IN THIS ISSUE

FRONT COVER: Sparse vegetation growing on a massive outcrop of weathered banded iron formation, surrounded by Eucalyptus woodlands and mulga shrublands, Johnston Range, Diemals Station. (Photograph by Steven Dillon, DEC.)

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CONTINUED OVER

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Small mammal and reptile assemblages of the semi-arid woodlands and *Acacia* sandplains in the southern rangelands of Western Australia

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ABSTRACT

As part of a broader study involving the control of introduced predators, the seasonal abundance of small vertebrate fauna was monitored in winter and spring during 2006 and 2007 at Mt Gibson Wildlife Sanctuary and Karara–Lochada Pastoral Stations in the Avon–Wheatbelt and Yalgoo bioregions in Western Australia. Ten small mammal, 30 reptile and three amphibian species were recorded at 24 sites within each of four land system types represented at both sites. The most-often recorded species of small mammal were *Mus musculus*, *Pseudomys hermannsburgensis*, *Notomys mitchelli, Sminthopsis dolichura* and *S. crassicaudata*, and of reptile were *Ctenotus mimetes* and *C. schomburgkii.* Species richness was greatest within the Euchre land system at Mt Gibson, characterized by low granite breakaways with alluvial plains and sandy tracts supporting *Eucalyptus* woodlands and *Acacia* shrublands. At Karara–Lochada species richness was greatest within the Pindar land system, characterized by red loamy sandplain supporting similar vegetation assemblages. Twenty-three of the total 43 small mammal, reptile and amphibian species were present at both sites, while 13 occurred only at Mt Gibson and seven only at Karara–Lochada. Faunal assemblage structure was different between stations, land systems and years. Over 50% of the difference in faunal assemblage structure was accounted for by six species: *N. mitchelli*, *S. dolichura* and *C. mimetes* (more abundant at Mt Gibson) and *C. schomburgkii*, *P. hermannsburgensis* and *M. musculus* (more abundant at Karara–Lochada). These same six species were also responsible for 52% of the difference in faunal assemblage structure between years. There was a general decline in small mammal and reptile abundance at the two stations in the second year of monitoring.

Keywords: mammals, rangelands, reptiles, trapping survey.

INTRODUCTION

The Australian Wildlife Conservancy (AWC) and Department of Environment and Conservation (DEC), in partnership with the Invasive Animals Co-operative Research Centre (IA CRC), commenced a project in 2006 to investigate techniques for the sustained control of introduced predators in the southern rangelands of Western Australia, with an emphasis on controlling feral cats (Richards & Algar 2008). At the treatment site, AWC's Mt Gibson Wildlife Sanctuary, a strategy for the control of introduced predators was implemented, and at the control site, DEC's Karara–Lochada Pastoral Station—in close proximity and with a similar suite of land system types—introduced predators were not controlled.

As part of the broader project to control the feral cat (*Felis catus*), fox (*Vulpes vulpes*) and wild dog (*Canis familiaris*) trio, the abundance of their prey items (small mammals, reptiles, birds and invertebrates) was monitored within the semi-arid *Eucalyptus* woodlands and sandplains dominated by *Acacia* shrublands on the two stations. These vegetation types characterize the semi-arid southern rangelands to the north of the wheatbelt zone in Western Australia. Other results of the broader project will be reported elsewhere, including papers within the same volume of this journal.

The small mammal and reptile fauna in the region has been documented in a number of unpublished, small-scale surveys conducted in association with mining companies (and other organizations such as DEC, AWC and Bush Heritage Australia) for particular reserves within the region and surrounding areas. In particular, information on small mammal and reptile species assemblages has been provided by DEC for areas to the north (Carnarvon Basin; Burbidge et al. 2000; McKenzie 2000; McKenzie et al. 2000), east (Goldfields; Burbidge et al. 1995), south (Wheatbelt; Burbidge et al. 2004; Kitchener et al. 1980a, 1980b) and west (Burbidge et al. 1989).

In this paper we document the small mammal and reptile species assemblages at 24 sites sampled in the two study areas (Mt Gibson and Karara–Lochada) within the semi-arid southern rangelands immediately to the north of the wheatbelt zone in Western Australia. We describe how the composition of these assemblages varies across land system types within and between the properties, and potential impacts of variation in rainfall.

METHODS

Mt Gibson Wildlife Sanctuary Study Site

Mt Gibson Wildlife Sanctuary is located approximately halfway between Wubin and Paynes Find in Western Australia (29º 36' 36.2" S, 117º 24' 31.3" E), and covers an area of 130,500 ha, straddling the boundary between the South-West and Eremaean Botanical Provinces (Fig. 1). The area has a semi-arid climate with hot dry summers and mild wet winters. Summer temperatures range between 19–36 °C (minimum–maximum), and winter temperatures between 6–18 °C. There are typically 9–11 months of predominantly dry weather, with an annual rainfall of 343 mm. Evapotranspiration rates are considerably higher than rainfall, with the annual average for the Paynes Find region being 2,480 mm.

Mt Gibson is characterized by mixed *Acacia* shrublands on sandplain and York Gum (*Eucalyptus loxophleba*), Salmon Gum (*E. salmonophloia*) and Gimlet (*E. salubris*) woodlands. The sanctuary contains 13 vegetation associations (Beard 1976). The dominant landforms are greenstone ranges in the north-east and banded ironstone formations to the north-west. Granites and gneisses of the Yilgarn Block underlie much of the area and outcrop as domes or breakaways (McKenzie & May 2003). The ranges are separated by gently sloping pediments and floodplains upslope from salt lakes and clay pans (McKenzie & May 2003). Sandplains occur extensively to the south. Drainage is internal and disorganized and an extensive salt lake, Lake Moore, bounds Mt Gibson Wildlife Sanctuary to the east.

The conservation organization AWC acquired the Mt Gibson pastoral lease, which had been managed conservatively for the preceding 20 years to promote environmental values, in 2001. The lease was subsequently destocked, removing most sheep (*Ovis aries*) and goats (*Capra hircus*). Fox control was conducted in 2004 and 2005 by AWC using 1080 dried meat baits laid by hand throughout the sanctuary. Prior to this, minimal predator control activities had been conducted by neighbouring pastoral lessees in an ad hoc manner and mostly directed towards baiting of wild dogs. Mt Gibson was chosen as a 'treatment' site in the predator control project, where introduced predators were controlled with an annual aerial baiting of 70,000 'Eradicat' baits over the entire pastoral lease in July 2006 and August 2007 (Richards & Algar 2008).

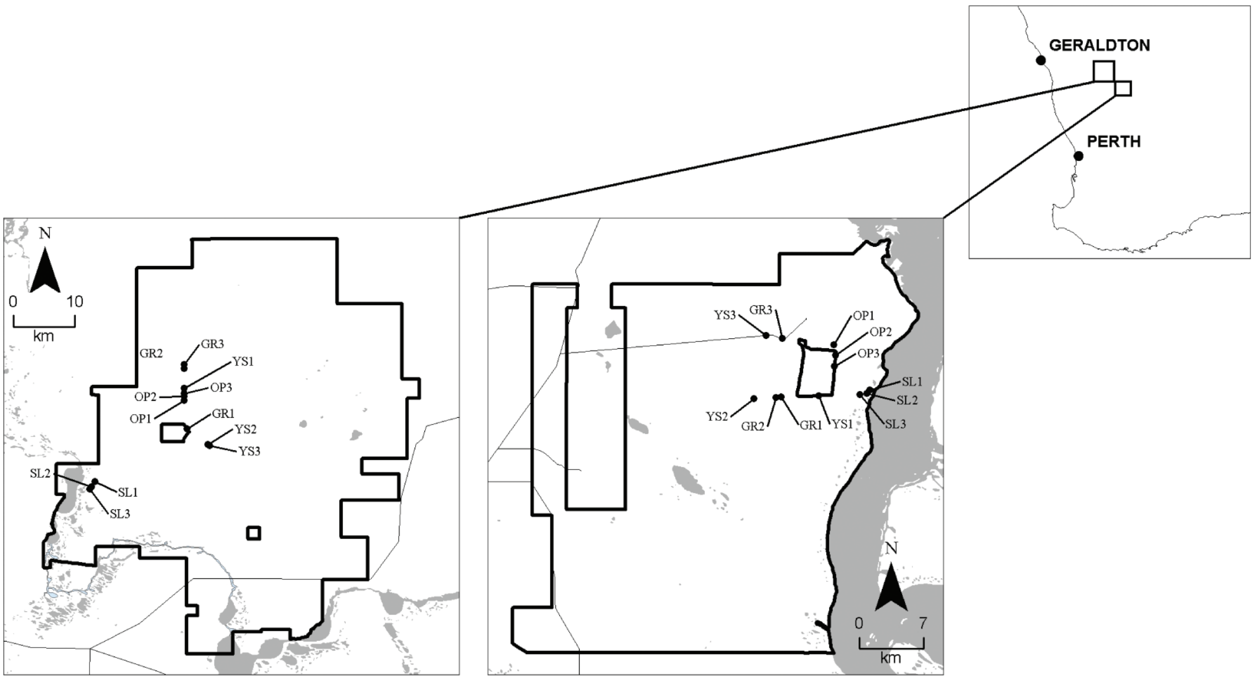

Figure 1. Location of Karara–Lochada Pastoral Station (left) and Mt Gibson Wildlife Sanctuary (right) in the southern rangelands region of Western Australia and the 24 quadrats described in this study.

Karara–Lochada Study Site

Karara (29° 14' 21" S, 116° 43' 44" E) and Lochada (29° 12' 60" S, 116° 33' 60" E) are adjacent pastoral stations managed by DEC and are located 86 km north of Mt Gibson Wildlife Sanctuary and 50 km east of Morawa. They cover an area of 109,300 ha and 114,600 ha respectively (Fig. 1). The average annual rainfall recorded for Karara is 312 mm (Bureau of Meteorology; based on records 1928–1939 and 1992–2008) and for Lochada is 327 mm (Bureau of Meteorology; based on records 1911–1939).

The climate, landforms, land systems and vegetation associations within the Karara–Lochada pastoral leases are similar to those found on Mt Gibson. Karara–Lochada also lies on the interface between the South West Botanical Province and the Eremaean Botanical Province, and mainly lies within the Yalgoo bioregion. There are at least 14 land types (Van Vreeswyk & Godden 1998) and 14 vegetation types (Beard 1976) on Karara. The area is characterized by mixed *Acacia* shrublands on sandplain and sparse York Gum woodlands. The stations lie within the Yilgarn craton and across the boundaries of the Murchison Plateau and the Salinaland Plateau, with frequent granite rises and low domes.

The pastoral leases have historically run Merino sheep, and feral goats have been mustered and sold in recent years. The properties were purchased by DEC in 2000 and 2002 and subsequently destocked for conservation purposes. Karara–Lochada was chosen as the 'control' site, where introduced predators were not baited. Minimal predator control had been conducted on the pastoral leases prior to this study, and was mostly undertaken by neighbouring pastoral lessees in an ad hoc manner to bait wild dogs.

Small Mammal and Reptile Trapping Surveys

Twelve sites were selected at each property, three within each of four 'land system' types (Department of Agriculture and Food Western Australia 1990) characteristic of both Karara–Lochada and Mount Gibson: 1) Joseph (YS; yellow sandplains)—undulating yellow sandplains supporting dense mixed *Acacia* shrublands on yellow sandplain; 2) Pindar (OP; Olympic plains)—red loamy sandplain supporting *Eucalyptus* woodlands and *Acacia* shrublands; 3) Euchre (GR; granite)—low granite breakaways with alluvial plains and sandy tracts supporting *Eucalyptus* woodlands and *Acacia* shrublands with patchy mallees on granitic breakaways; and 4) Carnegie (SL; salt lake)—salt lakes with fringing saline plains, dunes and sandy banks. Each site was approximately 1.6 ha, at least 0.5 km apart and adjacent to vehicle tracks for easy access (Fig. 1).

Surveys were conducted twice each year for two years: in winter (20–24 June 2006, 11–15 July 2007 at Mt Gibson and 26–30 June 2006, 6–10 July 2007 at Karara–Lochada), just prior to aerial predator baiting to assess potential prey abundance at its lowest; and in spring (25–29 September 2006, 3–7 October 2007 at Mt Gibson and 19–23 September 2006, 23–27 September 2007 at Karara–Lochada), when populations had potentially commenced receiving an influx of small mammal recruits after breeding. Each site was sampled using 25 pitfall traps (20 l plastic bucket with 7 m of wire mesh drift fence) and 25 Elliott traps (baited with universal bait of rolled oats, peanut butter and sardines). One pitfall trap and one Elliott trap were placed at each station (five rows 50 m apart with traps spaced at 20 m intervals along each row). All animals captured were marked with non-toxic paint, weighed and measured before release at the capture location. Recaptures were recorded and released with no additional measurements taken. Pitfall traps were open continuously for four nights and checked early each following morning. Elliott traps were baited each afternoon and checked early the following morning. Elliott traps were re-checked in the afternoon during warmer weather whilst re-baiting however no animals were captured during the day in any survey.

Statistical Analyses

All captures at each site within each year were combined into a species by site matrix for each year. These data were analyzed by a permutational multivariate repeated measures analysis of variance (PERMANOVA) using the PERMANOVA+ add-on to the PRIMER-E software package (Anderson et al. 2008). There were two fixed, orthogonal, between-site factors:

- station (two levels—Mt Gibson (MG) and Karara–Lochada (KL)),
- land system (four levels—YS, OP, GR and SL);

and one fixed, within-site factor:

- year (two levels—2006 and 2007).

All data were square-root transformed prior to analysis to ensure that similarity values were not dominated by a few highly abundant species (Clarke & Warwick 2001) and pairwise similarities between all sites were estimated by the Bray-Curtis similarity coefficient. Post-hoc comparisons between levels of factors were performed by PERMANOVA, using Monte Carlo sampling to generate probability levels as the number of unique permutations for each pairwise test were too low (Anderson et al. 2008).

Canonical Analysis of Principal Coordinates, or CAP analysis (Anderson & Willis 2003) was used to find the axes best capable of discriminating between both the station – land system and the station–year combinations of sites. The position of sites on these axes was overlayed with species vectors, indicating the strength and the direction of the Spearman rank correlation between those species and the CAP axes (Anderson et al. 2008). The identity of the species contributing the most to the separation of levels within significant factors was determined with the SIMPER routine within PRIMER-E.

RESULTS

Small Mammal and Reptile Trapping Surveys

Ten small mammal species (nine native, one introduced) were recorded at the 24 trapping sites distributed between Mt Gibson and Karara–Lochada Pastoral Stations in the four trapping sessions in 2006 and 2007 (Table 1). The introduced house mouse (*Mus musculus*) was captured at both sites. Seven native mammal species were captured at Mt Gibson and eight at Karara–Lochada, of which six species were captured at both sites. *Antechinomys laniger* was captured only at Karara–Lochada and *Ningaui yvonnae* and *Sminthopsis gilberti* only at Mt Gibson, however, all were single captures only.

The most commonly trapped small mammals were *Notomys mitchelli*, *S. dolichura*, *M. musculus* and *Pseudomys hermannsburgensis* at Mt Gibson, and *M. musculus* and *P. hermannsburgensis* at Karara–Lochada (Table 1). Small mammals were nearly twice as abundant at Mt Gibson than at Karara–Lochada. The average number of species trapped at each of the 24 sites was 9.8 (range 6–14).

Thirty reptile and three amphibian species were recorded at the 24 sites distributed between Mt Gibson and Karara–Lochada Pastoral Stations during the four trapping sessions (Table 1). Twenty-seven of these species were captured at Mt Gibson and 22 at Karara–Lochada, of which 16 species were captured at both sites. Of the 17 species captured at one property only, 12 were single captures and two were captures of two. *Gehyra variegata* was common at Mt Gibson (10 captures), but was not captured at Karara–Lochada, and *Strophurus assimilus*

Table 1

Total number of mammal, reptile and amphibian species trapped during the four survey periods.

Taxon	Species	Mt Gibson	Karara–Lochada
Mammals	*Antechinomys laniger*	–	1
	Mus musculus	47	69
	Ningaui yvonneae	1	–
	Notomys alexis	2	1
	Notomys mitchelli	99	9
	Pseudomys hermannsburgensis	41	68
	Sminthopsis crassicaudata	14	4
	Sminthopsis dolichura	97	9
	Sminthopsis gilberti	1	–
	Sminthopsis sp.	–	4
		302 (8 species)	**161 (8 species)**
Reptiles	*Brachyurophis semifasciata*	2	–
	Caimanops amphiboluroides	–	1
	Cryptoblepharus buchanani	2	1
	Ctenophorus cristatus	1	–
	Ctenophorus reticulatus	5	9
	Ctenophorus scutulatus	19	7
	Ctenotus mimetes	93	37
	Ctenotus pantherinus	7	2
	Ctenotus schomburgkii	48	73
	Ctenotus uber	–	1
	Diplodactylus granariensis	4	15
	Diplodactylus intermedius	2	–
	Diplodactylus pulcher	8	17
	Gehyra variegata	10	–
	Heteronotia binoei	1	1
	Lerista gerrardii	–	1
	Lerista muelleri complex	2	3
	Lerista nichollsi?	–	1
	Lialis burtonis	1	–
	Liopholis inornata	1	10
	Lucasium squarrosum	3	6
	Menetia greyii	5	11
	Nephrurus vertebralis	1	–
	Pogona minor	12	7
	Rhynchoedura ornata	1	–
	Strophurus assimilus	4	–
	Suta fasciata	1	–
	Tiliqua occipitalis	–	1
	Varanus caudilineatus	11	1
	Varanus gouldii	1	–
		245 (25 species)	**205 (20 species)**
Amphibians	*Neobatrachus pelabatoides*	5	1
	Neobatrachus sp.	–	4
	Pseudophryne occidentalis	1	–
		6 (2 species)	**5 (2 species)**

was captured four times at Mt Gibson but was not captured at Karara–Lochada. These species are likely to be present at both locations. Frogs were not targeted as part of the survey and were therefore rarely captured due to a lack of rainfall events during the four survey periods. Four *Neobatrachus* sp. were captured at Karara–Lochada and were unable to be identified, though were likely to be either *N. centralis*, *N. sutor* or *N. kunapalari*.

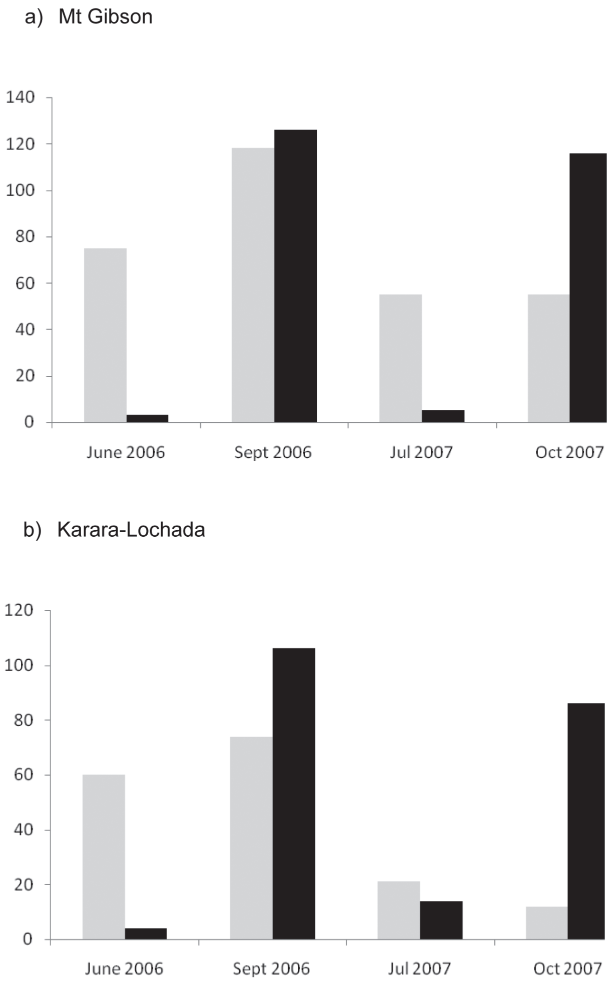

Figure 2. Number of small mammals (pale grey) and reptiles and amphibians (black) captured at: a) Mt Gibson and b) Karara–Lochada in 2006 and 2007.

The majority of reptiles were captured during the spring surveys (Fig. 2). Only two reptiles were captured in the two winter surveys at Mt Gibson and 13 at Karara–Lochada. As with mammals, the number of reptile captures was slightly higher at Mt Gibson than Karara–Lochada during the spring surveys and also appeared to decline from 2006 to 2007 at both stations.

During the two-year study period, Mt Gibson received an annual rainfall of 341 mm in 2006 and only 264 mm in 2007; the latter below the average annual rainfall of 343 mm and one of the lowest since recording commenced (Bureau of Meteorology records 1983 to 2007). Karara received an annual rainfall of 392 mm in 2006, and 196 mm in 2007; the latter also substantially below the average annual rainfall of 312 mm (Bureau of Meteorology records; based on records 1928–1939 and 1992–2008).

The land system type with the most abundant captures of small mammals, reptiles and amphibians over the four combined survey periods was GR at Mt Gibson and OP at Karara–Lochada (Table 2). The most abundant mammal and reptile species were captured across all four land system types. Overall, the average number of species per site trapped within the four land system types was highest in SL.

Statistical Analyses

Faunal assemblage structure was shown to be significantly different between stations, land systems and years (Table 3). There were also significant interactions between stations and land systems and stations and year. Pairwise

Table 2

Percentage of small mammal, reptile and amphibian captures over the four survey periods and the average number of species captured per site.

Land system	Mt Gibson	Karara–Lochada	Average # of species per site
Euchre (GR)	30.9% of 533 captures	18.8% of 377 captures	9.8
Pindar (OP)	23.7	40.0	10.2
Joseph (YS)	23.2	19.1	8.7
Carnegie (SL)	22.2	22.0	10.3

Table 3

Results of the PERMANOVA of the effect of station, land system and year on the structure of faunal assemblages at Mt Gibson and Karara–Lochada.

Source	df	Mean Square	Pseudo-F	p	# permutations
Station	1	12290.0	6.9376	*0.0002*	4980
Landsystem	3	9793.8	5.5284	*0.0002*	4981
Station x landsystem	3	3395.7	1.9168	*0.0076*	4974
Site (station x landsystem)	16	1771.6			
Year	1	9721.9	9.8269	*0.0002*	4984
Station x year	1	2609.4	2.6376	*0.0282*	4985
Landsystem x year	3	1173.0	1.1857	0.3030	4980
Station x landsystem x year	3	1378.8	1.3937	0.1748	4978
Residual	16	989.3			

Table 4

The abundances and contribution to separation of the assemblages at the two stations, Mt Gibson (MG) and Karara–Lochada (KL). Note: abundances are given as untransformed means across sites, while contribution to dissimilarity is based on the Bray-Curtis similarity indices, calculated on square-root transformed data.

Species	Average abundance at sites at MG	Average abundance at sites at KL	Contribution to dissimilarity
Notomys mitchelli	4.13	0.38	11.45%
Sminthopsis dolichura	3.88	1.58	10.37%
Ctenotus mimetes	3.88	0.42	9.29%
Ctenotus schomburgkii	2.00	3.04	8.88%
Pseudomys hermannsburgensis	1.63	2.83	7.78%
Mus musculus	2.04	2.88	5.83%
Total contribution			53.60%

Table 5

The abundances and contribution to separation of the assemblages in the two years, 2006 and 2007. Note: abundances are given as untransformed means across sites, while contribution to dissimilarity is based on the Bray-Curtis similarity indices, calculated on square-root transformed data.

Species	Average abundance at all sites in 2006	Average abundance at all sites in 2007	Contribution to dissimilarity
Mus musculus	4.25	0.67	12.45%
Ctenotus mimetes	3.63	1.83	9.20%
Ctenotus schomburgkii	2.21	2.83	9.12%
Pseudomys hermannsburgensis	2.96	1.50	8.61%
Notomys mitchelli	2.38	2.13	6.36%
Sminthopsis dolichura	3.00	1.29	6.35%
Total contribution			52.10%

post-hoc comparisons of stations within land systems showed significant differences in assemblage structure between the GP landsystems at Mt Gibson and Karara–Lochada ($p = 0.007$) and between the OP landsystems at Mt Gibson and Karara–Lochada ($p = 0.019$). There was no difference in the other two land systems across stations. Pairwise post-hoc comparisons of land systems within stations showed significant differences ($0.01 < p < 0.05$) between all land systems except OP and YS, and YS and GR, at Mt Gibson, and between all land systems except OP and YS, and GR and SL, at Karara–Lochada ($p < 0.01$ for GR v OP and $0.01 < p < 0.05$ for SL v YS, SL v OP and GR v YS).

Pairwise post-hoc comparisons of stations within years showed assemblages at Mt Gibson and Karara–Lochada to be different in both years (p(perm) = 0.0002 and 0.0004 based on 4983 and 4987 permutations, respectively). Similarly, assemblages recorded in 2006 and 2007 were different at both Mt Gibson and Karara–Lochada (p(perm) = 0.005 and 0.002 based on 4986 and 4987 permutations respectively).

Over 50% of the difference in faunal assemblage structure at Mt Gibson and Karara–Lochada was accounted for by six species: *Notomys mitchelli*, *Sminthopsis dolichura* and *Ctenotus mimetes* (all noticeably more abundant at Mt Gibson; Tables 1 and 4) and *C. schomburgkii*, *Pseudomys hermannsburgensis* and *M.musculus* (all more abundant at Karara–Lochada; Tables 1 and 4). These same six species were also responsible for 52% of the difference in faunal assemblage structure between years, with the four mammal species and *C. mimetes* decreasing in abundance from 2006 to 2007, and *C. schomburgkii* increasing in abundance (Table 5).

The high numbers of *C. mimetes* in the GR land system linked the GR sites and distinguished them from those in other land systems (Table 6). *C. schomburgkii* and *P. hermannsburgensis* were common at OP sites, the former contributing most to the difference between OP and SL sites, and both contributing to the difference

Table 6

Average similarity of the assemblages within and between land systems. For each pairwise comparison, the species contributing the most to the **similarity** of sites within land systems (diagonal) or the **differentiation** of sites between land systems (off-diagonal) are given. Percentages are the similarity between each land system pair. Species in bold indicate they are at a greater abundance in the land system heading the column.

	GR	YS	OP	SL
GR	35.8% *C. mimetes*			
YS	20.0% ***C. mimetes*** *N. mitchelli* *C. schomburgkii*	32.8% *C. schomburgkii* *N. mitchelli*		
OP	19.1% ***C. mimetes*** *C. schomburgkii*	30.9% *C. schomburgkii* ***N. mitchelli*** *Pseudomys*	33.4% *C. schomburgkii* *Pseudomys*	
SL	31.3% ***C. minetes*** *Pseudomys* *S. dolichura*	18.3% ***N. mitchelli*** *Pseudomys* *C. schomburgkii* *C. mimetes*	22.8% ***C. schomburgkii*** *Pseudomys* ***M. musculus***	36.2% *Pseudomys* *C. minetes*

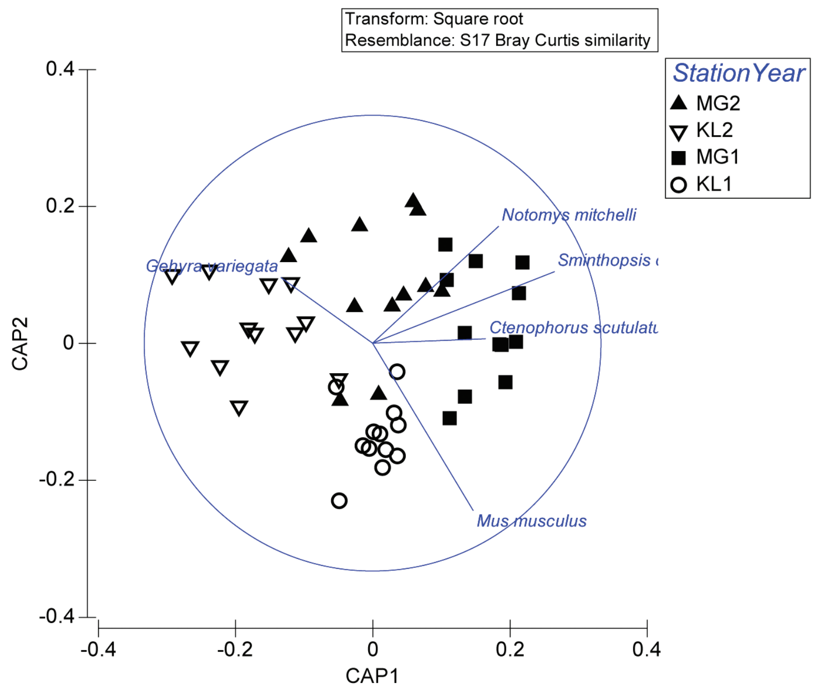

Figure 3. Separation of sites by station and year by Canonical Analysis of Principal Coordinates. Vectors show the direction of the contribution of some of the species with the highest Spearman rank correlations with the CAP axes. MG: Mt Gibson, KL: Karara-Lochada pastoral stations; 1: 2006, 2: 2007. Sminthopsis = Sminthopsis dolichura

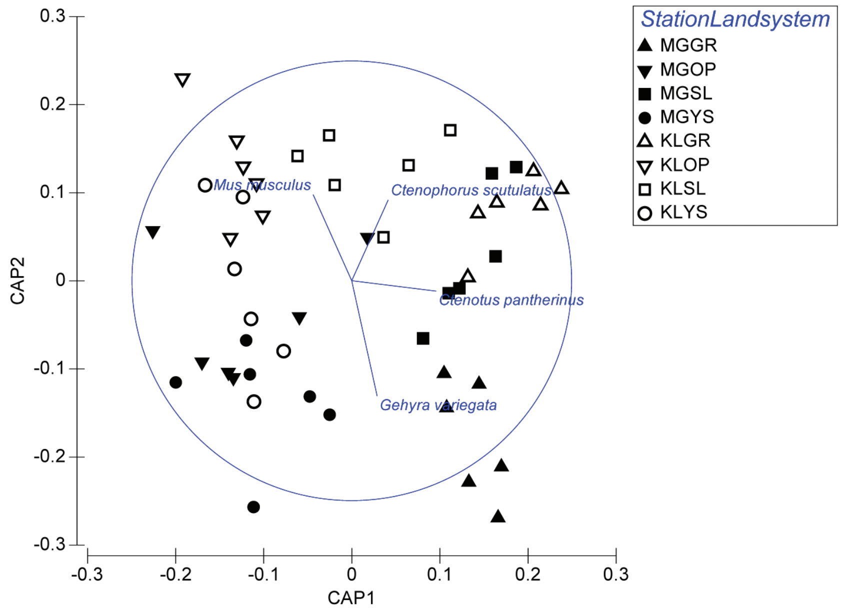

Figure 4. Separation of sites by station and land system by Canonical Analysis of Principal Coordinates. Vectors show the direction of the contribution of some of the species with the highest Spearman rank correlations with the CAP axes. MG: Mt Gibson, KL: Karara–Lochada pastoral stations; GR: Euchre, OP: Pindar, SL: Carnegie, YS: Joseph landsystems.

between OP and YS sites. SL sites were linked by higher abundances of *P. hermannsbergensis*, which contributed to the difference between those sites and sites in the other three land systems, while YS sites were linked by higher numbers of *C. schomburgkii* and *N. mitchelli* and these both contributed to the difference between YS and GR sites, with *N. mitchelli* contributing to the difference between YS and all other sites.

Stations and years separated on the first two CAP axes (Fig. 3). Based on 10 principal coordinate axes, CAP correctly classified 73% of the sites into their station–year groups. This was highly significant, with a trace statistic of 1.645 ($p = 0.0002$). Increasing numbers of *S. dolichura*, *S. crassicaudata*, *Ctenophorus scutulatus* and *N. mitchelli* were positively correlated with the CAP1 axis, while decreases in *M. musculus*, *P. hermannsburgensis*, *Lucasium squarrosum* and increases in *N. mitchelli, S. dolichura* and *G. variegata* correlated with the CAP2 axis.

Separation of stations and land systems was less clear (Fig. 4), with only 56% of the sites correctly classified into their station – land system groups, based on seven axes. However, this was also highly significant (trace statistic of 2.586, p = 0.0002). Increasing numbers of *Ctenotus pantherinus* and *Ctenophorus scutulatus* were positively correlated with the CAP1 axis, while decreases in *G. variegata* and increases in *M. musculus, C. scutulatus* and *S. crassicaudata* correlated with the CAP2 axis.

DISCUSSION

Faunal Assemblages of Mt Gibson and Karara–Lochada

The Mt Gibson and Karara–Lochada region possesses elements of both the South-West and Eremaean Botanical Provinces, with a blend of south-west and arid zone vegetation assemblages characteristic of the Yalgoo, Avon Wheatbelt and Murchison IBRA bioregions, and their associated faunal species. Ten small mammal, 30 reptile and three amphibian species were recorded at Mt Gibson Wildlife Sanctuary and Karara–Lochada Pastoral Stations in 2006 and 2007 over four survey periods.

The most-often recorded species of small mammal trapped at the two stations were similar, despite some variation between the four land system types and the two years surveyed. The ubiquitous introduced house mouse (*M. musculus*), the sandy inland mouse (*P. hermannsburgensis*), Mitchell's hopping-mouse (*N. mitchelli*), the little long-tailed dunnart (*S. dolichura*) and fat-tailed dunnart (*S. crassicaudata*) were the most common small mammals captured at both Mt Gibson and Karara–Lochada. It is interesting to note that *M. musculus* and the suite of small native mammals occurred together within each of the land systems at varying abundances, considering the suggestion that *M. musculus* may compete with other small granivores and insectivores or be potential predators of small reptiles (Burbidge et al. 2004; Cuthbert & Hilton 2004). The presence of introduced *M. musculus* did not significantly affect resident small mammal or reptile abundance during a six-year study at the Arid Recovery Reserve in South Australia (Moseby et al. 2009).

Other species trapped rarely included the spinifex hopping-mouse (*N. alexis*), Gilbert's dunnart (*S. gilberti*), the kultarr (*A. laniger*) and the southern ningaui (*N. yvonnae*), all of which were recorded at only one of the two stations. Based upon both the extant mammal fauna and original mammal fauna collected from remains at Mt Gibson (Baynes 2002), the region is regarded as representative of both the dry south-west and arid zone regions, highlighting the transitional nature of the region.

The average number of species trapped at each of the 24 sites was 9.8 (range 6–14). Burbidge et al. (2004) recorded an average of 10.4 vertebrate species (range 1–19) within 252 smaller 1 ha quadrats sampled in the Western Australian agricultural zone, to the south and west of the Mt Gibson and Karara–Lochada study sites. Burbidge et al. (2004) captured 16 small mammal species in the Western Australian agricultural zone. *M. musculus* was the most abundant small mammal. Three small mammal species captured at Mt Gibson and Karara–Lochada were not captured during the survey of the Western Australian agricultural zone: *N. yvonnae*, *N. mitchelli* and *N. alexis*, all of which occur on the extremities of their range further east. A previous trapping survey at Charles Darwin Reserve, immediately west of Mt Gibson, recorded five small mammal species, four of which were recorded in this study (Burbidge et al. 1989). Southgate and Masters (1996) recorded *P. hermannsburgensis, N. alexis* and *M. musculus* as the three dominant small mammals in the arid Wattarka National Park region in the Northern Territory, with three species of *Sminthopsis* captured regularly, but in lower numbers. These species represent a similar composition of native and introduced rodents and dasyurids to the suite of species recorded in this study.

Of the 30 reptile species trapped at Mt Gibson and Karara–Lochada, only two species were regarded as common (>120 captures): *C. mimetes* and *C. schomburgkii.* Other species captured regularly (>9 captures) included: *Ctenophorus reticulates*, *C.scutulatus, Diplodactylus pulcher, D. granariensis, Liopholis inornata, Gehyra variegata, Menetia greyii, Pogona minor* and *Varanus caudolineatus.* All these more common reptile species were captured at both stations, except *G. variegata*, which was only captured at Mt Gibson. Continued trapping at Mt Gibson on the same sites in 2008 revealed an additional three species of reptile (*Brachyurophis semifasciata, Rhamphotyphlops bicolour* and *Underwoodisaurus milii*; AWC unpub. data), and it is likely that additional searches and trapping, both within the grids and in adjacent areas within the same land system types, would unearth greater species richness. In particular, snakes, goannas and legless lizards are regarded as difficult to sample (Rolfe & McKenzie 2000).

Another 26 species of reptile have been captured or seen elsewhere on the 130,500 ha Mt Gibson Wildlife Sanctuary during previous and continued survey work, including: *Ctenophorus ornatus*, *C. salinarum, Ctenotus severus, Cyclodomorphus branchialis, Delma australis, D. butleri, Demansia psammophis, Lerista gerrardii, Lucasium maini, Eremiascincus richardsonii, Egernia depressa, Moloch horridus, Morethia butleri, M. obscura, Oedura reticulata, Parasuta monachus, Pseudonaja modesta, P. nuchalis, Pygopus nigriceps, Ramphotyphlops bicolour, R.* hamatus, *Simoselaps bertholdi, Strophurus strophurus, Tiliqua rugosa, Tiliqua occipitalis* and *Varanus tristis* (AWC unpub. data).

Fifty reptile species are therefore currently known to occur within the boundaries of the Mt Gibson Wildlife Sanctuary and Karara–Lochada pastoral leases. A broadscale stratified survey design at periods of peak reptile activity, which was not the intention of this study (instead based upon the relative abundance of vertebrate fauna during feral cat control activities; Richards & Algar 2008), would be required to more adequately sample faunal assemblages in the region.

Burbidge et al. (2004) captured 106 of the 142 reptile species known from the Western Australian agricultural zone. Those at Mt Gibson and Karara–Lochada represent a subset only. Burbidge et al. (1989) captured 29 reptile species at Charles Darwin Reserve, 18 of which were captured at Mt Gibson and Karara–Lochada also.

Land System Faunal Associations

The faunal assemblages, while of generally similar composition with regard to dominant small mammal and reptile species, were significantly different, varying between stations, land systems and years. At Mt Gibson, the small vertebrate assemblages from the Joseph (YS) and Pindar (OP) land systems could not be separated, but were different to those in the Carnegie (SL) and Euchre (GR) land systems, and assemblages from the YS and GR land systems could not be separated, but were different to the other two land systems. At Karara–Lochada, all four land systems could be separated based on faunal assemblages except OP and YS, and GR and SL. Assemblages at Mt Gibson were different from those at Karara–Lochada in all but the YS land system.

Six species were primarily responsible for the differentiation in faunal assemblages between the two stations: *N. mitchelli*, *S. dolichura* and *C. mimetes* were more abundant at Mt Gibson and *C. schomburgkii; P. hermannsburgensis* and *M. musculus* were more abundant at Karara–Lochada. Many species were captured only as single records. More intensive, more widespread and longer-term trapping would no doubt reveal a more realistic description of the abundance and distribution across land system types. Landform and fire history were not taken into account during this study, and both may play an important role in determining species distribution and abundance. Each of the four land system types within each station was described by the relative abundance of the most common small mammal and reptile species, though there was considerable overlap in presence/absence of those species between land systems and stations.

Changes in Relative Abundance between Years

The same six species were primarily responsible for the differentiation in faunal assemblage structure between years, with the four mammal species (*Notomys mitchelli*, *S. dolichura, P. hermannsburgensis* and *M. musculus*) and *Ctenotus mimetes* decreasing in abundance from 2006 to 2007, and *C. schomburgkii* increasing in abundance.

The below average rainfall recorded at Mt Gibson and Karara in 2007 may have contributed to the lower number of captures of small mammals and reptiles that year. The even lower captures of small mammals at Karara–Lochada in 2007 compared with 2006 may be due to the dry conditions, but in addition may also be due to a dramatic increase in fox numbers recorded throughout the station in the absence of predator control (Richards & Algar 2008; Algar & Richards 2010).

The population dynamics of arid zone mammals are typically driven by interactions between rainfall, resource availability and predation (Dickman et al. 2001). Some dasyurid species, such as *S. dolichura*, have predictable population fluctuations (Friend et al. 1997) while many rodents follow an eruptive pattern of rarity, and abundance when conditions are favourable (Predevac 1994). Rodents, particularly *N. alexis* and *P. bolami*, increased in abundance in the absence of predators (and rabbits) at the Arid Recovery Reserve in South Australia, however the abundance of most dasyurids and small lizards did not change significantly (Moseby et al. 2009). No such patterns were evident at the study sites during the two years of monitoring (Richards & Algar 2008; Algar & Richards 2010).

CONCLUSIONS

The faunal assemblages of the Mt Gibson and Karara–Lochada pastoral leases are typical of those found in the region and are likely to characterize the transitional zone between the south-west and arid zone faunas associated with the Yalgoo, Avon Wheatbelt and Murchison IBRA Bioregions. Additional trapping effort across land system types, the removal of pseudo-replication and opportunistic sampling would no doubt provide a suite of additional species that occur at Mt Gibson and Karara–Lochada, and provide more generalized information about regional faunal composition. While the faunal assemblages are similar, the differences in assemblage composition and species abundance between and within the two stations highlights local site differences within the broad land system types categorized by Department of Agriculture and Food (Western Australia; DAFWA) and based on Beard's (1976) vegetation mapping of Western Australia.

The interactions between species and with environmental conditions are without doubt complex. As is usually the case, longer-term monitoring is required to tease out these relationships and would no doubt contribute to further knowledge of the fauna occurring within the Avon–Wheatbelt and Yalgoo Bioregions and the southern rangelands region of Western Australia.

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REFERENCES

Algar D, Richards J (2010) Controlling introduced predators in the rangelands: the conclusion. *Landscope* **25,** 17–23.

Anderson MJ, Willis TJ (2003) Canonical analysis of principle coordinates: a useful method of constrained ordination for ecology. *Ecology* **84**, 511–525.

Anderson MJ, Gorley RN, Clarke KR (2008) *PERMANOVA + for PRIMER: Guide to Software and Statistical Methods.* PRIMER-E, Plymouth, UK.

Baynes A (2002) 'Final Report on the Original Mammal Fauna of Mount Gibson Station'. Unpublished Report.

Beard JS (1976) *The Vegetation of the Perenjori Area, Western Australia: Map and Explanatory Memoir 1:250,000 Series.* Vegmap Publications, Perth.

Burbidge AA, Dixon KW, Fuller PJ (1989) *The Flora and Fauna of Vacant Crown Land at White Well, Shire of Dalwallinu, Western Australia.* Technical Report No 24. Department of Conservation and Land Management, Perth.

Burbidge AH, Fuller PJ, McKenzie NL (1995) Vertebrate fauna. In *The Biological Survey of the Eastern Goldfields of Western Australia. Part 12. Barlee–Menzies Study Area* (eds GJ Keighery, NL McKenzie, NJ Hall). *Records of the Western Australian Museum* Supplement **49**, 208–245.

Burbidge AH, Johnstone RE, Fuller PJ, Stone P (2000) Terrestrial birds of the southern Carnarvon Basin, Western Australia: contemporary patterns of occurrence. *Records of the Western Australian Museum* Supplement **61**, 449–464.

Burbidge AH, Rolfe JK, McKenzie NL, Roberts JD (2004) Biogeographic patterns in small ground-dwelling vertebrates of the Western Australian wheatbelt. *Records of the Western Australian Museum* Supplement **67,** 109–137.

Clarke KR, Warwick RM (2001) *Change in Marine Communities: An Approach to Statistical Analysis and Interpretation.* Natural Environmental Research Group, UK.

