	± 1.1	2.06	± 1.1 ^{b}	2.47	± 1.4 ^{b}
Cu****	1.2	0.72	± 0.13 ^{a}	0.97	± 0.43 ^{ab}	3.4	± 0.42	1.84	± 0.7 ^{c}	1.67	± 0.76 ^{bc}
Fe^{NS}	35	48.7	± 13.3	38.4	± 9.8	50.5	± 12.0	42.3	± 8.8	54	± 13.1
K****	100	83.9	± 31.9 ^{a}	149.5	± 64.0 ^{b}	120	± 28.3	171.5	± 37.8 ^{b}	206.7	± 35.1 ^{b}
Mg****	89	41.9	± 25.4 ^{a}	68.8	± 54.8 ^{a}	430	± 127.3	229.5	± 114 ^{b}	182	± 125.1 ^{ab}
Mn****	62	17.1	± 16.2 ^{a}	28.7	± 27.4 ^{ab}	69.5	± 33.2	71.9	± 41.3 ^{b}	93.3	± 41.0 ^{b}
N (total)^{NS}	0.026	0.049	± 0.01	0.045	± 0.01	0.041	± 0.01	0.048	± 0.014	0.045	± 0.01
Na***	1	1.84	± 0.9 ^{a}	3.71	± 6.0 ^{a}	6.5	± 2.1	14.4	± 19.4 ^{b}	4	± 3.6 ^{ab}
Ni****	0.9	0.32	± 0.32 ^{a}	0.44	± 0.29 ^{a}	0.65	± 0.07	1.23	± 0.8 ^{b}	0.73	± 0.15 ^{ab}
Organic C (%) **	0.26	0.61	± 0.22 ^{a}	0.44	± 0.14 ^{b}	0.38	± 0.16	0.43	± 0.1 ^{ab}	0.37	± 0.10 ^{ab}
P^{NS}	6	6.84	± 4.6	5.67	± 1.8	4	± 1.4	6.23	± 2.5	11.3	± 5.1
pH****	5.1	4.18	± 0.3 ^{a}	4.49	± 0.33 ^{ab}	6.95	± 1.1	5.9	± 1.0 ^{c}	5.97	± 1.2 ^{bc}
S^{NS}	3	9.84	± 3.1	8.17	± 2.7	4	± 2.8	10.4	± 12.0	5	± 2.0
Zn***	1	0.78	± 0.32 ^{a}	1.11	± 0.63 ^{ab}	1.1	± 0.14	1.37	± 0.5 ^{b}	2.17	± 0.8 ^{b}
Site Physical Parameters											
Altitude (m)****	500	534.0	± 13.3 ^{a}	510.3	± 10.3 ^{b}	523	± 7.1	521.2	± 15.1 ^{ab}	489.3	± 5.9 ^{b}
Bare ground (%)^{NS}	92	94.2	± 3.1	95.1	± 1.7	95.5	± 0.7	95.7	± 2.1	93.3	± 7.2
Abundance-fragments**	1	5	± 0.7 ^{a}	4.1	± 0.7 ^{b}	4.5	± 0.7	4.9	± 0.6 ^{ab}	3.3	± 1.2 ^{ab}
Leaf litter (%)^{NS}	12	14.4	± 13.9	18.1	± 11.7	8.5	± 9.2	9	± 9.3	12	± 9.8
Topographical position****	5	1.7	± 0.7 ^{a}	3.7	± 1.0 ^{b}	3.5	± 0.7	2.8	± 1.2 ^{ab}	4.7	± 0.6 ^{b}
Outcrop abundance****	0	2.1	± 1.2 ^{a}	0.08	± 0.29 ^{b}	1	± 0.0	1.08	± 0.95 ^{ab}	0.33	± 0.58 ^{ab}
Slope*$^{+}$	1	9.1	± 10.6	2.3	± 1.8	10.5	± 2.1	3.3	± 2.9	1	± 0.0
Species Richness	10	14.1	± 3.2	14.6	± 5.4	14	± 8.5	15.8	± 4.9	16	± 5.6
Number of quadrats:	**1**	**19**		**12**		**2**		**13**		**3**	

Table 4

Taxa with indicator values ≥ 25 for the six community types of the Lake Mason Zone of the Gum Creek Greenstone belt. Significant taxa are shown at $p < 0.05$ (from Monte Carlo permutation test), levels of significance are indicated as: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$. Indicator values ≥ 25 are indicated by shading.

Indicator Species	Community Type 2	3	4	5	6
Ptilotus schwartzii **	60	20	0	0	0
Sida sp. golden calyces glabrous (HN Foote 32) *	58	0	0	0	0
Acacia quadrimarginea *	47	0	0	0	0
Prostanthera campbellii *	42	0	0	0	0
Dodonaea petiolaris	40	1	0	1	0
Acacia aneura var. *microcarpa* ***	38	24	0	4	5
Eremophila punctata	37	0	0	0	0
Eremophila latrobei subsp. *latrobei* ***	32	35	9	5	0
Grevillea berryana	28	8	0	1	0
Thryptomene decussata	26	0	0	0	0
Olearia humilis	25	2	0	0	0
Acacia aneura var. *argentea*	2	41	0	0	0
Acacia ramulosa var. *ramulosa*	0	40	0	1	0
Eremophila forrestii	0	39	0	1	10
Maireana convexa	2	29	0	1	0
Prostanthera althoferi subsp. *althoferi* **	1	0	90	0	0
Senna artemisioides subsp. *x artemisioides***	0	0	87	2	0
Grevillea inconspicua **	0	0	83	2	0
Austrostipa elegantissima *	0	2	72	4	0
Acacia burkittii *	0	0	65	2	7
Acacia xanthocarpa *	3	0	60	13	0
Eremophila exilifolia *	1	0	45	0	0
Hibiscus aff. *solanifolius*	0	0	43	1	0
Acacia burrowsiana	0	0	38	4	0
Senna sp. Meekatharra (E Bailey 1-26) **	7	0	0	71	0
Eremophila pantonii *	0	0	0	62	0
Maireana triptera *	0	1	0	54	0
Maireana georgei x *Enchylaena tomentosa*	5	0	0	53	0
Scaevola spinescens	3	4	0	44	7
Sclerolaena eriacantha *	0	0	0	40	12
Lepidium platypetalum	0	0	0	31	0
Eremophila oldfieldii subsp. *angustifolia*	1	0	0	26	0
Sclerolaena convexula **	0	0	0	0	67
Eremophila longifolia *	0	3	0	0	53
Rhagodia drummondii *	0	1	0	3	49
Solanum lasiophyllum *	1	8	0	14	47
Eremophila galeata	2	15	0	12	43
Spartothamnella teucriiflora	1	3	0	2	41
Abutilon otocarpum	1	0	0	0	29
Acacia aneura var. *conifera*	0	6	14	3	26
Eriachne helmsii	3	0	0	0	25
Number of quadrats	**19**	**12**	**2**	**13**	**3**

at significantly greater mean altitude than both community types 3 and 6 ($p < 0.0001$), which were associated with mid-slopes, pediments and outwash plains (Table 3). Soils collected from the quadrats at Lake Mason were acidic (mean pH 4.9 ± 1.1 SD) and typically shallow (2–50 cm) sandy loams or sandy clay loams. The presence of clay in the soil matrix was associated with quadrats on the footslopes, pediments and colluvial plains. Soils on the crests and upper slopes were entirely sandy loam soils. The majority of sites had >50% cover of coarse fragments, predominantly composed of BIF, weathered BIF, iron-enriched rock and associated metasediments (Table 3). Rock fragments were abundant in most quadrats, with an average cover of 20–50%. The sites typically had a high proportion of bare ground (mean 94.8% ± 2.8 SD) and sparse cover of leaf litter (mean 13.4% ± 11.8 SD).

There were significant intercorrelations amongst soil chemical properties (Table 3). The strongest intercorrelation occurred between soil pH and the elements Ca, Co, Cu, K, Mg, Mn, Na, Ni and Zn ($p < 0.01$). The strongest relationship was between Ca and Mg ($r_s = 0.93$, $p < 0.0001$). All of the soil elements, apart from Na, were negatively correlated with S ($p < 0.01$). There was no significant relationship between S and Na. Soil pH was highly correlated with Ca concentration ($p < 0.0001$). Species richness was strongly correlated with Ca concentration ($r_s = 0.40$, $p < 0.01$), but not soil pH ($p > 0.05$). Altitude was negatively correlated ($p < 0.01$) with soil depth, disturbance and topographical position and positively correlated with abundance of coarse fragments, exposed bedrock and slope. The strongest relationship amongst site physical parameters was the negative correlation between exposed bedrock and soil depth ($r_s = -0.75$, $p < 0.0001$).

There were significant differences in mean concentration of the soil chemical properties B, Ca, Co, Cu, K, Mg, Mn, Na, Ni and Zn between community types (Table 3). Soils from community type 2 had the lowest concentrations of all soil chemical elements, while soils from community types 5 and 6 had the highest concentrations of soil elements. There were significant differences in means for topographical position and abundance of exposed bedrock between communities ($p < 0.0001$). Community type 2, associated with crests and upper slopes (i.e. low value for topography) was significantly different from community types 3 and 6 with respect to topographical position, and significantly different from community type 3 for abundance of exposed bedrock (Table 3).