Cuthbert R, Hilton G (2004) Introduced house mice *Mus musculus*: a significant predator of threatened and endemic birds on Gough Island, South Atlantic Ocean? *Biological Conservation* **117**, 483–489.

Department of Agriculture and Food Western Australia (1990). *Soil – Land Systems of the South West of Western Australia.* Department of Agriculture and Food Western Australia, Perth.

Dickman CR, Haythornthwaite AS, McNaught GH, Mahon PS, Tamayo B, Letnic M. (2001) Population dynamics of three species of dasyurid marsupials in arid central Australia: a 10-year study. *Wildlife Research* **28**, 493–506.

Friend GR, Johnson BW, Mitchell DS, Smith GT (1997) Breeding, population dynamics and habitat relationships of *Sminthopsis dolichura* (Marsupialia: Dasyuridae) in semi-arid shrublands of Western Australia. *Wildlife Research* **24**, 245–262.

Kitchener DJ, Chapman A, Dell J, Muir BG, Palmer M (1980a) Lizard assemblage and reserve size and structure in the Western Australian wheatbelt – some implications for conservation. *Biological Conservation* **17**, 25–62.

Kitchener DJ, Chapman A, Muir BG, Palmer M (1980b) The conservation value for mammals of reserves in the Western Australian wheatbelt. *Biological Conservation* **18**, 179–207.

McKenzie NL (2000) Non-volant mammals of the southern Carnarvon Basin, Western Australia. *Records of the Western Australian Museum* Supplement **61,** 479–510.

McKenzie NL, May JE (2003) *A Biodiversity Audit of Western Australia's Biogeographical Subregions in 2002.* Department of Conservation and Land Management, Perth.

McKenzie NL, Rolfe JK, Aplin KP, Cowan MA, Smith LA (2000) Herpetofauna of the southern Carnarvon Basin, Western Australia. *Records of the Western Australian Museum* Supplement **61,** 335–360.

Moseby KE, Hill BM, Read JL (2009) Arid Recovery: a comparison of reptile and small mammal populations inside and outside a large rabbit, cat and fox-proof exclosure in arid South Australia. *Austral Ecology* **34**, 156–169.

Predevac M (1994) Population dynamics and environmental changes during natural irruptions of Australian desert rodents. *Wildlife Research* **21**, 569–582.

Richards J, Algar D (2008) Controlling feral animals in the rangelands. *Landscope* **23**, 52–58.

Rolfe JK, McKenzie NI (2000) Comparison of methods used to capture herpetofauna: an example from the Carnarvon Basin. *Records of the Western Australian Museum* Supplement **61,** 361–370.

Southgate R, Masters P (1996) Fluctuations of rodent populations in response to rainfall and fire in a central Australian hummock grassland dominated by *Plectrachne schinzii. Wildlife Research* **23**, 289–303.

Van Vreeswyk AME, Godden PT (1998) *Pastoral Resources and Their Management in the Sandstone – Yalgoo – Paynes Find Area, Western Australia.* Agriculture Western Australia, Perth.

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Terrestrial bird assemblages of the semi-arid woodlands and *Acacia* sandplains in the southern rangelands of Western Australia

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ABSTRACT

As part of a broader study involving the control of introduced predators, the seasonal presence of avian fauna was monitored in winter and spring during 2006 and 2007 at two study sites. The two sites, Mt Gibson Wildlife Sanctuary and Karara–Lochada Pastoral Stations, are located in the semi-arid *Eucalyptus* woodlands and *Acacia* shrublands within the Avon–Wheatbelt and Yalgoo bioregions of Western Australia. Sixty-eight bird species were recorded at Mt Gibson Wildlife Sanctuary and 60 species at Karara–Lochada Pastoral Stations; 94 species in total at the two sites. Bird species were recorded at 24 quadrats within four land system types represented at each of the study sites. Fifty-one of the species were present at both sites while 17 occurred only at Mt Gibson and nine only at Karara–Lochada, despite apparently similar habitat at the two locations. Opportunistic records of nesting species were also recorded.

Keywords: avian, conservation, pastoral, predator control, survey, wheatbelt.

INTRODUCTION

The Australian Wildlife Conservancy (AWC) and Department of Environment and Conservation (DEC), in partnership with the Invasive Animals Co-operative Research Centre (IA CRC), commenced a project in 2006 to investigate techniques for the sustained control of introduced predators in the southern rangelands of Western Australia (Richards & Algar 2008). At the treatment site, AWC's Mt Gibson Wildlife Sanctuary, a strategy for the control of introduced predators was implemented. At the control site nearby, DEC's Karara–Lochada Pastoral Stations, which has a similar suite of land system types, introduced predators were not controlled.

As part of this broader project to control the feral cat (*Felis catus*), fox (*Vulpes vulpes*) and wild dog (*Canis familiaris*), the abundance of their prey items (small mammals, reptiles, birds and invertebrates) was monitored at both sites within the semi-arid *Eucalyptus* woodlands and sandplains dominated by *Acacia* shrublands. These vegetation types characterize the semi-arid southern rangelands to the north of the wheatbelt zone in Western Australia. Other results of the broader project will be reported elsewhere, including papers within the same volume of this journal.

Bird fauna in the region has been documented after a number of unpublished, small-scale surveys conducted in association with mining companies (and other organizations such as DEC, AWC and Bush Heritage Australia) for particular reserves within the region and surrounding areas. In particular, information on bird species assemblages has been provided by DEC and the Western Australian Museum for areas to the north (Carnarvon Basin; Burbidge et al. 2000), east (Goldfields; Burbidge et al. 1995), south (Wheatbelt; e.g. Dell et al. 1979; Kitchener et al. 1979) and west (vacant Crown Land at White Wells; Burbidge et al. 1989).

In this paper we document the bird species assemblages in 24 quadrats at two study sites (Mt Gibson Wildlife Sanctuary and Karara–Lochada Pastoral Stations) within the semi-arid southern rangelands immediately to the north of the wheatbelt zone in Western Australia, and describe how the composition of these assemblages varies across land system types within and between the properties.

METHODS

Mt Gibson Wildlife Sanctuary Study Site

Mt Gibson Wildlife Sanctuary is located approximately half way between Wubin and Paynes Find in Western Australia (29° 36' 36.2" S, 117° 24' 31.3" E; Fig. 1) and covers an area of 130,500 ha straddling the boundary between the South-West and Eremaean Botanical Provinces. The area has a semi-arid climate with hot dry summers and mild wet winters. Summer temperatures range from 19–36 °C, and winter temperatures from 6–18 °C. There are typically 9–11 months of dry weather, with an annual rainfall of 343 mm (Bureau of Meteorology records 1983 to 2007), which arrives as gentle soaking rains and thundery showers in winter or in summer as occasional tropical cyclones or rain bearing depressions. Evapotranspiration rates are considerably higher than rainfall with the annual average for the Paynes Find region being 2,480 mm.

Mt Gibson Wildlife Sanctuary is characterized by mixed *Acacia* shrublands on sandplain and York Gum (*Eucalyptus loxophleba*), Salmon Gum (*E. salmonophloia*) and Gimlet (*E. salubris*) woodlands. The sanctuary contains 13 vegetation associations (Beard 1976). The dominant landforms are greenstone ranges in the north-east and banded ironstone formations to the north-west. Granites and gneisses of the Yilgarn Block underlie much of the area and outcrop as domes or breakaways (McKenzie & May 2003). The ranges are separated by gently sloping pediments and flood plains upslope from salt lakes and clay pans (McKenzie & May 2003). Sand plains occur extensively to the south. Drainage is internal and disorganized, and an extensive salt lake, Lake Moore, bounds Mt Gibson Wildlife Sanctuary to the east.

The Mt Gibson Pastoral Lease was granted in 1878 to graze sheep (*Ovis aries*) and has had a long history of pastoralism. The private, not for profit, conservation organization AWC acquired the lease in 2001, which had been managed conservatively for the preceding 20 years to promote environmental values. The lease was subsequently destocked, removing most sheep and goats (*Capra hircus*) and leaving a small resident flock of goats to satisfy Pastoral Lands Board requirements. Fox control was conducted in 2004 and 2005 by AWC using 1080 dried meat baits laid by hand throughout the pastoral lease. Prior to this, minimal predator control activities had been conducted by neighbouring pastoral lessees in an ad hoc manner and mostly directed towards baiting of wild dogs. Mt Gibson was chosen as a 'treatment' site, where introduced predators were controlled with an annual aerial baiting of 70,000 'Eradicat' baits over the entire pastoral lease in July 2006 and August 2007 in a collaborative effort between AWC, DEC and the IA CRC (Richards & Algar 2008).

Karara–Lochada Study Site

Karara (29° 14' 21"S, 116° 43' 44" E) and Lochada (29° 12' 60" S, 116° 33' 60" E) are adjacent reclaimed pastoral leases managed by DEC and located 86 km north-west of Mt Gibson Wildlife Sanctuary and 50 km east of Morawa, and cover an area of 109,300 and 114,600 ha respectively (Fig. 1). The average annual rainfall recorded for Karara is 312.3 mm (Bureau of Meteorology, based on records

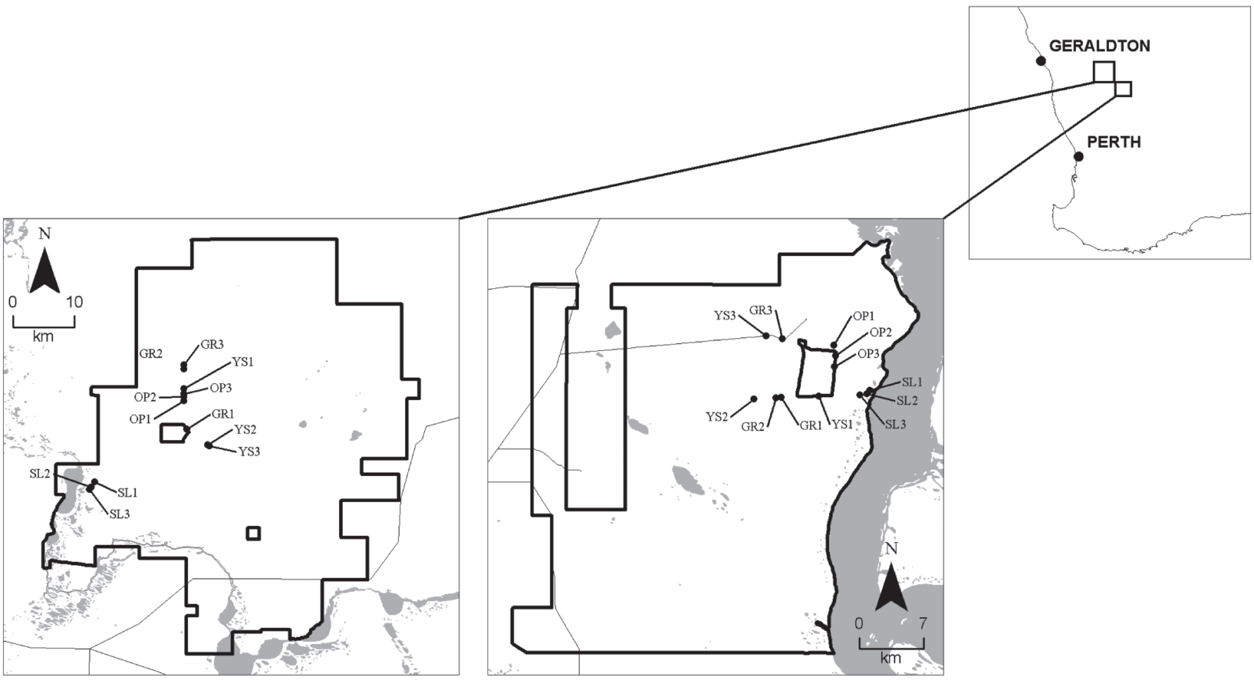

Figure 1. Location of Karara–Lochada Pastoral Stations (left) and Mt Gibson Wildlife Sanctuary (right) in the southern rangelands region of Western Australia, and the 24 quadrats described in this study. YS—yellow sandplains; OP—Olympic plains; GR—granite; SL—salt lake; the numerals 1 to 4 denote quadrat replicates within each land system.

1928–1939 and 1992–2008) and for Lochada is 327 mm (Bureau of Meteorology, based on records 1911–1939).

The climate, landforms, land systems and vegetation associations within the Karara–Lochada Pastoral Leases are similar to those found on Mt Gibson. Karara–Lochada also lies on the interface between the South West Botanical Province and the Eremaean Botanical Province, and mainly lies within the Yalgoo bioregion. There are at least 14 land types (Van Vreeswyk & Godden 1998) and 14 vegetation types (Beard 1976) on Karara–Lochada. The area is characterized by mixed *Acacia* shrublands on sandplain and sparse York Gum woodlands. The stations lie within the Yilgarn craton and across the boundaries of the Murchison Plateau and the Salinaland Plateau, with frequent granite rises and low domes.

The pastoral leases have historically run Merino sheep and feral goats have been mustered and sold in recent years. Lochada Pastoral Station was purchased by DEC in 2000 and Karara Pastoral Station in 2002. Both were subsequently destocked for conservation purposes. Karara–Lochada was chosen as the 'control' site, where introduced predators were not baited. Minimal predator control had been conducted on the pastoral leases prior to this study, and was mostly undertaken by neighbouring pastoral lessees in an ad hoc manner to bait wild dogs.

Bird Surveys

Twelve quadrats were selected at each site, including three within each of four habitat or 'land system' types (Department of Agriculture and Food Western Australia; DAFWA 1990) characteristic of both Karara–Lochada and Mount Gibson: 1) Joseph (YS; yellow sandplains)—undulating yellow sandplains supporting dense mixed *Acacia* shrublands; 2) Pindar (OP; Olympic plains)—red loamy sandplain supporting *Eucalyptus* woodlands and *Acacia* shrublands; 3) Euchre (GR; granite)—low granite breakaways with alluvial plains and sandy tracts supporting *Eucalyptus* woodlands and *Acacia* shrublands with patchy mallees on granitic breakaways; and 4) Carnegie (SL; salt lake)—salt lakes with fringing saline plains, dunes and sandy banks. The quadrats of approximately 16 ha were located adjacent to vehicle tracks for easy access (Fig. 1).

Bird surveys were conducted twice each year for two years in each of the 24 quadrats: in winter (20–24 June 2006, 11–15 July 2007 at Mt Gibson and 26–30 June 2006, 6–10 July 2007 at Karara–Lochada), just prior to predator baiting to assess potential prey abundance at its lowest; and in spring (25–29 September 2006, 3–7 October 2007 at Mt Gibson and 19–23 September 2006, 23–27 September 2007 at Karara–Lochada), when bird populations had received an influx of new recruits immediately after breeding. Each quadrat was sampled for an hour immediately following dawn and an hour prior to dusk in each sampling period with a single observer walking a random route through the quadrat, checking all micro-habitats, following up calls and locating as many birds as possible, while ensuring that the entire 16 ha were covered systematically. The objective of sampling was to determine species presence/absence at each quadrat. No effort was made to estimate abundance of species. Bird species names and taxon order were taken from Christidis and Boles (2008). Scientific names are listed in Appendix 1.

Statistical Analyses

The bird assemblage data were analysed by a permutational multivariate repeated measures analysis of variance (PERMANOVA) with two fixed, orthogonal, between-site factors:

- station (two levels—Mt Gibson [MG] and Karara–Lochada [KL]),
- land system (four levels—YS, OP, GR and SL);

and one fixed, within-site factor:

- year (two levels—2006 and 2007),

using the PERMANOVA+ add-on to the PRIMER-E software package (Anderson et al. 2008). Because the data were presence/absence, rather than abundance, no transformation was required. Pairwise similarities between all sites were estimated by the Bray–Curtis similarity coefficient.

Canonical Analysis of Principal Coordinates, or CAP analysis (Anderson & Willis 2003) was used to find the axes best capable of discriminating between the station – land system and station–year combinations of sites. The visual display of sites on these axes was overlayed with species vectors, indicating the strength and the direction of the Spearman rank correlation between those species and the CAP axes (Anderson et al. 2008). The identity of the species contributing the most to the separation of levels within significant factors was determined with the SIMPER routine within PRIMER-E.

Opportunistic Sightings

En route to the quadrats, opportunistic sightings were also recorded during bird survey periods. Details of species sighted, habitat and nesting biology were recorded and collated in order to add to the knowledge of distribution and natural history, particularly for species for which general biological knowledge is minimal.

RESULTS

Bird Surveys

A total of 94 bird species (58 passerines and 36 non-passerines) was recorded during the four bird survey periods at Mt Gibson and Karara–Lochada Pastoral Stations in the 24 quadrats and as opportunistic sightings (Appendix 1). Sixty-eight species were recorded at Mt Gibson Wildlife Sanctuary and 60 species at Karara–Lochada Pastoral Stations (Table 1). Of these species, 51 were found at both Mt Gibson and Karara–Lochada.

Nine bird species were recorded once only at Karara–Lochada during the survey periods: Peregrine Falcon, Little Corella, Mulga Parrot, Pallid Cuckoo, White-winged

Fairy-wren, Grey-fronted Honeyeater, Varied Sittella, Torresian Crow and Welcome Swallow. Similarly, 17 species were recorded once only at Mt Gibson during the survey periods: Spotted Nightjar, Brown Goshawk, Australian Hobby, Western Corella, Cockatiel, Black-eared Cuckoo, Rainbow Bee-eater, White-eared Honeyeater, Brown-headed Honeyeater, Black-faced Woodswallow, Magpie-Lark, Hooded Robin, Southern Scrub-robin, Rufous Songlark, White-backed Swallow and Tree Martin. Sixteen species were recorded at a single site only. Twenty-one species were recorded at >50% of sites, and 10 species were recorded at >80% of sites (Table 2).

Table 1

Number of bird species recorded at Mt Gibson and Karara–Lochada during the four survey periods, including opportunistic sightings.

Survey period	Mt Gibson	Karara–Lochada
June 2006	58	56
September 2006	54	40
July 2007	53	47
September/October 2007	48	67

Table 2

Frequency of occurrence of the most commonly encountered bird species in the 24 quadrats sampled at Mt Gibson and Karara–Lochada.

Species	No. of quadrats	Percent
Australian Ringneck	23	96
Crested Bellbird	23	96
Red-capped Robin	23	96
Inland Thornbill	22	92
Chestnut-rumped Thornbill	22	92
Spiny-cheeked Honeyeater	22	92
Singing Honeyeater	21	88
Grey Butcherbird	20	83
Grey Shrike-thrush	20	83
Rufous Whistler	20	83
Redthroat	19	79
Galah	18	75
Black-faced Cuckoo-shrike	17	71
Australian Raven	17	71
Common Bronzewing	17	71
White-fronted Honeyeater	17	71
Pied Butcherbird	14	58
Splendid Fairy-wren	13	54
Red-tailed Black-Cockatoo	12	50
Weebill	12	50
Yellow-throated Miner	12	50

Statistical Analyses

Bird assemblage structure was significantly different between stations, land systems and years (Table 3). There was also a significant interaction between stations and land systems. Pairwise post-hoc comparisons of stations within each land system showed that assemblages were only different in the OP and SL land systems, while comparisons of land systems within each station showed that at Mt Gibson, assemblages in OP and YS land systems were different from those in SL. At Karara–Lochada, assemblages in OP and YS were significantly different. All other pairwise comparisons were not significantly different.

Redthroats, Singing Honeyeaters, White-fronted Honeyeaters, Rufous Whistlers and Red-capped Robins were more commonly sighted at Mt Gibson, while Galahs were more common at Karara–Lochada. These six species explained 20% of the difference in assemblage structure between stations. From 2006 to 2007, there was a general increase in the sightings of Common Bronzewings, Galahs, Black-faced Cuckoo-shrikes, corvids and Red-capped Robins, and a decrease in sightings of White-fronted Honeyeaters, which together explained 25% of the difference in assemblage structure.

This is further illustrated by the separation of sites by year on the first two CAP axes (Fig. 2), which had correlations of 0.87 and 0.7, respectively, with the separation of the four station–year groups classifying 60% of the sites into their correct station–year groups. Increasing numbers of Red-capped Robins, corvids and Common Bronzewings were highly correlated with the first CAP axis, which effectively separated the two years.

The differences in species composition between land systems were considered separately at each station (Table 4). At Mt Gibson, sightings of Southern Whiteface in the SL land system separated SL assemblages from those in other land systems. At Karara–Lochada, the sightings of Splendid Fairy-wrens and Yellow-throated Miners in the OP land system differentiated OP assemblages from the

Table 3

Results of the PERMANOVA of the effect of station, land system and year on the structure of bird assemblages at Mt Gibson and Karara–Lochada.

Source	df	Mean Square	Pseudo-F	p	# permutations
Station	1	2714.5	2.1227	0.0366	4976
Landsystem	3	3786.8	2.9612	0.0002	4978
Station x landsystem	3	2260.1	1.7674	0.0142	4974
Site(Station x Landsystem)	16	1278.8			
Year	1	5867.9	5.0746	0.0002	4989
Station x year	1	2122.3	1.8354	0.0888	4986
Landsystem x year	3	1214.6	1.0504	0.3998	4968
Station x landsystem x year	3	1680.0	1.4528	0.0958	4971
Residual	16	1156.3			

Table 4

Average similarity of the assemblages within and between land systems at (a) Mt Gibson and (b) Karara–Lochada. For each pairwise comparison, the species contributing the most to the **similarity** of sites within land systems (diagonal) or the **differentiation** of sites between land systems (off-diagonal) are given. Species in bold indicate they are at a greater abundance in the land system heading the column.

a) Mt Gibson

	GR	YS	OP	SL
GR	50.5% Australian Ringneck Crested Bellbird			
YS	47.63%s Common Bronzewing Weebill	44.5% Australian Ringneck Crested Bellbird		
OP	36.4% Weebill Black-faced Cuckoo-shrike	42.6% **Common Bronzewing** Grey Butcherbird	48.1% Australian Ringneck Crested Bellbird	
SL	50.1% Pied Butcherbird Southern Whiteface	45.7% Pied Butcherbird Southern Whiteface	48.6% **Weebill** White-fronted Honeyeater	68.9% Australian Ringneck Inland Thornbill

b) Karara-Lochada

	GR	YS	OP	SL
GR	39.3% Chestnut-rumped Thornbill Spiny-cheeked Honeyeater			
YS	45.1% **White-browed Babbler** Grey Butcherbird	52.4% Chestnut-rumped Thornbill Crested Bellbird		
OP	46.0% Splendid Fairy-wren Yellow-throated Miner	53.1% Splendid Fairy-wren Yellow-throated Miner	60.4% Australian Ringneck Inland Thornbill	
SL	29.5% **Chestnut-rumped Thornbill** **White-browed Babbler**	35.0% **Redthroat** **Rufous Whistler** **Grey Shrike-thrush**	35.4% **Splendid Fairy-wren** **Redthroat**	34.8% Red-tailed Black-Cockatoo Australian Ringneck

other three, while Redthroats and Grey Shrike-thrush in the YS land system differentiated it from the SL land system.

These results suggest very specific patterns of station by land system assemblages, rather than general land system assemblages consistent across stations. Despite this, CAP analyses did not result in clear separation of station – land system groups (Fig. 3), classifying only 45% of sites into their correct groupings, even though correlations between the first two CAP axes and the separation were strong (0.87 and 0.83, respectively).

Opportunistic Sightings

An additional 17 bird species were recorded during the survey period as opportunistic sightings away from the 24 survey quadrats within the Mt Gibson and Karara–Lochada Pastoral Stations (Appendix 1).

Some bird species were found within particular landsystem types:

1 Joseph—Emu, Malleefowl, Wedge-tailed Eagle, Brown Falcon, Splendid Fairy-wren, White-fronted Honeyeater, Black-faced Woodswallow, White-

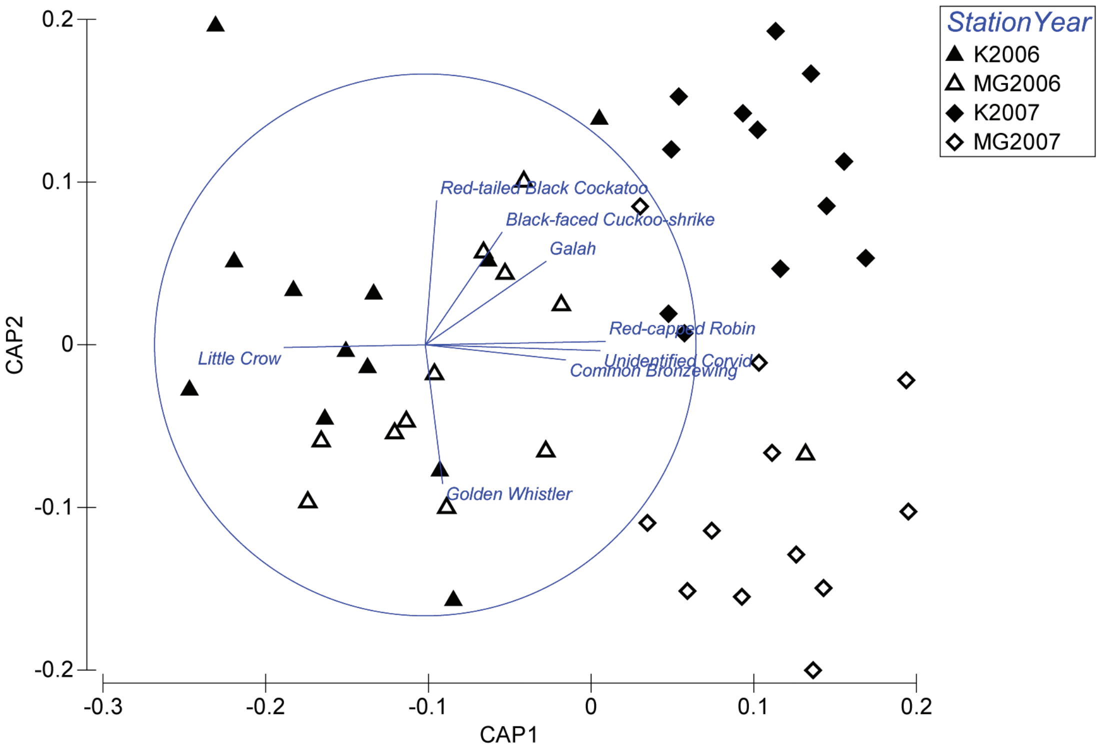

Figure 2. Separation of sites by station and year by Canonical Analysis of Principal Coordinates. Vectors show the direction of the contribution of some of the species with the highest Spearman rank correlations to the CAP axes. MG: Mt Gibson, KL: Karara–Lochada Pastoral Stations.

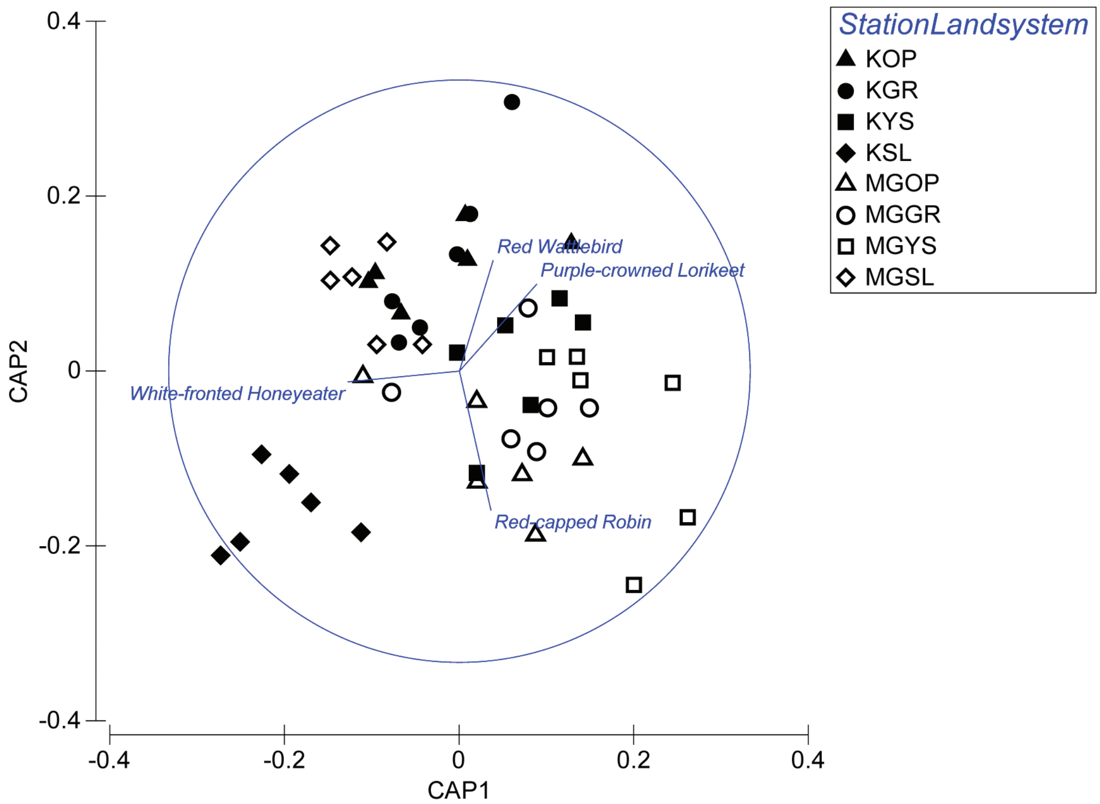

Figure 3. Separation of sites by station and land system by Canonical Analysis of Principal Coordinates. Vectors show the direction of the contribution of some of the species with the highest Spearman rank correlations with the CAP axes. MG: Mt Gibson, KL: Karara–Lochada Pastoral Stations; GR: Euchre, OP: Pindar, SL: Carnegie, YS: Joseph land systems.

backed Swallow (nesting in a disused yellow sand pit).

2 Pindar—Emu, Malleefowl, Wedge-tailed Eagle, Brown Falcon, Red-tailed Black-Cockatoo, Galah, Western Corella, Purple-crowned Lorikeet, Regent Parrot, Australian Ringneck, Mulga Parrot, Weebill, Chestnut-rumped Thornbill, Striated Pardalote, White-browed Babbler, Crested Bellbird, Black-faced Wood Swallow, Willie Wagtail, Black-faced Cuckoo-shrike, Tree Martin.

3 Euchre—Emu, Malleefowl, Common Bronzewing, Splendid Fairy-wren, Weebill, Yellow-rumped Thornbill, Chestnut Quail-thrush, Grey Shrike-thrush, Crested Bellbird, Red-capped Robin.

4 Carnegie—Emu, Splendid Fairy-wren, White-winged Fairy-wren.

A number of species were found nesting around the homesteads and associated buildings, including Crested Pigeon, Banded Lapwing, Galah, Australian Ringneck, Welcome Swallow and Zebra Finch.

DISCUSSION

Bird Assemblages of Mt Gibson and Karara–Lochada

The Mt Gibson and Karara–Lochada region possess elements of both the South West and Eremaean Botanical Provinces, with a blend of south-west and arid zone vegetation assemblages characteristic of the Yalgoo, Avon Wheatbelt and Murchison IBRA bioregions, and their associated faunal species.

Ninety-four species of bird were recorded at Mt Gibson Wildlife Sanctuary and Karara–Lochada Pastoral Stations in 2006 and 2007 over four survey periods during winter and spring. The most common and widespread species were the Australian Ringneck, Chestnut-rumped Thornbill, Inland Thornbill, Singing Honeyeater, Spiny-cheeked Honeyeater, Grey Shrike-thrush, Crested Bellbird, Grey Butcherbird and Red-capped Robin. The species are common throughout the southern rangelands and northern wheatbelt regions. A previous survey of vacant crown land at White Wells immediately to the south-west of Mt Gibson recorded 60 bird species (26 non-passerines, 34 passerines; Burbidge et al. 1989), 56 of which were recorded in this study.

The area is an important repository for a number of threatened bird species or species suffering some impact and formerly widely distributed across southern Western Australia, but now uncommon or confined to remnant areas of wheatbelt *Eucalyptus* woodland (Barrett et al. 2003). These species recorded during the surveys included Malleefowl, Square-tailed Kite, Peregrine Falcon, Shy Heathwren, Redthroat, Chestnut Quail-thrush and Hooded Robin.

Equally significant as nesting areas was the importance of species' requirements in a variety of landforms to suit individual needs. For example, members of the Psittaciformes (parrot families) were observed flying from nesting sites within *Eucalyptus* woodland to feed in the other three landform systems sampled during the study. The Salmon gum and York gum woodlands were particularly important areas for many hollow-nesting birds, such as Red-tailed Black-Cockatoo, Major Mitchell's Cockatoo, Galah, Western and Little Corellas, Cockatiel, Purple-crowned Lorikeet (during periods when *Eucalyptus* were flowering only), Regent Parrot, Australian Ringneck and Mulga Parrot. Elegant Parrots were sighted after the surveys on Karara Station; they may also have been using the woodland areas (Burbidge et al. 1989). Many of these species have declined in abundance through vegetation clearing in the wheatbelt and habitat degradation (Barrett et al. 2003; Saunders et al. 1985; Saunders & Ingram 1995).

Land System Bird Associations

There were no obvious patterns in bird assemblages across land systems and stations. Specific bird assemblages were associated with land system types at Mt Gibson and Karara–Lochada, however the delineation of these assemblages was not clear with the two years of presence/absence data collected. Redthroats, Singing Honeyeaters, White-fronted Honeyeaters, Rufous Whistlers and Red-capped Robins were more commonly sighted at Mt Gibson, while Galahs were more common at Karara–Lochada. Karara–Lochada has a more recent and intensive pastoral history than Mt Gibson and Galahs are recognized as a disturbance specialist.

Changes between Years

Between years, there was a general increase in the sightings of Common Bronzewings, Galahs, Black-faced Cuckoo-shrikes, corvids and Red-capped Robins, and a decrease in sightings of White-fronted Honeyeaters. Reasons for this increase are unclear.

CONCLUSIONS

The survey of bird species presence at Mt Gibson Wildlife Sanctuary and Karara–Lochada Pastoral Stations over a period of two years in two seasons has provided information of the bird assemblages present in the semi-arid *Eucalyptus* woodlands and *Acacia* shrublands of the northern wheatbelt and southern rangelands of Western Australia. Additional data will become available over the next few years as Birds Australia (Western Australia) will continue the bird surveys on Mt Gibson Wildlife Sanctuary.

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REFERENCES

Anderson MJ, Willis TJ (2003) Canonical analysis of principle coordinates: a useful method of constrained ordination for ecology. *Ecology* **84**, 511–525.

Anderson MJ, Gorley RN, Clarke KR (2008) *PERMANOVA + for PRIMER: Guide to Software and Statistical Methods*. PRIMER-E, Plymouth, UK.

Barrett GW, Silcocks A, Barry S, Cunningham R, Poulter R (2003) *The New Atlas of Australian Birds.* Birds Australia, Hawthorn East, Victoria.

Beard JS (1976) *The Vegetation of the Perenjori Area, Western Australia : Map and Explanatory Memoir 1:250,000 Series*. Vegmap Publications, Perth.

Burbidge AA, Dixon, KW, Fuller PJ (1989) *The Flora and Fauna of Vacant Crown Land at White Well, Shire of Dalwallinu, Western Australia*. Technical Report No 24. Department of Conservation and Land Management.

Burbidge AH, Fuller PJ, McKenzie NL (1995) Vertebrate fauna. In *The Biological Survey of the Eastern Goldfields of Western Australia. Part 12. Barlee–Menzies Study Area* (eds GJ Keighery, NL McKenzie, NJ Hall). *Records of the Western Australian Museum* Supplement **49**, 208–245.

Burbidge AH, Johnstone RE, Fuller PJ, Stone P (2000) Terrestrial birds of the southern Carnarvon Basin, Western Australia: contemporary patterns of occurrence. *Records of the Western Australian Museum* Supplement **61,** 449–464.

Christidis L, Boles WE (2008) *Systematics and Taxonomy of Australian Birds*. CSIRO Publishing, Collingwood, Victoria.

Dell J, Chapman A, Kitchener DJ, Muir BG (1979) Biological Survey of the Western Australian Wheatbelt. Part 9: Marchagee Nature Reserve. *Records of the Western Australian Museum* Supplement **8**, 50 pp.

Department of Agriculture and Food Western Australia (1990). *Soil – Land Systems of the South West of Western Australia*. Department of Agriculture and Food Western Australia, Perth.

Kitchener DJ, Chapman A, Dell J, Muir BG (1979) Biological Survey of the Western Australian Wheatbelt. Part 10: Buntine, Nugadong, and East Nugadong Nature Reserves and Nugadong Forest Reserve. *Records of the Western Australian Museum* Supplement **9**, 127 pp.

McKenzie NL, May JE (2003) *A Biodiversity Audit of Western Australia's Biogeographical Subregions in 2002*. Department of Conservation and Land Management, Perth, Western Australia.

Richards J, Algar D (2008) Controlling feral animals in the rangelands. *Landscope* **23**, 52–58.

Saunders DA, Ingram JA (1995) *Birds of Southwestern Australia: An Atlas of Changes in the Distribution and Abundance of Wheatbelt Avifauna.* Surrey Beatty and Sons, Chipping Norton, NSW.

Saunders DA, Rowley I, Smith GT (1985) The effects of clearing for agriculture on the distribution of cockatoos in the south-west of Western Australia. In *Birds of Eucalypt Forests and Woodlands: Ecology, Conservation, Management* (eds A Keast, H Recher, H Ford, D Saunders), pp 309–321. Surrey Beatty and Sons, Sydney.

Van Vreeswyk AME, Godden PT (1998) *Pastoral Resources and their Management in the Sandstone – Yalgoo – Paynes Find Area, Western Australia*. Agriculture Western Australia, Perth.

APPENDIX 1

List of bird species recorded at Mt Gibson Wildlife Sanctuary and Karara–Lochada Pastoral Stations in 2006 and 2007. OP = opportunistic sighting.

Common Name	Scientific Name	Karara–Lochada													Mt Gibson												
		Open Plain			Granite			Yellow Sand			Salt Lake				Open Plain			Granite			Yellow Sand			Salt Lake			
		1	2	3	1	2	3	1	2	3	1	2	3	OP.	1	2	3	1	2	3	1	2	3	1	2	3	OP
Emu	*Dromaius novaehollandiae*	x				x		x				x	x	x		x	x					x		x		x	x
Malleefowl	*Leipoa ocellata*													x					x				x				x
Australian Shelduck	*Tadorna tadornoides*													x													
Australian Wood Duck	*Chenonetta jubata*																										x
Common Bronzewing	*Phaps chalcoptera*	x			x	x	x			x				x						x	x	x	x	x	x	x	x
Crested Pigeon	*Ocyphaps lophotes*										x	x		x	x									x	x	x	x
Spotted Nightjar	*Eurostopodus argus*													x				x									
Australian Owlet-nightjar	*Aegotheles cristatus*													x													x
Square-tailed Kite	*Lophoictinia isura*													x					x		x			x			x
Brown Goshawk	*Accipiter fasciatus*													x												x	
Collared Sparrowhawk	*Accipiter cirrocephalus*												x								x						
Wedge-tailed Eagle	*Aquila audax*	x												x					x			x					x
Nankeen Kestrel	*Falco cenchroides*													x													
Brown Falcon	*Falco berigora*								x					x		x			x								x
Australian Hobby	*Falco longipennis*															x											
Peregrine Falcon	*Falco peregrinus*													x													
Banded Lapwing	*Vanellus tricolor*													x													
Australian Bustard	*Ardeotis australis*													x													
Painted Button-quail	*Turnix varius*																										x
Red-tailed Black-Cockatoo	*Calyptorhynchus banksii*	x	x	x					x	x	x	x	x	x	x	x	x							x			x
Major Mitchell's Cockatoo	*Lophochroa leadbeateri*						x							x		x	x	x									x
Galah	*Eolophus roseicapillus*	x	x	x	x			x	x	x	x	x	x	x	x	x	x		x				x	x	x	x	x
Western Corella	*Cacatua pastinator*														x									x			x
Little Corella	*Cacatua sanguinea*						x							x													
Cockatiel	*Nymphicus hollandicus*														x												
Purple-crowned Lorikeet	*Glossopsitta porphyrocephala*	x	x											x		x	x										x
Regent Parrot	*Polytelis anthopeplus*	x								x				x		x	x				x		x			x	x
Australian Ringneck	*Barnardius zonarius*	x	x	x		x		x	x		x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Mulga Parrot	*Psephotus varius*	x	x			x	x	x						x													x
Bourke's Parrot	*Neopsephotus bourkii*					x								x													x
Horsfield's Bronze-Cuckoo	*Chalcites basalis*									x				x		x											

Appendix 1 (cont.)