BIO-ENV

The BIO-ENV routine was used to compare the correlation between the species–site resemblance matrix and the environmental variables. The Rho statistic was 0.692 and the environmental variables identified during the BIO-ENV routine as significantly correlated with the resemblance matrix were Ca, Co, K, Mg and abundance of coarse fragments. The abundance of coarse fragments was not related to any of the soil chemistry ($p > 0.05$). The bubble plots for the soil chemical parameters showed a general clustering of quadrats from community types with higher concentrations of Co, K and Mg (community types 4, 5 and 6) than those with lower concentrations of these elements (community types 2 and 3; Fig. 4). The separation of quadrats in the bubble plots follows the pattern in the original MDS (Fig. 2), with clustering of similar community types. The separation of community type 1, a single quadrat with very little rock fragment on the surface, is clearly apparent on the MDS plot for abundance of coarse fragments.

DISCUSSION

Previously, 281 taxa had been recorded in the Lake Mason area. This survey recorded 134 taxa from 50 quadrats and adjacent areas. Only two taxa were documented range extensions, *Sauropus ramosissimus* (P3) and the putative identification of *Acacia* aff. *coolgardiensis*. The low number of annuals collected was attributed to the below average winter rainfall prior to the survey. Prior floristic surveys of the greenstone belts of the Yilgarn have recorded taxa of conservation significance and range specific endemics (see Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c). This survey of the Lake Mason Zone did not identify any taxa endemic to the Lake Mason Zone and only seven priority-listed taxa: *Acacia burrowsiana* (P1), *Stenanthemum mediale* (P1), *Baeckea* sp. London Bridge (ME Trudgen 5393; P3), *Baeckea* sp. Melita Station (H Pringle 2738; P3), *Calytrix erosipetala* (P3), *Sauropus ramosissimus* (P3) and *Grevillea inconspicua* (P4), were recorded. Within the Gum Creek Greenstone Belt, there were more taxa of conservation significance recorded at Lake Mason than the nearby Montague Range, which had five priority listed taxa (Thompson & Sheehy 2011).

Six distinct vegetation communities were identified following classification of the site resemblance matrix. Previous flora and vegetation studies in the Yilgarn Craton have found topographical position highly indicative of particular vegetation communities (Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c). The floristic communities identified from Lake Mason showed varying association with topography. Three of the six communities had strong affinities with either upland or lowland positions in the landscape; community 2 was allied with uplands, while communities 3 and 6 were linked to lowlands and adjacent colluvial plains. Underlying lithology also influenced partitioning of community types, with basalt substrates singularly associated with community type 4.

The tallest stratum of community types 2 and 3 were dominated by *A. aneura*. This is typical for the Murchison Region (Beard 1976; Beard 1990; Payne et al. 1998) and of flora in the Gum Creek Greenstone Belt (Kimseed Environmental 1998). Furthermore, taxa ubiquitous to other greenstone belts in the region were found across the Lake Mason Zone (i.e. *Eremophila forrestii*, *E. jucunda* and *E. latrobei* subsp. *latrobei*).