Common Name	Scientific Name	Karara–Lochada Open Plain			Karara–Lochada Granite			Karara–Lochada Yellow Sand			Karara–Lochada Salt Lake			Karara–Lochada	Mt Gibson Open Plain			Mt Gibson Granite			Mt Gibson Yellow Sand			Mt Gibson Salt Lake			Mt Gibson
		1	2	3	1	2	3	1	2	3	1	2	3	OP.	1	2	3	1	2	3	1	2	3	1	2	3	OP
Black-eared Cuckoo	*Chalcites osculans*													x		x											
Fan-tailed Cuckoo	*Cacomantis flabelliformis*													x													
Pallid Cuckoo	*Cacomantis pallidus*	x	x																								
Southern Boobook	*Ninox novaeseelandiae*													x													
Rainbow Bee-eater	*Merops ornatus*														x							x					
Rufous Treecreeper	*Climacteris rufa*													x													x
Splendid Fairy-wren	*Malurus splendens*	x	x	x	x				x					x		x			x	x	x		x	x	x	x	x
White-winged Fairy-wren	*Malurus leucopterus*									x	x	x	x														x
Shy Heathwren	*Calamanthus cautus*			x	x											x								x			
Redthroat	*Pyrrholaemus brunneus*	x	x	x	x	x	x		x	x				x	x		x		x	x	x		x	x	x		
Weebill	*Smicrornis brevirostris*		x	x	x				x	x				x	x	x	x			x	x	x	x				x
Western Gerygone	*Gerygone fusca*		x					x	x					x		x						x	x				
Slaty-backed Thornbill	*Acanthiza robustirostris*																										x
Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*							x			x			x	x	x						x			x	x	x
Chestnut-rumped Thornbill	*Acanthiza uropygialis*	x	x	x	x	x	x	x	x	x	x		x	x		x	x		x	x	x	x	x	x	x	x	x
Inland Thornbill	*Acanthiza apicalis*	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Southern Whiteface	*Aphelocephala leucopsis*	x	x	x	x		x				x		x	x		x								x	x	x	x
Spotted Pardalote	*Pardalotus punctatus*								x					x		x	x			x							x
Striated Pardalote	*Pardalotus striatus*	x						x						x		x	x				x						x
Singing Honeyeater	*Lichenostomus virescens*		x	x	x		x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
White-eared Honeyeater	*Lichenostomus leucotis*														x	x	x	x		x	x						
Yellow-plumed Honeyeater	*Lichenostomus ornatus*													x													x
Grey-fronted Honeyeater	*Lichenostomus plumulus*												x														x
White-fronted Honeyeater	*Purnella albifrons*	x	x			x		x		x		x	x	x		x		x	x	x	x		x	x	x	x	x
Yellow-throated Miner	*Manorina flavigula*	x	x	x	x			x	x		x			x		x	x			x	x			x			x
Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x
Red Wattlebird	*Anthochaera carunculata*	x	x					x		x	x		x	x		x	x										x
Crimson Chat	*Epthianura tricolor*													x													
Brown Honeyeater	*Lichmera indistincta*				x									x		x							x	x	x	x	x
Brown-headed Honeyeater	*Melithreptus brevirostris*														x					x		x					x
White-browed Babbler	*Pomatostomus superciliosus*		x	x		x	x							x							x			x			x
Chestnut Quail-thrush	*Cinclosoma castanotum*				x				x					x					x								x
Varied Sittella	*Daphoenositta chrysoptera*													x													
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x				x		x		x	

White-winged Triller	*Lalage sueurii*	x			x									x		x				x		x					x
Golden Whistler	*Pachycephala pectoralis*		x						x						x		x	x		x	x	x					
Rufous Whistler	*Pachycephala rufiventris*	x	x		x	x	x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x	x	x
Grey Shrike-thrush	*Colluricincla harmonica*		x	x		x		x	x	x			x	x	x	x	x	x	x	x	x	x		x	x		x
Crested Bellbird	*Oreoica gutturalis*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Black-faced Woodswallow	*Artamus cinereus*													x			x										x
Dusky Woodswallow	*Artamus cyanopterus*																										x
Grey Butcherbird	*Cracticus torquatus*	x	x	x	x			x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Pied Butcherbird	*Cracticus nigrogularis*	x			x		x	x	x		x	x		x		x						x		x	x	x	x
Australian Magpie	*Cracticus tibicen*	x					x	x			x		x	x		x				x				x		x	x
Grey Currawong	*Strepera versicolor*				x			x	x					x	x	x	x			x			x			x	x
Grey Fantail	*Rhipidura albiscapa*	x		x						x				x	x	x	x	x		x	x	x					x
Willie Wagtail	*Rhipidura leucophrys*				x					x			x	x						x		x	x	x	x	x	x
Australian Raven	*Corvus coronoides*	x	x				x	x		x	x		x	x			x	x				x	x	x			x
Little Crow	*Corvus bennetti*			x	x					x	x			x		x	x			x				x	x		
Torresian Crow	*Corvus orru*							x						x													
Magpie-lark	*Grallina cyanoleuca*													x							x					x	x
Jacky Winter	*Microeca fascinans*		x						x				x	x		x	x							x			x
Red-capped Robin	*Petroica goodenovii*		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Hooded Robin	*Melanodryas cucullata*																			x							
Western Yellow Robin	*Eopsaltria griseogularis*													x					x		x						x
Southern Scrub-robin	*Drymodes brunneopygia*																					x					
Rufous Songlark	*Cincloramphus mathewsi*													x													
White-backed Swallow	*Cheramoeca leucosterna*																						x				x
Welcome Swallow	*Hirundo neoxena*						x		x					x													x
Fairy Martin	*Petrochelidon ariel*													x													x
Tree Martin	*Petrochelidon nigricans*													x							x						x
Zebra Finch	*Taeniopygia guttata*													x													x
Australasian Pipit	*Anthus novaeseelandiae*										x	x		x													x

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A survey of ground-dwelling invertebrates from Mount Gibson Wildlife Sanctuary and Karara–Lochada Pastoral Stations

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ABSTRACT

As part of a broader project to investigate baiting techniques for the control of feral cats and foxes in the southern rangelands of Western Australia, the abundance of their prey items (small mammals, reptiles, birds and invertebrates) was monitored at the two study sites of Mt Gibson Wildlife Sanctuary and Karara–Lochada Pastoral Stations. The two sites are located in the semi-arid *Eucalyptus* woodlands and *Acacia* shrublands within the Avon-Wheatbelt and Yalgoo bioregions of Western Australia. The aim of this sub-project was to evaluate the potential available invertebrate prey species, as invertebrates are known to be part of the diet of cats and foxes, depending on availability of other prey types. Approximately 200 ground-dwelling invertebrate species were collected, however, limited conclusions about distribution across the landscape and between sampling periods could be drawn as the majority of all individuals collected were juveniles. Exceptions were ants, beetles and Araneomorph spiders; the majority of these collected were adults. Immature crickets were collected at 22 of the 24 quadrats and were the most common taxon encountered along with *Iridomyrmex chasei* (Formicidae). A total of 57 species from 13 genera of ants, 71 species representing 18 spider families and 49 species from at least 12 beetle families were recorded in 24 quadrats within four land system types represented at each of the study sites. It was important to document the ground invertebrate fauna as part of the prey resource and it also provides the beginnings of a ground invertebrate species list for the two properties that may be expanded during future survey work. The sampling period for invertebrate collection was restricted to the same time-frame used to survey small mammals, reptiles and birds, in order to provide a snapshot of the prey resource over this same period. The short duration of this trapping period, however, resulted in an insufficient sampling of the resident ground invertebrates for a quantifying analysis of the invertebrates collected during the survey.

Keywords: Arachnida, Coleoptera, Formicidae, ground invertebrate assemblage, rangelands, semi-arid woodlands.

INTRODUCTION

The Department of Environment and Conservation (DEC) and the Australian Wildlife Conservancy (AWC), in partnership with the Invasive Animals Co-operative Research Centre (IA CRC), commenced a project in 2006 to investigate techniques for the sustained control of introduced predators in the semi-arid *Eucalyptus* woodlands and *Acacia* shrubland sandplains of the semi-arid southern rangelands of Western Australia (Richards & Algar 2008). At the treatment site, AWC's Mt Gibson Wildlife Sanctuary, a strategy for the control of introduced predators was implemented. At the control site nearby, DEC's Karara-Lochada Pastoral Stations, which has a similar suite of land system types, introduced predators were not controlled.

The broader project to control introduced predators (cats *Felis catus* and foxes *Vulpes vulpes*), and monitor the abundance of their normal prey items (small mammals, reptiles, and birds) at the two stations, also presented an opportunity to document the ground invertebrate fauna active during the same period. Other results of the broader project will be reported elsewhere, including papers within the same volume of this journal.

Knowledge of the ground invertebrate fauna in the region is limited but assemblages have been documented for some surrounding areas (Abensperg-Traun 1996; Carnarvon Basin: Harvey et al. 2000; Wheatbelt: Durrant 2004; Guthrie & Waldock 2004; Harvey et al. 2004; and unpublished records, WA Museum). In this paper we document the ground invertebrate species assemblages in 24 quadrats at the two study sites.

METHODS

Mt Gibson Wildlife Sanctuary Study Site

Mt Gibson Wildlife Sanctuary is located at 29° 36' S, 117° 24' E and covers an area of 130,500 ha straddling the boundary between the South-West and Eremaean Botanical Provinces. The area has a semi-arid climate with hot dry summers and mild wet winters. Summer temperatures range from 19–36 °C, and winter temperatures range from 6–18 °C. There are typically 9–11 months of dry weather, with an annual rainfall of 343 mm (Bureau of Meteorology records 1983 to 2007), which arrives as gentle soaking rains and thundery showers in winter or in summer as occasional tropical cyclones or rain bearing depressions. Evapotranspiration rates are considerably higher than rainfall, with the annual average for the Paynes Find region being 2,480 mm.

Mt Gibson Wildlife Sanctuary is characterized by mixed *Acacia* shrublands on sandplain and York gum (*Eucalyptus loxophleba*), Salmon gum (*E. salmonophloia*) and Gimlet (*E. salubris*) woodlands. The sanctuary contains 13 vegetation associations (Beard 1976). The dominant landforms are greenstone ranges in the north-east and banded ironstone formations to the north-west. Granites and gneisses of the Yilgarn Block underlie much of the area and outcrop as domes or breakaways (McKenzie & May 2003). The ranges are separated by gently sloping pediments and flood plains upslope from salt lakes and clay pans (McKenzie & May 2003). Sandplains occur extensively to the south. Drainage is internal and disorganized and an extensive salt lake, Lake Moore, bounds Mt Gibson Wildlife Sanctuary to the east. Mt Gibson Pastoral Lease was acquired by AWC in 2001 and subsequently destocked, removing most sheep (*Ovis aries*) and goats (*Capra hircus*).

Karara–Lochada Study Site

Karara (29° 14' S, 116° 43' E) and Lochada (29° 12' S, 116° 33' E) are adjacent, reclaimed pastoral leases, purchased for the creation of conservation reserves, and managed by DEC. The site is located 86 km north-west of Mt Gibson Wildlife Sanctuary, and the two leases cover an area of 109,300 and 114,600 ha respectively. The average annual rainfall recorded for Karara is 312.3 mm (Bureau of Meteorology, based on records 1928–1939 and 1992–2008) and for Lochada is 327 mm (Bureau of Meteorology, based on records 1911–1939).

The climate, landforms, land systems and vegetation associations within the Karara–Lochada Pastoral Leases are similar to those found on Mt Gibson. Karara–Lochada also lies on the interface between the South West Botanical Province and the Eremaean Botanical Province, and mainly lies within the Yalgoo bioregion. There are at least 14 land types (Van Vreeswyk & Godden 1998) and 14 vegetation types (Beard 1976) on Karara–Lochada. The area is characterized by mixed *Acacia* shrublands on sandplain and sparse York gum woodlands. The stations lie within the Yilgarn Craton and across the boundaries of the Murchison Plateau and the Salinaland Plateau, with frequent granite rises and low domes. Lochada Pastoral Station was purchased by DEC in 2000 and Karara Pastoral Station in 2002 and both were subsequently destocked for conservation purposes.

Invertebrate Surveys

Twelve quadrats were selected at each site within four habitat or 'land system' types (Department of Agriculture and Food Western Australia; DAFWA 1990) characteristic of both Karara–Lochada and Mount Gibson: 1) Joseph—undulating yellow sandplains supporting dense mixed *Acacia* shrublands; 2) Pindar—red loamy sandplain supporting *Eucalyptus* woodlands and *Acacia* shrublands; 3) Euchre—low granite breakaways with alluvial plains and sandy tracts supporting *Eucalyptus* woodlands and *Acacia* shrublands with patchy mallees on granitic breakaways; and 4) Carnegie—salt lakes with fringing saline plains, dunes and sandy banks. Each quadrat was 50 x 50 m, at least 0.5 km apart and adjacent to vehicle tracks for easy access.

Ground invertebrate surveys were conducted twice each year, over five consecutive days, for two years in each of the 24 quadrats: in winter (20–24 June 2006, 11–15 July 2007 at Mt Gibson and 26–30 June 2006, 6–10 July 2007 at Karara-Lochada), just prior to predator baiting to assess potential ground invertebrate abundance at its lowest; and in spring (25–29 September 2006, 3–7 October 2007 at Mt Gibson and 19–23 September 2006, 23–27 September 2007 at Karara–Lochada), when invertebrate populations were potentially at their greatest.

Each quadrat contained five pitfall traps; one at each corner and one in the middle. Each pitfall trap consisted of a two-litre UV resistant plastic jar (80 mm neck diameter) inserted into a PVC sleeve dug into the ground, flush with the ground surface. To form a continuous surface between the ground and jar lip, an acrylic ring covered in glued sand was attached between the PVC sleeve and jar lip. Two hoop iron stands fitted between the PVC sleeve and jar supported a 200 mm x 200 mm colourbond roof approximately four centimetres above the ground surface. A mix of one litre ethylene glycol with 4% formalin was used as the preserving fluid in each pitfall trap. At the end of each five-day sampling period each pitfall trap was emptied and sealed with a lid, replaced in the PVC sleeve, ready to be reset with fresh preservative at the next sampling period. Samples were returned to the laboratory, washed in water and stored in 75% ethanol until sorting, processing and identification.

Taxonomy

Adult specimens were identified using taxonomic literature (Bänninger 1940; Heterick 2009; Matthews 1980, 1984, 1987; Matthews & Bouchard 2008; Matthews & Lawrence 2005; Roig-Juñent 2000). A morphospecies approach was adopted where confidently assigning specimens to known described or undescribed taxa was difficult and available literature insufficient (Harvey et al. 2000). Specimens from the survey were lodged with the Western Australian Museum (WAM).

RESULTS

Approximately 200 taxa from 14 orders of ground-dwelling invertebrates were collected in the survey. The majority of material across all groups were juveniles (and usually very early instars or nymph stages) and could not be identified conclusively to genus, therefore they are only identified to the ordinal level and placed into provisional morphospecies where possible. This precludes any statistical analysis comparing assemblage structure between sampling periods or between quadrats, therefore the data presented here is of inventory nature only. A list of major groups recorded is presented in Table 1 (a provisional list of identifications is available on request).

The majority of the Orthoptera appear to be early instar nymphs of one taxon, and occured in 22 of the 24 quadrats. Centipedes were recorded in 15 quadrats, only OP02 had representatives collected in three sampling periods (June 2006, Sept 2006 and Sept 2007). No centipedes were recorded in July 2007. Ten species of terrestrial Lepidoptera larvae representing various instars were collected from 11 quadrats, plus 12 species of Hemiptera, and four roach taxa (plus juveniles) were recorded from eight quadrats. All five scorpion species were recorded in either September 2006 or 2007, from separate quadrats.

The Formicidae (ants), Coleoptera (beetles) and

Table 1

All taxonomic groups recorded in the 24 quadrats across all sampling periods are presented below. Mount Gibson: GR, granite; OP, open plain; SL, salt lake; YS, yellow sand; Part A: 20–24 June 2006, 25–29 September 2006; Part B: 11–15 July 2007, 3–7 October 2007. Karara–Lochada: KGR, granite; KOP, open plain; KSL, salt lake; KYS, yellow sand; Part C: 26–30 June 2006, 19–23 September 2006; Part D: 6–10 July 2007, 23–27 September 2007. Note: "1" indicates presence of a group; "Total" refers to the number of groups present at a quadrat, and "Taxon Total" refers to the number of taxa within a group across all quadrats.

Part A

June 2006	GR01	GR02	GR03	OP01	OP02	OP03	SL01	SL02	SL03	YS01	YS02	YS03	TAXON TOTAL
Areneomorphae	0	1	0	1	0	1	0	2	0	0	2	0	**7**
Mygalomorphae	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Pseudoscorpions	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Scorpions	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Blattodea	0	0	0	0	0	0	1	0	0	0	0	0	**1**
Chilopoda	0	1	0	0	1	0	0	1	0	1	0	0	**4**
Coleoptera (adult)	0	0	0	0	1	0	0	1	0	0	2	2	**6**
Coleoptera (larvae)	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Diplopoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Formicidae	0	0	0	3	0	0	1	4	1	2	0	0	**11**
Hemiptera	0	0	0	0	0	0	3	1	0	0	0	0	**4**
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Isoptera	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Lepidoptera (larvae)	0	1	0	0	0	0	1	1	0	1	0	0	**4**
Mantodea	0	0	0	0	0	0	1	0	0	0	0	0	**1**
Orthoptera	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Phasmatoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
TOTAL	**0**	**3**	**0**	**4**	**3**	**1**	**7**	**10**	**1**	**4**	**4**	**2**	**39**

September 2006	GR01	GR02	GR03	OP01	OP02	OP03	SL01	SL02	SL03	YS01	YS02	YS03	TAXON TOTAL
Areneomorphae	3	0	1	4	5	5	2	1	1	0	9	2	**33**
Mygalomorphae	0	0	1	0	0	3	0	0	0	0	0	0	**4**
Pseudoscorpions	1	0	0	1	0	0	0	0	0	0	0	0	**2**
Scorpions	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Blattodea	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Chilopoda	0	0	0	0	1	0	0	0	1	0	0	0	**2**
Coleoptera (adult)	0	0	3	0	2	5	2	5	1	1	3	2	**24**
Coleoptera (larvae)	0	0	0	0	0	1	0	0	0	0	0	0	**1**
Diplopoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Formicidae	0	0	4	8	1	1	4	9	7	4	1	2	**41**
Hemiptera	0	0	0	0	1	0	1	2	0	0	0	0	**4**
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Isoptera	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Lepidoptera (larvae)	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Mantodea	0	0	0	0	0	0	1	0	0	0	0	0	**1**
Orthoptera	1	1	0	1	4	1	2	4	0	0	0	0	**14**
Phasmatoda	0	1	0	0	0	0	0	0	0	0	0	0	**1**
TOTAL	**5**	**2**	**9**	**14**	**16**	**16**	**12**	**21**	**10**	**5**	**13**	**6**	**129**

Table 1 (cont.)

Part B

July 2007	**GR01**	**GR02**	**GR03**	**OP01**	**OP02**	**OP03**	**SL01**	**SL02**	**SL03**	**YS01**	**YS02**	**YS03**	**TAXON TOTAL**
Areneomorphae	0	0	3	2	2	7	1	1	1	0	1	1	**19**
Mygalomorphae	0	0	1	1	0	0	0	0	0	1	0	0	**3**
Pseudoscorpions	0	0	1	0	0	1	0	0	0	0	0	0	**2**
Scorpions	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Blattodea	0	0	0	1	0	0	2	0	0	0	0	0	**3**
Chilopoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Coleoptera (adult)	2	3	1	0	0	3	0	2	0	0	5	1	**17**
Coleoptera (larvae)	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Diplopoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Formicidae	5	1	4	6	1	7	7	4	10	1	0	2	**47**
Hemiptera	0	0	1	0	0	1	0	0	2	0	0	0	**4**
Isopoda	0	0	0	0	0	0	1	0	0	0	0	0	**1**
Isoptera	0	0	0	1	0	0	0	0	0	0	1	0	**2**
Lepidoptera (larvae)	0	0	0	0	0	2	0	0	0	1	0	0	**3**
Mantodea	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Orthoptera	0	0	0	1	0	2	0	0	1	0	0	0	**4**
Phasmatoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
TOTAL	**7**	**4**	**11**	**12**	**3**	**23**	**11**	**7**	**14**	**2**	**7**	**4**	**105**

October 2007	**GR01**	**GR02**	**GR03**	**OP01**	**OP02**	**OP03**	**SL01**	**SL02**	**SL03**	**YS01**	**YS02**	**YS03**	**TAXON TOTAL**
Areneomorphae	4	1	3	1	2	4	1	3	1	1	9	2	**32**
Mygalomorphae	0	0	1	0	0	0	0	0	0	0	2	0	**3**
Pseudoscorpions	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Scorpions	0	0	0	0	0	0	1	0	0	0	0	1	**2**
Blattodea	3	0	0	0	0	0	0	0	1	0	0	2	**6**
Chilopoda	0	0	2	0	1	0	1	0	0	0	0	2	**6**
Coleoptera (adult)	5	8	2	0	2	1	2	2	1	1	2	4	**30**
Coleoptera (larvae)	0	0	0	0	0	0	0	0	1	0	0	0	**1**
Diplopoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Formicidae	8	5	3	7	4	0	5	2	7	2	0	1	**44**
Hemiptera	2	1	2	3	2	3	0	3	2	1	2	1	**22**
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Isoptera	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Lepidoptera (larvae)	1	1	0	0	0	0	0	0	0	0	0	0	**2**
Mantodea	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Orthoptera	5	3	1	3	4	3	2	0	0	3	0	1	**25**
Phasmatoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
TOTAL	**28**	**19**	**14**	**14**	**15**	**11**	**12**	**10**	**13**	**8**	**15**	**15**	**174**

Araneae (spiders) were the only groups conclusively identified and 175 taxa were recorded from the two sites (57 species from 13 genera of ants, 71 species representing 18 spider families and 49 species from at least 12 beetle families). From these three groups only, site richness varied from two to 35 species (KGR03 and YS02 respectively) with an average of 16.6 species, (s.d. ± 8.1; n = 24 quadrats). One hundred species or 57% of the fauna were recorded at one site only. The most common species encountered were *Iridomyrmex chasei* (Formicidae), present in 22 quadrats, the spider taxon Molycriinae sp.2, present in 10 quadrats, and *Carenum* sp.3 (Carabidae, Coleoptera) present in eight quadrats. The genera represented by the most species were the ant genera *Iridomyrmex*, *Camponotus*, *Crematogaster*, *Monomorium* and *Pheidole* (fifteen, eight, six and six species respectively) and the beetle genus *Carenum* with seven species.

DISCUSSION

The aim of this study was to evaluate the potential ground invertebrate prey species for feral cats and foxes at Mt Gibson Wildlife Sanctuary and Karara–Lochada Pastoral Stations. Invertebrates are known to be part of the diet of both species (Triggs et al. 1984), depending on availability of other prey types. Catling (1988) found that when rabbits were absent foxes preyed extensively on invertebrates, and they can become locally important for feral cats when other prey types become scarce (Paltridge et al. 1997). Generally it appears that both predators take more invertebrates during the warmer months (Triggs et al. 1984; Catling 1988; Paltridge et al. 1997) and more often as juveniles rather than adults (Catling 1988). Invertebrate groups found to be targeted as major food sources during summer and autumn by foxes are Orthoptera, Blattodea, Lepidoptera, and both adult and larval Coleoptera, especially scarab beetles (McIntosh

Table 1 (cont.)

Part C

June 2006	**KGR01**	**KGR02**	**KGR03**	**KOP01**	**KOP02**	**KOP03**	**KSL01**	**KSL02**	**KSL03**	**KYS01**	**KYS02**	**KYS03**	**TAXON TOTAL**
Areneomorphae	0	1	0	3	1	0	0	1	2	0	0	0	**8**
Mygalomorphae	1	2	0	2	2	0	1	3	1	0	0	0	**12**
Pseudoscorpions	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Scorpions	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Blattodea	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Chilopoda	1	1	0	1	0	0	0	1	1	1	0	0	**6**
Coleoptera (adult)	1	1	0	1	0	0	0	0	0	0	1	1	**5**
Coleoptera (larvae)	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Diplopoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Formicidae	0	2	0	5	2	0	3	3	1	0	2	0	**18**
Hemiptera	1	1	0	1	1	0	0	1	0	0	0	0	**5**
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Isoptera	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Lepidoptera (larvae)	0	0	0	0	1	0	1	0	0	1	0	0	**3**
Mantodea	0	1	0	0	0	0	0	0	0	0	0	0	**1**
Orthoptera	0	0	0	1	2	0	0	0	0	0	0	0	**3**
Phasmatoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
TOTAL	**4**	**9**	**0**	**14**	**9**	**0**	**5**	**9**	**5**	**2**	**3**	**1**	**61**

September 2006	**KGR01**	**KGR02**	**KGR03**	**KOP01**	**KOP02**	**KOP03**	**KSL01**	**KSL02**	**KSL03**	**KYS01**	**KYS02**	**KYS03**	**TAXON TOTAL**
Areneomorphae	1	4	2	1	1	0	3	1	3	11	0	1	**28**
Mygalomorphae	0	2	1	0	1	0	0	0	0	8	0	0	**12**
Pseudoscorpions	0	0	0	1	0	0	0	0	0	0	0	0	**1**
Scorpions	0	0	1	0	0	0	0	0	0	0	0	1	**2**
Blattodea	0	0	0	0	1	0	0	0	0	1	0	0	**2**
Chilopoda	0	1	0	0	1	0	0	0	0	2	0	0	**4**
Coleoptera (adult)	0	6	0	0	5	0	0	0	3	4	2	0	**20**
Coleoptera (larvae)	0	1	0	0	0	0	0	0	0	0	0	0	**1**
Diplopoda	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Formicidae	4	0	0	5	3	0	2	2	3	3	4	8	**34**
Hemiptera	0	0	0	0	0	0	1	0	0	1	0	1	**3**
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Isoptera	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Lepidoptera (larvae)	0	0	0	0	0	0	0	0	1	2	0	0	**3**
Mantodea	1	0	0	0	0	0	0	1	0	0	0	0	**2**
Orthoptera	1	0	0	3	0	0	4	3	3	1	3	4	**22**
Phasmatoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
TOTAL	**7**	**14**	**4**	**10**	**13**	**0**	**10**	**7**	**13**	**33**	**9**	**15**	**135**

1963; Martensz 1971; Coman 1973; Ryan & Croft 1974; Catling 1988; Griffin 1990). McIntosh (1963) found that centipedes and to a lesser extent, scorpions and spiders were also consumed. A study on foxes from the Dandarragan Plain found they were concentrating on beetles during spring and autumn (Griffin 1990).

The sampling period for invertebrates was restricted to the same time-frame used to survey small mammals, reptiles and birds (Richards et al. 2011a, 2011b), to provide a snapshot of the potential ground invertebrate resource at this time. The short duration of this trapping period resulted in an insufficient sampling of the resident ground invertebrates and therefore has prevented a quantifying analysis of the invertebrates collected during the survey. Harvey et al. (2004) sampled for 12 months and collected an average of 21.9 spider species per site (s.d. = 8.3) across the wheatbelt, compared with an average of 5.4 spider species (s.d. = 4.5) per quadrat over five days in this survey. The number of ant genera expected in the northern wheatbelt is 31 to 40 (Heterick 2009; Shattuck 1999), however only 13 ant genera were collected. There were also strong indications that the beetle fauna was highly under-represented in the survey (author's unpublished data).

Of the invertebrate groups recorded, few have the potential as food items for either foxes or cats. The taxa recorded in this survey that have the potential to be at risk from predation by cats or foxes are adult centipedes, *Urodachus* scorpions, the larger spiders (Mygalomorphinae, Lycosidae, Miturgidae and Sparassidae), larvae of Lepidoptera and Coleoptera, and Orthoptera. However, due to the short duration of the trapping period, little can be concluded from this survey in regards to evidence of either predator affecting current populations of these invertebrate groups. Trapping success can be affected by year to year population variation, weather conditions, individual species trappability and length of sampling period, however, the invertebrates collected in this survey

Table 1 (cont.)

Part D

July 2007	KGR01	KGR02	KGR03	KOP01	KOP02	KOP03	KSL01	KSL02	KSL03	KYS01	KYS02	KYS03	TAXON TOTAL
Areneomorphae	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Mygalomorphae	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Pseudoscorpions	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Scorpions	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Blattodea	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Chilopoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Coleoptera (adult)	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Coleoptera (larvae)	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Diplopoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Formicidae	0	0	0	0	2	0	0	0	0	0	0	0	**2**
Hemiptera	0	0	1	0	0	0	0	0	0	0	0	0	**1**
Isopoda	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Isoptera	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Lepidoptera (larvae)	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Mantodea	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Orthoptera	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Phasmatoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
TOTAL	**0**	**0**	**1**	**0**	**5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**6**
September 2007	**KGR01**	**KGR02**	**KGR03**	**KOP01**	**KOP02**	**KOP03**	**KSL01**	**KSL02**	**KSL03**	**KYS01**	**KYS02**	**KYS03**	**TAXON TOTAL**
Areneomorphae	2	2	0	1	2	0	4	3	2	2	0	0	**18**
Mygalomorphae	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Pseudoscorpions	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Scorpions	1	0	0	0	0	0	0	0	0	0	0	0	**1**
Blattodea	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Chilopoda	1	0	0	0	0	0	0	0	0	0	0	0	**1**
Coleoptera (adult)	0	0	0	0	0	0	0	0	0	0	2	0	**2**
Coleoptera (larvae)	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Diplopoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Formicidae	2	2	0	10	9	0	1	1	0	1	0	0	**26**
Hemiptera	1	1	0	2	1	0	2	4	0	1	0	0	**12**
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Isoptera	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Lepidoptera (larvae)	0	0	0	0	0	0	0	0	1	0	0	0	**1**
Mantodea	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Orthoptera	1	4	1	4	2	4	1	3	2	0	0	1	**23**
Phasmatoda	0	0	0	0	0	0	0	0	0	0	0	0	**0**
TOTAL	**8**	**9**	**1**	**17**	**15**	**4**	**8**	**11**	**5**	**4**	**2**	**1**	**85**

are typical of the northern agricultural region and surrounding semi-arid region (Harvey et al. 2004; Heterick 2009) and provide the beginnings of an invertebrate species list for the two properties that may be expanded during future survey work.

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REFERENCES

Abensperg-Traun M, Smith GT, Arnold GW, Steven DE (1996) The effects of habitat fragmentation and livestock-grazing on animal communities in remnants of gimlet *Eucalyptus salubris* woodland in the Western Australian wheatbelt. I. Arthropods. *Journal of Applied Ecology* **33**, 1281–1301.

Bänninger M (1940) On Australian Pamborini, Ozaenini and Scaritini (Coleoptera: Carabidae). *Novitate Zoology* **42,** 203–213.

Beard JS (1976) *The Vegetation of the Perenjori Area, Western Australia : Map and Explanatory Memoir 1:250,000 Series*. Vegmap Publications, Perth.

Catling PC (1988) Similarities and contrasts in the diets of foxes, *Vulpes vulpes*, and cats, *Felis catus*, relative to fluctuating prey populations and drought. *Australian Wildlife Research* **15**, 307–317.

Coman, BJ (1973) The diet of red foxes, *Vulpes vulpes* L., in Victoria. *Australian Journal of Zoology* **21**, 391–401.

Department of Agriculture and Food Western Australia (1990) *Soil – Land Systems of the South West of Western Australia.* Department of Agriculture and Food Western Australia, Perth.

Durrant B (2004) Biogeographical patterns of zodariid spiders (Araneae: Zodariidae) in the wheatbelt region, Western Australia. *Records of the Western Australian Museum* Supplement **67**, 203–216.

Griffin S (1990) An investigation into predation on invertebrates by the red fox, *Vulpes vulpes*, in Watheroo and Alexander Morrison National Parks, Western Australia (unpublished).

Guthrie NA and Waldock JM (2004) Patterns in the composition of the jumping spider (Arachnida: Araneae: Salticidae) assemblage from the wheatbelt region, Western Australia. *Records of the Western Australian Museum* Supplement **67**, 217–230.

Harvey MS, Sampey A, West PLJ, Waldock JM (2000) Araneomorph spiders from the southern Carnarvon Basin, Western Australia: a consideration of regional biogeographic relationships. *Records of the Western Australian Museum* Supplement **61**, 295–320.

Harvey MS, Waldock JM, Guthrie NA, Durrant BJ, McKenzie NL (2004) Patterns in the composition of ground-dwelling araneomorph spider communities in the Western Australian Wheatbelt. *Records of the Western Australian Museum* Supplement **67**, 257–292.

Heterick BE (2009) A guide to the ants of south-western Australia. *Records of the Western Australian Museum* Supplement **76**, 7–205.

Martensz PN (1971) Observations on the food of the fox, *Vulpes vulpes* (L.), in an arid environment. *CSIRO Wildlife Research* **16**, 73–75.

Matthews EG (1980) *A Guide to the Genera of Beetles of South Australia.* Part I. *Archostemata and Adephaga.* Special Educational Bulletin Series. South Australian Museum, Adelaide.

Matthews EG (1984) *A Guide to the Genera of Beetles of South Australia.* Part III. *Polyphaga: Eucinetoidea, Dascilloidea and Scarabaeoidea.* Special Educational Bulletin Series. South Australian Museum, Adelaide.

Matthews EG (1987) *A Guide to the Genera of Beetles of South Australia.* Part IV. *Polyphaga: Tenebrionoidea.* Special Educational Bulletin Series. South Australian Museum, Adelaide.

Matthews EG, Bouchard P (2008) *Tenebrionid Beetles of Australia: Descriptions of Tribes; Keys to Genera; Catalogue of Species.* Australian Biological Resources Study, Canberra.

Matthews EG, Lawrence JF (2005) New taxa, new synonymy and new generic records for Australian Tenebrionidae (Coleoptera). *Annales Zoologici* (Warszawa) **55**, 531–547.

McIntosh DL (1963) Food of the fox in the Canberra District. *CSIRO Wildlife Research* **8,** 1–20.

McKenzie NL, May JE (2003) *A Biodiversity Audit of Western Australia's Biogeographical Subregions in 2002.* Department of Conservation and Land Management, Perth, Western Australia.

Paltridge R, Gibson D, Edwards G (1997) Diet of the feral cat (*Felis catus*) in Central Australia. *Wildlife Research* **24**, 67–76.

Richards J, Algar D (2008) Controlling feral animals in the rangelands. *Landscope* **23**, 52–58.

Richards J, Algar D, Hamilton N, Hilmer S, Rolfe J, Onus M, Prince J (2011) Small mammal and reptile assemblages of the semi-arid woodlands and *Acacia* sandplains in the southern rangelands of Western Australia. *Conservation Science Western Australia* **8**, 1–10.

Richards J, Hamilton N, Fuller PJ, Algar D, Prince J (2010) Terrestrial bird assemblages of the semi-arid woodlands and *Acacia* sandplains in the southern rangelands of Western Australia. *Conservation Science Western Australia* **8**, 11–21.

Roig-Juñent S (2000) The subtribes and genera of the tribe Broscini (Coleoptera: Carabidae): cladistic analysis, taxonomic treatment, and biogeographical considerations. *Bulletin of the American Museum of Natural History* **255**, 1–90.

Ryan GE, Croft JD (1974) Observations on the food of the fox, *Vulpes vulpes* (L.), in Kinchega National Park, Menindee, N.S.W. *Australian Wildlife Research* **1**, 89–94.

Shattuck SO (1999) *Australian Ants: Their Biology and Identification.* CSIRO Publishing, Collingwood, VIC.

Sneath PHA, Sokal RR (1973) *Numerical Taxonomy: The Principles and Practice of Numerical Classification.* Freeman, San Francisco.

Triggs B, Brunner H, Cullen JM (1984) The food of fox, dog and cat in Croajingalong National Park, South-Eastern Victoria. *Australian Wildlife Research* **11**, 491–499.

Van Vreeswyk AME, Godden PT (1998) *Pastoral Resources and their Management in the Sandstone – Yalgoo – Paynes Find Area, Western Australia.* Agriculture Western Australia, Perth.

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Vascular flora of Leeuwin–Naturaliste National Park

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ABSTRACT

A list of the vascular flora of Leeuwin–Naturaliste National Park is provided for the first time. The park contains a vascular flora of at least 1233 taxa (984 natives and 249 weeds). Important features of the Park's flora include a large number of geographically significant flora (range ends and highly disjunct populations), a number of rarely recorded species, Leeuwin–Naturaliste Ridge endemics, a series of widespread species with distinctive forms and a large number of state listed conservation taxa. The Park contains a diverse range of native flora typical of the Leeuwin–Naturaliste Ridge and is of outstanding conservation value.

Keywords: Leeuwin–Naturaliste National Park, vascular flora.

INTRODUCTION

The Busselton–Augusta area contains four major physiographic regions: the Swan and Scott Coastal Plains, the Blackwood Plateau and the Leeuwin–Naturaliste Ridge. These regions are separated and defined by the Darling and Dunsborough series of faults (Lowry 1967). These regions are further subdivided as outlined previously (Fig. 1; Keighery et al. 2010).

The Leeuwin–Naturaliste Ridge occurs west of the Dunsborough fault and is composed of pre-Cambrian crystalline granitic and gneissic rocks of the Leeuwin Block, often overlain with laterite and sand. The ridge is further divided into two major landform units: the Margaret River Plateau, which stretches approximately 90 km from Dunsborough to Augusta; and the Leeuwin–Naturaliste Coast stretching from Cape Naturaliste to islands off Cape Leeuwin (Tille & Lantzke 1990; Tille 1996). The Leeuwin–Naturaliste Coast is a discontinuous ridge of Tamala limestone and sands with underlying and occasionally outcropping Leeuwin block granite. This unit contains the Leeuwin–Naturaliste National Park, which meets the plateau in the south in the Boranup Forest (part of the Leeuwin–Naturaliste National Park) and Reserve 14779 (West Bay Block, Augusta).

Leeuwin–Naturaliste National Park extends from Bunker Bay on the eastern side of Cape Naturaliste, to Cape Leeuwin, south of Augusta, a distance of about 100 km (Fig. 1). The Park includes 28 separate reserves that together have an area of approximately 15,600 ha. While this is a relatively large area the Park is highly fragmented and is often confined to the narrow coastal reserve.

A management plan was prepared for the Leeuwin–Naturaliste National Park in 1989 (Frewer et al. 1989), and has now completed its life span. The Department of Environment and Conservation is preparing a new plan for the Park as part of a series of plans for the near coastal Blackwood District conservation reserves, which also covers the Scott National Park, Gingilup Swamps Nature Reserve (on the Scott Coastal Plain) and Forest Grove, Bramley and Yelverton National Parks.

General check lists of the vascular flora of the areas covered in the new management plan were provided in the paper on the Warren Biogeographic Region (Lyons et al. 2000). A series of other papers have detailed the vascular flora of some of the areas. Robinson and Keighery (1997) and Gibson et al. (2001) described the flora of the Scott National Park; the latter also included the Gingilup Swamps Nature Reserve. Keighery et al. (2010) described the flora of the parks and forest reserves of the Margaret River Plateau. This paper on the Leeuwin–Naturaliste National Park completes the comprehensive listing of the vascular flora and the conservation-significant flora for all areas covered by the forthcoming plan.

METHODS

Data on species distributions for the Park were extracted from the database developed by Lyons et al. (2000). Additional surveys were undertaken on an ad hoc basis between 2000 to 2007 by GJ and BJ Keighery in the various habitats distinguished in the Park (see below). The database of Lyons et al. (2000) was compiled from survey data and herbarium records as detailed in that publication. In all, over 30,000 records were used to compile the flora lists, of which approximately 35% were derived from collections held in the Western Australian Herbarium and 65% from field surveys. Many of the herbarium records were vouchers from the field surveys. Nomenclature generally follows Paczkowska and Chapman (2000).

The analysis of the conservation status of taxa is based on a consideration of each taxon's known range and occurrence in reserves. This consideration takes into account herbarium records and survey records as outlined above. Smith (2010) was sourced for information on state listed Declared Rare Flora (DRF) and Priority Flora. Priority Flora are given a code from P1–P4 (Smith 2010).

The park contains a very large range of soils, plant communities and habitats (Lowry 1967; Smith 1973; Tille & Lantzke 1990). These range from sandy beaches, coastal limestone and granite cliffs, aeolian dunes, limestone outcrops, granite outcrops, duplex and lateritic soils, fresh and brackish lakes and springs, with several creeks and rivers dissecting these areas. The varied geologies and soils support a corresponding complex of plant communities, including coastal herblands and grasslands, sedgelands, heath, shrublands and woodlands to tall forest. The considerable diversity of soils, climate and vegetation and the geographic extent (>100 km long) meant that it was not practicable to allocate species to particular plant communities, soil type and/or location. Hence the Park is divided into 11 separate sections (Fig. 1) and taxa recorded for each block (Appendix 1).

RESULTS AND DISCUSSION

Total Flora

A total of 1233 vascular plant taxa have been recorded from within the boundaries of the National Park, of which 249 are naturalized aliens or weeds (Table 1, Appendix 1).

The largest families were the Orchidaceae (115 native, 1 weed), Fabaceae (65 native, 17 weeds), Asteraceae (58 native, 30 weeds), Cyperaceae (55 native, 7 weeds), Myrtaceae (54 native, 1 weed), Stylidiaceae (42 native), Apiaceae (39 native, 2 weeds), Ericaceae (37 native), Proteaceae (34 native), Poaceae (31 native, 47 weeds), Restionaceae (29 native), Goodeniaceae (25 native) and Asparagaceae (25 native). The largest genera of native

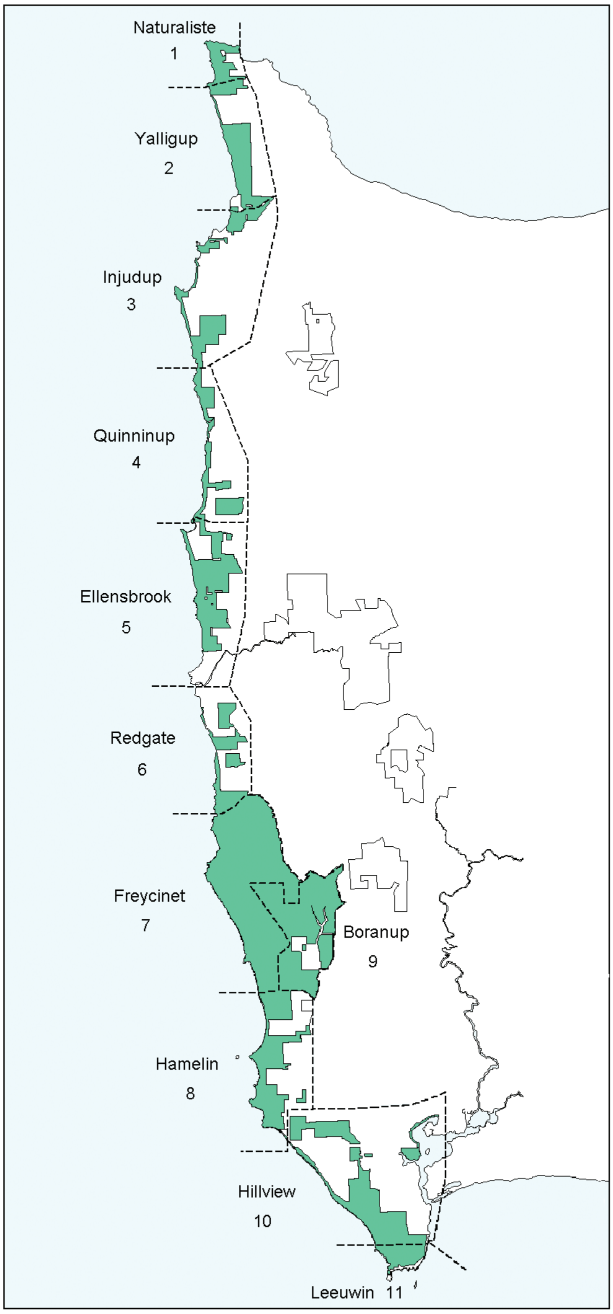

Figure 1. Map of the 11 blocks of the Leeuwen–Naturaliste National Park for which flora lists were compiled.

Table 1

Species richness of major national parks in southern Western Australia

Name	Area (ha)	Number native and weed taxa	Endemics	Reference
Fitzgerald River	329,000	1748 (104 weeds)	75	Chapman & Newbey (1995)
Stirling Range	115,600	1571 (93 weeds)	87	Keighery (1993)
Kalbarri	186,000	1071 (53 weeds)	23	Keighery et al. (2000)
Mount Lesueur	27,500	821 (93 weeds)	9	Hopper & Burbidge (1990)
Leeuwin–Naturaliste	15,600	1232 (249 weeds)	5	This paper

species were *Stylidium* (37), *Caladenia* (36), *Acacia* (28), *Leucopogon* (23), *Drosera* (17), *Hibbertia* (15), *Schoenus* (15), *Lomandra* (13) and *Thysanotus* (11).

The overall composition of the flora is typical of that of the high rainfall zone of south-west Australia (Hopper 1979; Lyons et al. 2000). There is a predominance of herbaceous elements from the Orchidaceae, Asteraceae, Cyperaceae, Stylidiaceae, Asparagaceae and Restionaceae families. As a consequence, the shrub-dominated, species-rich families of the Kwongan—the Proteaceae (34), Ericaceae (37) and Goodeniaceae (25)—although present in the top 12 families for species diversity, do not dominate the flora of Leeuwin-Naturaliste.

Species diversity

The flora of the Park is particularly rich and is comparable to that of the major parks of southern Western Australia (Table 1), despite its relatively small area compared with many of these parks. This illustrates that species richness is relatively widespread in southern Western Australia and is not confined to areas dominated by Kwongan. These features are considered in more detail below.

Geographically Interesting Flora

Range ends

Thirty-seven taxa are recognized at the end of their range within the Park's boundaries. These northern and southern range ends are associated with particular habitats and changes in rainfall.

Northern range ends

Thirteen taxa have their northern-most populations in the Park on Cape Naturaliste: *Acacia triptycha*, *Apium prostratum* var. *filiforme*, *Caladenia applanata* subsp. *applanata*, *Caladenia gardneri*, *Caladenia infundibularis*, *Calytrix acutifolia* subsp. *acutifolia*, *Chorilaena quercifolia*, *Cyanicula gertrudeae*, *Banksia sessilis* var. *cordata* (P4), *Eutaxia myrtifolia*, *Gonocarpus hexandrus* subsp. *serratus*, *Hibbertia grossulariifolia* and *Hyalospermum simplex* subsp. *graniticola*. *Hakea oleifolium*, which was thought to end its range on Cape Naturaliste, has been located on the Swan Coastal Plain at Dunsborough (Webb et al. 2009). Although geographically at a similar latitude it is outside the Park.