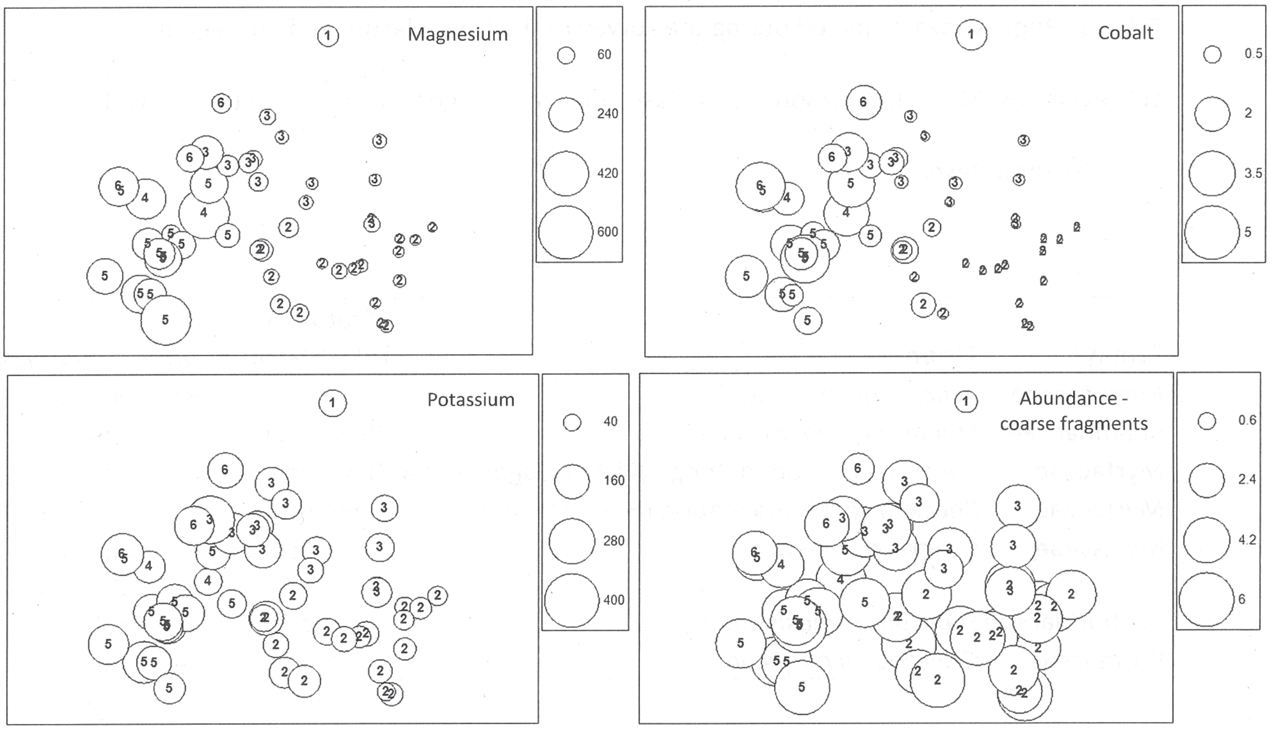


Figure 4. Bubble plots of four of the highly correlated environmental parameters identified from the BIO-ENV routine (Rho = 0.692). The plot for calcium was excluded as the trace element was highly positively correlated with magnesium ($p < 0.0001$). Increase in the size of the bubble indicates increasing value of the variable. The numerals inside the bubbles correspond to the community types.

Environmental Parameters

The soils of the Lake Mason Zone were highly acidic (mean pH = 4.9), which is typical of weathered regolith (Slattery et al. 1999). Where soil pH approached neutral or alkaline values, there were concomitant higher calcium concentrations, which suggested the presence of calcareous soils. Soil textures were generally sandy loam, with sandy clay loams occurring only at mid- to lower slopes and on adjacent colluvial plains where deeper soil profiles routinely form. The soil physical parameters of the Lake Mason Zone were typical of regolith associated with the Yilgarn Craton (Anand & Paine 2002). The variability in soil chemical parameters was similar to those from other greenstone and ironstone ranges in the Yilgarn Craton (Gibson 2004a, 2004b; Gibson et al. 1997; Gibson & Lyons 1998a, 1998b 2001a, 2001b; Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c).

The Gum Creek Greenstone Belt is composed of both metabasalt and ultramafic rocks (Tingey 1985), which are known to have high to very high concentrations of Mg (LeBas 2000; Gray & Murphy 2002). Sulphides and carbonates are readily leached from the profile, mobilising elements such as S, Na, Ca, Mg, Mn, Co, Cu, Ni and Zn (Butt et al. 2000; Britt et al. 2001; Anand 2005). Calcrete accumulation has been linked with lowland communities (Anand et al. 1997); in this study, higher calcium concentrations were recorded in communities on the footslopes, pediments and colluival plains.

Variation in concentrations of four soil trace elements (Ca, Co, K and Mg) and the abundance of coarse fragments explained 69.2% of the difference in the site resemblance matrix. This suggests that the underlying regolith and weathering of the profile influences the floristic composition. Weathering of the regolith mobilises elements, leaching some and retaining others in varying concentrations (Britt et al. 2001; Anand 2005). Those trace elements with higher concentrations (e.g. Mg, K) have not been leached to the same extent as others, whereas higher Fe concentrations are likely due to the weathering of iron-enriched rock (Gray & Murphy 2002). Notably, community type 2, recorded from upland quadrats, had the lowest mean concentration of the soil trace elements Ca, Co, Cu, K, Mg, Mn, Na and Ni. This suggested that these sites likely had shallower soil depth, had undergone extensive weathering, or developed on non-mafic bedrock.

Conservation Significance

The Lake Mason region has a long history of grazing, mineral exploration and mining. At present, the majority of the land around the Lake Mason Zone has been destocked. However, the area bears the evidence of gridline tracks and drill holes associated with mineral exploration. The history of land disturbance, combined with the low rainfall preceding the survey, were likely contributing factors to the poor representation of annuals and generally low species richness.

While the range generally had low levels of species richness compared with other BIF ranges in the Yilgarn, the range is still an important repository of taxa of conservation significance and distinct floristic communities. The majority of the Lake Mason Zone is on former pastoral lease now managed by the Department of Environment and Conservation, however, official incorporation into the conservation estate (i.e. designation of specific reserve status) remains incomplete. Thus, any future mineral exploration or development proposals should maintain the conservation significance of the area and employ best practice to protect the significant taxa and floristic communities.

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REFERENCES

Anand RR (2005) Weathering history, landscape evolution and implications for exploration. In *Regolith Landscape Evolution Across Australia: A Compilation of Regolith Landscape Case Studies with Regolith Landscape Evolution Models* (eds RR Anand, P de Broekert), pp. 2–40. Cooperative Research Centre for Landscape Environments and Mineral Exploration, Perth.

Anand RR, Phang C, Wildman JE, Lintern MJ (1997) Genesis of some calcrete in the southern Yilgarn Craton, Western Australia: Implications for mineral exploration. *Australian Journal of Earth Sciences* **44**, 87–103.

Anand RR, Paine M (2002) Regolith geology of the Yilgarn Craton, Western Australia: implications for exploration. *Australian Journal of Earth Sciences* **49**, 3–162.

Anderson MJ, Robinson J (2003) Generalised discrimination analysis based on distances. *Australian and New Zealand Journal of Statistics* **45**, 301–318.

Beard JS (1976) *Vegetation Survey of Western Australia. Murchison 1:1,000,000 Vegetation Series. Explanatory Notes to Sheet 6. Vegetation of the Murchison.* University of Western Australia Press, Perth.

Beard JS (1990) *Plant Life of Western Australia.* Kangaroo Press, Perth.

Belbin L (1989) *PATN Technical Reference.* CSIRO Division of Wildlife and Ecology, ACT.

Blatchford T (1899) *A Geological Reconnaissance of the Country at the Heads of the Murchison and Sandford Rivers, in the Murchison, East Murchison, and Peak Hill Goldfields.* Report of Torrington Blatchford, B.A. Assistant Government Geologist.

Britt AF, Smith RE, Gray DJ (2001) Element mobilities and the Australian regolith – a mineral exploration perspective. *Marine Freshwater Research* **52**, 25–39.

Bureau of Meteorology (2009) *Climate Statistics for Australian Locations.* Available at http://www.bom.gov.au/climate/averages/ [Accessed May 2009].

Butt CRM, Lintern MJ, Anand RR (2000) Evolution of regoliths and landscapes in deeply weathered terrain – implications for geochemical exploration. *Ore Geology Reviews* **16**, 167–183.

Cassidy KF, Champion DC, Krapez B, Barley ME, Brown JA, Blewett RS, Groenewald PB, Tyler IM (2006) *A Revised Geological Framework for the Yilgarn Craton, Western Australia.* Geological Survey of Western Australia, Record 2006/8, Perth.

Clarke KR, Warwick RM (2001) *Change in Marine Communities: An Approach to Statistical Analysis and Interpretation*, 2nd ed. PRIMER-E, Plymouth.

Clarke KR, Gorley RN (2006) *PRIMER v6: User Manual/Tutorial.* PRIMER-E, Plymouth.

Chen SF, Painter MGM (2005) *Sandstone, Western Australia. Western Australian Geological Survey 1:100,000 Geological Series Sheet 2742.* Western Australia Geological Survey, Perth.

Churchward HM (1977) *Landforms, Regoliths and Soils of the Sandstone – Mt Keith Area, Western Australia.* Division of Land Resources Management CSIRO, Land Resources Management Series No. 2, Australia.

Connolly RR (1959) Montague Range. In *Iron Ores in Western Australia* (ed RR Connolly), pp. 46–72. Geological Survey of Western Australia, Mineral Resource Bulletin 7, Perth.

Department of Conservation and Land Management (2001) 'Black Range and Lake Mason Pastoral Leases 2001–2006. Interim Management Guidelines'. Department of Conservation and Land Management, Perth.

Dufrêne M, Legendre P (1997) Species assemblages and indicator species: The need for a flexible asymmetrical approach. *Ecological Monographs* **67**, 345–366.

Elias M, Bunting JA, Wharton PH (1982) *Explanatory Notes on the Glengarry 1:250,000 Geological Sheet, Western Australia.* Geological Survey of Western Australia, Perth.

Faith D, Minchin P, Belbin L (1987) Compositional dissimilarity as a robust measure of ecological distance. *Vegetatio* **69**, 57–68.

Gibson CG (1908) *Report upon the Auriferous Deposits of Barrambie and Errolls (Cue District) and Gum Creek (Nannine District) in the Murchison Goldfield; also Wiluna (Lawlers District), in the East Murchison Goldfield.* Bulletin 34, Geological Survey of Western Australia, Perth.