Four taxa end their range in the Yallingup/Moses Rock area within the margins of the 1,000 mm isohyet. These are:

- *Caladenia abbreviata* (P3), which occurs in coastal dunes from William Bay to Yallingup;
- *Caladenia pholcoidea* subsp. *pholcoidea*, which has its northern limit near Gracetown;
- *Eucalyptus diversicolor* (Karri) Mount Many Peaks to Porongurups and north to the Cape Clairault area; and
- *Hydrocotyle hirta*, which is found on seeps and granite slopes from the Porongurups to Moses Rock.

A series of clay-based perched wetlands are found on the eastern margin of the park at Boranup. This habitat is similar to some wetland habitats on the Scott River Coastal Plain, and a number of taxa that are more characteristic of the flora of the Scott Coastal Plain (Keighery & Robinson 1992; Robinson & Keighery 1997) were found here. Seven of these taxa are at, or near, their northern range limits, being: *Acacia hastulata*, *Actinotus* sp. Walpole (P3), *Aotus tenuis* ms, *Astartea* sp. Scott River (P4), *Leucopogon paradoxus*, *Lysinema conspicuum* and *Melaleuca basicephala* (P4).

Two taxa, *Leucopogon distans* and the recently described *Agrostocrinum scabrum* subsp. *littorale* (Keighery 2004), are at the northern extent of their range on the granites at Cape Leeuwin. The population of *Agrostocrinum* is one of only three known, highly disjunct populations recorded from Mount Manypeaks, Mutton Bird Island and Cape Leeuwin.

Freshwater springs and seepages are a feature of the Leeuwin–Naturaliste Ridge. *Hydrocotyle plebeya*, found in almost permanent fresh water, occurs in scattered populations from the Porongurups north to Turners Spring and Devils Pool.

Southern range ends

Eleven taxa are clustered in the northern part of the ridge either on granites or limestone soils. These taxa are:

- *Alyogyne huegelii* var. *glabrescens* – disjunct southern population near Canal Rocks.
- *Alyogyne huegelii* var. *huegelii* – disjunct southern population near Cape Freycinet.
- *Alyxia buxifolia* – the taxon delineated as the typical Swan Coastal Plain coastal variant of this widespread arid taxon ends south of Yallingup.
- *Caladenia chapmanii* – southern limit Cape Freycinet area.
- *Caladenia huegelii* (DRF) – southern limit near Yallingup.
- *Caladenia longicauda subsp. clivicola* – southern limit Cape Naturaliste.
- *Leucopogon tenuis* – southern limit at Moses Rock.
- *Petrophile axillaris* – a disjunct population from Yalgorup of this species is found in the Cosy Corner-Cape Freycinet area.
- *Pittosporum ligustifolium* – southern limit near Canal Rocks.
- *Rhagodia baccata* subsp. *dioica* and *Rhagodia baccata* subsp. *baccata* – Wilson (1983) notes that Cape Naturaliste is the southern margin of the overlap zone between these subspecies which extends north to Guilderton.
- *Trachymene coerulea* subsp. *coerulea* – a disjunct population of this subspecies is found in the Cosy Corner-Cape Freycinet area.

Disjunct populations

Ten taxa, which are all associated with restricted habitats, have significant disjunct populations within the Park:

- *Borya constricta* – a highly disjunct taxon, common on granite in the wheatbelt with scattered populations in the northern Jarrah Forest, southern forests and Leeuwin–Naturaliste ridge.
- *Pteris vittata* – a tropical fern found in permanent wetlands, with a series of highly disjunct populations at Pilbara Gorges, Yanchep and Boojimup (Leeuwin–Naturaliste).
- *Malva preissiana* – the large-leaved, white-flowered, island form of this plant is typically an offshore island guanophile; the only extant mainland record of this taxon is on the granites of the tip of Cape Leeuwin.
- *Lepidium foliosum* – this is another offshore island guanophile, with its only extant mainland record from the granites of the tip of Cape Leeuwin
- *Stylidium affine* – there is a disjunct series of populations found on Cape Naturaliste (Lowrie et al. 1998).
- *Petrophile serruriae* – a series of disjunct populations of this taxon is found in the south-western extent of its range on the Busselton Swan Coastal Plain, Whicher Scarp and Leeuwin–Naturaliste Ridge.
- *Beyeria viscosa* – occurs along the coast from Geraldton to Cape Leeuwin then disjunct to Esperance.
- *Hibbertia spicata* subsp. *spicata* – disjunct from Perth hills area on Cape Naturaliste.
- *Amblysperma minor* (P2) – a disjunct population is located near Gracetown; this taxon is normally found in claypans on the Swan Coastal Plain and Jarrah Forest.
- *Thysanotus arbuscular* – there is a disjunct series of populations found on Cape Naturaliste.

Co-occurring Closely Related Taxa

There is a series of co-occurring closely related taxa, including the previously mentioned *Alyogyne huegelii* varieties (var. *glabrescens* and var. *huegelii*) and *Rhagodia baccata* subspecies (subsp. *dioica* and subsp. *baccata*). A series of *Hyalosperma* species and subspecies—*Hyalosperma cotula*, *Hyalosperma simplex* subsp. *graniticola* and *Hyalosperma simplex* subsp. *simplex*—co-occur at Sugarloaf Rock. These populations could have taxonomic significance.

Rarely Recorded Taxa

While three taxa—*Sium latifolium*, *Samolus valerandi* and *Calystegia soldanella*—could be considered as part of the group of disjunct populations, they are so uncommon that they are best considered as poorly known or rarely recorded taxa. The first two taxa are currently listed as weeds in Western Australia but should be listed as native taxa, as is the third taxon.

Sium latifolium

This soft, perennial herb is a cosmopolitan species that is considered native in eastern Australia, but is still listed as a weed in Western Australia (Florabase 2009). It occurs chiefly in permanent wetlands along the ridge with a disjunct population near Pemberton.

Samolus valerandi

This soft perennial herb is a cosmopolitan species that is considered native to eastern Australia, but is still listed as a weed in Western Australia (Western Australian Herbarium 1998–). It occurs chiefly in permanent wetlands along the ridge with a disjunct population north of Gingin.

Calystegia soldanella

This strand plant is widely distributed along the coasts of southern Australia, however, it has been recorded at only two locations in Western Australia, Ellen Brook in Leeuwin–Naturaliste and near Chatham Island off Walpole.

Taxa Centred on the Park

A number of plant species are endemic to the Busselton to Augusta area, while others are limited to the major physiographic regions such as the Leeuwin–Naturaliste Ridge. A number of these taxa have been considered Park endemics, despite at times having populations that extend beyond the Park. However, the majority of the populations of these taxa are in the Park and the Park is crucial to their conservation. Of the 15 taxa listed below 13 are Leeuwin–Naturaliste Ridge endemics.

- *Acacia subracemosa* (P2) – almost entirely confined to the Leeuwin–Naturaliste ridge, from Augusta to Cape Clairault.
- *Bossiaea disticha* – confined to the Leeuwin–Naturaliste Ridge between Augusta and the Ellen Brook area (Keighery 1996).
- *Caladenia citrina* – a local endemic to the Northern Margaret River Plateau and Leeuwin–Naturaliste Ridge.
- *Caladenia excelsa* (DRF) – distributed between Yallingup and Karridale along the Leeuwin–Naturaliste Ridge; at least four populations are in the Park. Leeuwin–Naturaliste is the only conservation reserve for this species.
- *Caladenia nivalis* – apparently confined to the Park, between Moses Rock and Sugarloaf Rock.
- *Caladenia pholcoidea* subsp. *augustensis* – confined to the Cape Leeuwin area.
- *Caladenia* sp Boranup (M Spencer 71) – confined to the Boranup area.
- *Caladenia viridescens* (DRF) – Cape Naturaliste endemic.
- *Eucalyptus calcicola* subsp. *calcicola* – confined to coastal dunes and limestone hills near Boranup.

- *Hydrocotyle hammelensis* ms – only recorded for the Cape Naturaliste area, with an unconfirmed record for Rottnest island.
- *Kennedia lateritia* (DRF) – confined to granites of Cape Leeuwin.
- *Kunzea ciliata* – confined to the Leeuwin–Naturaliste Ridge from Smiths' Beach to Yallingup.
- *Stylidium lowrieanum* – Leeuwin–Naturaliste Ridge, from Karridale to Cape Naturaliste.
- *Thomasia triloba* – apparently endemic to the Ridge as the only known populations are from Boranup.
- *Wurmbea calcicola* (DRF) – confined to the northern portion of Cape Naturaliste.

Morphological Variants

Another feature of the flora of the Park is the number of unusual forms of normally widespread species that are restricted to the Leeuwin–Naturaliste Ridge. Several of these forms require further investigation to determine if they deserve taxonomic recognition.

Haloragis digyna subsp. nov.

Populations of this species along the Leeuwin–Naturaliste Ridge are disjunct from the other populations that range from Albany to Esperance. The populations differ in leaf and pubescence from those in the main portion of the species' range. Accurate localities are south coastal survey records from between Cosy Corner to Cape Naturaliste (N Gibson & M Lyons[1], pers. comm.) at Hooley Road, Kilcarnup and Cape Naturaliste.

Brachycome iberidifolia

A prostrate, succulent-leaved form is found on coastal granites at Cape Leeuwin, Cosy Corner and Moses Rock. These breed true from seed (Keighery, pers. obs.).

Eryngium pinnatifidum (Coastal Granite; G Keighery 1885)

A small, hard-leaved form of this taxon is found on the coastal granites at Cape Leeuwin, Cosy Corner and Moses Rock.

Gastrolobium bilobum, *Banksia littoralis*, *Jacksonia horrida*, *Kunzea ciliata* and *Viminaria juncea* all have prostrate forms and together dominate a low, wet heath north of Moses Rock. These species have bred true from seed (Keighery pers. obs.).

Xanthosia atkinsoniana var. limestone (Gibson & Lyons 321)

This widespread species of the Jarrah Forest is normally found on laterites. In the Park it is found in a series of disjunct populations on coastal limestones. These have very different leaves from the typical form.

Bossiaea disticha

A variety of forms are known in this taxon, a northern yellow flowered form south of the Ellen Brook and a prostrate form at Cape Freycinet (Keighery 1996).

Boronia anceps

The population north of Moses Rock is a low to almost prostrate, leafy shrub with many stems compared with the type form on the Scott River, which is a tall and slender shrub with few branches (Wilson, 1998). This form appears morphologically closer to the *Boronia fastigiata/spathulata* complex than the Scott River populations.

Calothamnus graniticus subsp. *graniticus* (P4)

This subspecies is confined to the Cape Naturaliste area, however, even within this area several forms are known. A hairy-leaved form is found around Sugarloaf Rock and a glabrous form in the Meelup Regional Park.

Eucalyptus marginata x *megacarpa* (GK 5332; P4)

A hybrid stand of several long-lived trees are found near Sugar Loaf Rock on Cape Naturaliste.

Declared Rare and Priority Flora

The Park contains five taxa of Declared Rare Flora (*Kennedia lateritia, Caladenia viridescens, C. excelsa, C. huegelii* and *Wurmbea calcicola)*. No taxa are listed as Priority 1, but five species—*Actinotus* sp. Walpole (JR Wheeler 3786), *Acacia subracemosa*, *Agrostocrinum scabrum* subsp. *littorale*, *Hydrocotyle hamelinensis* ms and *Millotia tenuifolia* var. *laevis*—are listed as P2. Eight species are listed as P3 (*Acacia latericola* glabrous variant [BRM 6765], *Amblysperma minor*, *Boronia anceps*, *Bossiaea disticha*, *Galium leptogonium*, *Meeboldina thysanantha*, *Pimelea ciliata* subsp. *longituba*, and *Pultenaea pinifolia*), and nine species as P4 (*Acacia semitrullata*, *Anthotium junciforme*, *Calothamnus graniticus* subsp. *graniticus*, *Dryandra sessilis* var. *cordata*, *Eucalyptus calcicola* subsp. *calcicola*, *Eucalyptus marginata* x *megacarpa*, *Eucalyptus rudis* subsp. *cratyantha*, and *Melaleuca basicephala*). Nine species have been removed from the Priority Flora list since 2008. These are: *Acacia hastulata* (was P3), *Acacia mooreana* (was P2), Andersonia *involucrata* (was P4), *Caladenia longicauda* subsp. *clivicola* (was P4), *Caladenia arrecta* (was P4), Caladenia *plicata* (was P4), *Calothamnus pallidiflorus* (was P4), *Thomasia triloba* (was P3) and *Thysanotus arbuscular* (was P4). Most of these taxa have been discussed under the previous headings, except for the eight below.

- *Acacia latericola* glabrous variant (BRM 6765; P3) – mainly confined to the granites of Cape Naturaliste, with a single record from the Scott Plains.

[1] N Gibson and M Lyons, Department of Environment and Conservation, Kensington, WA.

- *Acacia semitrullata* (P4) – occurs on sandy soils from Yarloop south to Collie, Donnybrook, Whicher Range and Nannup.
- *Anthotium junciforme* (P4) – a wetland species found in scattered populations from Three Springs to the Scott River.
- *Galium leptogonium* (P3) – this inconspicuous herb is found in scattered populations from Cape Leeuwin to Eucla.
- *Meeboldina thysanantha* (P3) – a wetland species found from Walpole to Collie, with many populations on the Blackwood Plateau.
- *Millotia tenuifolia* var. *laevis* (P2) – scattered populations from Dowerin Serpentine and Collie. The southern most known populations are from Cape Naturaliste.
- *Pimelea ciliata* subsp. *longituba* (P3) – a rarely recorded taxon occurring from Busselton to Whichcliffe. The Leeuwin–Naturaliste population is at the southern margins of the known range.
- *Pultenaea pinifolia* (P3) – occurs normally along water-courses from Busselton area to Nannup.

Weeds

The elongated shape of the Park gives it a huge perimeter to area ratio, exposing much of the Park to human disturbance. Disturbance, both in and nearby the Park, includes legal and illegal camping, past grazing, poorly planned rehabilitation, "enrichment" plantings, numerous tracks, eutrophication and altered hydrology of creek-lines originating outside the Park, old farm houses, and past and present settlements. These disturbances have all contributed to the introduction and maintenance of a very large number of weeds in the Park.

The most serious weeds in the Park include Arum Lily (*Zantedeschia aethiopica*), Victorian Tea Tree (*Leptospermum laevigatum*), Wild Pelargonium (*Pelargonium alchemilloides*), Freesias (*Freesia* hybrids), Black Flag (*Ferraria crispa*) and Watsonia (*Watsonia* species). These taxa have the ability to invade and alter many habitats in the Park. Another weed, the aggressive perennial Buffalo Grass (*Stenotaphrum secundatum*), threatens fresh water wetlands. Coastal dunes and beaches have been invaded by *Pelargonium capitatum*, *Euphorbia paralias*, *Ammophila arenaria*, and *Ehrharta villosa*. The latter was often planted for dune stabilization. The unique granite communities of the Park are invaded by thistles (*Carduus pycnocephalus*, *Centaurea melitensis* and *Cirsium vulgare*).

Widespread weeds present throughout the Park include the grasses *Avena barbata*, *Briza maxima*, *Briza minor*, *Bromus diandrus*, *Cynodon dactylon*, *Ehrharta calycina*, *Ehrharta longiflora*, *Lagurus ovatus* and *Lolium* species. These weeds contribute to increased fire hazards and compete with native herbs for space and nutrients. Potentially serious weeds that require monitoring and control to prevent their spread through the park include *Gladiolus caryophyllaceus*, *Gazania linearis* and *Hyparrhenia hirta*.

Because of its early association with the port and settlement, the Hamelin Bay area has a number of localized weeds that could be subject to eradication targets: *Ursinia speciosa*, *Mercurialis annua*, and *Pentzia suffruticosa*. The Declared thistle weed, *Berkhya rigida*, is also found in this area south to Cape Leeuwin and is currently subject to control measures.

Comparisons to other Conservation Reserves of the Busselton to Augusta Region

Leeuwin–Naturaliste National Park occurs almost entirely on the western margin of the Leeuwin Ridge Landform unit of Tille and Lantzke (1990). One reserve, the reserve at West Bay Augusta, is on the Margaret River Plateau.

With a large geographic spread and diverse flora, Leeuwin–Naturaliste National Park could be expected to conserve much of the flora of the Busselton to Augusta region. To assess this, a comparison of total native floras of the parks of the area was undertaken. The Park has a total native flora of 984 taxa and Scott National Park has 744 (Gibson et al. 2001), giving a combined total native flora of 1188 taxa for these reserves. The parks share 542 taxa between them, with another 446 taxa being only recorded for Leeuwin–Naturaliste and 186 only for Scott.

A similar comparison with the parks of the Margaret River Plateau (Keighery et al. 2010) showed that these differences relate primarily to several wetland habitats that are found in the Scott National Park but not in the parks of the Margaret River Plateau or Leeuwin–Naturaliste Ridge. These Scott National Park habitats are the:

- diverse fresh-water and brackish wetlands characterised by species such as *Apium prostratum*, *Bolboschoenus caldwellii*, *Ottelia ovalifolia*, *Ruppia megacarpa* and *Villarsia violifolia*); and
- Scott Wet Ironstones characterised by *Loxocarya magna*, *Banksia nivea* subsp. *uliginosa*, *Chordifex isomorphus*, *Hakea tuberculata* and *Grevillea manglesioides* subsp. *ferricola*.

Two other groups of plants are also absent from Leeuwin–Naturaliste Ridge but are found in the Scott National Park, being:

- species that range from the Albany to Augusta area, including *Eremosyne pectinata*, *Banksia occidentalis* and *Leucopogon tenuicaulis*); and
- a number of Scott Coastal Plain endemics including *Adenanthos detmoldii*, *Calothamnus* aff. *crassus* and *Grevillea brachystylis* subsp. *australis*.

The parks of the Margaret River Plateau, which contain 644 native taxa, also differ markedly in composition. The parks have a combined flora of 1172 species, with 441 taxa only recorded for Leeuwin–Naturaliste, 647 shared between these parks and 83 only recorded for the Plateau parks.

The differences between the Margaret River Plateau and Leeuwin–Naturaliste parks relate to the presence of two habitats on the Margaret River Plateau, not located on the Leeuwin–Naturaliste Ridge, being:

- deep sands characterised by *Conospermum teretifolium*, *Acacia mooreana*, *Phlebocarya filifolia* and *Stirlingia latifolia*; and
- laterised uplands characterised by *Calothamnus sanguineus*, *Melaleuca trichophylla*, *Marianthus candidus* and *Bossiaea aquifolium*.

There are also a set of restricted or rare habitats, found in the Margaret River Plateau parks and reserves.

The majority of the taxa present in the Leeuwin–Naturaliste National Park that are absent from both the Scott National Park and the Margaret River Plateau parks and reserves are associated with the beaches, limestone and granite soils. These three habitats are absent from the Scott National Park and the Margaret River Plateau parks and reserves. It is these habitats that contribute to the unique flora of the Leeuwin–Naturaliste National Park. Each of these habitats supports both widespread and restricted taxa, such as:

- Coast – widespread taxa include *Spinifex hirsutus* and *Scaevola crassifolia*, restricted taxa include *Calystegia soldanella*;
- Limestones – widespread taxa include *Acacia littorea*, restricted taxa include *Banksia sessilis* var. *cordata*; and
- Granites – widespread taxa include *Pelargonium australe*, restricted taxa include *Agrostocrinum scabrum* subsp. *littorale*.

No other area in WA has such an extensive area of limestones associated with granites in a near coastal location. These habitats support a set of restricted taxa and forms of widespread taxa. It is expected that further detailed work will recognise further restricted taxa.

Although 80–90 plots were established in the south coast survey (Gibson & Lyons, pers. comm.), and these formed the basis for the lists in Lyons et al. (2000) and here, there is a need to complete this study and expand the systematic quadrat-based survey of the plant communities of the Leeuwin–Naturaliste Ridge to supplement the existing information on the flora and plant communities of the area. Several granitic heath communities from the northern sections of the park from Sugarloaf Rock to Cape Naturaliste are already listed by DEC as Priority Ecological Communities.

Of the total 1377 native taxa listed from all six parks, only 350 (c. 29%) are recorded from all parks. The parks, each covering different geomorphic areas (Leeuwin–Naturaliste Ridge, Margaret Plateau and Scott Coastal Plain) have complementary floras, each containing a different subset of plants from the geomorphic regions within which they occur, rather than being composed mainly of very widespread elements.

CONCLUSIONS

The Leeuwin–Naturaliste National Park has a diverse flora of over 980 native vascular plant taxa. The major features of the native vascular flora of the Park are:

- A large number of geographically significant flora, namely range ends and highly disjunct populations, centred on three areas (Cape Leeuwin, Cape Naturaliste to Smiths Beach and Hamelin Bay).
- Several rarely recorded species for Western Australia, usually associated with wetlands.
- A significant component of endemic flora of the Leeuwin–Naturaliste Ridge is centred on, and conserved in the Park.
- A number of widespread species with distinctive forms on the Leeuwin–Naturaliste Ridge.
- A large number of state-listed conservation taxa are protected in the Park.

The Park contains a diverse range of native flora and is of outstanding conservation value.

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REFERENCES

Chapman A, Newbey KR (1995) A biological survey of the Fitzgerald area. *CALMScience Supplement* **3**, 1–258.

Frewer P, Raven T, Taylor N, Cockman B, Batchelor M, Orr K (1989) *Leeuwin–Naturaliste National Park Management Plan 1989–1999*. Department of Conservation and Land Management, Perth.

Gibson N, Keighery GJ, Lyons MN (2001) Vascular flora of Scott National Park, Camping Reserve 12951 and Gingilup Swamps Nature Reserve, Western Australia. *CALMScience* **3**, 411–432.

Hopper SD (1979) Biogeographical aspects of speciation in the south west Australian flora. *Annual Review of Ecology and Systematics* **10**, 399–422.

Hopper SD, Burbidge AA (1990) Significance of the Lesueur area. In *Nature Conservation, Landscape and Recreation Values of the Lesueur Area* (eds AA Burbidge, SD Hopper, S van Leeuwin), pp 111–115. Environmental Protection Authority Bulletin 424, Environmental Protection Authority, Perth.

Keighery GJ (1993) *Mountains of Mystery. Appendix: Flora List and Synopsis of the Flora of the Stirling Range National Park*. Department of Conservation and Land Management, Perth.

Keighery GJ (1996) Boranup Bossiaea (*Bossiaea disticha*): distribution and biology. *Western Australian Naturalist* **21,** 97–101.

Keighery GJ (2004) A taxonomic revision of the genus *Agrostocrinum* (Phormiaceae). *Nuytsia* **15,** 245–252.

Keighery GJ, Gibson N, Lyons MN, Burbidge AH (2000) Flora and vegetation of the southern Carnarvon Basin. *Records of the Western Australian Museum* Supplement **61,** 77–154.

Keighery G, Lyons M, Gibson N, Keighery B (2010) Vascular flora of the Margaret River Plateau National Parks, State Forest and Conservation Reserves, south-western Western Australia. *Conservation Science Western Australia* **7,** 481–502.

Keighery GJ, Robinson C (1992) 'A survey of declared rare flora and other plants in need of special protection of the Scott Plains: A report to Australian National Parks and Wildlife Service, Endangered Species Programme'. Department of Conservation and Land Management, Perth.

Lowrie A, Coates DJ, Kenneally KF (1998) A taxonomic review of the *Stylidium caricifolium* complex (Stylidiaceae) from south-west Western Australia. *Nuytsia* **12,** 43–57.

Lowry, DC (1967) *1:25,000 Geological Series Explanatory Notes. Busselton and Augusta.* Geological Survey Western Australia, Perth.

Lyons MN, Keighery GJ, Gibson N, Wardell-Johnson G (2000) The vascular flora of the Warren bioregion, south-west Western Australia: composition, reservation status and endemism. *CALMScience* **3,** 181–250.

Paczkowska G, Chapman AR (2000) *The Western Australian Flora: A Descriptive Catalogue.* Wildflower Society of Western Australia Inc., Department of Conservation and Land Management and Botanic Gardens & Parks Authority, Perth.

Robinson CJ, Keighery GJ (1997) Vegetation and flora of Scott National Park and adjacent recreation reserves. *Western Australian Naturalist* **21,** 213–233.

Smith FG (1973) *Vegetation Map Busselton–Augusta.* Department of Agriculture, South Perth.

Smith MG (2010) *Declared Rare and Priority Flora List for Western Australia.* Department of Environment and Conservation, Perth.

Tille PJ (1996) *Wellington–Blackwood Land Resource Survey, Land Capability Study Assessment for the Wellington–Blackwood Survey.* Land Resources Series No. 14, Department of Agriculture, Perth.

Tille PJ, Lantzke NC (1990) *Busselton, Margaret River, Augusta, Land Capability Study.* Land Resources Series No. 5, Department of Agriculture, Perth.

Webb A, Keighery B, Keighery G, Longman V, Black A, O'Connor A (2009) *The Flora and Vegetation of the Busselton Plain (Swan Coastal Plain).* Department of Environment and Conservation, Perth.

Western Australian Herbarium (1998–) *Florabase—The Western Australian Flora.* Department of Environment and Conservation. http://florabase.dec.wa.gov.au/ [last accessed 2009].

Wilson PG (1983) A taxonomic review of the tribe Chenopodieae (Chenopodiaceae) in Australia. *Nuytsia* **4,** 135–262.

Wilson PG (1998) New names and new taxa in the genus *Boronia* from Western Australia. *Nuytsia* **12,** 119–154.

APPENDIX 1

Vascular flora of Leeuwin–Naturaliste National Park by 11 geographic areas (see Figure 1 for location of areas). Conservation codes follow Smith (2010).

*Naturalised/	Name	1	2	3	4	5	6	7	8	9	10	11	con
Adiantaceae													
	Adiantum aethiopicum				+	+					+	+	
	Anogramma leptophylla					+							
	Cheilanthes austrotenuifolia	+	+	+	+	+						+	
	Cheilanthes sieberi subsp. sieberi									+			
Aizoaceae													
*	Aptenia cordifolia			+									
*	Carpobrotus edulis	+		+					+			+	
	Carpobrotus modestus	+	+				+	+	+			+	
	Carpobrotus virescens	+	+	+	+	+		+	+		+	+	
	Disphyma crassifolium subsp. clavellatum				+								
*	Droseranthum candens							+	+				
*	Mesembryanthemum crystallinum		+					+				+	
*	Tetragonia decumbens	+	+	+	+	+	+	+	+			+	
	Tetragonia implexicoma	+	+	+	+	+	+	+	+			+	
	Tetragonia tetragonoides	+										+	
Alliaceae													
*	Allium triquetrum				+					+			
Amaranthaceae													
	Alternanthera denticulata				+				+			+	
	Alternanthera nodiflora											+	
	Ptilotus drummondii var drummondii	+	+		+			+	+	+	+		
	Ptilotus manglesii	+			+	+	+						
	Ptilotus sericostachyus subsp. roseus	+											
	Ptilotus sericostachyus subsp. sericostachyus	+	+						+			+	
	Ptilotus stirlingii			+	+			+	+	+	+	+	
Amaryllidaceae													
*	Amaryllis belladona					+				+			
*	Narcissus tazetta	+				+				+			
Asparagaceae													
	Agrostocrinum hirsutum	+	+	+	+	+	+	+	+	+	+	+	
	Agrostocrinum scabrum subsp. littorale											+	P2
	Arthropodium capillipes	+	+										
*	Asparagus asparagoides	+	+	+		+	+			+	+	+	
	Caesia micrantha	+	+	+	+	+	+		+	+	+	+	
	Caesia occidentalis							+		+	+	+	
	Chamaescilla corymbosa var. corymbosa	+	+	+	+	+	+	+	+	+		+	
	Corynotheca micrantha	+	+	+				+		+	+	+	
	Hodgsoniola junciformis		+							+			
	Johnsonia acaulis	+	+	+	+	+				+			
	Johnsonia lupulina			+	+	+		+		+	+	+	
	Laxmannia sessiliflora subsp. australis				+								
	Sowerbaea laxiflora	+	+	+	+	+	+		+	+	+	+	
	Thysanotus arbuscular	+											
	Thysanotus arenarius	+	+		+		+	+	+		+	+	
	Thysanotus dichotomus	+			+						+	+	
	Thysanotus gracilis		+										
	Thysanotus manglesianus	+	+		+	+	+				+	+	
	Thysanotus multiflorus	+	+							+		+	
	Thysanotus patersonii	+	+						+	+	+	+	
	Thysanotus sparteus				+					+	+	+	
	Thysanotus tenellus			+	+								
	Thysanotus thyrsoideus		+										
	Thysanotus triandrus									+	+	+	
	Tricoryne elatior	+	+		+		+		+	+	+	+	
	Tricoryne humilis		+		+		+	+	+	+	+	+	

*Naturalised/ Name	1	2	3	4	5	6	7	8	9	10	11	con
Apiaceae												
Actinotus glomeratus								+	+	+	+	
Actinotus omnifertilis									+		+	
Actinotus sp. Walpole (J.R. Wheeler 3786)									+			P3
* Ammi majus		+										
Apium annuum	+	+		+	+	+		+		+	+	
Apium prostratum var prostratum			+	+	+	+				+	+	
Apium prostratum var filiforme	+	+		+	+	+		+		+	+	
Berula erecta					+					+	+	
Centella asiatica	+			+	+	+				+	+	
Daucus glochidiatus	+	+	+	+	+	+		+	+	+	+	
Eryngium pinnatifidum var painnatifidum	+	+	+		+	+	+		+			
Eryngium pinnatifidum var Coastal Granite (Keighery 1885)					+				+		+	+
* Foeniculum vulgare		+						+			+	
Homalosciadium homalocarpum	+	+	+	+			+	+	+	+	+	
Hydrocotyle alata	+			+				+		+	+	
Hydrocotyle blepharocarpa		+	+			+		+		+	+	
Hydrocotyle callicarpa	+	+	+	+				+	+	+	+	
Hydrocotyle diantha	+	+	+	+				+		+	+	
Hydrocotyle hamelinensis ms	+	+								+		P2
Hydrocotyle hirta					+				+		+	
Hydrocotyle hispidula	+	+	+					+		+	+	
Hydrocotyle pilifera var. glabrata								+			+	
Hydrocotyle pilifera var. pilifera								+				
Hydrocotyle plebeya						+				+	+	
Hydrocotyle scutellifera					+	+						
Hydrocotyle tetragonocarpa						+	+	+			+	
Pentapeltis peltigera	+	+		+		+						
Pentapeltis silvatica										+		
Platysace compressa		+						+				
Platysace filiformis	+			+	+				+	+	+	
Platysace haplosciadia				+						+		
Platysace pendula		+		+					+	+	+	
Platysace tenuissimsa					+	+	+		+	+	+	
Trachymene coerulea var coerulea							+	+				
Trachymene pilosa	+	+	+	+	+	+	+	+	+	+	+	
Xanthosia atkinsoniana							+			+		
Xanthosia candida	+	+	+	+		+	+		+		+	
Xanthosia ciliata					+							
Xanthosia huegelii	+	+		+	+	+			+			
Xanthosia singuliflora									+			
Xanthosia tasmanica								+	+	+	+	
Apocynaceae												
Alyxia buxifolia	+		+									
* Vinca major		+			+				+			
Araceae												
* Zantedeschia aethiopica	+	+	+	+	+	+		+	+	+	+	
Asphodelaceae												
Bulbine semibarbata	+	+		+	+		+	+			+	
* Trachyandra divaricata	+	+	+	+	+			+		+	+	
Aspleniaceae												
Asplenium aethiopicum					+				+		+	
Asplenium trichomanes							+		+	+	+	
Asteraceae												
Actites megalocarpa	+	+	+	+	+	+	+	+		+	+	
Amblysperma minor			+	+								P2
Amblysperma scapigera	+	+							+		+	
Amblysperma spathulata									+		+	
Angianthus preissianus			+	+					+		+	
* Arctotheca calendula	+	+	+	+	+		+	+	+	+	+	
* Arctotheca populifolia	+	+	+	+	+	+	+	+		+	+	
* Arctotheca calendula x populifolia	+	+	+				+	+			+	

*Naturalised/	Name	1	2	3	4	5	6	7	8	9	10	11	con
	Asteridea pulverulenta	+	+		+	+		+	+		+	+	
*	Berkhya rigida						+		+			+	
	Brachyscome iberidifolia	+	+	+	+	+	+	+	+			+	
*	Carduus pycnocephalus	+	+	+	+		+		+	+		+	
*	Centaurea melitensis	+	+					+	+				
*	Cisium vulgare	+								+	+	+	
*	Conyza bonariensis	+							+	+	+	+	
*	Conyza parva					+			+	+	+	+	
*	Conyza sumatrensis	+	+		+	+			+	+	+	+	
	Cotula australis	+											
	Cotula coronopifolia	+			+	+			+			+	
	Cotula cotuloides	+	+		+				+			+	
*	Cotula turbinata	+	+	+									
	Craspedia variabilis		+		+			+	+				
*	Crepis capillaris											+	
*	Dittrichia graveolens	+		+					+				
	Euchiton sphaericus	+	+			+			+	+		+	
*	Filago gallica					+					+		
*	Gazania linearis	+								+			
	Gnaphalium indutum				+				+				
*	Hedypnois rhagadioloides	+							+			+	
	Helichrysum luteo-album	+	+		+	+			+		+	+	
	Helichrysum macranthum		+	+	+								
	Hyalospermum cotula	+	+		+			+	+	+	+	+	
	Hyalospermum simplex subsp. graniticola	+											
	Hyalospermum simplex subsp. simplex	+							+				
*	Hypochaeris glabra	+	+	+	+	+	+		+	+	+	+	
*	Hypochaeris radicata										+	+	
	Ixiolaena viscosa	+	+		+	+			+	+	+	+	
	Lagenophora huegelii	+	+	+	+	+	+	+	+		+	+	
*	Leontodon saxatilis	+			+				+	+	+	+	
	Leptorhynchos scaber				+			+	+		+	+	
	Leucophyta brownii	+	+	+	+	+	+	+	+			+	
	Millotia myosotidifolia	+						+	+		+	+	
	Millotia tenuifolia var laevis	+											P2
	Millotia tenuifolia var tenuifolia		+	+	+	+							
	Myriocephalus helichrysoides	+											
	Olearia axillaris	+	+	+	+	+	+	+	+	+		+	
	Olearia cassiniae										+		
	Olearia ciliata	+											
	Olearia elaeophila										+	+	
	Olearia paucidentata	+				+			+	+	+	+	
	Olearia rudis			+						+	+	+	
	Ozothamnus cordatus	+	+	+		+		+	+		+	+	
	Ozothamnus ramosus							+	+	+	+		
*	Pentzia suffruticosa								+				
	Picris angustifolia subsp. angustifolia								+		+	+	
	Picris squarrosa											+	
	Pithocarpa pulchella var. melanostigma	+							+				
	Podolepis gracilis	+	+		+			+		+	+	+	
	Podolepis lessonii			+	+	+		+					
	Podolepis rugata var rugata									+	+		
	Podotheca angustifolia	+	+		+		+	+	+	+		+	
	Podotheca chrysantha								+				
	Podotheca gnaphaloides	+											
	Pterochaeta paniculata	+	+	+							+		
	Quinetia urvillei	+	+		+	+	+	+	+				
	Rhodanthe citrina	+	+	+			+	+	+	+		+	
	Rhodanthe corymbosa	+	+										
*	Senecio diaschides				+		+						
*	Senecio elegans	+	+	+	+	+	+		+		+	+	
	Senecio hispidulus var hispidulus								+	+		+	
	Senecio multicaulis subsp. multicaulis								+	+	+		
	Senecio pinnatifolius	+	+	+		+	+	+	+		+	+	
	Senecio quadridentatus								+			+	
	Senecio ramosissimus			+			+	+	+	+	+	+	
*	Sigesbeckia orientalis									+		+	

*Naturalised/ Name		1	2	3	4	5	6	7	8	9	10	11	con
	Siloxerus filifolius									+			
	Siloxerus humifusus	+	+	+	+	+				+		+	
	Siloxerus multiflorus	+	+	+			+						
*	Sonchus asper	+		+	+	+	+	+	+	+		+	
	Sonchus hydrophilus	+	+		+	+	+			+		+	
*	Sonchus oleraceus	+	+	+	+	+	+	+		+		+	
*	Symphotrichum subulatum				+	+	+		+	+	+	+	
*	Urospermum picroides	+											
*	Ursinia anthemoides	+	+	+			+	+	+				
*	Ursinia speciosa								+				
*	Vellerophyton dealbatum	+							+	+	+	+	
	Waitzia nitida	+							+			+	
	Waitzia suaveolens		+						+			+	
Boraginaceae													
*	Echium plantagineum			+									
	Myosotis australis	+										+	
Boryaceae													
	Borya constricta				+	+							
	Borya scirpoidea		+										
	Borya sphaerocephala											+	
Brassicaceae													
*	Brassica napus	+											
*	Brassica tournefortii	+	+		+			+		+			
*	Cakile maritima	+	+	+	+		+	+	+		+	+	
*	Cardamine hirsuta									+			
	Cardamine paucijuga											+	
*	Diplotaxis muralis					+			+	+	+	+	
*	Heliophila pusilla	+	+	+		+		+	+	+	+	+	
*	Hornungia procumbens								+				
*	Lepidium africanum								+				
*	Lepidium didymum											+	
	Lepidium foliosum											+	
	Lepidium rotundum	+						+	+	+			
*	Lobularia maritima	+						+					
*	Matthiola incana		+										
*	Rhaphanus raphanistrum					+							
*	Rorippa nasturtium-aquaticum								+	+		+	
*	Sisymbrium irio									+	+	+	
*	Sisymbrium officinale											+	
	Stenopetalum robustum	+	+	+		+		+	+	+	+		
Caesalpiniaceae													
	Labichea punctata	+					+						
Campanulaceae													
*	Wahlenbergia capensis	+											
	Wahlenbergia gracilenta										+	+	
	Wahlenbergia multicaulis					+			+				
	Wahlenbergia preissii	+	+		+		+	+	+		+	+	
Caryophyllaceae													
*	Cerastium glomeratum	+	+	+			+	+	+	+	+	+	
*	Cerastium pumillum	+										+	
*	Illecebrum verticillatum	+											
*	Petrohagia velutina	+	+		+	+	+	+			+	+	
*	Sagina maritima			+	+			+	+			+	
*	Silene gallica var gallica	+	+		+	+			+	+			
*	Silene gallica var quinquivunerula	+	+			+		+	+		+	+	
*	Silene nocturna	+							+				
*	Spergula arvensis								+		+		
*	Spergularia diandra	+						+	+			+	
*	Stellaria media	+	+					+					

*Naturalised/	Name	1	2	3	4	5	6	7	8	9	10	11	con
	Casuarinaceae												
	Allocasuarina fraseriana	+	+	+		+			+			+	
	Allocasuarina humilis	+	+		+	+					+	+	
	Centrolepidaceae												
	Aphelia cyperoides	+	+		+	+	+			+	+	+	
	Centrolepis alepyroides								+				
	Centrolepis aristata	+			+	+	+	+	+	+			
	Centrolepis drummondiana	+	+	+	+	+			+	+			
	Centrolepis fasicularis									+			
	Centrolepis pilosa					+							
	Centrolepis polygyna			+	+	+	+		+			+	
	Chenopodiaceae												
	Atriplex cinerea	+		+	+		+					+	
	Atriplex hypoleuca					+						+	
	Atriplex isatidea	+	+		+	+	+						
*	Atriplex prostrata				+	+	+					+	
*	Chenopodium album								+			+	
*	Chenopodium glaucum											+	
*	Chenopodium murale	+	+	+			+	+	+				
	Chenopodium pumilio	+											
	Dysphania glomulifera subsp. glomulifera	+											
	Enchylaena tomentosa	+	+	+									
	Halosarcia halocnemoides subsp. halocnemoides										+		
	Halosarcia pergranulata subsp. pergranulata										+		
	Maireana brevifolia	+							+			+	
	Rhagodia baccata subsp. baccata	+	+	+	+	+	+		+	+	+	+	
	Rhagodia baccata subsp. dioica	+											
	Sarcocornia blackiana				+		+		+				
	Sarcocornia quinqueflora subsp. quinqueflora	+		+	+	+	+					+	
	Suaeda australis					+	+					+	
	Threlkeldia diffusa	+	+	+	+	+	+	+	+				
	Clusiaceae												
*	Hypericum perforatum var. angustifolium									+	+	+	
	Colchicaceae												
	Burchardia congesta	+	+	+	+	+		+	+	+		+	
	Burchardia multiflora	+			+					+		+	
	Wurmbea calcicola	+											DRF
	Wurmbea dioica subsp. alba			+		+					+		
	Wurmbea monantha			+				+	+		+		
	Convolvulaceae												
	Calystegia soldanella					+							
	Dichondra repens	+	+	+		+			+	+		+	
*	Ipomaea indica											+	
	Wilsonia backhousei				+								
	Wilsonia humilis				+								
	Crassulaceae												
	Crassula closiana									+			
	Crassula colorata var. colorata	+	+	+	+		+	+	+				
	Crassula colorata var. acuminata							+			+		
	Crassula decumbens	+											
	Crassula exserta									+			
	Crassula extrorsa											+	
*	Crassula glomerata	+	+	+	+	+	+	+	+		+	+	
*	Crassula natans var. minus	+		+	+					+		+	
	Crassula tetramera											+	
*	Crassula thunbergiana subsp. thunbergiana						+		+			+	
	Cuscutaceae												
*	Cuscuta epithymum	+			+	+	+		+			+	

*Naturalised/ Name		1	2	3	4	5	6	7	8	9	10	11	con
Cyperaceae													
	Baumea acuta				+	+	+					+	
	Baumea articulata						+				+	+	
	Baumea juncea		+		+	+	+	+	+	+		+	
	Baumea preissii subsp. laxa			+						+		+	
	Baumea preissii subsp. preissii				+		+						
	Baumea vaginalis									+			
	Carex appressa					+	+						
*	Carex divisa	+											
	Carex inversa	+											
	Carex preissii	+	+	+	+	+		+	+	+		+	
	Chorizandra cymbaria									+		+	
	Chorizandra enodis									+		+	
	Cyathochaeta avenacea		+			+			+	+	+	+	
	Cyathochaeta clandestina					+			+	+			
*	Cyperus congestus					+							
*	Cyperus eragrostis				+	+	+						
*	Cyperus laevigatus								+			+	
*	Cyperus polystachyos				+								
*	Cyperus tenellus	+	+		+	+			+	+	+	+	
	Evandra aristata									+			
	Ficinia nodosa	+	+	+	+	+	+	+	+	+	+	+	
	Gahnia trifida	+	+		+				+	+	+		
	Gymnoschoenus anceps									+			
	Isolepis cernua	+	+	+	+	+						+	
	Isolepis cyperoides	+	+	+	+	+				+		+	
	Isolepis fluitans								+		+		
	Isolepis marginata	+	+	+		+	+		+			+	
	Isolepis oldfieldiana									+			
*	Isolepis prolifer			+	+	+						+	
	Isolepis setiformis									+		+	
	Isolepis stellata	+	+		+	+	+						
	Lepidosperma effusum	+	+		+	+	+	+		+	+	+	
	Lepidosperma gladiatum	+	+	+	+	+	+	+	+		+	+	
	Lepidosperma leptostachyum								+	+	+	+	
	Lepidosperma longitudinale				+		+						
	Lepidosperma pubisquameum										+	+	
	Lepidosperma squamatum	+	+	+	+	+	+	+	+	+	+	+	
	Lepidosperma striatum	+			+								
	Lepidosperma tenue		+		+	+	+						
	Lepidosperma tetraquetrum					+				+		+	
	Mesomelaena graciliceps	+			+	+				+		+	
	Mesomelaena stygia			+	+								
	Mesomelaena tetragona								+	+	+	+	
	Schoenoplectus validus					+	+					+	
	Schoenus asperocarpus	+			+								
	Schoenus bifidus											+	
	Schoenus cruentus									+		+	
	Schoenus curvifolius	+			+	+				+		+	
	Schoenus discifer					+						+	
	Schoenus efoliatus								+	+	+	+	
	Schoenus grandiflorus	+	+	+	+	+	+	+	+	+	+	+	
	Schoenus lanatus										+	+	
	Schoenus nitens				+			+		+		+	
	Schoenus subbarbatus				+	+							
	Schoenus subbulbosus		+			+				+			
	Schoenus subflavus	+	+						+	+			
	Schoenus sublateralis				+				+				
	Schoenus sublaxus							+					
	Schoenus unispiculatus	+											
	Tetraria capillaris		+	+	+	+		+	+	+	+		
	Tetraria octandra	+	+					+	+	+	+	+	
	Tricostularia neesii var. neesii								+	+		+	
Dasypogonaceae													
	Acanthocarpus preissii	+	+	+	+	+		+	+		+	+	
	Baxteria australis			+									