Gibson N (2004a) Flora and vegetation of the Eastern Goldfields Ranges: Part 6. Mt Manning Range. *Journal of the Royal Society of Western Australia* **87**, 35–47.

Gibson N (2004b) Flora and vegetation of the Eastern Goldfields Ranges: Part 7. Middle and South Ironcap, Digger Rock and Hatter Hill. *Journal of the Royal Society of Western Australia* **87**, 49–62.

Gibson N, Coates DJ, Thiele KR (2007) Taxonomic research and the conservation status of flora in the Yilgarn Banded Iron Formation ranges. *Nuytsia* **17**, 1–12.

Gibson N, Lyons MN (1998a) Flora and vegetation of the Eastern Goldfields Ranges: Part 2. Bremer Range. *Journal of the Royal Society of Western Australia* **81**, 107–117.

Gibson N, Lyons MN (1998b) Flora and vegetation of the Eastern Goldfields Ranges: Part 3. Parker Range. *Journal of the Royal Society of Western Australia* **81**, 119–129.

Gibson N, Lyons MN (2001a) Flora and vegetation of the Eastern Goldfields ranges: Part 4. Highclere Hills. *Journal of the Royal Society of Western Australia* **84**, 71–81.

Gibson N, Lyons M (2001b) Flora and vegetation of the Eastern Goldfields ranges: Part 5. Hunt Range, Yendilberin and Watt Hills. *Journal of the Royal Society of Western Australia* **84**, 129–142.

Gibson N, Lyons MN, Lepschi BJ (1997) Flora and vegetation of the eastern goldfields ranges, Part 1: Helena and Aurora Range. *CALMScience* **2**, 231–246.

Gray J, Murphy B (2002) Parent material and soil distribution. *Natural Resource Management* **5**, 2–12.

Griffin TJ (1990) Southern Cross Province. In *Geology and Mineral Resources of Western Australia: Western Australia Geological Survey* (eds AF Trendall, JS Myers, RM Hocking), pp. 60–77. Memoir 3, Geological Survey of Western Australia, Perth.

Hennig P (1998) Soils. In *An Inventory and Condition Survey of the Sandstone – Yalgoo – Paynes Find Area, Western Australia* (eds AL Payne, AME van Vreeswyk, HJR Pringle, K A Leighton, P Hennig), pp. 95–118. Technical Bulletin No. 90, Agriculture Western Australia, South Perth.

Kimseed Environmental (1998) 'Mt. Townsend Project. A Report on Flora, Vegetation, Vertebrate Fauna and Soils'. Unpublished report prepared for Gidgee Gold Mine (Arminco Mining Pty Ltd). Kimseed Environmental Pty Ltd, Perth.

Le Bas MJ (2000) Reclassification of the high-Mg and picritic volcanic rocks. *Journal of Petrology* **41**, 1467–1470.

Legendre P, Legendre L (1998) *Numerical Ecology,* 2nd ed. Elsevier Science, Amsterdam.

Leighton KA (1998) Climate. In *An Inventory and Condition Survey of the Sandstone – Yalgoo – Paynes Find Area, Western Australia* (eds AL Payne, AME Van Vreeswyk, HJR Pringle, KA Leighton, P Hennig), pp. 19–37. Technical Bulletin No. 90, Agriculture Western Australia, South Perth.

Mabbutt JA, Litchfield WH, Speck NH, Sofoulis J, Wilcox DG, Arnold JA, Brookfield M, Wright RL (1963) *General Report on the Lands of the Wiluna-Meekatharra Area, Western Australia, 1958.* CSIRO, Land Research Series No. 7, Melbourne.

Markey AS, Dillon SJ (2008a) Flora and vegetation of the banded iron formations of the Yilgarn Craton: the central Tallering Land System. *Conservation Science Western Australia* 7, 121–149.

Markey AS, Dillon SJ (2008b) Flora and vegetation of the banded iron formations of the Yilgarn Craton: the Weld Range. *Conservation Science Western Australia* 7, 151–176.

Meissner R, Caruso Y (2008a) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Koolanooka and Perenjori Hills. *Conservation Science Western Australia* 7, 73–88.

Meissner R, Caruso Y (2008b) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Jack Hills. *Conservation Science Western Australia* 7, 89–103.

Meissner R, Caruso Y (2008c) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Mount Gibson and surrounding area. *Conservation Science Western Australia* 7, 105–120.

McCune B, Mefford MJ (1999) *PC-ORD. Multivariate Analysis of Ecological Data, Version 4.* MjM Software Design, Glenden Beach, Oregon, USA.

McDonald RC, Isbell RF, Speight JG, Walker J, Hopkins MS (1998) *Australian Soil and Land Survey: Field Handbook,* 2nd ed. Department of Primary Industries and Energy and CSIRO Australia.

Mehlich A (1984) Mehlich 3 soil test extractant: A modification of Mehlich 2. *Communications of Soil Science and Plant Analysis* **15**, 1409–1416.

Myers JS (1993) Precambrian history of the West Australian Craton and adjacent orogens. *Annual Review of Earth and Planetary Sciences.* **21**, 453–485.

Myers JS, Swagers C (1997) The Yilgarn Craton. In *Greenstone Belts* (eds M de Wit, LD Ashwal), pp. 640–656. Clarendon Press, Oxford.

Paczkowska G, Chapman AR (2000) *The Western Australian Flora: A Descriptive Catalogue.* Wildflower Society of Western Australia, Western Australian Herbarium, CALM and Botanic Garden Authority, Perth.

Payne AL, Van Vreeswyk AME, Pringle HJR (1998) Land Systems. In *An Inventory and Condition Survey of the Sandstone – Yalgoo – Paynes Find Area, Western*

Australia (eds AL Payne, AME Van Vreeswyk, HJR Pringle, KA Leighton, P Hennig), pp. 187–344. Technical Bulletin No. 90, Agriculture Western Australia, South Perth.

Pringle HJR (1994) Vegetation. In *An Inventory and Condition Survey of the north-eastern Goldfields, Western Australia* (eds HJR Pringle, AME Van Vreeswyk, SA Gilligan), pp 118–127. Technical Bulletin No. 87, Agriculture Western Australia, South Perth.

Pringle HJR (1998a) Ecological Assessment. In *An Inventory and Condition Survey of the Sandstone – Yalgoo – Paynes Find Area, Western Australia* (eds AL Payne, AME Van Vreeswyk, HJR Pringle, KA Leighton, P Hennig), pp 131–186. Technical Bulletin No. 90, Agriculture Western Australia, South Perth.

Pringle HJR (1998b) Vegetation. In *An Inventory and Condition Survey of the Sandstone – Yalgoo – Paynes Find Area, Western Australia* (eds AL Payne, AME Van Vreeswyk, HJR Pringle, KA Leighton, P Hennig), pp. 119–129. Technical Bulletin No. 90, Agriculture Western Australia, South Perth.

Rayment GE, Higginson FR (1992) *Australian Laboratory Handbook of Soil and Water Chemical Methods.* Inkata Press, Melbourne.

Slattery WJ, Conyers MK, Aitken RL (1999) Soil pH, aluminium, manganese and lime requirements. In *Soil Analysis: An Interpretation Manual* (eds KI Peverill, LA Sparrow, DJ Reuter), pp. 103–128. CSIRO Publishing, Collingwood.

Senior SL (1995) *Sandstone from Gold to Wool and Back Again.* Shire of Sandstone, Sandstone, Western Australia.

Sokal RR, Rolf FJ (1995) *Biometry.* WH Freeman and Co., New York.

Thackway R, Cresswell ID (1995) *An Interim Biogeographic Regionalisation for Australia: A Framework for Setting Priorities in the National Reserves System Cooperative Program – Version 4.0.* National Reserves System Cooperative Program, Australian Nature Conservation Agency, Canberra.

Thompson WA, Sheehy NB (2011) Flora and vegetation of banded iron formations of the Yilgarn Craton: the Montague Range Zone of the Gum Creek Greenstone Belt. *Conservation Science Western Australia* **8**, 95–118.

Tingey RJ (1985) *Sandstone, Western Australia, 1:250,000 Geological Series – Explanatory Notes, Sheet SG/50-16.* Geological Survey of Western Australia, Perth.

Wyche S (2004) *Lake Mason, Western Australia. Western Australian Geological Survey 1:100,000 Geological Series Sheet 2842.* Geological Survey of Western Australia, Perth.

Wyche S, Chen SF, Doyle MG (2004) *Recent Mapping in the Sandstone Region: Implications for Gold Mineralization.* Geological Survey of Western Australia, Record 2004/5, Perth.

APPENDIX A

Flora list for the Lake Mason Zone of the Gum Creek Greenstone Belt, including opportunistic collections from areas adjacent to the survey quadrats. Nomenclature follows Packowska and Chapman (2000).

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

Amaranthaceae
- *Ptilotus obovatus*
- *Ptilotus roei*
- *Ptilotus schwartzii*

Anthericaceae
- *Thysanotus* sp.

Apiaceae
- *Trachymene* sp.