*Naturalised/ Name	1	2	3	4	5	6	7	8	9	10	11	con
Calectasia narragara		+			+						+	
Dasypogon bromeliifolius		+		+	+	+			+			
Dasypogon hookeri		+			+	+						
Kingia australis		+		+	+							
Lomandra caespitosa	+	+							+		+	
Lomandra drummondii	+											
Lomandra hermaphrodita		+										
Lomandra integra		+	+				+	+	+			
Lomandra micrantha subsp. micrantha	+	+									+	
Lomandra nigricans			+	+	+				+			
Lomnadra odora	+											
Lomandra pauciflora	+		+		+		+	+	+	+	+	
Lomandra preissii	+											
Lomandra purpurea									+		+	
Lomandra sericea		+							+		+	
Lomandra sonderi	+	+									+	
Lomandra suaveolens	+	+		+	+						+	
Dennstaedtiaceae												
* Histiopteris incisa					+							
Pteridium esculentum	+	+	+	+	+			+	+		+	
Dilleniaceae												
Hibbertia amplexicaulis		+	+				+	+	+		+	
Hibbertia commutata	+	+	+	+	+			+	+			
Hibbertia cueniformis	+	+	+	+	+	+	+	+	+	+	+	
Hibbertia cunninghamii	+	+	+	+							+	
Hibbertia furfuracea			+	+	+	+	+	+	+		+	
Hibbertia grossulariifolia			+	+	+	+	+	+	+		+	
Hibbertia hypericoides	+	+	+	+	+		+	+	+		+	
Hibberia inconspicua				+							+	
Hibbertia notibractea				+	+	+	+					
Hibberia perfoliata									+		+	
Hibbertia pilosa									+	+	+	
Hibbertia racemosa	+	+	+	+		+	+	+		+	+	
Hibbertia rhadinopoda	+	+							+			
Hibbertia serrata	+	+	+	+			+	+	+			
Hibbertia spicata subsp. spicata	+											
Droseraceae												
Drosera dichrosepala				+								
Drosera erythrorhiza subsp. erythrorhiza	+	+	+	+			+	+	+	+	+	
Drosera fimbriata				+								
Drosera gigantea subsp. gigantea				+								
Drosera glanduligera	+	+	+					+	+	+	+	
Drosera huegelii				+								
Drosera leucoblasta				+								
Drosera macrantha subsp.macrantha	+							+		+		
Drosera menziesii subsp. menziesii	+			+			+					
Drosera menziesii subsp. penicillaris	+								+			
Drosera pallida	+						+	+	+	+	+	
Drosera platystigma		+										
Drosera pulchella									+			
Drosera stelliflora				+							+	
Drosera stolonifera	+	+	+				+			+	+	
Drosera sulphurea									+			
Drosera tubaestylis	+	+					+				+	
Ericaceae												
Acrotriche cordata							+	+			+	
Andersonia caerulea	+				+		+	+	+		+	
Astroloma ciliatum	+	+		+	+	+	+	+	+		+	
Astroloma drummondii	+								+			
Andersonia involucrata	+											
Andersonia micrantha				+								
Astroloma pallidum	+		+	+						+	+	
Brachyloma preissii		+							+			

*	Naturalised/ Name	1	2	3	4	5	6	7	8	9	10	11	con
	Conostephium pendulum						+						
	Leucopogon assimilis				+	+					+	+	
	Leucopogon australis	+						+					
	Leucopogon capitellatus	+			+					+		+	
	Leucopogon carinatus				+								
	Leucopogon conostephioides	+	+			+							
	Leucopogon cordatus				+		+	+	+	+			
	Leucopogon distans							+					
	Leucopogon elatior			+	+		+						
	Leucopogon elegans				+		+		+	+	+	+	
	Leucopogon glabellus			+								+	
	Leucopogon hirsutus		+			+					+	+	
	Leucopogon obovatus							+	+	+		+	
	Leucopogon oxycedrus	+		+									
	Leucopogon parviflorus	+	+	+	+	+	+	+	+	+		+	
	Leucopogon pendulus								+	+	+	+	
	Leucopogon propinquus	+	+	+	+	+	+	+	+	+	+	+	
	Leucopogon pulchellus	+			+								
	Leucopogon racemulosus									+			
	Leucopogon revolutus					+	+						
	Leucopogon paradoxus									+			
	Leucopogon tenuis	+		+									
	Leucopogon unilateralis			+									
	Leucopogon verticillatus		+			+		+		+	+	+	
	Lysinema ciliatum	+	+			+	+						
	Lysinema conspicuum									+			
	Sphenotoma capitatum								+	+		+	
	Sphenotoma gracile							+		+			
	Styphelia tenuiflora	+											
	Euphorbiaceae												
	Adriana quadripartita	+	+		+								
	Ampera ericoides									+	+	+	
	Ampera volubilis									+			
	Beyeria viscosa	+	+	+	+	+							
*	Euphorbia helioscopia								+				
*	Euphorbia paralias	+	+		+	+			+	+		+	
*	Euphorbia peplus	+	+	+		+			+	+	+	+	
*	Mercurialis annua								+				
	Monotaxis grandiflora	+											
	Monotaxis occidentalis							+				+	
	Phyllanthus calycinus	+	+	+	+	+	+	+	+	+	+	+	
	Poranthera huegelii								+	+	+	+	
	Poranthera microphylla	+	+		+	+			+	+	+	+	
	Pseudanthus virgatus				+								
	Fabaceae												
	Aotus cordifolia					+							
	Aotus gracillima			+		+				+			
	Aotus sp. Scott River (Kenneally 2371)									+			
	Bossiaea aquifolium subsp. aquifolium		+		+	+							
	Bossiaea disticha					+			+	+	+	+	P3
	Bossiaea eriocarpa	+	+		+	+	+	+	+	+		+	
	Bossiaea linophylla		+		+	+	+	+	+	+	+	+	
	Bossiaea ornata	+	+			+		+	+				
	Bossiaea praetermissa						+			+			
	Bossiaea rufa					+		+	+	+		+	
	Callistachys lanceolata		+		+	+		+		+		+	
*	Chaemacytissus palmensis					+							
	Chorizema aciculare subsp. aciculare	+	+										
	Chorizema cordatum		+							+			
	Chorizema diversifolium	+	+	+		+		+				+	
	Chorizema ilicifolium								+				
	Chorizema nanum	+	+		+		+			+			
	Chorizema rhombeum	+	+			+	+			+			
	Daviesia angulata	+											

*Naturalised/	Name	1	2	3	4	5	6	7	8	9	10	11	con
	Daviesia cordata	+											
	Daviesia decurrens					+							
	Daviesia divaricata	+	+		+								
	Daviesa horrida	+	+										
	Daviesia inflata		+										
	Daviesia physodes	+	+										
	Daviesia preissii	+	+										
	Dillwynia sp A (R. Coveny 8036)	+											
*	Dipogon lignosus									+			
	Euchilopsis linearis			+									
	Eutaxia epacridoides	+											
	Eutaxia myrtifolia		+	+	+				+			+	
	Eutaxia virgata			+	+					+	+		
	Gastrolobium bilobum				+	+		+				+	
	Gastrolobium praemorsum									+			
	Gastrolobium spinosum		+										
*	Genista linifolia									+			
	Gompholobium capitatum		+		+								
	Gompholobium confertum	+											
	Gompholobium knightianum		+					+	+	+	+		
	Gompholobium marginatum		+					+	+	+	+	+	
	Gompholobium ovatum		+										
	Gompholobium polymorphum		+					+	+	+	+	+	
	Gompholobium preissii	+	+	+				+	+	+	+		
	Gompholobium tomentosum	+	+		+		+	+	+	+	+		
	Hardenbergia comptoniana	+	+	+	+	+	+	+	+	+	+	+	
	Hovea chorizemifolia	+	+	+	+		+	+		+	+	+	
	Hovea elliptica		+			+			+	+		+	
	Hovea pungens						+						
	Hovea trisperma	+	+	+									
	Isotropis cuneifolia	+	+			+		+	+	+		+	
	Jacksonia furcellata	+	+										
	Jacksonia horrida	+	+	+	+	+	+	+	+	+	+	+	
	Jacksonia sternbergiana	+	+										
	Kennedia carinata									+		+	
	Kennedia coccinea	+	+		+	+		+	+	+	+	+	
	Kennedia lateritia											+	DRF
	Kennedia prostrata	+	+			+		+	+	+		+	
	Latrobea tenella									+			
*	Lathryus tingitanus								+	+			
*	Lotus angustissimus	+	+	+	+	+	+	+	+	+	+	+	
*	Lotus suaveolens			+	+			+	+	+			
*	Lupinus luteus		+										
*	Medicago polymorpha		+					+					
*	Melilotus indicus	+	+	+		+		+	+		+		
	Mirbelia dilatata	+	+	+	+	+				+			
	Nemcia capitata	+											
*	Ornithopus compressus		+	+		+				+	+	+	
*	Ornithopus pinnatus					+							
	Pultenaea brachytropis		+									+	
	Pultenaea pinifolia									+			P3
	Pultenaea reticulata	+			+		+			+			
	Sphaerolobium drummondii	+								+			
	Sphaerolobium medium	+	+										
	Sphaerolobium nudiflorum									+			
	Sphaerolobium vimineum				+	+							
	Templetonia retusa	+	+	+	+	+		+	+	+	+	+	
*	Trifolium arvense	+	+										
*	Trifolium campestre var. campstre	+		+	+	+			+				
*	Trifolium cernuum var. cernuum								+	+	+	+	
*	Trifolium glomeratum	+	+	+									
*	Vicia sativa subsp. sativa											+	
	Viminaria juncea	+	+	+	+	+				+	+		
Frankeniaceae													
	Frankenia pauciflora	+		+	+				+		+	+	

*Naturalised/ Name	1	2	3	4	5	6	7	8	9	10	11	con
Fumariaceae												
* Fumaria bastardii		+										
* Fumaria capreolata	+		+				+		+		+	
* Fumaria muralis	+		+								+	
Gentianaceae												
* Centaurium erythraea	+	+	+	+	+	+	+	+	+	+	+	
Centaurium spicatum				+						+		
* Centaurium tenuiflorum	+			+		+						
* Cicendea filiformis					+						+	
Geraniaceae												
* Erodium botrys	+											
* Erodium cicutarium	+	+	+			+	+	+			+	
* Geranium molle	+	+	+			+					+	
Geranium solanderi	+	+		+	+	+		+	+		+	
* Pelargonium alchemilloides								+				
Pelargonium australe								+				
* Pelargonium capitatum	+	+	+	+	+	+		+			+	
Pelargonium littorale subsp. littorale	+	+	+				+	+	+			
Goodeniaceae												
Anthotium junciforme			+	+								P4
Dampiera alata			+									
Dampiera coronata				+								
Dampiera hederacea					+				+	+	+	
Dampiera leptoclada			+									
Dampiera linearis	+	+	+		+		+	+	+	+	+	
Dampiera trigona	+		+		+				+			
Diaspasis filifolia										+		
Goodenia caerulea				+				+			+	
Goodenia etoniana								+			+	
Goodenia micrantha			+	+				+				
Goodenia pulchella			+						+			
Goodenia pusilla									+			
Lechenaultia biloba	+			+								
Lechenaultia expansa	+											
Scaevola anchusifolia	+											
Scaevola calliptera	+		+		+		+	+	+			
Scaevola crassifolia	+	+	+	+				+	+			
Scaevola globulifera								+	+	+	+	
Scaevola lanceolata			+		+							
Scaevola nitida	+	+	+					+	+	+	+	
Scaevola striata var striata									+			
Scaevola thesoides									+			
Velleia macrophylla									+			
Velleia trinervis			+						+	+	+	
Haemodoraceae												
Anigozanthos flavidus		+	+		+		+	+	+			
Anigozanthos humilis	+	+					+					
Anigozanthos manglesii subsp. manglesii		+		+	+	+	+		+			
Anigozanthos viridis subsp. viridis			+									
Conostylis aculeata subsp.aculeata	+	+	+	+	+	+	+	+	+	+	+	
Conostylis aculeata subsp. gracilis	+											
Conostylis aculeata subsp. preissii	+										+	
Conostylis candicans subsp.calcicola		+			+							
Conostylis laxiflora		+	+							+	+	
Conostylis serrulata							+					
Conostylis setigera subsp.setigera		+		+		+		+	+			
Haemodorum discolor		+										
Haemodorum laxum		+		+			+	+	+	+		
Haemodorum simplex			+									
Haemodorum sparsiflorum		+	+									
Haemodorum spicatum		+						+	+	+	+	
Phelbocarya ciliatum	+	+	+	+		+	+		+			
Tribonanthes australis			+	+							+	
Tribonanthes violacea			+	+	+						+	

*Naturalised/ Name	1	2	3	4	5	6	7	8	9	10	11	con
Haloragaceae												
Gliscrocaryon aureum		+	+									
Gonocarpus benthamii subsp.benthamii			+								+	
Gonocarpus diffusus											+	
Gonocarpus hexandrus subsp. integrifolius											+	
Gonocarpus hexandrus subsp. serratus					+						+	
Gonocarpus paniculatus				+								
Halorhagis digyna	+				+	+	+					
Meionectes brownii	+			+		+				+	+	
Myriophyllum salsugineum								+				
Hypoxidaceae												
Hypoxis glabella var. glabella		+						+	+		+	
Hypoxis occidentalis var occidentalis				+				+				
Hypoxis vaginatus var vaginatus							+					
Iridaceae												
* Chasmanthe floribunda						+			+			
* Ferraria crispa subsp. crispa									+			
* Freesia hybrid	+	+							+		+	
* Gladiolus angustus	+											
* Gladiolus cardinalis									+			
* Gladiolus caryophyllaceus	+											
* Gladiolus undulatus								+	+		+	
* Moraea flaccida	+		+									
Orthrosanthus laxus var. laxus	+	+						+	+		+	
Orthrosanthus polystachyus									+	+	+	
Patersonia occidentalis var angustifolium					+				+		+	
Patersonia occidentalis var occidentalis	+	+	+	+	+	+	+	+	+	+	+	
Patersonia pygmaea											+	
Patersonia umbrosa var. umbrosa										+	+	
Patersonia umbrosa var. xanthina		+	+	+	+		+	+	+	+	+	
* Romulea rosea	+	+	+	+	+	+	+	+	+	+	+	
* Sparaxis bulbilifera	+	+		+	+				+		+	
* Watsonia marginata					+							
* Watsonia meriana var bulbillifera		+			+							
* Watsonia verschfieldii				+					+			
Isoetaceae												
Isoetes drummondii				+								
Juncaceae												
Juncus amabilis				+	+				+			
* Juncus articulatus				+	+						+	
* Juncus bufonius	+			+	+	+		+	+	+	+	
Juncus caespiticius	+				+			+		+	+	
* Juncus capitatus	+				+	+		+	+	+	+	
Juncus holoschoenus			+		+	+				+		
Juncus kraussii subsp. australiensis			+	+	+	+		+			+	
* Juncus microcephalus		+	+		+	+			+		+	
Juncus oxycarpus											+	
Juncus pallidus				+							+	
Juncus pauciflorus				+	+				+			
Juncus planifolius			+	+	+				+			
Luzula meridionalis	+		+	+		+		+		+	+	
Juncaginaceae												
Triglochin calcitrapum	+	+	+	+	+		+			+		
Triglochin centrocarpum	+			+	+			+	+			
Triglochin huegelii					+						+	
Triglochin lineare									+	+	+	
Triglochin minutissima			+	+				+			+	
Triglochin mucronata			+					+			+	
Triglochin striatum			+	+	+			+			+	
Triglochin trichophorum							+	+		+		

*Naturalised/ Name	1	2	3	4	5	6	7	8	9	10	11	con
Lamiaceae												
Hemiandra glabra subsp. glabra	+											
Hemiandra pungens var. pungens	+	+	+		+							
Hemigenia podalyrina	+	+									+	
Hemigenia rigida								+		+		
Hemigenia sericea	+											
* Mentha pulegium					+			+	+			
* Mentha spicata					+						+	
* Stachys arvensis	+	+	+						+	+	+	
Westringia dampieri		+				+						
Lauraceae												
Cassytha flava	+	+		+	+	+	+	+				
Cassytha glabella								+	+	+	+	
Cassytha micrantha									+		+	
Cassytha racemosa forma racemosa	+	+	+	+	+	+	+	+	+	+	+	
Cassytha racemosa forma pilosa							+	+				
Lentibulariaceae												
Utricularia inaequalis								+				
Utricularia menziesii									+		+	
Utricularia multifida			+	+				+			+	
Utricularia tenella			+					+	+			
Utricularia violacea					+			+	+		+	
Linaceae												
Linum marginale								+		+	+	
* Linum trigynum	+	+										
Lindsaeaceae												
Lindsaea linearis	+	+	+		+	+	+		+	+		
Lobeliaceae												
Grammatotheca bergiana					+	+			+			
Isotoma hypocrateriformis	+	+	+	+	+			+	+	+	+	
Isotoma scapigera			+		+		+	+				
Lobelia alata	+		+	+	+	+		+			+	
Lobelia heterophylla								+				
Lobelia rarifolia							+	+			+	
Lobelia rhombifolia	+								+		+	
Lobelia rhytidosperma		+		+							+	
Lobelia tenuior	+	+	+	+		+	+	+	+		+	
* Monopsis debilis		+		+								
Loganiaceae												
Logania campanulata				+	+							
Logania serpyllifolia subsp. angustifolia	+	+				+	+	+	+	+	+	
Logania serpyllifolia subsp. serpyllifolia	+		+					+	+	+		
Logania vaginalis	+		+	+				+	+	+	+	
Phyllangium divergens											+	
Phyllangium paradoxum	+	+		+			+	+	+			
Loranthaceae												
Nuytsia floribunda	+	+	+	+	+	+			+	+	+	
Lycopodiaceae												
Phylloglossum drummondii	+	+	+								+	
Lythraceae												
* Lythrum hyssopifolia				+	+				+		+	
Malvaceae												
Alogyne huegelii var glabrescens			+									
Alogyne huegelii var huegelii							+	+				
Malva preissiana											+	
Myoporum caparoides											+	
Myoporum insulare			+	+		+						

*Naturalised/ Name	1	2	3	4	5	6	7	8	9	10	11	con
Myoporum oppositifolia			+			+	+	+	+			
Sida hookeriana					+		+		+		+	
Menyanthaceae												
Villarsia albiflora				+					+			
Villarsia capitata								+				
Villarsia latifolia		+	+	+	+		+	+	+			
Villarsia parnassifolia				+				+	+			
Mimosaceae												
Acacia alata var alata	+	+			+			+	+	+	+	
Acacia browniana var. browniana							+		+			
Acacia cochlearis	+	+	+	+	+		+	+	+	+	+	
Acacia cyclops	+	+	+				+	+		+		
Acacia divergens			+					+	+	+	+	
Acacia extensa			+		+	+		+				
Acacia gilbertii				+					+			
Acacia hastulata									+			
Acacia huegelii	+	+		+	+							
Acacia latericola					+							
Acacia latericola glabrous variant (BR Maslin 6765)	+											P3
Acacia littorea	+	+	+	+	+	+	+	+	+	+	+	
Acacia mooreana	+	+	+									
Acacia myrtifolia	+			+	+			+	+	+	+	
Acacia nervosa	+								+			
Acacia obovata											+	
Acacia pulchella var. glaberrima	+	+	+	+	+	+	+	+	+	+	+	
Acacia pulchella var. pulchella	+	+	+						+		+	
Acacia rostellifera	+	+	+	+	+	+	+	+		+	+	
Acacia saligna	+	+	+	+		+	+					
Acacia semitrullata		+										P4
Acacia stenoptera	+	+		+		+	+	+				
Acacia subracemosa							+		+		+	P2
Acacia tetragonocarpa			+	+								
Acacia triptycha			+									
Acacia uliginosa							+		+			
Acacia urophylla					+				+		+	
Paraserianthes lophantha subsp. lophantha			+	+	+				+		+	
Moraceae												
* Ficus carica					+							
Myrtaceae												
Agonis flexuosa var flexuosa	+	+	+	+	+	+	+	+	+	+	+	
Agonis linearifolia		+			+	+		+	+			
Agonis parviceps		+	+	+					+			
Agonis fragrans									+			
Astartea affinis		+	+	+	+	+		+	+	+	+	
Astartea laricifolia				+	+						+	
Astartea leptophylla				+								
Astartea sp. Scott River (Backshall 88233)									+			
Baeckea camphorosmae	+			+	+		+		+			
Beaufortia sparsa									+			
Calothamnus graniticus subsp. graniticus	+	+										P4
Calothamnus lateralis									+		+	
Calothamnus pallidiflorus			+		+							
Calothamnus sanguineus	+			+								
Calytrix acutifolia subsp. acutifolia	+											
Calytrix angulata				+							+	
Calytrix flavescens	+	+		+	+							
Darwinia citriodora	+	+	+									
Eucalyptus calcicola subsp. calcicola							+	+	+			P4
Eucalyptus calophylla	+	+	+	+	+			+	+	+	+	
Eucalyptus cornuta	+	+					+	+			+	
Eucalyptus diversicolor							+		+	+	+	
Eucalyptus marginata subsp. marginata	+		+	+	+		+	+	+	+	+	
Eucalyptus marginata x megacarpa (Keighery 5332)	+											P4

*Naturalised/ Name	1	2	3	4	5	6	7	8	9	10	11	con
Eucalyptus megacarpa					+		+	+	+			
Eucalyptus patens				+								
Eucalyptus rudis subsp. cratyantha				+								P4
* Eucalyptus utilis				+								
Homalospermum firmum									+	+		
Hypocalymma angustifolium		+							+		+	
Hypocalymma robustum	+	+	+	+	+	+	+		+			
Kunzea ciliata		+	+	+								
Kunzea glabrescens			+					+	+			
Kunzea micrantha subsp. micrantha						+	+					
Kunzea rostrata											+	
Kunzea recurva						+	+	+	+			
Kunzea recurva x sulphurea(G/B Keighery 1247)									+			
Kunzea spathulata					+	+			+			
Kunzea sulphurea									+			
* Leptospermum laevigatum	+	+			+							
Melaleuca basicephala									+			P4
Melaleuca huegelii subsp. huegelii	+	+	+	+	+	+	+	+		+	+	
Melaleuca incana subsp. incana	+	+			+				+		+	
Melaleuca lanceolata	+	+	+	+		+	+				+	
Melaleuca lateritia									+			
Melaleuca pauciflora									+			
Melaleuca preissiana		+					+		+		+	
Melaleuca rhaphiophylla				+								
Melaleuca systena	+	+	+	+	+	+	+	+	+		+	
Melaleuca thymoides		+	+	+	+	+						
Micromyrtus racemosa var carinata		+										
Pericalymma crassipes									+			
Pericalymma ellipticum var ellipticum									+			
Thryptomene saxicola	+		+	+				+				
Verticordia plumosa var. plumosa				+								
Olacaceae												
Olax benthamiana								+			+	
Onagraceae												
Epilobium billardierianum subsp. billardierianum	+	+	+								+	
Epilobium billardierianum subsp. cinereum				+							+	
Epilobium hirtigerum		+	+	+						+	+	
* Oenothera stricta subsp. stricta					+							
Ophioglossaceae												
Ophioglossum lusitanicum	+	+	+					+			+	
Orchidaceae												
Caladenia abbreviata			+					+				
Caladenia applanata subsp. applanata	+	+	+	+		+	+				+	
Caladenia arrecta									+			P4
Caladenia attingens subsp. attingens	+	+	+	+				+	+			
Caladenia bicalliata subsp. bicalliata					+	+	+					
Caladenia brownii										+		
Caladenia cairnsiana											+	
Caladenia chapmanii	+	+						+				
Caladenia citrina	+											
Caladenia corynephora										+	+	
Caladenia exselsa		+	+	+	+	+						DRF
Caladenia ferruginea	+		+		+			+	+		+	
Caladenia flava subsp. flava	+	+	+	+	+		+	+	+		+	
Caladenia flava subsp. sylvestris	+	+										
Caladenia gardneri			+								+	
Caladenia georgei	+	+	+		+							
Caladenia hirta subsp. hirta	+	+	+	+	+			+	+	+	+	
Caladenia huegelii		+										
Caladenia infundibularis	+	+	+	+	+	+		+	+	+	+	
Caladenia latifolia	+	+	+	+	+			+	+	+	+	
Caladenia longicauda subsp. longicauda											+	
Caladenia longicauda subsp. clivicola	+											

*Naturalised/ Name	1	2	3	4	5	6	7	8	9	10	11	con
Caladenia longicauda subsp. merrittii									+			
Caladenia longiclavata	+											
Caladenia macrostylis	+		+				+		+	+	+	
Caladenia marginata		+						+	+	+	+	
Caladenia nana subsp. unita	+	+		+	+			+	+		+	
Caladenia nivalis	+	+	+	+								
Caladenia paludosa										+	+	
Caladenia pholocoidea subsp. pholocoidea	+	+			+						+	
Caladenia pholocoidea subsp. augustensis	+											
Caladenia plicata					+							
Caladenia reptans subsp. reptans	+			+	+				+		+	
Caladenia rhomboidiformis	+		+	+	+				+		+	
Caladenia thinicola		+										
Caladenia sp. Boranup (M. Spencer 71)									+			
Caladenia viridescens	+											DRF
Corybas despectans									+			
Corybas recurvus									+		+	
Cryptostylis ovata									+	+		
Cyanicula deformis	+	+								+	+	
Cyanicula gemmata								+	+	+	+	
Cyanicula gertrudiae		+										
Cyanicula sericea								+	+	+	+	
Cyrtostylis huegelii		+			+				+	+	+	
Cyrtostylis robusta				+								
* Disa bracteata		+				+		+	+	+	+	
Diuris amplissima	+	+	+	+								
Diuris corymbosa		+		+								
Diuris laevis					+			+	+			
Diuris laxiflora	+			+								
Diuris longifolia		+		+					+			
Drakaea glyptodon									+		+	
Drakaea livida				+			+					
Drakaea thynniphila				+								
Elythranthera brunonis	+			+	+		+		+	+	+	
Elythranthera emarginata	+				+							
Eriochilus dilatatus subsp. dilatatus										+	+	
Eriochilus dilatatus subsp. multiflorus	+				+	+			+			
Eriochilus heleonomos			+									
Eriochilus scaber subsp. scaber	+		+				+		+			
Leporella fimbriata		+							+		+	
Leptoceras menziesii							+	+	+	+	+	
Lyperanthus serratus							+	+	+		+	
Microtis alba					+				+			
Microtis atrata				+					+			
Microtis media subsp. densiflora	+											
Microtis media subsp. media								+	+	+	+	
Paracaleana nigrita					+							
Praecoxanthus aphyllus	+	+		+		+						
Prasophyllum brownii							+					
Prasophyllum calcicola		+		+			+	+				
Prasophyllum elatum		+		+				+			+	
Prasophyllum fimbria	+	+										
Prasophyllum gracile		+		+			+					
Prasophyllum hians								+				
Prasophyllum parvifolium		+		+		+						
Pterostylis aspera		+										
Pterostylis barbata									+			
Pterostylis brevisepala		+		+				+				
Pterostylis sp. Cauline Leaves (Gibson & Lyons 1490)							+		+	+	+	
Pterostylis pyramidalis					+							
Pterostylis recurva		+	+		+			+	+	+		
Pterostylis rogersii		+										
Pterostylis sp. Crinkle Leaves (G. Keighery 13426)				+	+							
Pterostylis turfosa		+		+								
Pterostylis vittata		+		+	+			+	+	+	+	
Pyrorchis nigricans					+		+	+	+	+		
Thelymitra cornicina								+			+	

*Naturalised/ Name		1	2	3	4	5	6	7	8	9	10	11	con
	Thelymitra antennifera	+	+		+				+				
	Thelymitra benthamiana		+										
	Thelymitra crinita	+	+	+	+	+							
	Thelymitra flexuosa							+				+	
	Thelymitra fuscolutea		+						+		+	+	
	Thelymitra graminea			+	+					+	+	+	
	Thelymitra granitora		+							+		+	
	Thelymitra macrophylla										+	+	
	Thelymitra mucida			+	+								
	Thelymitra villosa	+											
	Thelymitra vulgaris	+	+		+			+	+		+	+	
									+			+	
Orobanchaceae													
*	Orobanche minor	+	+	+	+	+			+		+	+	
Oxalidaceae													
	Oxalis exilis	+	+		+	+		+	+	+		+	
*	Oxalis glabra									+		+	
*	Oxalis incarnata									+			
*	Oxalis pes-caprae	+			+	+							
Philydraceae													
	Philydrella pygmaea				+				+	+			
Phormiaceae													
	Dianella brevicaulis	+	+		+	+	+		+	+		+	
	Dianella revoluta var. revoluta	+	+	+	+	+	+	+	+	+		+	
	Stypandra glauca	+	+	+	+				+	+		+	
Pinaceae													
*	Pinus pinaster					+				+			
Pittosporaceae													
	Billardiera drummondiana var collina											+	
	Billardiera floribunda	+										+	
	Billardiera fusiformis		+	+		+	+	+	+	+		+	
	Billardiera laxiflora								+				
	Billardiera parviflora var. parviflora	+	+		+					+		+	
	Billardiera variifolia	+	+					+	+	+		+	
	Cheiranthera preissiana var planifolia									+	+		
	Marianthus candidus	+	+	+	+		+	+	+	+	+	+	
	Marianthus erubescens		+										
	Marianthus tenuis	+	+	+		+	+	+	+	+	+	+	
	Pittosporum ligustifolium	+		+									
Planataginaceae													
	Plantago debilis	+	+		+			+					
*	Plantago lanceolata	+	+		+				+	+	+	+	
*	Plantago major	+			+	+			+				
Plumbaginaceae													
*	Limonium sinuatum	+	+	+					+				
Poaceae													
*	Aira caryophyllea	+	+	+	+	+	+					+	
*	Aira cupiana	+								+	+		
*	Aira praecox								+				
*	Ammophila arenaria	+		+	+	+						+	
	Amphipogon amphipogonoides	+	+	+							+	+	
	Amphipogon debilis	+	+	+				+			+	+	
	Amphipogon laguroides subsp. laguroides	+	+										
	Amphipogon strictus		+	+					+	+	+	+	
	Amphipogon turbinatus	+	+		+	+	+	+	+			+	
*	Anthoxanthum odoratum	+	+	+	+	+			+	+	+	+	
	Austrodanthonia caespitosa								+		+		
	Austrodanthonia occidentalis	+											

*Naturalised/	Name	1	2	3	4	5	6	7	8	9	10	11	con
	Austrodanthonia pilosa								+				
	Austrodanthonia setacea	+	+	+	+	+		+	+			+	
	Austrostipa compressa	+	+			+	+	+	+	+		+	
	Austrostipa elegantissima	+											
	Austrostipa flavescens	+	+			+	+	+	+		+		
	Austrostipa mollis		+										
	Austrostipa semibarbata	+	+		+	+			+	+			
*	Avellina michelii	+	+	+			+		+		+	+	
*	Avena barbata	+	+	+	+	+			+	+	+		
*	Briza maxima	+	+	+	+	+	+	+	+	+	+	+	
*	Briza minor	+	+	+	+	+							
	Bromus arenarius	+	+		+								
*	Bromus cathcarticus							+	+	+	+	+	
*	Bromus diandrus	+	+	+	+	+	+		+			+	
*	Bromus hordeaceus	+	+										
*	Bromus madritense	+	+		+								
*	Cynodon dactylon		+	+									
*	Cynosurus echinatus					+			+				
*	Desmazeria rigida	+		+				+	+				
	Deyeuxia quadriseta		+			+			+			+	
	Dichelachne crinita	+						+	+	+	+	+	
*	Digitaria sanguinalis			+	+				+	+		+	
	Echinopogon ovatus			+		+							
*	Ehrharta calycina	+	+	+	+	+							
*	Ehrharta erecta	+							+			+	
*	Ehrharta longifolia	+	+	+	+	+	+		+	+			
*	Ehrharta villosa					+	+					+	
	Elymus scaber	+	+									+	
*	Glyceria declinata				+	+							
	Hemarthria uncinata var uncinata								+				
*	Holcus lanatus		+	+	+	+				+	+	+	
*	Hordeum geniculatum							+					
*	Hordeum leporinum	+	+		+								
*	Hyparrhena hirta				+								
	Lachnagrostis filformis	+				+							
*	Lagurus ovatus	+	+	+	+	+				+	+	+	
*	Lolium perenne	+	+										
*	Lolium rigidum	+	+	+	+	+	+		+	+	+	+	
*	Lolium temulentum								+			+	
	Microlaena stipoides var stipoides	+	+	+	+	+		+	+	+	+	+	
	Neurachne alopecuroidea	+	+		+	+	+						
*	Panicum capillare var capillare	+							+				
*	Paraphlois incurva	+	+		+	+							
*	Paspalum dilatatum				+							+	
*	Paspalum distichum			+	+	+							
*	Paspalum urvillei				+								
*	Paspalum vaginatum	+			+	+	+					+	
*	Pennisetum clandestinum		+		+					+		+	
*	Pennisetum purpureum			+									
*	Pentaschistis airoides	+		+		+				+	+	+	
*	Phleum arenarium		+	+									
*	Phleum pratense					+							
*	Poa annua											+	
	Poa drummondiana	+	+		+			+	+	+			
	Poa poiformis		+	+	+	+	+	+	+			+	
	Poa porphyroclados	+			+	+			+	+			
*	Polypogon monspeliensis				+	+			+	+		+	
	Polypogon tenellus								+				
	Spinifex hirsutus	+	+	+	+	+	+	+	+		+	+	
	Spinifex longifolius	+	+	+		+	+	+	+		+		
*	Sporobolus indicus var capensis		+		+				+	+		+	
	Sporobolus virginicus				+	+	+	+	+			+	
*	Stenotraphum secundatum				+	+		+	+	+		+	
	Tetrarrhena laevis		+	+		+	+	+	+	+		+	
*	Vulpia fasciculata								+				
*	Vulpia myuros	+	+		+	+	+		+		+		

*Naturalised/ Name	1	2	3	4	5	6	7	8	9	10	11	con
Podocarpaceae												
Podocarpus drouynianus					+	+	+	+	+	+	+	
Polygalaceae												
Comesperma calymega	+	+						+	+			
Comesperma confertum	+	+	+		+	+	+		+			
Comesperma flavum									+			
Comesperma nudiusculum									+			
Comesperma virgatum				+			+	+	+		+	
										+		
Polygonaceae												
* Acetosella vulgaris				+								
* Emex australis	+	+										
Muehlenbeckia adpressa	+		+		+	+	+	+	+	+	+	
Persicaria decipiens			+	+							+	
Persicaria prostrata		+		+								
* Rumex crispus				+	+							
Portulacaceae												
Calandrinia brevipedata	+	+					+			+		
Calandrinia composita				+								
Calandrinia corrigioloides	+											
Calandrinia granulifera	+	+										
Calandrinia liniflora	+		+	+	+							
Calandrinia sp. SW Coastal (J. Dodd 753)	+	+										
Potamogetonaceae												
Potamogeton drummondii						+						
Potamogeton pectinatus				+			+					
Primulaceae												
* Anagallis arvensis var. arvensis	+	+		+	+	+			+			
* Anagallis arvensis var. caerulea	+	+	+	+	+			+	+	+	+	
Samolus junceus				+								
Samolus repens var repens				+	+	+	+	+			+	
* Samolus valerandi			+	+	+						+	
Proteaceae												
Adenanthos barbiger subsp. barbiger		+	+	+								
Adenanthos meisneri	+	+	+	+		+	+					
Adenanthos obovatus	+			+					+			
Banksia attenuata	+	+	+	+	+	+	+					
Banksia dellyeana var lindleyana	+	+	+	+	+	+	+					
Banksia delleyana var sylvestris									+			
Banksia grandis	+	+		+			+		+		+	
Banksia illicifolia		+	+	+	+	+			+			
Banksia littoralis		+	+	+					+			
Banksia nivea var nivea				+			+					
Banksia seminuda								+				
Banksia sessilis var cordata	+	+		+	+	+	+	+	+	+	+	P4
Conospermum caerulum subsp. debile	+			+								
Conospermum capitatum subsp. glabratum	+	+		+			+		+			
Grevillea quercifolia		+			+	+						
Grevillea vestita subsp. vestita	+				+						+	
Hakea amplexicaulis					+				+			
Hakea ceratophylla			+		+							
Hakea linearis							+	+	+	+		
Hakea lissocarpha	+				+	+	+				+	
Hakea oleifolia	+	+		+		+	+	+	+	+	+	
Hakea prostrata	+	+	+	+	+	+	+	+	+	+		
Hakea ruscifolia	+			+	+	+	+	+	+	+	+	
Hakea sulcata									+			
Hakea trifurcata	+	+	+	+								
Hakea varia			+	+	+	+						
Isopogon sphaerocephalus		+										
Persoonia elliptica	+	+		+			+	+	+			

*Naturalised/ Name	1	2	3	4	5	6	7	8	9	10	11	con
Persoonia longifolia		+	+	+		+	+		+			
Petrophile axillaris						+	+	+				
Petrophile linearis	+	+	+	+	+	+						
Petrophile serruriae				+	+							
Synaphea floribunda		+										
Synaphea gracillima				+								
Synaphea petiolaris	+	+		+	+							
Xylomelon occidentale		+			+				+			
Pteridaceae												
Pteris vittata					+	+		+				
Ranunculaceae												
Clematis linearifolia	+	+										
Clematis pubescens	+		+	+	+		+	+	+		+	
Ranunculus colonorum		+	+		+		+	+	+	+	+	
* Ranunculus muricatus		+						+			+	
Ranunculus pumilio		+										
Ranunculus sessiliflorus subsp. sessiliflorus								+				
Restionaceae												
Anarthria gracilis				+	+	+						
Anarthria laevis	+				+							
Anarthria prolifera				+	+	+			+			
Anarthria scabra	+	+	+		+		+	+	+	+	+	
Chaetanthus aristatus									+		+	
Chaetanthus leptocarpoides									+			
Desmocladus asper	+	+		+	+			+	+			
Desmocladus fasciculatus	+	+		+					+			
Desmocladus flexuosus	+	+	+	+	+	+	+	+	+		+	
Empodisma gracillimum									+			
Hypolaena exsulca		+	+	+	+	+	+		+			
Hypolaena macrotepala				+								
Hypolaena pubescens				+							+	
Hypolaena viridis							+	+				
Leptocarpus laxus									+			
Lepyrodia muirii									+			
Loxocarya cinerea	+	+	+	+	+	+	+	+	+	+		
Lyginia barbata	+		+	+	+	+		+	+	+		
Meeboldina cana									+			
Meeboldina coangustata									+			
Meeboldina crebriculmis									+			
Meeboldina denmarkica							+					
Meeboldina scariosa				+	+		+		+			
Meeboldina tephrina				+					+			
Meeboldina thysanantha									+			P3
Melanostachya ustulata									+		+	
Sporodanthus strictus									+			
Stenotalis ramosissima				+	+						+	
Stenotalis ramosissima				+	+						+	
Rhamnaceae												
Cryptandra arbutiflora var tubulosa	+	+	+	+		+						
Spyridium globulosum	+	+	+	+	+	+	+	+	+	+	+	
Trymalium floribundum subsp. trifidum		+			+		+	+	+		+	
Trymalium ledifolium var. rosmarinifolium	+	+	+				+					
Rosaceae												
* Acaena echinata	+							+	+		+	
* Rubus bellobatus								+	+			
* Rubus discolor				+								
* Rubus ulmifolius										+	+	
Rubiaceae												
* Galium divaricatum			+								+	
Galium leptogonium									+	+		P3

*Naturalised/ Name		1	2	3	4	5	6	7	8	9	10	11	con
*	Galium murale	+	+		+				+		+	+	
	Opercularia apiciflora		+			+		+	+	+	+		
	Opercularia echinocephala				+								
	Opercularia hispidula			+		+		+	+	+		+	
	Opercularia vaginata	+	+		+	+	+	+	+				
	Opercularia volubilis					+				+			
*	Sherardia arvensis	+		+		+		+	+	+	+		
Ruppiaceae													
	Ruppia megacarpa							+	+				
Rutaceae													
	Boronia alata	+	+	+	+	+	+	+	+	+		+	
	Boronia anceps				+								P3
	Boronia crenulata subsp. crenulata						+	+	+	+			
	Boronia crenulata subsp. pubescens	+			+								
	Boronia dichotoma	+											
	Boronia gracilipes					+				+	+	+	
	Boronia molloyae		+			+							
	Boronia ramosa subsp. anethifolia		+										
	Boronia stricta						+						
	Chorilaena quercifolia			+	+			+		+		+	
	Diplolaena dampieri	+	+	+	+			+	+			+	
	Diplolaena microcephala									+		+	
	Philotheca spicata	+	+	+	+	+		+	+	+	+		
	Rhabdinothamnus anceps			+	+	+		+		+		+	
Santalaceae													
	Exocarpus odoratus								+			+	
	Exocarpus sparteus	+		+		+		+	+	+			
	Leptomeria scrobiculata										+		
	Leptomeria squarrulosa							+		+	+	+	
	Santalum acuminatum	+	+		+	+	+	+	+	+			
Sapindaceae													
	Dodonaea aptera	+	+	+	+		+						
	Dodonaea ceratocarpa		+	+	+							+	
Schizaeaceae													
	Schizaea fistulosa											+	
Scrophulariaceae													
*	Bartsia trixago	+	+	+	+	+			+	+			
*	Dischisma arenarium	+	+	+	+	+			+		+		
	Grattiola pubescens				+	+	+		+	+	+	+	
*	Parentucellia latifolia	+			+	+	+	+	+	+	+		
*	Parentucellia viscosa	+			+				+		+		
*	Verbascum virgatum	+				+				+			
*	Veronica arvensis					+							
	Veronica distans	+	+	+		+		+	+	+			
	Veronica plebeia				+						+		
Selaginellaceae													
	Selaginella gracillima			+	+	+			+	+		+	
Solanaceae													
	Anthocercis littorea		+		+			+	+	+		+	
*	Physalis peruviana					+				+			
*	Solanum americanum					+						+	
*	Solanum linnaeanum											+	
*	Solanum nigrum					+				+		+	
	Solanum symonii					+		+	+	+	+	+	
Stackhousiaceae													
	Stackhousia pubescens	+	+		+	+		+	+	+	+		
	Tripterococcus brunonis	+	+	+			+	+	+	+	+		

*Naturalised/ Name	1	2	3	4	5	6	7	8	9	10	11	con
Sterculiaceae												
Guichenotia ledifolia	+		+									
Lasiopetalum floribundum					+				+			
Rulingia corylifolia											+	
Rulingia cygnorum	+											
Rulingia grandiflora										+		
Thomasia cognata	+	+		+								
Thomasia heterophylla									+			
Thomasia purpurea			+									
Thomasia triloba									+			
Thomasia triphylla	+	+	+	+	+		+	+			+	
Stylidiaceae												
Levenhookia dubia		+		+				+				
Levenhookia pauciflora							+	+	+	+	+	
Levenhookia preissii		+										
Levenhookia pusilla	+	+	+	+	+	+	+		+			
Levenhookia stipitata	+	+	+	+	+							
Stylidium adnatum var adnatum	+	+	+				+	+	+			
Stylidium affine	+										+	
Stylidium amoenum		+	+		+		+		+		+	
Stylidium brevis	+	+		+	+		+		+			
Stylidium breviscapum		+										
Stylidium bulbiferum				+								
Stylidium caespitosum									+			
Stylidium calcaratum	+	+			+	+			+	+		
Stylidium carnosum									+			
Stylidium ciliatum					+				+			
Stylidium crassifolium			+								+	
Stylidium despectum									+			
Stylidium diversifolium	+								+			
Stylidium ecorne	+			+	+		+					
Stylidium emarginatum								+	+			
Stylidium fasciculatum				+		+	+	+	+	+	+	
Stylidium glaucum				+								
Stylidium guttatum			+						+			
Stylidium hesperium				+	+			+				
Stylidium innundatum				+							+	
Stylidium junceum	+								+			
Stylidium laciniatum							+		+			
Stylidium lowrieanum		+	+		+	+	+	+				
Stylidium luteum				+								
Stylidium mimeticum									+			
Stylidium neurophyllum	+	+	+									
Stylidium perpusillum					+	+						
Stylidium petiolare	+			+					+			
Stylidium piliferum	+			+	+							
Stylidium pygmaeum									+			
Stylidium repens var. repens				+	+	+						
Stylidium rhynchocarpum			+		+		+	+	+		+	
Stylidium scandens									+		+	
Stylidium schoenoides	+	+	+									
Stylidium spathulatum	+											
Stylidium squamotuberosum									+			
Stylidium violaceum					+	+						
Thymelaeaceae												
Pimelea angustifolia			+	+					+		+	
Pimelea argentea								+	+	+		
Pimelea ciliata subsp. longituba										+		P3
Pimelea clavata								+	+		+	
Pimelea ferruginea	+	+	+	+	+	+	+	+		+	+	
Pimelea hispida									+		+	
Pimelea imbricata var piligera					+							
Pimelea lanata			+									
Pimelea longiflora subsp. longiflora			+				+					

*Naturalised/ Name	1	2	3	4	5	6	7	8	9	10	11	con
Pimelea preissii	+	+						+	+		+	
Pimelea rosea subsp. rosea	+	+			+	+		+	+	+	+	
Pimelea spectabilis	+	+			+						+	
Pimelea suaveolens subsp. suaveolens		+										
Pimelea sylvestris					+		+	+	+	+	+	
Tremandraceae												
Tetratheca affinis	+		+	+								
Tetratheca filiformis							+		+			
Tetratheca hirsuta	+	+				+	+					
Tetratheca setigera	+		+	+	+	+			+			
Tremandra diffusa		+			+		+		+	+	+	
Tremandra stelligera					+				+		+	
Typhaceae												
* Typha orientalis				+	+	+					+	
Urticaceae												
Parietaria debilis	+	+	+	+			+	+	+	+	+	
* Soleirolia soleirolii										+	+	
Violaceae												
Hybanthus calycinus	+	+		+	+	+						
Hybanthus debilissimus								+	+		+	
* Viola odorata									+			
Xanthorrhoeaceae												
Xanthorrhoea gracilis	+	+		+	+		+					
Xanthorrhoea preissii	+	+	+	+	+	+	+	+	+	+	+	
Xyridaceae												
Xyris gracillima									+			
Xyris lacera									+			
Xyris roycei									+			
Zamiaceae												
Macrozamia fraseri	+	+	+	+	+	+	+	+	+	+	+	
Zygophyllaceae												
Nitraria billardierei	+	+				+		+		+		

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Flora and vegetation of banded iron formations of the Yilgarn Craton: the Lee Steere Range

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ABSTRACT

The Lee Steere Range is located on the northern edge of the Yilgarn Craton, adjacent to the Capricorn Orogeny, c. 200 km north-east of the township of Wiluna. Fifty permanent vegetation quadrats were established, with all vascular flora and a series of environmental attributes recorded. A total of 100 taxa were recorded, representing 27 families and 40 genera. A single taxon of conservation significance was identified, which also represented a c. 200 km range extension for this taxon. Two putative taxa were collected; further material is required for confirmation. Five floristic communities were identified from the survey; these communities were strongly associated with topographical position, local geology and edaphic factors. The Lee Steere Range is a relatively intact banded ironstone formation with little evidence of disturbance. Any future exploration or development should ensure that the important conservation values and condition of the range are retained.