Asclepiadaceae
- *Marsdenia australis*

Asteraceae
- *Olearia humilis*

Brassicaceae
- *Lepidium oxytrichum*
- *Lepidium platypetalum*

Caesalpiniaceae
- *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*
- *Senna* sp. Meekatharra (E Bailey 1–26)

Chenopodiaceae
- *Dissocarpus paradoxus*
- *Enchylaena tomentosa*
- *Enchylaena tomentosa* var. *tomentosa*
- *Maireana convexa*
- *Maireana georgei* x *Enchylaena tomentosa*
- *Maireana triptera*
- *Rhagodia drummondii*
- *Sclerolaena convexula*
- *Sclerolaena diacantha*
- *Sclerolaena eriacantha*
- *Sclerolaena fusiformis*

Convolvulaceae
- *Duperreya sericea*

Euphorbiaceae
- *Sauropus ramosissimus* P3

Goodeniaceae
- *Scaevola spinescens*

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

Lobeliaceae
- *Isotoma petraea*

Loranthaceae
- *Lysiana casuarinae*

Malvaceae
- *Abutilon otocarpum*
- *Abutilon oxycarpum*
- *Hibiscus* aff. *coatesii*
- *Hibiscus* aff. *solanifolius*
- *Hibiscus gardneri*
- *Sida ectogama*
- *Sida* sp. dark green fruits (S van Leeuwen 2260)
- *Sida* sp. Excedentifolia (JL Egan 1925)
- *Sida* sp. golden calyces glabrous (HN Foote 32)

Mimosaceae
- *Acacia* aff. *coolgardiensis*
- *Acacia aneura* hybrid
- *Acacia aneura* var. *alata/microcarpa* BRM 9083
- *Acacia aneura* var. *argentea*
- *Acacia aneura* var. *argentea* (narrow phyllode variant) BRM 9745
- *Acacia aneura* var. *argentea* (short phyllode variant) BRM 9300
- *Acacia aneura* var. *conifera*
- *Acacia aneura* var. *microcarpa*
- *Acacia aneura* var. *microcarpa* (broad, incurved phyllode variant) BRM 9929
- *Acacia aneura* var. *tenuis* BRM 9296
- *Acacia burkittii*
- *Acacia burrowsiana* P1
- *Acacia craspedocarpa*
- *Acacia paraneura*
- *Acacia pruinocarpa*
- *Acacia quadrimarginea*
- *Acacia ramulosa* var. *ramulosa*
- *Acacia rhodophloia*
- *Acacia sibirica*
- *Acacia tetragonophylla*
- *Acacia thoma*
- *Acacia xanthocarpa*

Myoporaceae
- *Eremophila alternifolia*
- *Eremophila exilifolia*
- *Eremophila forrestii*
- *Eremophila galeata*
- *Eremophila granitica*
- *Eremophila jucunda*
- *Eremophila lachnocalyx*
- *Eremophila latrobei* subsp. *latrobei*
- *Eremophila longifolia*
- *Eremophila oldfieldii* subsp. *angustifolia*
- *Eremophila oppositifolia* subsp. *angustifolia*
- *Eremophila pantonii*
- *Eremophila punctata*

Appendix A (cont.)

Myrtaceae
- *Baeckea* sp. London Bridge (ME Trudgen 5393) P3
- *Baeckea* sp. Melita Station (H Pringle 2738) P3
- *Calytrix desolata*
- *Calytrix erosipetala* P3
- *Eucalyptus kingsmillii* subsp. *kingsmillii*
- *Eucalyptus lucasii*
- *Micromyrtus sulphurea*
- *Thryptomene decussata*

Nyctaginaceae
- *Boerhavia coccinea*

Phormiaceae
- *Dianella revoluta* var. *divaricata*

Poaceae
- *Aristida contorta*
- *Aristida holathera* var. *holathera*
- *Austrostipa elegantissima*
- *Cymbopogon* sp.
- *Enneapogon caerulescens*
- *Eragrostis eriopoda/xerophila/setifolia* complex
- *Eriachne helmsii*
- *Eriachne mucronata*
- *Eriachne pulchella* subsp. *pulchella*
- *Triodia* sp.

Proteaceae
- *Grevillea berryana*
- *Grevillea inconspicua* P4
- *Hakea leucoptera* subsp. *sericipes*
- *Hakea preissii*
- *Hakea recurva*

Rhamnaceae
- *Stenanthemum mediale* P1

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

Rutaceae
- *Philotheca brucei* subsp. *brucei*

Santalaceae
- *Exocarpos aphyllus*
- *Santalum lanceolatum*
- *Santalum spicatum*

Sapindaceae
- *Dodonaea adenophora*
- *Dodonaea petiolaris*
- *Dodonaea rigida*

Solanaceae
- *Lycium australe*
- *Solanum lasiophyllum*
- *Solanum orbiculatum* subsp. *orbiculatum*

Sterculiaceae
- *Brachychiton gregorii*