Keywords: banded ironstone, Earaheedy, floristic communities, Gascoyne, Yilgarn.

INTRODUCTION

The Lee Steere range is located approximately 200 km northeast of Wiluna. The range is located on the north-east edge of the Yilgarn Craton and bordered by Capricorn Orogen. The range is the significant feature in the landscape, which is generally characterised by low relief (Commander et al. 1982). The Lee Steere Range represents erosional uplands with scree slopes and pediments transitioning to mixed alluvial deposits associated with extensive salt lakes to the south (Commander et al. 1982). The region is known as Kurrara–Kurrara by the Wiluna Aboriginal group within the Ngaanyatjarra Council. The first European explorers to venture near the Range were part of John Forrest's party (1874), who travelled via the Parker Ranges north of Lee Steere (Beard 1974). Other early explorers to the area include members of the LA Wells Expedition (1896–97; Commander et al. 1982).

STUDY SITE

Lee Steere Range is located in the south-eastern pocket of the Gascoyne Bioregion (Thackway & Creswell 1995) and trends west-north-west. The range is approximately 90 km in length and c. 6–8 km wide, occurring within 25° 26' S and 25° 39' S latitude and 121° 30' E and 122° 22' E longitude. The Range is c. 17 km north by road of the former Earaheedy homestead, which is now abandoned. The primary access is via the Sydney Heads Pass Road, which bisects the western portion of the Range, connecting the Earaheedy and Glen-Ayle leases.

Land Use History

Lee Steere Range extends across the northern portion of the former Earaheedy pastoral lease, with the remainder of the range located on unallocated crown land (UCL) and the neighbouring Carnegie Pastoral Lease. The Earaheedy pastoral lease, established in 1903, primarily stocked sheep, and Carnegie, established in 1921, stocked cattle (Commander et al. 1982). Following the acquisition of the Earaheedy pastoral lease by the Department of Environment and Conservation (DEC; then Conservation and Land Management in 2001), the property was destocked, the homestead removed and the artificial watering points closed. The property has been officially named Kurrara-Kurrara, in recognition of the Aboriginal heritage of the area, and nomination for inclusion in the conservation estate is pending. Active and pending exploration tenements are held over the Range (Department of Mines 2009).

Climate

Lee Steere Range falls into the portion of the Gascoyne bioregion defined as desert, with hot summers and cool winters, with the highest rainfall events associated with summer cyclonic activity. The closest weather station is the former Earaheedy homestead, which ceased operations in 2000 (Bureau of Meteorology 2009). The closest active weather station is at Carnegie, which is situated 140 km east of the homestead. Average annual rainfall at Earaheedy is 240.5 mm (based on records from 1946 to 2000), with the months of February and September having the highest (50.5 mm) and lowest (3.4 mm) mean monthly rainfall, respectively. The lowest annual rainfall was recorded in 1972 (78.1 mm) and the highest rainfall recorded in 1947 (529.7 mm). The single largest rainfall event occurred on 3 February 1980, with 202 mm rain recorded.

Temperatures were recorded at Earaheedy from 1952 to 1988. The average annual maximum is 29.9 °C and average annual minimum is 15.2 °C for the area. The hottest temperatures occur between October and April, with mean maximum temperatures exceeding 30 °C. January is the hottest month, with the mean maximum and mean minimum temperatures of 38.6 °C and 23.9 °C, respectively. The hottest daily maximum on record is 46 °C on 22 December 1972. The lowest daily minimum temperatures occur between June and August, where mean minimum temperatures are below 10 °C. The coolest month of the year is July, with the average maximum and minimum daily temperature of 20.4 °C and 5.6 °C, respectively. The coldest minimum temperature of -3.6 °C was recorded on 23 June 1981. Temperatures below 0 °C have been recorded between June and August, with July having a mean number of 1.5 days with temperatures <0 °C.

Geology

The geology of the Lee Steere Range has been described and mapped on the Stanley 1:250,000 map sheet (Commander et al. 1982) and the 1:100,000 Earaheedy (Hocking et al. 2001) and Lee Steere map sheets (Hocking & Pirajno 2004). The Lee Steere Range trends predominantly west-north-west, at the juncture of the Yilgarn Craton (c. 3.0 to 2.6 Ga; Myers 1993, Myers & Swagers 1997) and the Capricorn Orogen to the north and east. The Yilgarn Craton features a series of greenstone belts that have undergone low grade metamorphism (Myers & Swagers 1997). The majority of the Range is between c. 525 and 600 m above sea level, with the adjacent aeolian sands, colluvial and alluvial sediments sitting c. 500 m above sea level. The highest points in the Range are Mt Royal (625 m) and Mt Evelyn (631 m), which are associated with the Mudan Hills in the western extent of the Range.

At the juncture of the Yilgarn Craton and Capricorn Orogen is the Stanley Fold Belt, which includes the Lee Steere Range. The Stanley Fold Belt represents deformation resulting in tightly folded and faulted rocks (Myers 1990; Hocking et al. 2001; Abeysinghe 2005) of the Earaheedy Group (1.8–1.7 Ga; Myers 1993). The bedrock of the Lee Steere Range is Archaean granitoid, overlain by Early Proterozoic formations of the Earaheedy Group within the Nabberu Basin (Commander et al. 1982; Abeysinghe 2005). Degradational processes have exposed bedrock of the early Proterozoic period, which forms the majority of the Range, including the Mudan Hills of the western portion of the Range. The Sydney Heads Pass Road, adjacent to the Mudan Hills, bisects the Range. Sydney Heads Pass contains conglomerate and sandstone of undetermined age (Commander et al. 1982; Abeysinghe 2005).

The northern slopes of the Range are predominantly composed of the Yelma Formation, which is characterised by quartz-rich sandstone, arkose and shale (Commander et al. 1982). The central and southern slopes of the Range are composed of the younger Frere Formation, dominated by granular and laminar iron formations, hematite shale, chert, shale and minor carbonates (Commander et al. 1982). The Frere Formation in the Earaheedy Basin has been proposed as the greatest potential resource for iron in the region (Pirajno et al. 2002), with early assays of Mt. Ooloongathoo, in the far western portion of the Range, indicating 60% iron (Abeysinghe 2005). Quaternary aeolian sands border most of the northern slopes of the Range, while adjacent to the southern slopes are predominantly colluvial sediments transitioning to mixed alluvium and lake deposits.

General soil structure for uplands in the Yilgarn Craton is shallow stony soils on the crests, transitioning down slope to gravelly sandy loams, then finer sandy clay loams and light clays overlain by colluvium (Anand & Paine 2002). Breakaways, pediments and associated erosional plains are principally stony sandy loams to sandy clay loams with occasional underlying hardpans (Anand & Paine 2002). Beard (1990) described the prevailing soil types of the Gascoyne as shallow stony soils on the ranges, with red-brown hardpans overlain by earthy loams dominating the colluvial plains. Areas of lower relief are principally red loams with ironstone gravels and quartz pebbles overlying hardpan. Areas adjacent to and underlying salt lakes are associated with lime, gypsum and red clays (Beard 1974).

Vegetation

Lee Steere occurs within the Ashburton Botanical District (Beard 1990) of the Gascoyne bioregion, according to the current Interim Biogeographic Regionalisation of Australia (IBRA; Thackway & Creswell 1995; Department of the Environment and Water Resources 2004). Beard (1974) traversed the Gascoyne while mapping the 1:1,000,000 Great Victoria Desert map sheet. The Lee Steere Range was described as a shrub steppe flanked by *Acacia aneura* (mulga) to the north and south of the range within the Carnegie Salient (Beard 1974). The shrub steppe of the Carnegie Salient consists of scattered *Acacia* spp. shrubs over hummock grasslands of *Triodia pungens* (Beard 1974).

The Gascoyne region marks the transition from the shrublands of the Murchison to the hummock grasslands typical of the more arid environments (Beard 1990). Beard (1990) described the Lee Steere Range as dominated by spinifex, transitioning further south to mulga woodlands. Beard (1990) noted distinct vegetation changes approaching the Little Sandy Desert, north of the Carnegie Salient. In particular, within the Mudan Hills, Beard (1974) highlighted the presence of *Triodia melvillei* amongst *Acacia pruinocarpa* and *Eucalyptus setosa* with shrubs of *Ptilotus obovatus*, *Eremophila latrobei* and *Thryptomene maisonneuvei*. The low-lying flats adjacent to the ranges are predominantly low mulga woodlands interspersed with *A. pruinocarpa* and *Psydrax latifolia* (Beard 1990).

There have been no systematic flora surveys undertaken on the Lee Steere Range. Recent surveys on greenstone belts and associated ironstone formations 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 aimed to record the floristic diversity, describe vegetation patterns and examine environmental correlates on the Lee Steere Range.

METHODS

Fifty 20 x 20 m permanent quadrats were established in mid-September 2008. The quadrats were placed so as to capture the topographical, geological and geomorphological variation across the length and breadth of the range, including the Mudan Hills. Access was limited through the central portion of the Range due to few existing tracks. Survey methods followed those of previous surveys on Greenstone belts in the Yilgarn Craton (e.g. Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c). Quadrats were located across a broad topological sequence from hill crests down slope to the colluvial deposits at the base of the range, in areas with minimal disturbance or modification. Thus, we avoided areas with heavy grazing, evidence of clearing or exploration-related disturbance.

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

Vegetation structure was determined by assigning dominant taxa to the relevant stratum, noting emergent taxa where appropriate (McDonald et al. 1998). All vascular plants were recorded from within the quadrat 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 Western Australian Herbarium (WA Herbarium). Additional specimens were collected adjacent to the plots, contributing to the overall species list for the range. Representative material for all taxa was lodged at the WA Herbarium. Nomenclature generally follows Paczkowska and Chapman (2000).

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) was calculated using a modified Kjeldahl digest (method S10; Rayment & Higginson 1992).

The classification and ordination analyses were undertaken on a data matrix of the perennial species that were recorded in more than one quadrat, which is consistent with previous Greenstone belt studies (Gibson 2004a, 2004b). The dissimilarity between sites was determined using the Bray–Curtis measure and the Resemblance routine in PRIMER v6 (Clarke & Gorley 2006). The Bray–Curtis measure is a widely-used assessment of ecological distance, which reflects differences in relative abundance and compositional change (Legendre & Legendre 1998; Anderson & Robinson 2003), and provides quantitative output for similarity between samples (Faith et al. 1987). The species by site matrix was classified using flexible unweighted pair-group mean average (UPGMA, $\beta = -0.1$; Belbin 1989). The similarity profile (SIMPROF) routine in PRIMER v6 was used to determine, a priori, similarities in the structure of communities between samples ($p < 0.05$). Non-metric Multi-Dimensional Scaling (MDS) of the site similarity matrix was used to highlight groups determined through the SIMPROF procedure.

The degree of association between individual species with each community group, as determined by SIMPROF, was measured using indicator species analysis (Dufrêne & Legendre 1997). Indicator values examine information on constancy and fidelity of occurrence of each species. Statistical significance of the indicator values was determined by using the Monte Carlo randomization procedure performed with 1000 iterations in 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 that contribute most to the similarity within a community and dissimilarity between 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). An environmental data matrix was created using soil chemical properties and site physical characteristics. The BIO-ENV routine within in PRIMER v6 was used to determine those environmental variables most highly correlated with the species resemblance matrix (Clarke & Gorley 2006). The environmental variables were log(1+x) transformed and normalised prior to performing the BIO-ENV routine. The resulting environmental variables identified through the BIO-ENV process were then analysed using Kruskal–Wallis nonparametric analysis of variance, with post-hoc significance testing at $\alpha = 0.05$ (Sokal & Rolf 1995).

RESULTS

A total of 100 species from 27 families and 40 genera were recorded in the 50 quadrats on the Lee Steere Range (Fig. 1). A further eight taxa were collected from areas adjacent to the quadrats. The dominant families were Mimosaceae (17 taxa), Malvaceae (12 taxa), Poaceae (12 taxa), Caesalpiniaceae (11 taxa), and Myoporaceae (9 taxa). The genera with the greatest representation were *Acacia* (17 species), *Senna* (11 species), *Eremophila* (9 species), and *Sida* (7 species). The majority of the taxa recorded were perennial shrubs. There were nine annuals, two geophytes and a single weed species identified.

Priority Taxon

A single priority-listed taxon was identified from the Lee Steere Range. *Baeckea* sp. Melita Station (H Pringle 2738; P3) was recorded from four quadrats, all located on the crest or upper slopes of the range. *Baeckea* sp. Melita Station (H Pringle 2738) is an upright shrub of up to 2.5 m height with a distinctive hooked apex on the leaf. The species is primarily distributed on ironstones throughout the Murchison bioregion, with the Lee Steere Range populations the second to be recorded within the Gascoyne bioregion. Furthermore, the populations recorded on Lee

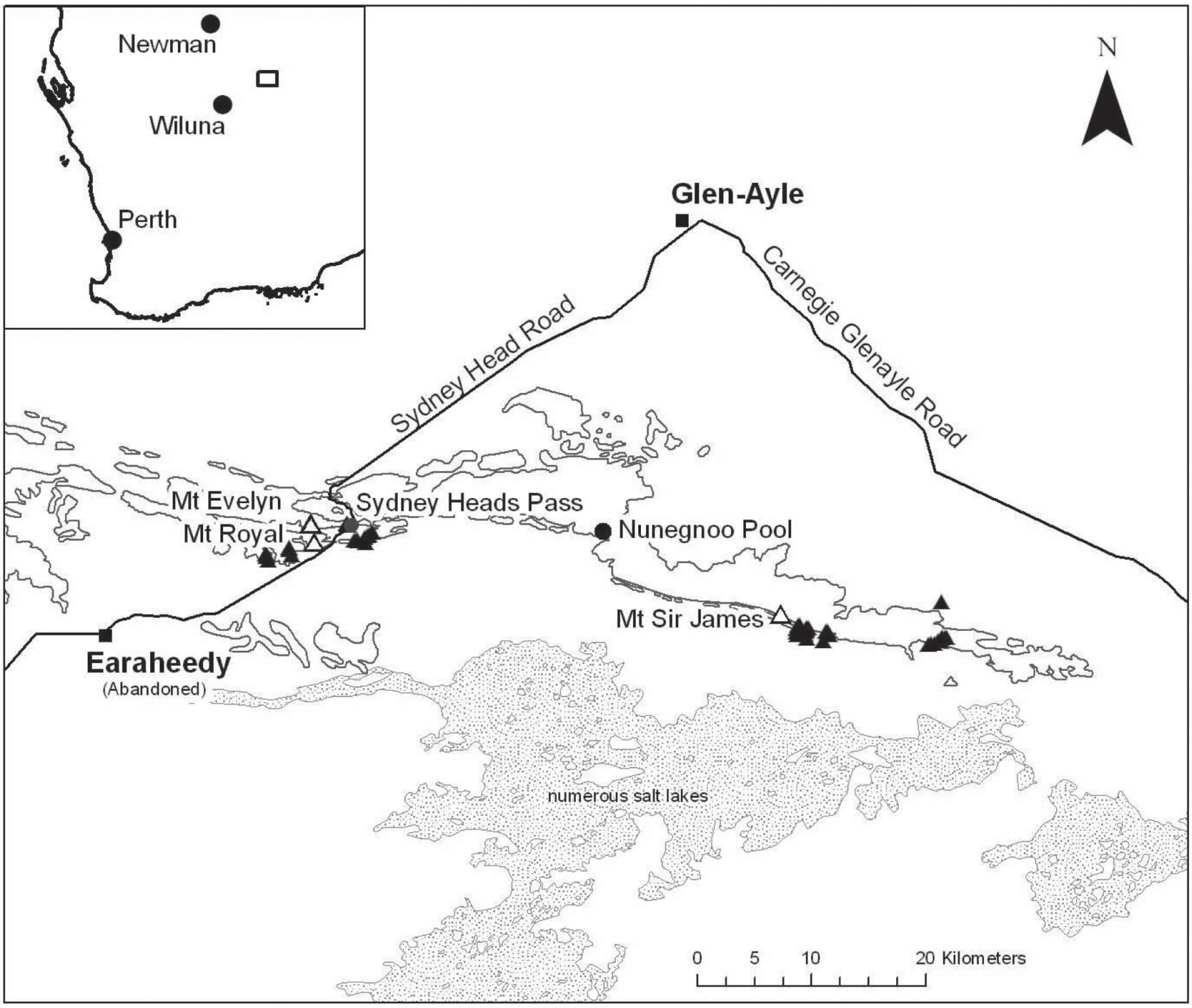

Figure 1. Map showing the location of the Lee Steere Range survey area, with major landforms and landmarks indicated. The locations of the 50 permanent quadrats are marked by triangles (▲).

Steere represent a range extension of approximately 200 km to the north-east. The nearest population of *B.* sp. Melita Station (H Pringle 2738) to Lee Steere occurs south-east of Wiluna.

Range Extensions

In addition to the priority taxon, a further five species recorded on the Lee Steere range had their known distributions extended by c. 100–200 km. This includes a c. 150 km range extension for *Hibiscus gardneri* AS Mitch. ms. *Lepidium oxytrichum* is widespread throughout large areas of the Eremaean botanical province, with the collections primarily occurring from the southern Pilbara to the Coolgardie bioregions. The single collection from the Lee Steere Range extends the distribution of this species c. 100 km east from the nearest locality at the edge of the Little Sandy Desert. Additional specimens have been collected c. 400 km east from Lee Steere in the Gibson and Great Victoria Deserts. *Sida ectogama* is a dioecious shrub primarily known from the Murchison bioregion. The collections from Lee Steere extend the distribution of this species c. 200 km east-north-east from the township of Wiluna. The geophyte *Cheilanthes brownii* has been widely recorded from the Murchison, Pilbara and Kimberley; the Lee Steere collection represents a c. 200 km range extension east. *Stenanthemum petraeum* is known from disjunct collections from the northern Murchison/Gascoyne and the Central Ranges. The collection of this species from the Lee Steere Range extends its known range by c. 200 km north-east from the nearest collection in the Joyner's Find Range south-west of Wiluna. The records from the edge of the Gibson Desert/ Central Ranges are c. 450 km east-south-east of the Lee Steere Range. The disjunct distribution and range extensions are likely a result of lack of sampling.

Possible New Variety/Species

A potentially new variety within the *Acacia aneura* complex (mulga) was identified during this survey. *Acacia aneura* aff. *argentea* was identified as a possible new variety due to resin differing from *A. aneura* var. *argentea*. *Acacia aneura* aff. *argentea* exhibits resin that is translucent aging to opaque on the branchlets (B Maslin pers. comm.[1]). The *A. aneura* complex is currently undergoing taxonomic revision and preliminary alliances based on characters such as pods, branchlet ribs and resin, phyllodes and new shoots have been identified. Typical *A. aneura* var. *argentea* occurs within the mulga alliance identified by winged pods and opaque resin (B Maslin pers. comm.). The specimens collected during the survey were sterile and pods were not located to aid in identification.

A single specimen identified from the genera *Trianthema*, collected from the salt flats south of the range, does not match any of the collections in the WA Herbarium. The specimen has been given the phrase name *Trianthema* sp. Lee Steere (WA Thompson and NB Sheehy 639). Insufficient material was present to provide additional information and further collections are needed.

Hybrids/Integrades

Interspecific hybrids of *Senna* and integrades of *A. aneura* were collected during the survey. All hybrids were matched with collections held at the WA Herbarium. Two interspecific hybrids of *Senna* were identified. A single integrade within the *A. aneura* complex was identified. At present, the revision of the *A. aneura* complex has identified a series of integrades between varieties within the complex. The survey recorded *A. aneura* var. *alata*/ *microcarpa*, which exhibits resin characteristics of both varieties (translucent and opaque) on the branchlets (B Maslin pers. comm.). Taxonomic work is underway to determine whether they are separate entities or gradations within a single variant.

Floristic Communities

Eight taxa of the 100 species identified from the survey were amalgamated into three species complexes. All annual, singletons and specimens identified only to genera level were removed before statistical analyses. The resulting species by site matrix analysed contained 70 species from 50 quadrats. The minimum and maximum species recorded per quadrat were seven and 27, respectively. The average species richness across all quadrats was 15.1 ± 3.7 SD.

The classification routine based on hierarchical clustering separated the taxa into six species groups (A–F; Table 1). The most widespread taxa occured in species

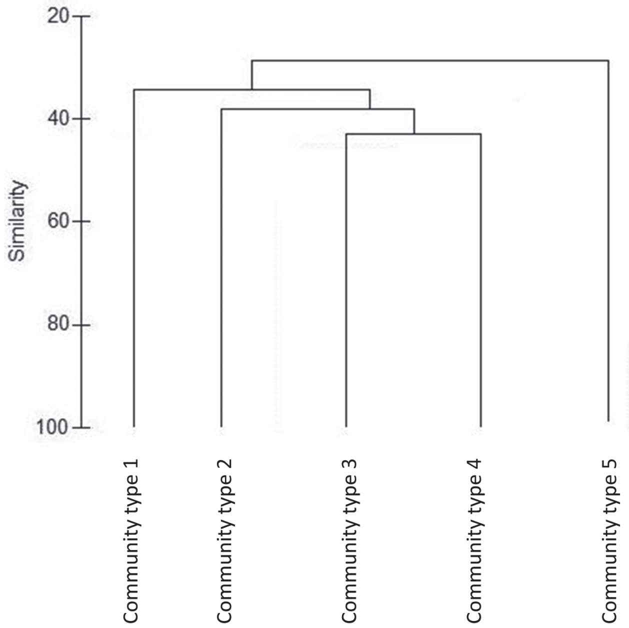

Figure 2. Summary dendrogram of community types for the Lee Steere Range based on the matrix of 70 species x 50 sites. The five community types displayed are derived from the SIMPROF routine.

[1] Bruce Maslin, Western Australian Herbarium, Department of Environment and Conservation, Perth.

group D, which was represented in all of the community types. The SIMPROF routine identified five community types (Fig. 2). The two-way table highlighted the relationship between the species and site groups (Table 1). The MDS routine displayed the interrelationship between the sites, based on the resemblance matrix (Fig. 3). The separation of community types was highlighted in multi-dimensional space, with quadrats with similar taxonomic composition occurring closer together. The resulting 3D stress value was 0.15.

Community type 1 was generally located on the mid-slopes of banded ironstone formation (BIF) with gentle to moderate gradients, and was recorded from four quadrats. Community structure was tall open *Acacia* shrubland, particularly *A. quadrimarginea*, over a sparse to open mid-stratum of *Eremophila margarethae* and *Senna glaucifolia* shrubs, with open hummock grasslands of *Triodia melvillei*. Indicator species analyses (Table 2) suggested that *A.quadrimarginea*, *A. rhodophloia*, *Eremophila margarethae*, *Keraudrenia velutina* subsp. *elliptica*, *Senna glaucifolia*, *Stenanthemum petraeum* and *Triodia melvillei* were typical taxa for this community. This community type was strongly allied with species group D, with minor representative taxa from species group F (Table 1). There were no taxa from species groups A, B or C in this community. This community type was relatively species poor, with seven to 13 taxa recorded per quadrat.

Soils from this community had low potassium (40–50 mg kg^{-1}, mean = 45.2 ± 4.6 SD) and phosphorus (4–5 mg kg^{-1}, mean= 4.5 ± 0.6 SD; Table 3) concentrations. Coarse fragments, primarily weathered banded ironstone, were a significant component of the bare ground, with some presence of exposed bedrock of weathered ironstone. Soils were strongly acidic (pH 3.9–4.1) sandy loams.

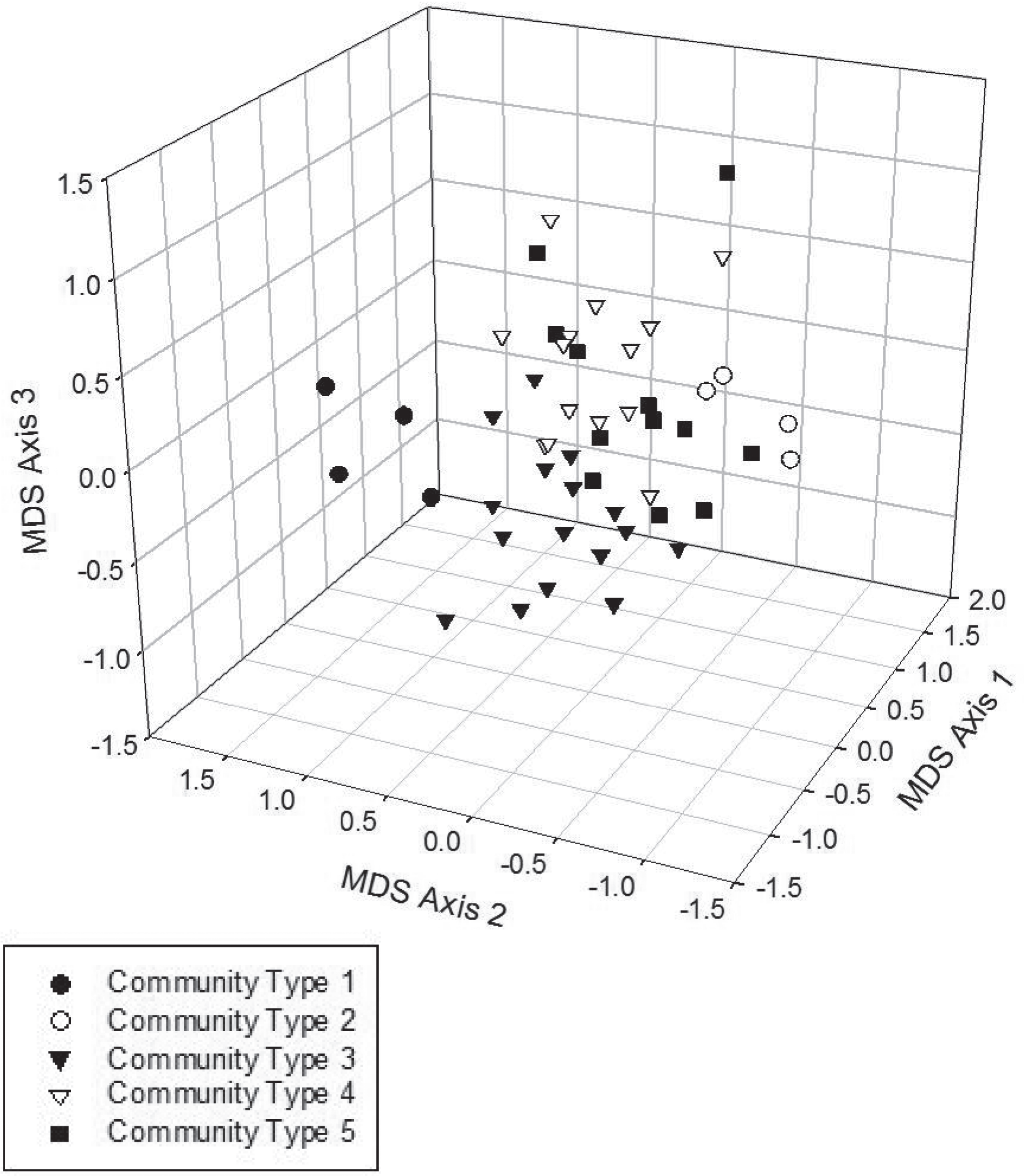

Figure 3. 3D graph of the first three axes of the MDS ordination of survey plots on the Lee Steere Range (stress level = 0.15). Data is a matrix of 70 species x 50 survey sites; taxa are perennial species occurring in more than a single quadrat.

Table 1

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

Table 2

Taxa with indicator values ≥ 25 for the five community types of the Lee Steere Range. Significant taxa are shown at $p < 0.05$ (from Monte Carlo permutation test), levels of significance * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$. Indicator values ≥ 25 are denoted by shading.

Indicator Species	Community Type 1	2	3	4	5
Acacia quadrimarginea ***	69	0	0	0	0
Keraudrenia velutina subsp. *elliptica**	43	0	0	0	1
*Stenanthemum petraeum***	40	0	18	1	0
Eremophila margarethae **	36	0	17	22	4
Acacia rhodophloia	32	0	2	0	4
Senna glaucifolia	27	12	0	12	5
Triodia melvillei	25	6	22	21	11
Senna glutinosa subsp. x *luerssenii* **	0	68	0	0	1
Tribulus suberosus **	0	55	0	23	2
*Solanum ellipticum**	0	43	0	0	1
*Ptilotus obovatus***	0	40	0	7	40
Sida sp. Golden calyces glabrous (HN Foote 32) **	0	40	3	0	0
Ptilotus schwartzii ***	0	33	22	20	6
Dodonaea petiolaris	3	31	10	0	6
Sida sp. Excedentifolia (JL Egan 1925)	0	27	12	9	8
Acacia aneura var. *microcarpa*	7	26	20	26	5
Acacia citrinoviridis ***	0	0	56	18	0
Eremophila granitica **	0	0	55	0	1
Cheilanthes brownii *	0	8	33	0	0
Baeckea sp. Melita Station (H Pringle 2738)	0	0	25	0	0
Eragrostis eriopoda complex **	0	11	4	38	11
Eriachne mucronata	0	4	21	27	0
Acacia tetragonophylla ***	0	4	0	3	58
Enchylaena tomentosa var. *tomentosa***	0	0	0	0	58
Rhagodia eremaea **	0	5	0	2	49
Hakea lorea **	0	0	0	0	42
Acacia aneura var. *alata* (narrow phyllode variant) *	0	0	0	9	39
Grevillea striata **	0	0	0	1	36
Acacia pruinocarpa *	4	0	0	20	34
Evolvulus alsinoides var. *villosicalyx* *	0	0	0	0	25
Number of quadrats	**4**	**4**	**16**	**14**	**12**

Community type 2 was a group of four quadrats with a high cover of coarse weathered ironstone fragments over strongly acidic (pH 4.1–4.6) sandy loams found from the mid-slopes to the crests (Table 3). The unifying characteristics of this community were the open shrubland of *A. aneura var. microcarpa* over *E. latrobei* subsp. *latrobei* with a sparse cover of *Ptilotus obovatus*, *P. schwartzii* and *Tribulus suberosus*. Typical species were tall shrubs of *A. aneura* var. *microcarpa*, a mid-stratum of *Dodonaea petiolaris*, *P. obovatus* and *Senna glutinosa* subsp. x *luerssenii* and a lower stratum of *P. schwartzii*, *Sida* sp. Excedentifolia (JL Egan 1925) and *S.* sp. golden calyces glabrous (HN Foote 32), *Solanum ellipticum*, and *T. suberosus* (Table 2). Taxa from this community type were strongly represented in species group D, with few species from groups A, B, C, and E (Table 1). There were no taxa from species group F found in this community type.

Species richness ranged from 10 to 23 taxa per quadrat (mean 15.3 ± 5.5 SD). Typical coarse fragments were composed of weathered iron enriched rock, quartz and associated metasediments with the presence of bedrock associated with those locations further upslope. Exposed bedrock included both laminar and granular weathered ironstone.

Community type 3 was the most wide spread of all the floristic communities. It occurred on the crests and upper slopes of ironstone formations in 16 quadrats. This community type was composed of sparse talls shrubs of *A. aneura* var. *microcarpa* and *A. citrinoviridis* over isolated to sparse shrubland of *E. latrobei* subsp. *latrobei*, *E. margarethae* with isolated *P. schwartzii*. Typical taxa in this community were *A. citrinoviridis*, *Baeckea* sp. Melita Station (H Pringle 2738), *E. granitica* and *Cheilanthes brownii* (Table 2). This community was primarily allied with species groups D and E, with no taxa from groups A and C (Table 1). Species richness ranged from 10 to 18 taxa per quadrat (mean 13.6 ± 2.4 SD; Table 3).

The upper portions of the range, adjacent to the crests, were typically moderately steep gradients. An abundance of coarse fragments, characteristic of upper slopes of degradational landscapes, was recorded in all quadrats in this community type. Coarse fragments were principally weathered laminar and granular ironstone, hematite, quartz and associated metasediments. Exposed bedrock of laminar and granular iron-enriched rock was present across the community, varying from very slightly rocky (<2%) to very rocky (20–50%). The underlying soils were strongly acidic (pH 3.9–4) sandy loams (Table 3).

Community type 4 was primarily located on the mid- to lower slopes and pediments, but was occasionally found further upslope. The community was recorded in 14 quadrats. Community structure was tall, sparse to open shrublands of *A. aneura* var. *microcarpa* with a sparse mid-stratum of *E. latrobei* subsp. *latrobei* over isolated hummock grassland of *Triodia melvillei* and isolated grasses of *Eragrostis eriopoda* complex. Indicator values identified *A. aneura* var. *microcarpa*, *E. eriopoda* complex and *Eriachne mucronata* as typical taxa for this community type (Table 2). This community type has the greatest representation of taxa from species group D, with few taxa from the remaining species groups. Species richness ranged from 11 to 22 taxa per quadrat, with a mean 16.1 ± 3.3 SD.

Coarse fragments were typically weathered laminar ironstones, hematite, quartz and associated metasediments, which were common to very abundant. Soils were highly acidic (pH 4–4.9) sandy loams to sandy clay loams (Table 3). The quadrat that had soil pH of 4.9 also had a higher calcium content (170 mg kg^{-1}), suggesting the presence of calcareous soils. Exposed bedrock, principally weathered laminar and granular ironstone, was minimal across the sites, typically <2%.

Community type 5 was generally found on the lower footslopes and adjacent colluvium, and was recorded in 12 quadrats. The community typically consisted of sparse shrubland of *A. tetragonophylla* with isolated shrubs of *Eremophila latrobei* subsp. *latrobei* and *P. obovatus*. Other taxa occurring in this community included sparse or open woodlands of *A. pruinocarpa* and isolated *Rhagodia eremaea*. Typical species associated with this community were *A. aneura* var. *alata* (narrow phyllode variant), *A. pruinocarpa*, *A. tetragonophylla*, *Enchylaena tomentosa* var. *tomentosa*, *Evolvulus alsinoides* var. *villosicalyx*, *Grevillea striata*, *Hakea lorea*, *P. obovatus*, and *R. eremaea* (Table 2). Taxa from this community type were primarily found in species groups B and D, with few taxa from the remaining groups (Table 1). Species richness ranged from 13 to 27 taxa per quadrat (mean 17.5 ± 3.3 SD).

The community occured on strongly acidic (pH 4.1–5.2) sandy loams to sandy clay loams (Table 3). Those locations with greater pH values were associated with higher calcium levels, which suggested the presence of calcareous soils. Quadrats in this community had slight to extremely abundant cover of weathered laminar and granular ironstone coarse fragments. There was almost no exposed bedrock associated with this community type.

Environmental Parameters

Soils were strongly acidic (mean pH 4.2 ± 0.3 SD) and typically shallow (2–50 cm) sandy loams or sandy clay loams (Table 3). A higher clay fraction in the soil matrix was associated with quadrats on the footslopes, pediments and colluvial plains. The majority of sites had >50% cover of coarse fragments, predominantly composed of weathered granular and laminar ironstones. Rock fragments were abundant at most survey sites, with an average cover category 4.42 (20–50% cover class; Table 3). The sites typically had a high proportion of bare ground (mean 90.7% ± 6.4 SD) and very sparse cover of leaf litter (mean 9% ± 5.7 SD).

There were significant intercorrelations between soil chemical properties (Table 3). Molybdenum was excluded from the analysis as it was below the level of detection. There were highly significant positive intercorrelations ($p < 0.01$) between Ca, Co, K, Mg, Mn, Ni, P and Zn. Sulphur, Fe and organic carbon were strongly positively intercorrelated ($p < 0.01$). Sulphur was highly negatively correlated with Ca, Co, K, Mg and Mn ($p < 0.01$). The strongest intercorrelation ($p < 0.0001$) was between N, Fe and organic carbon. Soil pH was highly positively correlated ($p < 0.001$) with Ca, Co, K, Mg, Mn and Ni, and strongly negatively correlated with Fe ($p < 0.0001$).

The strongest positive correlation between site physical characteristics was between slope and runoff ($p < 0.0001$; Table 3). There were two main intercorrelated groups, which in turn were primarily negatively correlated to one another. The first intercorrelated group was altitude, abundance of coarse fragment, abundance of rock outcrop, runoff and maximum coarse fragment size ($p < 0.01$). The second group contained soil depth, landform element (e.g. hillslope, plain) and topographical position (e.g. crest, upper slope). Species richness was positively correlated with landform element and morphology position ($p < 0.01$) and strongly intercorrelated with soil pH and Ca, Co, K, and Mg ($p < 0.01$).

All five community types were included in the analyses with post-hoc comparison of means ($\alpha = 0.05$; Table 3). Soils from community type 1 had the highest organic carbon content, the lowest concentrations of K and Mg ($p < 0.01$), and the least amount of bare ground present ($p < 0.05$). Community type 1 differed significantly from community type 5 for all of these parameters, except proportion of bare ground. Community type 1 had

Table 3

Summary statistics for environmental variables, separated by community type, for the Lee Steere Range. Mean values with standard deviation are listed for community types. Differences were determined using Kruskal–Wallis non-parametric analysis of variance. Significance values are indicated by * ($p < 0.01$ = **, $p < 0.001$ = ***, $p < 0.0001$ = ****); post-hoc differences were set at $\alpha = 0.05$. Units of measurements for the parameters are: soil chemicals = mg/kg; abundance of fragments and outcrop abundance = categorical maximum (0 = 0%, 1 = <2%, 2 = 2–10%, 3 = >10–20 %, 4 = >20–50 %, 5 = >50–90 %, 6 = >90%); topographical position: 1 = crest, 2 = upper slope, 3 = mid-slope, 4 = lower slope, 5 = flat; species richness = number of taxa per quadrat.

	Community Types									
Soil Parameters	**Type 1**		**Type 2**		**Type 3**		**Type 4**		**Type 5**	
B ^{NS}	0.09 ± 0.08		0.14 ± 0.08		0.10 ± 0.09		0.12 ± 0.10		0.12 ± 0.11	
Ca**	66.3 ± 21.9	ab	103.5 ± 20.9	ab	71.3 ± 35.6	a	83.4 ± 36.4	ab	183.1 ± 161.6	b
Cd ^{NS}	5.00E-03 ± 0		6.25E-03 ± 2.50E-03		6.25E-03 ± 3.87E-03		5.36E-03 ± 1.34E-03		7.50E-03 ± 4.52E-03	
Co****	0.05 ± 5.00E-03	ab	0.08 ± 0.05	ab	0.05 ± 0.00	a	0.09 ± 0.09	ab	0.14 ± 0.11	b
Cu ^{NS}	0.43 ± 0.05		0.38 ± 0.05		0.43 ± 0.09		0.43 ± 0.06		0.42 ± 0.11	
Fe***	44 ± 11.3	ab	52.8 ± 21.9	ab	48.5 ± 10.8	a	31.5 ± 4.1	b	35.1 ± 16.2	b
K***	45.3 ± 4.6	a	87 ± 11.0	b	55.1 ± 14.3	a	57.6 ± 14.8	ab	72.7 ± 14.8	b
Mg****	12.3 ± 4.2	a	24.5 ± 6.0	ab	15.6 ± 5.6	a	20.5 ± 7.9	ab	34 ± 13.0	b
Mn***	8 ± 3.6	ab	11 ± 2.9	ab	8.6 ± 3.1	ab	9.1 ± 9.9	a	17.3 ± 13.5	b
N (total)**	0.054 ± 0.02	ab	0.0573 ± 0.02	ab	0.05 ± 0.02	a	0.04 ± 7.19E-03	b	0.05 ± 0.04	ab
Na ^{NS}	0.63 ± 0.25		0.88 ± 0.25		1.2 ± 1.0		1.2 ± 0.8		1.4 ± 0.98	
Ni ^{NS}	0.08 ± 0.03		0.1 ± 0.0		0.08 ± 0.03		0.09 ± 0.02		0.14 ± 0.09	
Organic C (%)**	0.75 ± 0.23	ab	0.65 ± 0.22	ab	0.63 ± 0.23	a	0.37 ± 0.10	b	0.55 ± 0.42	ab
P***	4.5 ± 0.6	a	16.3 ± 7.8	bc	7.8 ± 3.0	abcd	5.1 ± 1.1	bcd	10.6 ± 9.5	abc
pH***	4 ± 0.1	abcd	4.3 ± 0.2	abcde	4.0 ± 0.1	abcd	4.2 ± 0.2	abde	4.5 ± 0.4	bde
S***	5 ± 1.2	ab	4 ± 0.8	ab	5.6 ± 1.0	a	4.6 ± 1.2	a	2.9 ± 1.0	b
Zn ^{NS}	0.9 ± 0.4		0.98 ± 0.3		0.76 ± 0.3		0.68 ± 0.2		1.44 ± 1.4	
Site Physical Parameters										
Altitude (m)**	542 ± 15.2	ab	558 ± 14.8	ab	562 ± 18.9	a	536 ± 17.5	b	540 ± 16.1	ab
Bare ground (%) ^{NS}	79.5 ± 6.1		95.5 ± 1.0		93.1 ± 3.2		91.1 ± 5.9		89.1 ± 7.1	
Abundance-fragments**	4.8 ± 0.5	ab	5.0 ± 0.0	ab	5.1 ± 0.3	a	4.6 ± 0.6	ab	4.1 ± 0.9	b
Leaf litter (%) ^{NS}	6.5 ± 5.9		10.3 ± 3.3		6.5 ± 2.7		9.2 ± 4.9		12.3 ± 8.4	
Topographical position****	2.4 ± 0.9	ab	1.9 ± 0.9	ab	1.6 ± 0.5	a	3.4 ± 1.2	b	3.8 ± 0.9	b
Outcrop abundance***	1.3 ± 1.0	ab	1.3 ± 1.3	ab	2.4 ± 1.0	a	0.8 ± 0.8	b	0.3 ± 0.9	b
Slope ^{NS}	6.8 ± 7.8		11.8 ± 10.5		11.9 ± 10.2		5.1 ± 4.0		8.8 ± 8.8	
Species Richness	10.3 ± 2.8		15.3 ± 5.5		13.6 ± 2.4		16.1 ± 3.3		17.5 ± 3.3	
No. Quadrats	**4**		**4**		**16**		**14**		**12**	

significantly less bare ground than both community types 2 and 3. Community type 2 had the greatest proportion of bare ground and the highest concentration of the cation K. The concentration of K in soils from community type 2 was significantly different from community types 1 and 3. Community type 3 was found in the highest positions in the landscape (i.e. low number for topographical position), and had the greatest abundance of coarse fragments and exposed bedrock, the highest concentrations of Fe and S, and lowest soil pH and concentration of Co (Table 3). There were significant differences between community types 3 and 5 for abundance of coarse fragments and exposed bedrock, topographical position, soil pH and Co, Fe, Mg, and S concentrations. Altitude, abundance of coarse fragments and exposed bedrock, topographical position and Fe concentration were significantly different between community types 3 and 4.

Community type 4, at the lowest mean altitude, had the lowest Mn and Zn concentrations, which were significantly different from means from community type 5. Community type 5 was significantly different from community type 3 for many of the site and soil characteristics (Table 3). Community type 5 had the highest mean species richness, soil pH, Ca, Co, Mg, Mn and Zn concentrations, and the lowest mean Fe and S concentrations. It also had the highest mean categorical value for morphology position and the lowest mean value for abundance of coarse fragments and exposed bedrock.

BIO-ENV

Five environmental variables, Mg, S, abundance of rock outcrop, bare ground and cardinal aspect (e.g. N, E, S, W), were highly correlated with the resemblance matrix (Rho statistic = 0.513). There was a strong intercorrelation amongst the trace elements Mg and S and abundance of rock outcrop ($p < 0.01$). The variation in rock outcrop abundance overlain on the MDS 3-dimensional graph was clearly delineated in the bubble plot, with sites with higher proportion of rock outcrop clustering together (Figure 4). Sites with high rock outcrop abundance also had a high proportion of bare ground, however, the separation of sites according to percent bare ground is less distinct. The bubble plots for Mg and S showed that sites that had low Mg values also had high concentrations of S; this is particularly evident for community types 1 and 5 (Figure 4).

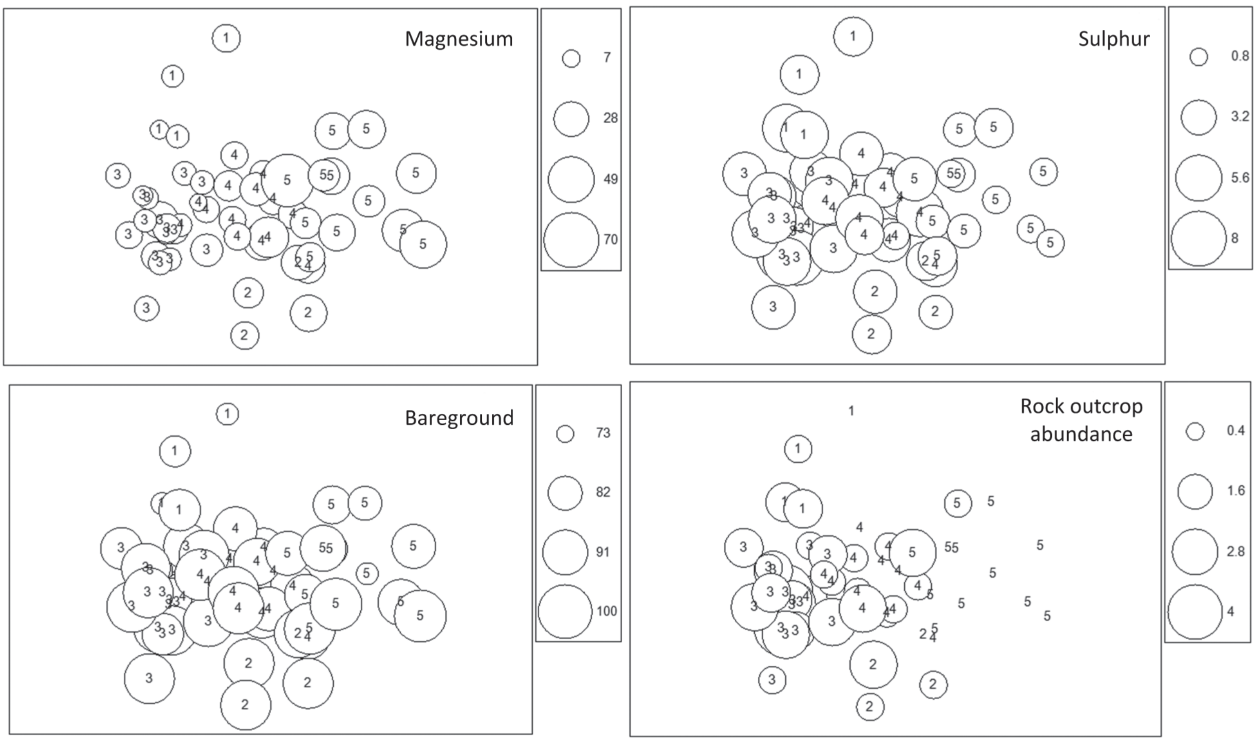

Figure 4. Bubble plots representing four of the highly correlated environmental parameters identified from the BIO-ENV routine (Rho = 0.513), overlayed on the MDS ordination output. Increase in the size of the bubble indicates increasing value of the variable. The numbers inside the bubbles represent the community types. The graphical output for cardinal aspect was not included as it was not as meaningful in two dimensions. The unit of measurements for the variables are as follows: Mg and S = mg/kg; bareground = %; rock outcrop abundance = categorical maximum (0 = 0%, 1 = <2%, 2 = 2–10%, 3 = >10–20 %, 4 = >20–50 %, 5 = >50–90 %, 6 = >90%).

DISCUSSION

No prior floristic surveys had been conducted on the Lee Steere Range, and records from the WA Herbarium are associated with sporadic opportunistic collections. There were 108 taxa recorded during this survey, which was lower than many of the other floristic surveys of the greenstone belts of the Yilgarn Craton (Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c). Poor representation of annual taxa was associated with the low annual rainfall preceding the survey. The precipitation for the five months prior to the survey (April–August 2008) was 68.4 mm at Carnegie, where the mean rainfall during the same period is typically 89.2 mm (BOM 2009).

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 Lee Steere Range did not identify any taxa endemic to the range, and only a single priority-listed (P3) taxon, *Baeckea* sp. Melita Station (H Pringle 2738). The collections held at the WA Herbarium of *B.* sp. Melita Station (H Pringle 2738) suggest that the distribution of the taxon is widespread but restricted to ironstone related substrates. This is the second record of *B.* sp. Melita Station (H Pringle 2738) for the Gascoyne bioregion and a 200 km range extension. We suggest a review of the conservation status of this taxon with a view of removing its conservation status. This survey recorded range extensions and improved knowledge of the distribution of other taxa, including the geophyte *Cheilanthes brownii*. The survey also recorded a potential new variant within the *A. aneura* complex. Revision of the *A. aneura* complex is currently underway to clarify whether the putative new variant is a valid determination or whether it is an intergrade of known variants.

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 community types in this survey were associated with particular positions in the landscape, with the strongest separation seen between community 3 (typical of uplands) and communities 4 and 5 (both associated with footslopes, pediments and colluvial plains). Species richness generally increased with distance down slope and in areas with higher pH and higher concentrations of Ca, Co, K and Mg.

Environmental Characteristics

In general, the Lee Steere Range was characterised by highly acidic soils, primarily sandy loams, with sandy clay loams on the footslopes and colluvial plains. The strong acidic nature of the soils (mean pH 4.18) was indicative of regolith that has undergone extensive weathering (Slattery et al. 1999). The soil physical parameters of the Lee Steere Range were typical of regolith associated with the Yilgarn Craton (Anand & Paine 2002). The concentrations and variation in soil trace elements were similar to those from other greenstone and ironstone ranges in the Yilgarn Craton (Gibson 2004a, 2004b; Gibson & Lyons 1998a, 1998b, 2001a, 2001b; Gibson et al. 1997; Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c).

The weathering of the regolith has influenced the concentration of trace elements in the soils. Regolith studies have shown that sulphides and carbonates are readily leached from the profile (Butt et al. 2000; Anand 2005). Calcrete accumulation has been linked with lowland communities (Anand et al. 1997), thus higher calcium concentrations are associated with communities on the footslopes, pediments and colluival plains. The prevalence of Mg in the soil is also associated with the presence of ultra-mafic rocks (LeBas 2000) and concentrations of Fe are indicative of weathered soils and the underlying regolith (Gray & Murphy 2002). These patterns were evident at Lee Steere. In particular, community type 5 (lowland community with high species richness) had the greatest soil pH and concentrations of the trace elements Ca, Co, Mg, Mn and Zn.

Conservation Significance

This survey was limited by access to the range. However where the range was traversed, condition on the southern flanks was considered good, despite the below average rainfall. There was no evidence of grazing by goats, as seen on many of the other greenstone belts of the Yilgarn. Disturbance to vegetation appeared to be from kangaroos and camels; the Earaheedy lease was destocked in 2001 and cattle were not sighted while on the Carnegie lease on the eastern portion of the range. There are active and pending exploration tenements covering the Range and adjacent pediments, but no evidence of exploration was seen during the survey. While the majority of the Range occurs on land now managed by the Department of Environment and Conservation, it is not incorporated into the secure conservation estate. The Range represents an intact example of the northern margin of the Yilgarn Craton.

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REFERENCES

Abeysinghe PB (2005) *Mineral Occurrences and Exploration Potential of the Earaheedy Area, Western Australia.* Report 96, Western Australia Geological Survey, Perth.

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 (1974) *Vegetation Survey of Western Australia. Great Victoria Desert 1:1,000,000 Vegetation Series. Explanatory Notes to Sheet 3. Vegetation of the Great Victoria Desert Area.* 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.

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.

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.

Commander DP, Muhling PC, Bunting JA (1982) *Stanley, Western Australia, 1:250,000 geological series. Explanatory Notes, Sheet SG/51-6.* Geological Survey of Western Australia, Perth.

Department of the Environment and Water Resources (2004) *Interim Biogeographic Regionalisation for Australia* (IBRA) Version 6.1. Department of the Environment and Water Resources, Canberra.

Department of Mines and Petroleum (2009) *Tengraph®* Online. Available at: http://www.dmp.wa.gov.au/3980.aspx [Accessed May 2009].

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

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

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.

Hocking RM, Adamides NG, Pirajno F, Jones JA (2001) *Geology of the Earaheedy 1:100,000 sheet. Western Australia Geological Survey, 1:100,000 Geological Series Explanatory Notes.* Western Australia Geological Survey, Perth.

Hocking RM, Pirajno F (2004) *Lee Steere, Western Australia. Western Australian Geological Survey 1:100,000 Geological Series, Sheet 3346.* Western Australia Geological Survey, 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.

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 (1990) Gascoyne Complex. In *Geology and Mineral Resources of Western Australia: Western Australia Geological Survey, Memoir 3* (eds AF Trendall, JS Myers, RM Hocking), pp. 198–210. Geological Survey of Western Australia, Perth.

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.

Pirajno F, Hocking RM, Jones JA (2002) *Evolution of Palaeoproterozoic basins in the Eastern Capricorn Orogen, Western Australia: Implications for Mineralization*. Report 2002/5, Western Australia Geological Survey, 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.

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.

APPENDIX A

Flora list for the Lee Steere Range, including opportunistic collections adjacent to the survey plots. Nomenclature follows Packowska and Chapman (2000). * indicates a weed species.

Acanthaceae
- *Harnieria kempeana* subsp. *muelleri*

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

Aizoaceae
- *Trianthema* sp. Lee Steere Range (WA Thompson & NB Sheehy WAT 639)

Amaranthaceae
- *Ptilotus obovatus*
- *Ptilotus schwartzii*

Asclepiadaceae
- *Rhyncharrhena linearis*
- *Sarcostemma viminale* subsp. *australe*

Asteraceae
- *Calotis hispidula*
- *Calotis plumulifera*
- *Podolepis canescens*
- *Vittadinia eremaea*

Brassicaceae
- *Lepidium oxytrichum*
- *Stenopetalum anfractum*

Caesalpiniaceae
- *Senna artemisioides* subsp. *filifolia*
- *Senna artemisioides* subsp. *helmsii*
- *Senna artemisioides* subsp. *oligophylla* x sp. Meekathera
- *Senna artemisioides* subsp. x *artemisioides*
- *Senna artemisioides* subsp. x *helmsii* x *glaucifolia*
- *Senna artemisioides* subsp. x *sturtii*
- *Senna glaucifolia*
- *Senna glutinosa* subsp. *glutinosa*
- *Senna glutinosa* subsp. x *luerssenii*
- *Senna* sp. Austin (A Strid 20210)
- *Senna* sp. Meekatharra (E Bailey 1–26)

Chenopodiaceae
- *Dysphania cristata*
- *Enchylaena tomentosa* var. *tomentosa*
- *Maireana georgei*
- *Maireana glomerifolia*
- *Maireana planifolia*
- *Maireana villosa*
- *Rhagodia eremaea*
- *Sclerolaena convexula*
- *Sclerolaena cornishiana*

Convolvulaceae
- *Evolvulus alsinoides* var. *villosicalyx*

Frankeniaceae
- *Frankenia laxiflora*

Goodeniaceae
- *Goodenia macroplectra*
- *Goodenia tenuiloba*
- *Goodenia triodiophila*
- *Scaevola spinescens*

Gyrostemonaceae
- *Gyrostemon ramulosus*

Haloragaceae
- *Haloragis gossei* var. *gossei*

Lamiaceae
- *Spartothamnella teucriiflora*

Loranthaceae
- *Amyema gibberula* var. *gibberula*
- *Amyema hilliana*
- *Lysiana murrayi*

Malvaceae
- *Abutilon fraseri*
- *Hibiscus burtonii*
- *Hibiscus* cf. *gardneri*
- *Hibiscus sturtii*
- *Sida ectogama*
- *Sida fibulifera*
- *Sida* sp. dark green fruits (S van Leeuwen 2260)
- *Sida* sp. Excedentifolia (JL Egan 1925)
- *Sida* sp. Golden calyces glabrous (HN Foote 32)
- *Sida* sp. verrucose glands (FH Mollemans 2423)

Mimosaceae
- *Acacia aneura* aff. *argentea* (translucent aging to opaque resin)
- *Acacia aneura* GOK – BRM
- *Acacia aneura* var. *alata* (narrow phyllode variant) BRM 9058
- *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 citrinoviridis*
- *Acacia cuthbertsonii* subsp. *cuthbertsonii*
- *Acacia pachyacra*
- *Acacia pruinocarpa*
- *Acacia quadrimarginea*
- *Acacia ramulosa* var. *linophylla*
- *Acacia rhodophloia*
- *Acacia tetragonophylla*

Moraceae
- *Ficus brachypoda*

Myoporaceae
- *Eremophila eriocalyx*
- *Eremophila exilifolia*
- *Eremophila foliosissima*
- *Eremophila granitica*
- *Eremophila latrobei* subsp. *latrobei*
- *Eremophila linearis*
- *Eremophila malacoides*
- *Eremophila margarethae*
- *Eremophila platycalyx* subsp. *platycalyx*
- *Eremophila punctata*
- *Eremophila spectabilis*

Appendix A (cont.)

Myrtaceae
- *Aluta maisonneuvei subsp. auriculata*
- *Baeckea* sp. Melita Station (H Pringle 2738) P3
- *Corymbia deserticola* subsp. *deserticola*
- *Eucalyptus oldfieldii*
- *Eucalyptus socialis*
- *Lamarchea sulcata*
- *Thryptomene decussata*

Papilionaceae
- *Swainsona affinis*

Poaceae
- *Aristida holathera*
- *Enneapogon caerulescens*
- *Eragrostis eriopoda* complex
- *Eriachne mucronata*
- *Eriachne pulchella* subsp. *pulchella*
- *Monachather paradoxus*
- *Thyridolepis xerophila*
- *Triodia basedowii*
- *Triodia melvillei*

Portulacaceae
- **Portulaca oleracea*

Proteaceae
- *Grevillea berryana*
- *Grevillea striata*
- *Hakea lorea*

Rhamnaceae
- *Stenanthemum petraeum*

Rubiaceae
- *Psydrax latifolia*
- *Psydrax rigidula*
- *Psydrax suaveolens*

Santalaceae
- *Anthobolus leptomerioides*
- *Santalum lanceolatum*
- *Santalum spicatum*

Sapindaceae
- *Dodonaea petiolaris*

Solanaceae
- *Solanum ashbyae/lasiophyllum* complex
- *Solanum ellipticum*
- *Solanum orbiculatum* subsp. *orbiculatum*

Sterculiaceae
- *Keraudrenia velutina* subsp. *elliptica*

Zygophyllaceae
- *Tribulus suberosus*

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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

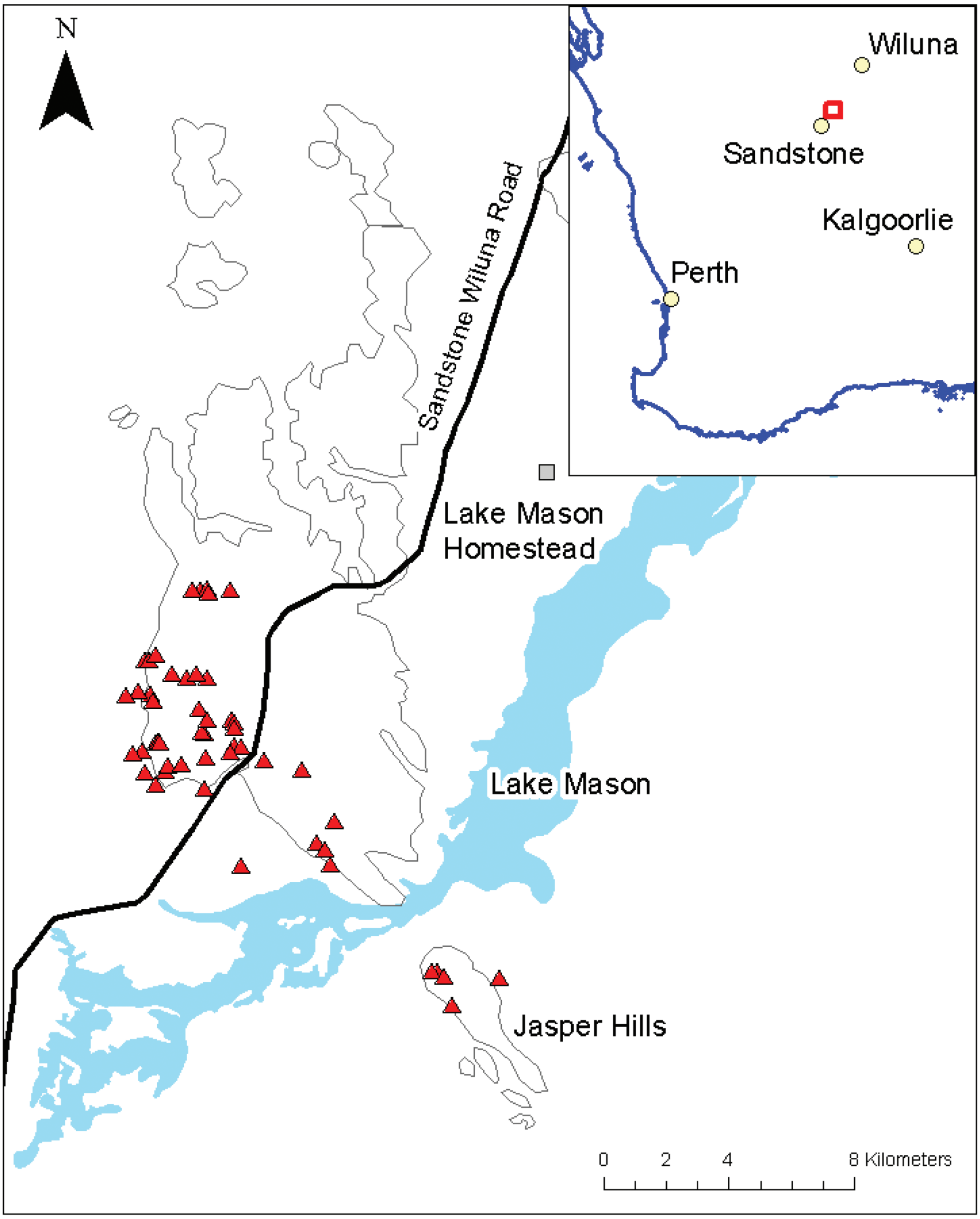

Figure 1. Map showing the location of the Lake Mason Range survey area, with major landforms and landmarks indicated. The locations of the 50 permanent quadrats are marked by triangles (▲).

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).

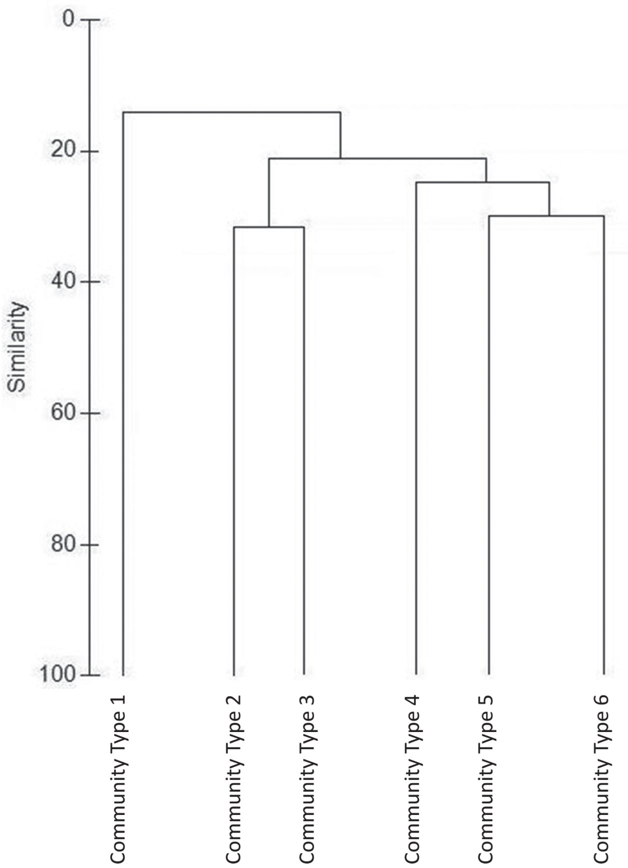

Figure 2. Summary dendrogram of community types for the Lake Mason Zone of the Gum Creek Greenstone Belt. The six community types displayed in the dendrogram are derived from the classification analyses of the 77 perennial species found in 50 quadrats.

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.

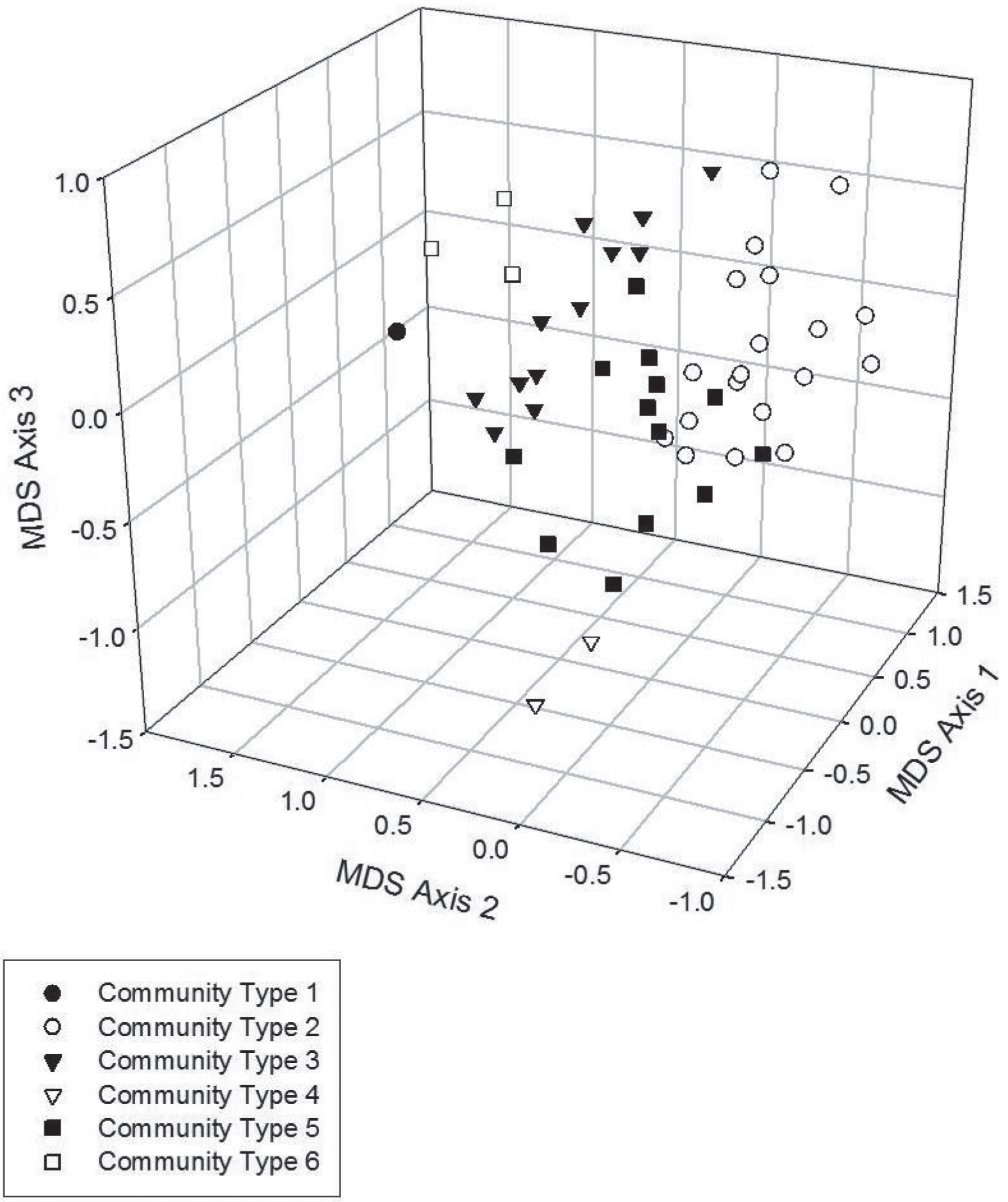

Figure 3. 3D graph (stress level = 0.14) of the first three axes of the MDS ordination of survey plots on the Lake Mason Zone of the Gum Creek Greenstone Belt. Data is a matrix of 77 species x 50 survey sites; taxa are perennial species occurring at more than a single plot.

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.

	Community Type				
Indicator Species	**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*).

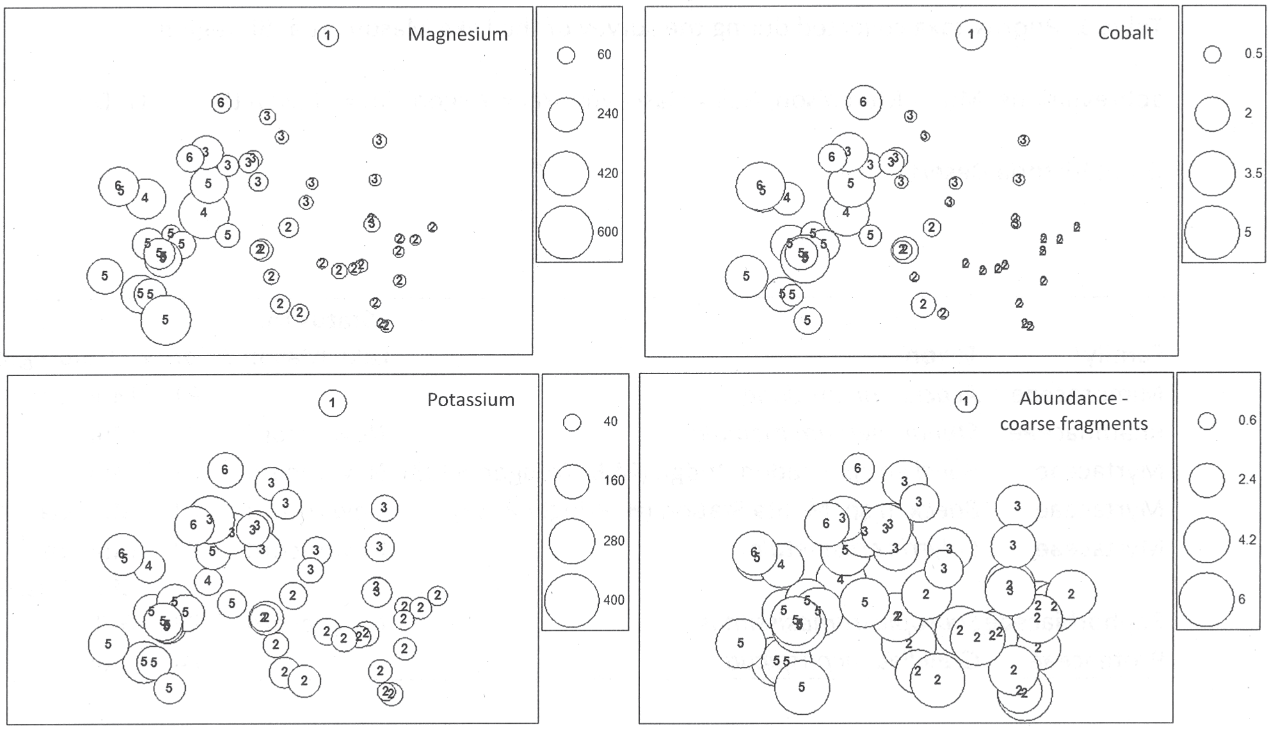

Figure 4. Bubble plots of four of the highly correlated environmental parameters identified from the BIO-ENV routine (Rho = 0.692). The plot for calcium was excluded as the trace element was highly positively correlated with magnesium ($p < 0.0001$). Increase in the size of the bubble indicates increasing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

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

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ABSTRACT

The Montague Range of the Gum Creek Greenstone Belt is located in the central portion of the Yilgarn Craton, c. 70 km north of the township of Sandstone. Fifty permanent vegetation quadrats were established, within which all vascular flora and a series of environmental attributes were recorded. A total of 91 taxa were recorded, representing 28 families and 43 genera. Five taxa of conservation significance were identified, including *Acacia burrowsiana* (P1), *Stenanthemum mediale* (P1), *Calytrix praecipua* (P3), *Sauropus ramosissimus* (P3), and *Baeckea* sp. Melita Station (H Pringle 2738; P3). A single putative variant of the *Acacia aneura* complex was identified; further material of *A. aneura* aff. *argentea* is required for confirmation. Three taxa (*A. aneura* aff. *argentea*, *A. aneura* var. *conifera*, *A. cockertoniana*) represented significant range extensions. No weeds or regional endemics were collected during the survey. Six floristic communities were identified from the survey, which were related to topographical position, geology and edaphic factors. The Montague Range 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 Montague Range is a distinct landform within the Gum Creek Greenstone belt in the Yilgarn Craton. The Gum Creek Greenstone belt is separated into two zones trending north-west, the Montague Range Zone and the Lake Mason Zone. The Montague Range Zone is located north and east of the Lake Mason Zone. Erosional processes have exposed the underlying Archaean regolith that forms the Montague Range. The result is a highly dissected landscape with widespread lateritic breakaways (Kimseed Environmental 1998). In addition to the exposed bedrock, the range contains alluvial drainage systems and scree slopes formed by the weathering of regolith, which contribute to the pediments and adjacent colluvial plains (Tingey 1985).

STUDY SITE

The Montague Range is situated in the centre of the Murchision bioregion (Interim Biogeographic Regionalisation of Australia—IBRA; Thackway & Cresswell 1995), approximately 70 km north of Sandstone and 100 km southwest of Wiluna, within the Wiluna and Sandstone Shires (Fig. 1). The greenstone belt trends north-west, covering c. 55 km from north to south, with a width c. 6–7 km. The latitudinal and longitudinal boundaries of the Range are roughly 27° 00” S, 27° 30” S and 119° 20” E and 119° 35” E, respectively. The land tenure for the Range includes Gidgee pastoral lease and the former Kaluwiri and Lake Mason pastoral leases, which are both now owned by the Department of Environment and Conservation (DEC) and managed for conservation.

Land Use History

The Murchison Region has a long history of pastoralism and mineral exploration, particularly gold mining. The Montague Range bears the evidence of both activities, including cattle grazing, gridlines, drill holes and mining pits. Access to the Range is facilitated by mineral exploration and gridline tracks. 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). The Gidgee pastoral lease covers the majority of the central and north-west portion of the Range. Gidgee has a mixed history of stocking sheep, cattle and horses, as well as mining activities (Senior 1995).

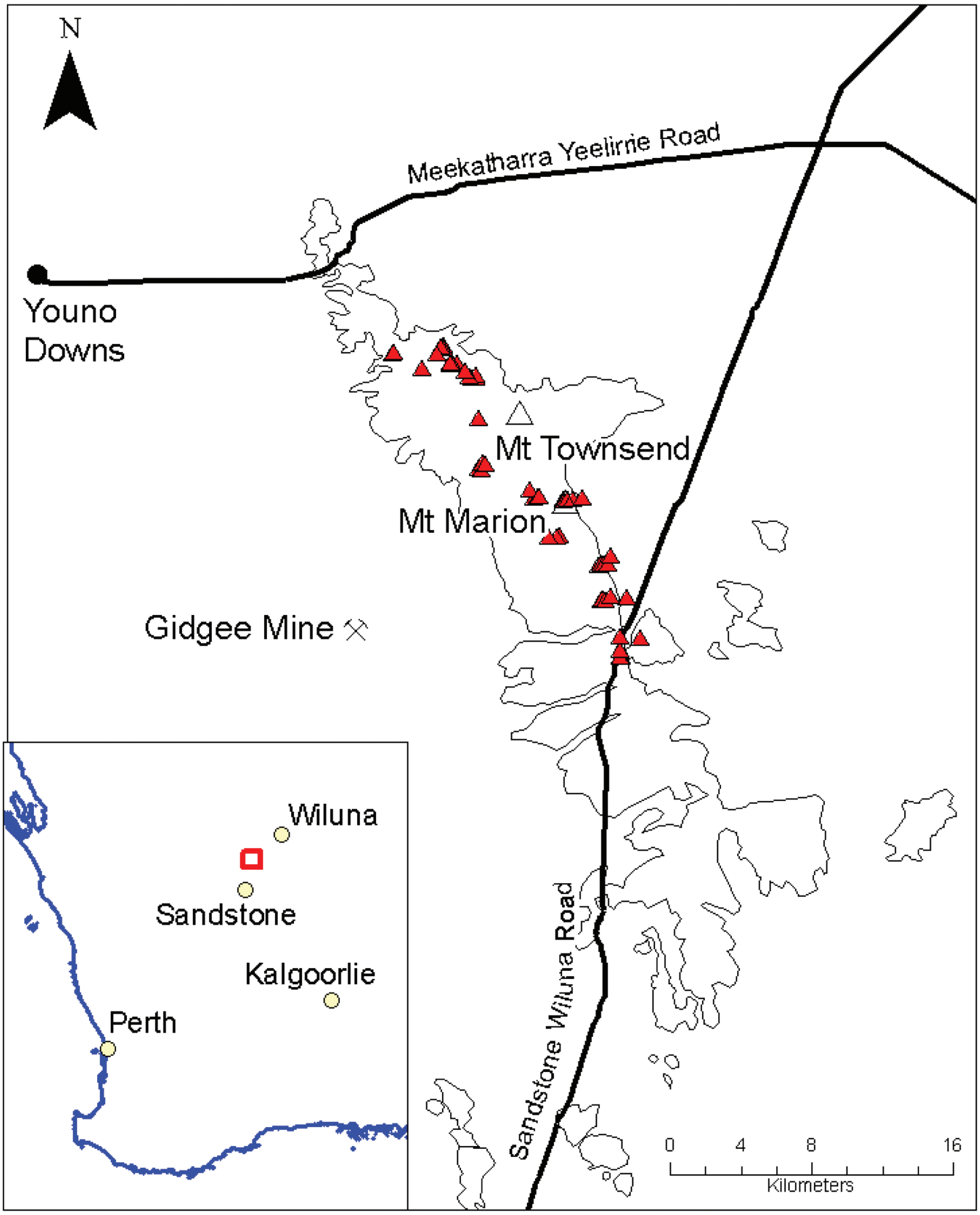


Figure 1. Map showing the location of the Montague Range survey area, with major landforms and landmarks indicated. The locations of the 50 permanent quadrats are marked by solid triangles (▲).

Lake Mason is named for the surveyor and leaseholder Henry GB Mason, who passed through the region in 1900 (Senior 1995). The Lake Mason station initially stocked cattle and later focused on sheep (Senior 1995) until the property was purchased 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 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).

The Gum Creek Greenstone Belt has the largest recorded gold production for the region, at 39 t, which is primarily associated with mafic rocks (Wyche et al. 2004). There are active mining and exploration leases on the Range at present (Department of Mines and Petroleum 2009). Open pit gold mining operated by Arminco Mining Pty Ltd occurred two kilometres west of Mt. Townsend, in the northern portion of the range, during the late 1990s. Legend Mining still operates a gold mine at Gidgee, which is currently under 'care and maintenance' (Wyche et al. 2004).

Climate

The Montague Range 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.

The closest weather station to Montague Range is Yeelirie, located c. 55 km east of the Range. Average annual rainfall at Yeelirie is 238 mm, based on records from 1928 to 2009. March and September have the highest (31.5 mm) and lowest (4.2 mm) mean monthly rainfall, respectively. The highest annual rainfall was recorded in 1975 (506.8 mm) and the lowest rainfall recorded in 1950 (42.8 mm). The single highest rainfall event occurred on 30 March 1931, with 99.1 mm of rain recorded.

Temperatures have been recorded at Yeelirie from 1973 to 2009. The average annual maximum is 28.7 °C and average annual minimum is 12.7 °C. The highest temperatures occur between November and March, with mean maximum temperatures exceeding 30 °C. January is the hottest month, with the record for mean maximum and mean minimum temperatures at 37.9 °C and 31.6 °C, respectively. The highest daily maximum on record is 46 °C recorded on 11 February 1991. The lowest daily minimum temperatures occur between May and September, 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 28.6 °C and 3.5° C, respectively. The coldest minimum temperature of –5.1 ° C was recorded on 27 July 2000.

Geology

The Montague Range has been mapped and described on the Sandstone 1:250,000 geological sheet (SG/50-16; Tingey 1985) and straddles the Montagu (Wyche & Doyle 2006) and Youno Downs (Chen et al. 2006) 1:100,000 map sheets. The Montague Range Zone of the Gum Creek Belt lies entirely in the northern portion of the Youanmi Terrane within the Southern Cross Domain in the Yilgarn Craton (Cassidy et al. 2006). The Yilgarn Craton is composed of crustal rocks primarily formed during the Late Archaean (3.0–2.6 Ga; Myers 1993; Myers & Swagers 1997). The Yilgarn Craton occurs as a series of greenstone belts that have undergone low grade metamorphism (Myers & Swagers 1997) and are primarily surrounded by granitoid (Anand & Paine 2002).

The Range is part of the larger Gum Creek Greenstone Belt, occupying the north-east portion of the belt. Elevations are between c. 550 and 600 m above sea level (see Tingey 1985). The Montague Range features the highest point on the Sandstone map sheet (SG/50-16), Mt. Townsend (660 m), and another noted peak, Mt. Marion (646 m; Tingey 1985). The Cenozoic deposits of the lower slopes, flats and outwash, are situated at c. 550 m or below.

The Montague Range trends north-north-west, the typical orientation of the greenstone belts of the Southern Cross Domain (Griffin 1990). The predominant geology of the Range includes metabasalts, interspaced with irregular sequences of banded iron formations (BIF), metamorphosed ultramafic rocks and minor occurrences of metasediments (Tingey 1985). The northern portion of the greenstone belt is largely overlain by deeply weathered profiles of ferruginised duricrust (Tingey 1985). The central and southern section of the Range is principally composed of metabasalt with metamorphosed mafic complexes and minor occurrences of quartzite and slate (Tingey 1985). The ferruginous material from Mt. Townsend and Mt. Marion has an iron ore content of 30.1% and 33.6%, respectively (Connolly 1959).

Adjacent to the eastern periphery of the Range are significant areas of granite, including deeply weathered profiles and sandplains composed of residual and aeolian sands (Wyche & Doyle 2006). The lower slopes, particularly along the western boundary, are composed of ferruginous gravel and grit with colluvial material derived from reworked ferruginous duricrust and gravel. The lower slopes and the adjacent outwash, which incorporates alluvial drainage lines linked to surrounding floodplains, are allied to Cenozoic depositional activities (Wyche & Doyle 2006).

Murchison Region soils are typically red-brown hard pans overlain by shallow earthy loams, with the hills primarily shallow stony loams (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, poorly developed and acidic in nature (Churchward 1977; Hennig 1998). Soil texture of the greenstone belts is typically loam to clay loam overlain by sandy loam and loams. Dominant soil types of the Montague Range are stony soils on the hills (Beard 1976; Churchward 1977), with shallow calcareous loams interspersed with shallow red earths and shallow calcareous red clayey sands associated with breakaways (Hennig 1998). The Jundee land system, prevalent beyond the western flanks of the range, is predominantly composed of shallow hardpans with minor occurrences of deeper red earths (Hennig 1998).

Vegetation

Montague Range is situated within the Wiluna sub-Region of the Austin Botanical District in the Eremaean Province (Beard 1976). The vegetation of the Murchison Region is dominated by *Acacia aneura* (mulga; Beard 1990). Beard (1976) classified the Montague Range as low mulga woodland with adjacent areas of mulga and minor occurrences of marble gum (*Eucalyptus gonglyocarpa*) and shrub steppe sandplains. Structurally, the community is dominated by tall *Acacia* shrubs (>3 m), over sparse cover of low shrubs (1–2 m) with ephemeral herbs present under favourable conditions (Beard 1990). Other than *A. aneura*, all other species are predominantly non-dominant when defining community composition (Beard 1990).

The mulga communities on the rocky slopes are generally composed of tall shrubs of *A. aneura*, *A. quadrimarginea*, *A. grasbyi* and *Hakea lorea* over a mid-stratum of *Senna* sp. (formerly *Cassia*), *Eremophila clarkei*, *E. latrobei* and *Ptilotus obovatus* with an annual understorey (Beard 1976). Beard (1976) did not differentiate between the vegetation communities growing on granites and greenstones. The surrounding sandplains predominantly contain 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).

The Montague Range is predominantly the Bevon land system, with gently undulating low rises, irregular hills and stony plains with breakaways and occasional ridges of BIF (Pringle & van Vreeswyk 1994; Payne et al. 1998). There are also elements of the Brooking (ridges of BIF), Felix (gently undulating stony plains and low rises) Gabinantha (ridges and hills of greenstone), Sherwood (granite overlain by stony plains and breakaways) and Violet (gently inclined stony or gravelly plains) land systems on the Range, with the Jundee (outwash composed of ironstone gravels over hardpans) land system abutting the western flanks and the Yanganoo (gently inclined hardpans) and Bullimore (sandplains) land systems dominating the eastern plains adjacent to the Range (Payne et al. 1998).

The Bevon land system supports eight vegetation communities, principally mulga shrublands, *Acacia* shrublands or *Acacia* and *Eremophila* shrublands on stony plains, with occasional cover of stony plains of bluebush mixed shrubland (Pringle 1998a, 1998b). Common tall shrubs include *A. burkittii*, *A. quadrimarginea*, *A. ramulosa* and *A. tetragonophylla* (Pringle 1998a, 1998b). Other widespread taxa in these communities are *Eremophila* sp. (e.g. *E. forrestii* and *E. latrobei*), *Ptilotus obovatus*, *Senna* sp., *Solanum lasiophyllum* (Kimseed Environmental 1998), *Sida* sp. and *Scaevola spinescens* (Pringle 1998a, 1998b). Additional taxa, frequently occurring in the bluebush shrublands, are low chenopods shrubs such as *Maireana georgei*, *M. glomerifolia*, and *M. triptera* (Pringle 1998a, 1998b).

Previous regional mapping (i.e. Beard 1976; Payne et al. 1998) has provided an overview of vegetation structure and composition associated with the greenstone belts and granites 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 aimed to record the floristic diversity, describe vegetation patterns and examine environmental correlates associated with the Montague Range in the Gum Creek Greenstone belt.

METHODS

In early October 2008, fifty 20 x 20 m permanent quadrats were established across the Montague Range so that the topographical, geological and geomorphological variation across the length and breadth of the range was represented. Survey sampling took place within 551–651 m range of elevation. Quadrats were located so that the vegetation communities associated with the greenstone belt, particularly the occurrence of BIF and associated geology, were captured. Survey methods followed those of previous surveys on greenstone belts in the Yilgarn Craton (e.g. Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c). Quadrats were located across a broad topological sequence from hill crests down slope to the colluvial deposits below the range, in areas with minimal disturbance or modification. Thus, we avoided placing quadrats where heavy grazing, evidence of clearing or exploration-related disturbance was obvious.

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 percent (%) cover. The seven cover classes were: zero cover (0); <2% cover (1); 2–10% (2); 10–20% (3); 20–50% (4); 50–90% (5); >90% (6). Site disturbance was ranked between zero and three, with zero (0) representing no effective disturbance and three (3) being extensively cleared. Runoff was recorded as 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 assigning dominant taxa to the relevant stratum, noting emergent taxa where present (McDonald et al. 1998). The cover of all vascular plants within each quadrat was recorded using the cover classes (D >70%, M 30–70%, S 10–30%, V <10%, I isolated plants, or L isolated clumps). Plant material was collected for verification and vouchering at the Western Australian Herbarium (WA Herbarium). Additional specimens were collected from areas adjacent to the plots, which contributed 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 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). Molybdenum was excluded from the analyses as it was below the level of detection. 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 86 perennial taxa recorded in more than one quadrat, which is consistent with previous greenstone belt studies (Gibson 2004a, 2004b). 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), providing quantitative output for similarity between samples (Faith et al. 1987). The species by site matrix was then classified using flexible unweighted pair-group mean average (UPGMA, β = –0.1) in 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 quadrats. A two-way table was created based on these classification routines. Non-metric Multi-Dimensional Scaling (MDS) was used to highlight groups determined through the SIMPROF procedure.

The degree of association of individual species with each community group, as determined by SIMPROF, was measured using indicator species analysis (Dufrêne & Legendre 1997). Indicator values examine information on constancy and fidelity of each species. Statistical significance of the indicator values were 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% 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 α = 0.05 (Sokal & Rolf 1995), using groups determined by the SIMPROF routing. An environmental data matrix was created that included soil chemical properties and site physical characteristics. The BIO-ENV routine within the BEST analyses procedure in PRIMER v. 6 was used to determine which environmental variables had the highest correlation with the site resemblance matrix (Clarke & Gorley 2006). For the BIO-ENV routine, the environmental variables were transformed [log(1+x)] and normalised prior to analyses.

RESULTS

A total of 91 taxa from 28 families and 43 genera were recorded across 50 quadrats on the Montague Range (Fig. 1). A further 13 species were collected from areas adjacent to the quadrats. The dominant families represented on the range were Mimosaceae (23 taxa), Myoporaceae (10 taxa), Chenopodiaceae (9 taxa) and Caesalpiniaceae (6 taxa). The genera with the greatest representation were *Acacia* (23 species), *Eremophila* (10 species) and *Senna* (6 species). The majority of the taxa found on the range were perennial shrubs. There were two annuals, two geophytes and no weed species recorded from the quadrats.

Species richness ranged between six and 21 taxa per quadrat, with an average richness per quadrat of 11.9 + 3.4 SD. Nine taxa were amalgamated into four species complexes during analyses. All annuals, singletons and specimens unidentifiable beyond genus were removed from the original species matrix, which resulted in a matrix of 86 taxa x 50 sites.

Priority Taxa

Five priority-listed taxa were collected during the survey (Table 1). All of these taxa have been previously recorded

Table 1

Priority taxa recorded from the Montague Range. Bioregion abbreviations: Mur = Murchison, Gas = Gascoyne, Yal = Yalgoo, GD = Gibson Desert, GVD = Great Victoria Desert, LSD = Little Sandy Desert.

Family	Taxon	Status for Montague	Status	Bioregion
Mimosaceae	*Acacia burrowsiana*	New record	P1	Mur, Gas
Rhamnaceae	*Stenanthemum mediale*	New record	P1	Mur
Myrtaceae	*Baeckea* sp. Melita Station (H Pringle 2738)	New record	P3	Mur, Gas, Yal
Myrtaceae	*Calytrix praecipua*	New record	P3	Mur, Gas, GVD, LSD
Euphorbiaceae	*Sauropus ramosissimus*	New record	P3	Mur, Gas, GD, GVD

in the Murchison IBRA region, but represent new records for the Montague Range. There were nine new populations of *Stenanthemum mediale* (P1) identified during the survey. Prior to the survey, there were only nine records on the WA Herbarium database, Florabase (Western Australian Herbarium 1998–) for this species. Taxa of conservation significance recorded include a new population of *A. burrowsiana* (P1) and three new populations of each of the following taxa: *Baeckea* sp. Melita Station (H Pringle 2738; P3), *Calytrix praecipua* (P3) and *Sauropus ramosissimus* (P3).

Possible New Variety in the Mulga Complex

A potential new variety within the *Acacia aneura* complex (mulga) was identified during this survey. This putative new variety was first collected during a flora survey on the BIF of Lee Steere Range in the Gascoyne IBRA Region (Thompson & Sheehy 2011b). *Acacia aneura* aff. *argentea* (translucent aging to opaque) was identified as a possible new variety due to resin differing from *A. aneura* var. *argentea* (B Maslin pers. comm.[1]). Typical *A. aneura* var. *argentea* occurs within the mulga alliance identified by winged pods and opaque resin (B Maslin pers. comm.). A single specimen collected during the survey was sterile and pods were not located to aid in identification. Further collections are necessary to verify the putative new variety.

Range Extensions

Range extensions for three taxa were recorded during the survey. The putative new variety of *A. aneura* aff. *argentea* (translucent aging to opaque) was previously identified from the Lee Steere Range in the south-east portion of the Gascoyne IBRA Region. The Montague Range population is a range extension of c. 250 km south-west of its only other known locality. *Acacia aneura* var. *conifera* has a scattered distribution in the Eremaean botanical region. The collection from Montague Range represents a range extension of c. 200 km to the south-west of the closest population on the northern boundary of the Murchison IBRA Region. The *A. cockertoniana* collected on the Montague Range is an extension of c. 200 km north-east from the closest population. *Acacia cockertoniana* is known primarily from the southern and south-western portion of the Murchison IBRA Region.

Hybrids/Integrades

A single hybrid and two interspecific hybrids were recorded during the survey. All hybrids were known from collections held at the WA Herbarium. The hybrid collected was *Maireana georgei* x *Enchylaena tomentosa*. The interspecific hybrids were *Prostanthera althoferi* subsp. *althoferi* x *campbellii* and *Senna glaucifolia* x *artemisioides* subsp. x *sturtii*.

[1] Bruce Maslin, Western Australian Herbarium, Department of Environment and Conservation, Perth.

Floristic Communities

The classification routine based on hierarchical clustering separated the taxa into six species groups (A–F; Table 2). The most widespread species group, C, was composed of taxa considered ubiquitous across the Range. Six community types were identified, based on the clustering of samples and the SIMPROF routine (Fig. 2). Three of the vegetation communities recognized were recorded in two or fewer quadrats. The relationship between species groups and community types are discussed below. The MDS routine showed the interrelationship between the sites, based on the resemblance matrix. Quadrats with a similar suite of taxa clustered together, which corresponded to community type; represented on the 3D graph as the least distance between points. The resulting stress value was 0.15 (Fig. 3).

Community type 1 was recorded in two quadrats, MNTG 14 and MNTG 23, both located in the upper portion of the landscape where soils had relatively high pH values (5.2 and 7.4, respectively; Table 3). High Ca concentrations from both quadrats suggested the presence of calcareous soils. Sites were sandy loam soils overlain by a moderate cover of weathered iron-enriched coarse fragments.

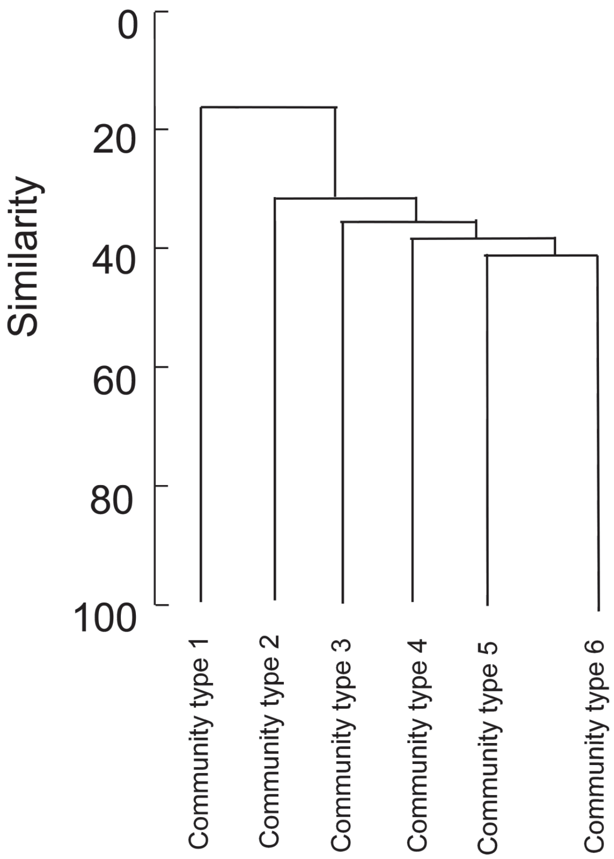


Figure 2. Summary dendrogram, derived from the classification analyses of the 86 taxa by 50 site matrix, for the Montague Range Zone of the Gum Creek Greenstone Belt. The six community types displayed were determined by the SIMPROF routine.

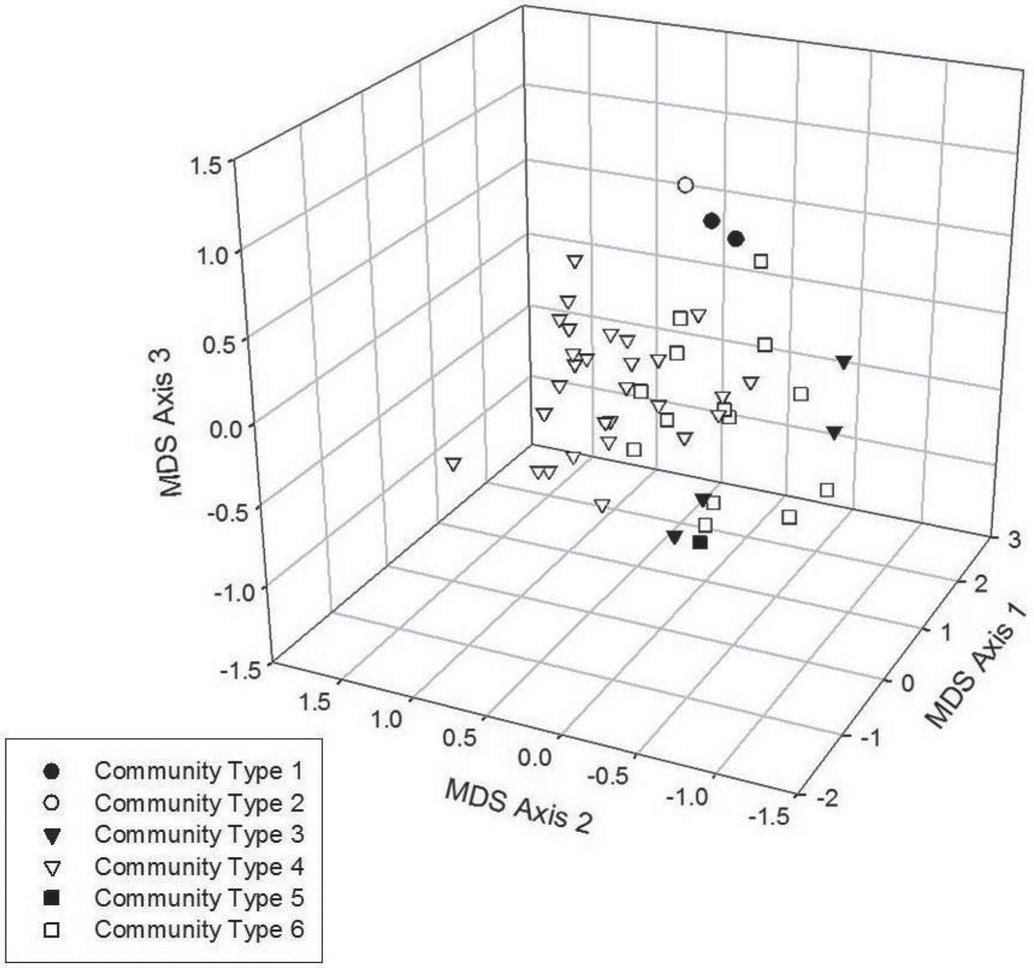


Figure 3. 3D representation of the first three axes of the MDS ordination of survey plots on the Montague Range (stress 0.15). Data were the matrix of 86 perennial species from 50 survey sites.

The community consisted of tall open shrubland of *A. aneura* over sparse shrubs of *Ptilotus obovatus*, *Scaevola spinescens*, *Lepidium platypetalum* and *M. triptera*. Indicator values (IV, Table 4) suggested that typical species include *A. sibirica*, *Eremophila longifolia*, *Enchylaena tomentosa* var. *tomentosa*, *L. platypetalum*, *M. triptera*, *P. obovatus*, *Santalum spicatum* and *Scaevola spinescens*. This community type was weakly allied with species groups B, C, and F, with no taxa from the remaining species groups (Table 2). The sites were relatively species poor, with 13 and 11 taxa recorded, respectively.

Community type 2 was recorded in a single quadrat, located in the middle of the range on a south-south-east facing crest. The quadrat had strongly acidic (pH 4) sandy loam soils with coarse fragments of weathered iron-enriched rock and associated metasediments and no exposed bedrock (Table 3). Comparatively, the quadrat was species poor, with only 10 taxa recorded during the survey. The community was described as an open shrubland of *A. aneura* and *A. rhodophloia* over sparse shrubs of *Eremophila forrestii* and *E. punctata* with isolated *E. jucunda*. This community type was associated with species groups C and D (Table 2).

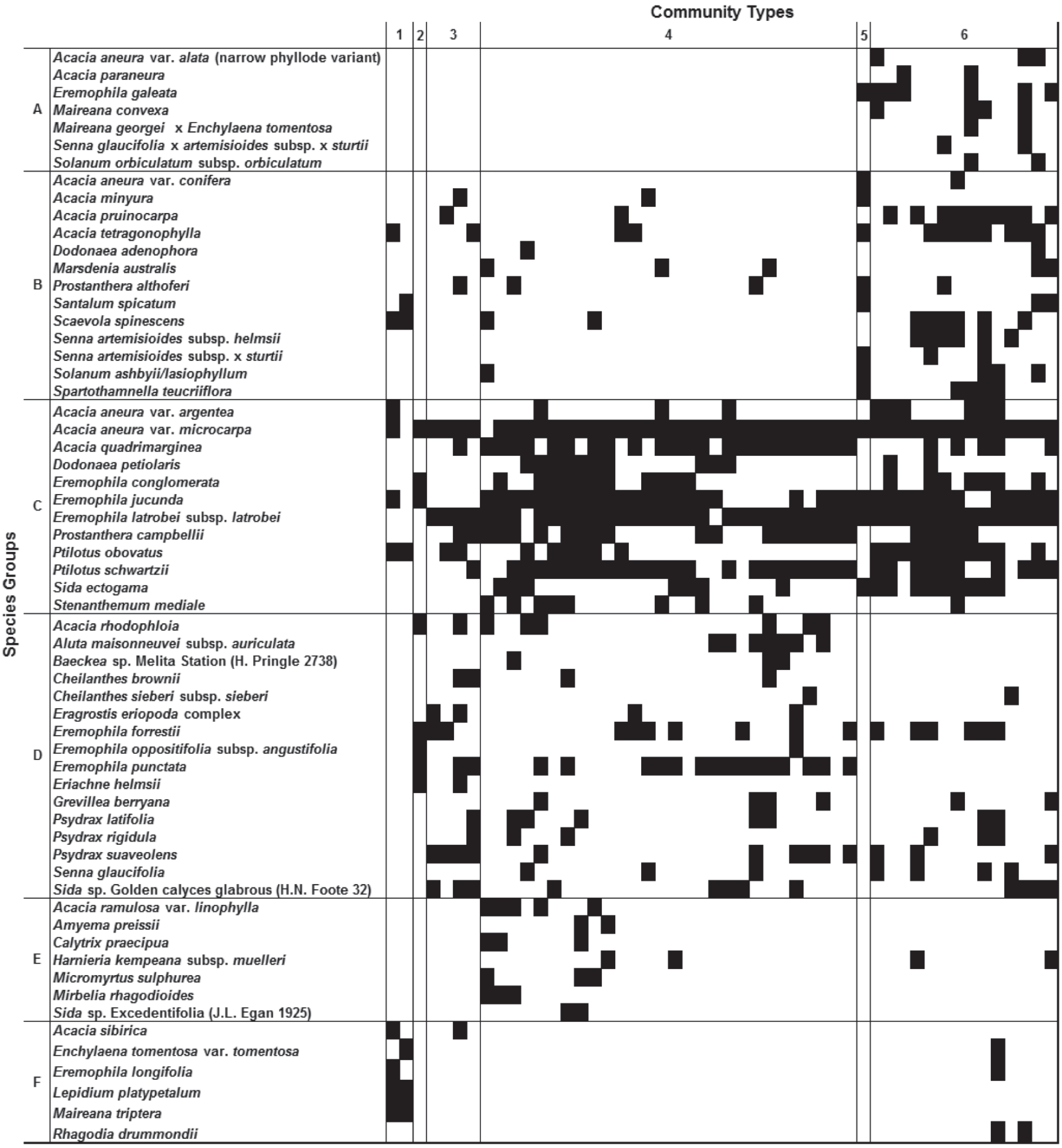
Community type 3 was composed of sparse to open shrubland of *A. aneura* var. *microcarpa* over isolated *E. latrobei* subsp. *latrobei* and *Psydrax suaveolens*, with isolated *Sida* sp. golden calyces glabrous (HN Foote 32). Typical species were *A. aneura* var. *microcarpa*, *E. latrobei* subsp. *latrobei*, *P. suaveolens*, *S.* sp. golden calyces glabrous (HN Foote 32), *Eragrostis eriopoda* complex, *Eriachne helmsii* and the geophyte *Cheilanthes brownii* (Table 4). The taxa from this community type were predominantly from species groups C and D (Table 2).

The community type was identified from four quadrats located on the steeper upper slopes to the pediments at the base of the range. All the quadrats were characterised by strongly acidic soils (pH 3.8–4.1) with relatively low concentrations of sulphur and a moderate to abundant covering of coarse fragments composed of BIF (Table 3). The quadrats had varying species richness, ranging from six to 18 taxa per quadrat. The classification routine indicated that community types 3 and 4 were closely allied (Fig. 2).

Community type 4 was the most widespread of all the community types identified, recorded from 28 quadrats. This community was not restricted to a particular

Table 2

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



topographical position or landform, as it occurred from the crests to the lower slopes of the range. Community structure was characteristically tall shrubs of *A. aneura* var. *microcarpa* and *A. quadrimarginea*, mid-stratum shrubs *Eremophila latrobei* subsp. *latrobei*, *E. jucunda* and sparse *Ptilotus schwartzii*. Indicator species of this community were *A. aneura* var. *microcarpa*, *A. quadrimarginea*, *Dodonaea petiolaris*, *E. jucunda*, *E. longifolia*, *E. punctata*, *Aluta maisonneuvei* subsp. *auriculata*, *Prostanthera campbellii*, and *Ptilotus schwartzii* (Table 4).

This community type was represented by species in group C, composed of taxa generally not restricted by gradients in the landscape, with some association with species group D (Table 2). The similarity with species group D appeared to be associated with quadrats in the northern portion of the Range. There were six to 16 taxa per quadrat. The community occurs on strongly acidic soils (pH 3.8–4.3; Table 3).

Table 3

Summary statistics for environmental variables, separated by community type, for the Montague Range 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. Significance values are indicated by * (p < 0.05 = *, p < 0.01 = **, p < 0.001 = ***, p < 0.0001 = ****); post-hoc differences were set at α = 0.05. Units of measurements for the parameters are: soil chemicals = mg/kg; abundance of fragments and outcrop abundance = categorical maximum (0 = 0%, 1 = <2%, 2 = 2–10%, 3 = >10–20 %, 4 = >20–50%, 5 = >50–90%, 6 = >90%); topographical position: 1 = crest, 2 = upper slope, 3 = mid-slope, 4 = lower slope, 5 = flat; species richness = number of taxa per quadrat.

	Community Types					
Soil Parameters	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 5**	**Type 6**
B ^{NS}	0.45 ± 0.07	0.3	0.14 ± 0.18	0.11 ± 0.12	0.05	0.09 ± 0.07
Ca****	2200 ± 2687	31.0	160.0 ± 94.9 ^{ab}	83.7 ± 59.1 ^{a}	200.0	210.0 ± 88.7 ^{b}
Cd^{NS}	7.50E-03 ± 0.0	5.00E-03	5.00E-03 ± 0.0	0.01 ± 0.0	5.00E-03	6.79E-03 ± 0.0
Co****	0.87 ± 0.42	0.05	0.073 ± 0.04 ^{ab}	0.06 ± 0.02 ^{a}	0.42	0.30 ± 0.24 ^{b}
Cu^{NS}	1.8 ± 0.6	0.7	0.63 ± 0.10	0.71 ± 0.14	1.2	0.81 ± 0.20
Fe*	27.5 ± 7.8	29.0	62.8 ± 38.1 ^{ab}	49.6 ± 16.7 ^{a}	35.0	36.5 ± 5.3 ^{b}
K****	69.0 ± 33.9	21.0	49.5 ± 16.3 ^{ab}	36.9 ± 14.8 ^{a}	64.0	96.1 ± 38.2 ^{b}
Mg****	270.0 ± 56.6	7.0	29.8 ± 14.7 ^{ab}	18.0 ± 9.4 ^{a}	58.0	48.6 ± 19.4 ^{b}
Mn****	28.0 ± 12.7	5.0	10.5 ± 1.91 ^{ab}	7.6 ± 3.7 ^{a}	25.0	21.5 ± 9.2 ^{b}
N (total)^{NS}	0.04 ± 0.0	0.03	0.073 ± 0.04	0.05 ± 0.01	0.05	0.05 ± 0.01
Na**	75.0 ± 19.8	0.5	1.5 ± 1.68 ^{ab}	1.23 ± 1.38 ^{a}	2.0	3.1 ± 2.3 ^{b}
Ni***	0.50 ± 0.14	0.1	0.23 ± 0.13 ^{ab}	0.12 ± 0.06 ^{a}	0.3	0.24 ± 0.09 ^{b}
Organic C (%)^{NS}	0.46 ± 0.13	0.4	1.1 ± 0.85	0.62 ± 0.2	0.42	0.57 ± 0.15
P^{NS}	6.5 ± 0.7	4.0	11.5 ± 8.74	8.0 ± 7.7	5.0	5.9 ± 1.6
pH****	6.3 ± 1.6	4.0	4.0 ± 0.13 ^{ab}	4.0 ± 0.2 ^{a}	4.3	4.4 ± 0.3 ^{b}
S***	140.0 ± 155.6	19.0	10.5 ± 2.08 ^{ab}	12.4 ± 2.7 ^{a}	5.0	7.4 ± 3.1 ^{b}
Zn***	1.6 ± 0.6	0.4	1.1 ± 0.25 ^{a}	0.78 ± 0.5 ^{b}	1.1	1.2 ± 0.4 ^{a}
Site Physical Parameters						
Altitude (m)^{NS}	580.5 ± 14.8	611.0	585.8 ± 45.4	589.8 ± 19.0	575.0	580.6 ± 13.3
Bare ground (%)^{NS}	97.5 ± 0.7	88.0	94.5 ± 4.5	96.3 ± 2.4	97.0	96.1 ± 2.2
Abundance-fragments^{NS}	5.0 ± 0.0	4.0	4.5 ± 0.6	4.8 ± 0.6	4.0	4.5 ± 0.7
Leaf litter (%)^{NS}	5.0 ± 1.4	20.0	11.0 ± 7.8	9.3 ± 5.6	6.0	11.8 ± 10.3
Topographical position**	1.5 ± 0.7	1.0	3.3 ± 1.5 ^{ab}	2.3 ± 1.2 ^{a}	5.0	3.7 ± 0.9 ^{b}
Outcrop abundance*	0.5 ± 0.7	0.0	1.8 ± 2.1 ^{ab}	1.5 ± 1.3 ^{a}	0.0	0.4 ± 0.6 ^{b}
Slope^{NS}	5.5 ± 0.7	2.0	15.5 ± 15.1	9.9 ± 8.8	2.0	5.4 ± 3.7
Species Richness	12.0 ± 1.4	10.0	10.8 ± 5.5	10.8 ± 2.6	17.0	14.3 ± 3.3
Number of Quadrats	**2**	**1**	**4**	**28**	**1**	**14**

Community type 5 was identified from one quadrat and was closely allied with community type 6 and species groups B and C (Figure 2; Table 2). The community was found on an east-north-east flat with a moderate cover of coarse fragments of weathered iron-enriched rock and strongly acidic sandy clay loam soils (pH 4.3; Table 3). The quadrat was relatively species rich compared with the majority of other quadrats, with 17 taxa recorded. The community was described as an open tall shrubland of *A. aneura* with isolated mallees of *Eucalyptus lucasii* over isolated shrubland of *Eremophila galeata*, *E. jucunda* and *S. ectogama*.

Community type 6 was generally found on the mid- to lower-slopes, pediments and colluvial plains adjacent to the range; recorded in 14 quadrats. The community was described as sparse to open tall shrubland of *A. aneura* var. *microcarpa* over open shrubland of *E. latrobei* subsp. *latrobei* and *E. jucunda*. Other species contributing to this community included sparse cover of *A. pruinocarpa* trees and mid- to lower-stratum shrubs including *P. obovatus*, *P. schwartzii* and *S. ectogama*. Indicator values identified the following species as typical of the community: *A. aneura* var. *microcarpa*, *A. pruinocarpa*, *E. conglomerata*, *E. galetea*, *E. jucunda*, *E. latrobei* subsp. *latrobei*, *M. convexa*, *P. obovatus*, *P. schwartzii*, *Senna artemisioides* subsp. *helmsii*, *Sida ectogama* and *Spartothamnella teucriiflora* (Table 4). This community had representatives from all species groups, however, the closest relationships are with species groups B and C (Table 2).

The community was characterised by shallow acidic sandy loam and sandy clay loam soils (pH 4.0–5.1). The quadrats typically were covered by moderate to abundant coarse fragments of weathered BIF, iron-enriched rock, quartz and associated metasediments, with the presence of exposed bed rock associated with quadrats further upslope from the base of the range. The mean species richness was 14.3 ± 3.3 SD, ranging from eight to 21 taxa per quadrat (Table 3).

Environmental Variables

The soils of the Montague Range were typically strongly acidic, with a mean pH of 4.17 ± 0.56 SD and a range of 3.8 to 7.4 (Table 3). There were only three quadrats where soil pH was >5 and only a single quadrat with soil pH of 7.4. The quadrats with higher pH values concomitantly had high soil Ca concentrations (>300 mg kg^{-1}). The soils collected on the Range were skeletal to shallow red-brown sandy loams and sandy clay loams. The high clay fraction in the soil matrix was typically associated with quadrats on the footslopes, pediments and colluvial plains. The majority of sites had >50% cover of coarse fragments, predominantly composed of weathered laminar ironstones and iron enriched rock. Rock fragments were abundant at most survey sites, with an average cover category 4.6, which approaches 50–90% cover category (Table 3). The quadrats typically had a high proportion of bare ground (mean 96% ± 2.7 SD) and very sparse cover of leaf litter (mean 10.1% ± 7.3 SD).

Table 4

Taxa with indicator values ≥ 25 for three of the six community types of the Montague Range Zone. Communities with ≤ 3 representative sites were excluded from the analysis. 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.

	Community Types		
Indicator Species	**3**	**4**	**6**
*Psydrax suaveolens***	70	3	3
Sida sp. golden calyces glabrous (HN Foote 32) *	46	3	7
*Cheilanthes brownii**	44	1	0
Eragrostis eriopoda complex *	44	1	0
Acacia aneura var. *microcarpa*	34	31	34
Eremophila latrobei subsp. *latrobei*	34	29	34
Acacia sibirica	25	0	0
Eriachne helmsii	25	0	0
Acacia quadrimarginea *	4	47	9
*Eremophila jucunda**	0	38	45
Ptilotus schwartzii	3	38	29
Eremophila punctata	24	28	0
Dodonaea petiolaris	0	26	4
Prostanthera campbellii	17	25	9
Aluta maisonneuvei subsp. *auriculata*	0	25	0
*Acacia pruinocarpa***	6	0	51
*Sida ectogama**	0	7	46
*Eremophila galeata***	0	0	43
Senna artemisioides subsp. *helmsii***	0	0	43
*Ptilotus obovatus**	17	3	41
*Acacia tetragonophylla**	7	1	37
*Scaevola spinescens**	0	1	37
Acacia aneura var. *argentea**	0	2	34
*Maireana convexa**	0	0	29
*Spartothamnella teucriiflora**	0	0	29
Eremophila conglomerata	0	17	28
Number of quadrats	**4**	**28**	**14**

There were strong intercorrelations between soil chemical properties ($p < 0.01$; Table 3). Soil pH and the elements Ca, Co, K, Mg, Mn, Na, Ni and Zn were all positively intercorrelated ($p < 0.01$). All soil chemical properties were negatively correlated with sulphur ($p < 0.01$), except Na and Ni ($p > 0.05$). Species richness was positively related to Ca, K, Mg and Na content (p < 0.01). Iron content, soil nitrogen and organic carbon were highly intercorrelated ($p < 0.001$), with the strongest relationship among all soil chemical properties between soil nitrogen and organic carbon ($r_s = 0.91$, $p < 0.0001$).

Abundance of coarse fragments and exposed bedrock, soil depth, runoff and slope were all highly intercorrelated ($p < 0.01$), with the strongest relationship of all site physical characteristics between runoff and slope ($r_s = 0.82$, $p < 0.0001$; Table 3). Other strong relationships existed between topographical position (e.g. 1 = crest to 5 = outwash) and abundance of exposed bedrock ($r_s = -0.61$, $p < 0.0001$). There were no significant correlations between species richness and site physical parameters ($p > 0.01$).

Community types recorded in two or fewer quadrats (types 1, 2 and 5) were excluded from the analyses comparing environmental variables between communities. There were significant differences ($p < 0.05$) between community types 4 and 6 for Ca, Co, Fe, Mg, Mn, Na, Ni, S, soil pH, and topographical position and rock outcrop abundance (Table 3). There were significant differences between community type 4 and types 3 and 6 for Zn ($p < 0.001$). Community type 4 had the lowest mean values for soil pH and the trace elements Ca, Co, Mg, Mn, Na and Ni, and the highest concentrations of Fe and S.

BIO-ENV

The PRIMER BIO-ENV routine examined which environmental variables best correlated with the patterns in the site resemblance matrix. Mg, Ni, S, altitude and abundance of rock outcrop had the highest correlation with the patterns within the site resemblance matrix (Rho = 0518). Magnesium was strongly correlated with Ni ($r_s = 0.77$, $p < 0.0001$) and S ($r_s = -0.49$, $p < 0.001$). Altitude and abundance of exposed bedrock were positively correlated ($r_s = 0.38$, $p < 0.01$). The high values for altitude and abundance of exposed bedrock were almost in complete opposition to the those of the soil trace elements (Fig. 4). In particular, community type 2, with high values for all three trace elements, was clearly separated from the other sites (Fig. 4).

DISCUSSION

Flora and Vegetation Communities

There were 104 taxa recorded during the survey (91 of which were from quadrats). This was markedly lower than many of the flora surveys in the greenstone belt flora of the Yilgarn Craton (e.g. Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c), and lower than flora surveys carried out in association with the Mt. Townsend Project, which identified 131 taxa (Kimseed Environmental 1998). However, prior to this survey there were only 72 species lodged at the WA Herbarium from the vicinity of the Montague Range. Poor representation of annual taxa and lower absolute numbers of taxa collected during the survey was associated with the low annual rainfall preceding the survey.

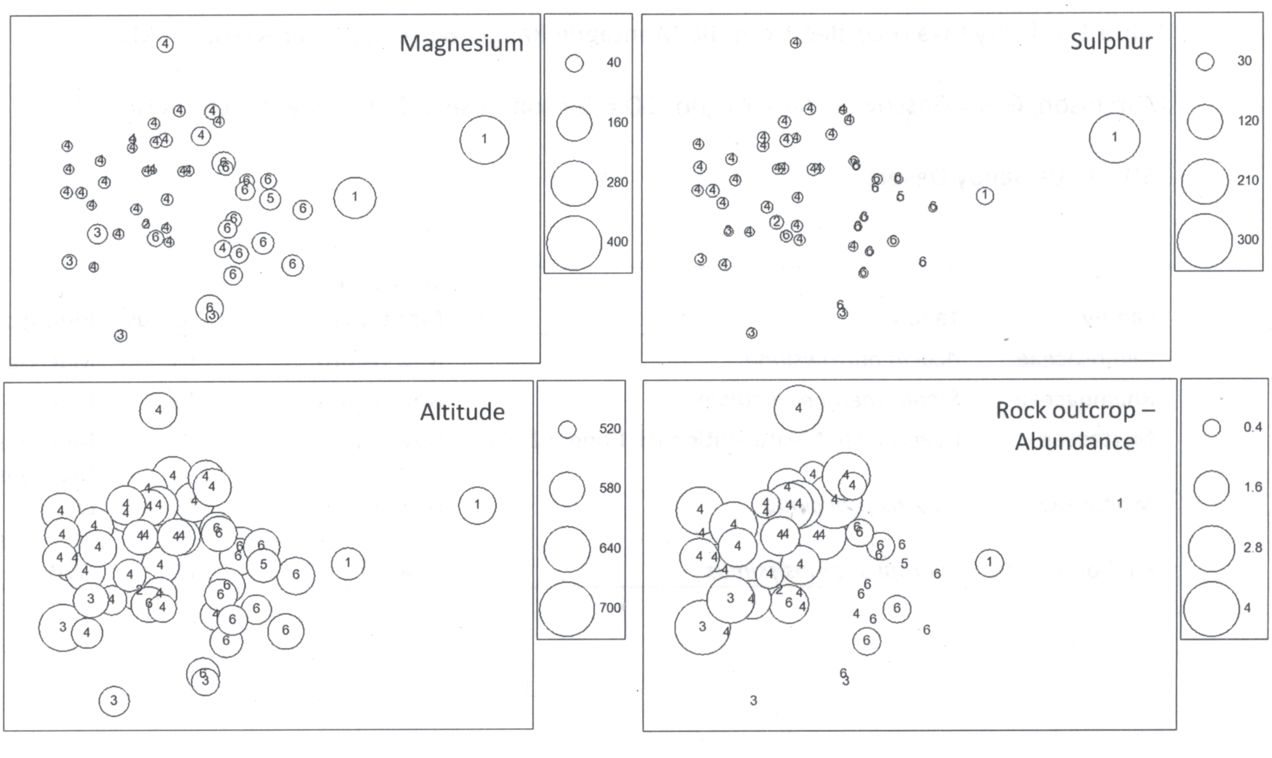


Figure 4. Bubble plots of the four most highly correlated environmental parameters identified from the BIO-ENV routine (Rho = 0.518) overlaid on the MDS ordination. The plot for nickel was excluded as the trace element was highly positively correlated with magnesium (p < 0.0001). Increase in the size of the bubble correlates with increasing value of the variable. The numbers inside the circles correspond to the community types.

Previous flora surveys of the greenstone belts of the Yilgarn Craton have identified taxa endemic to specific upland formations and taxa of conservation significance (Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c). The flora survey of the Montague Range Zone of the Gum Creek Greenstone belt identified no endemic taxa and five priority listed taxa, which was lower than the seven priority tax recorded from the Lake Mason Zone of the Gum Creek Greenstone belt (Thompson & Sheehy 2011a). *Stenanthemum mediale* (P1) is regionally restricted and known from populations at Jack Hills (c. 100 km west of Meekatharra) and Youno Downs and Yeelirie, which are both adjacent to Montague Range. This taxon has been recorded as occurring on Montague Range (Kimseed Environmental 1998), but vouchered specimens were not lodged with the WA Herbarium. It is recommended that *S. mediale* is downlisted from P1 to P2, as nine new populations were recorded on the Montague Range and a single population was recorded in the Lake Mason Zone, south of Montague (Thompson & Sheehy 2011a). A further three taxa collected during the survey represent range extensions of 200 km or greater, including the putative new variety of *Acacia aneura* aff. *argentea*.

Six distinct vegetation communities were identified following classification of the site resemblance matrix. This is similar to other greenstone belt studies (Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c). The communities generally were not restricted to a specific topographical position in the landscape, the exception being those communities identified from a single quadrat. The community types found on Montague Range had a more general distribution with regards to topography and landscape element. The BIO-ENV routine showed that altitude was highly correlated with the site resemblance matrix, however, there are inherently more complex relationships influencing the vegetation patterns than simple topographical position in the landscape.

Acacia aneura dominated all vegetation communities, generally as the tallest stratum. This is typical for the Murchison Region (Beard 1976; Beard 1990; Payne et al. 1998), and of flora surveys undertaken in the immediate vicinity (Kimseed Environmental 1998). Furthermore, taxa ubiquitous to other greenstone belts in the region were found across the Montague Range (e.g. *Eremophila jucunda*, *E. latrobei* subsp. *latrobei*). The primary source of similarity was the presence of some ubiquitous taxa within community types. For example, *A. aneura* over *E. latrobei* subsp. *latrobei* with sparse *Ptilotus schwartzii* were indicator taxa in both community type 4 on Montague Range Zone and community type 2 at Lake Mason Zone (Thompson & Sheehy 2011a).

Environmental correlates

Most of the soils on the Montague Range were highly acidic, as is typical of weathered regolith (Slattery et al. 1999). Where soil pH approached neutral or alkaline values, there were concomitant higher calcium concentrations, suggesting 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 Montague Range are typical of regolith associated with the Yilgarn Craton (Anand & Paine 2002). The variability in soil trace element concentrations were 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 colluvial plains.

Altitude, abundance of exposed bedrock and concentrations of soil trace elements (Mg, Ni, and S) were correlated with 51.8% of the site resemblance matrix. This suggested that the position, underlying regolith and weathering of the profile has influenced the floristic composition. Weathering of the regolith mobilises elements, leaching some and retaining others in varying concentrations (Britt et al. 2001; Anand 2005). Those elements with higher concentrations (e.g. Mg, K) are most likely not leached to the same extent as others, whereas higher Fe concentrations are likely attributed to the weathering of iron-enriched rock (Gray & Murphy 2002).

Community type 1 had soil physical characteristics typical of mafic sites (e.g. higher Mg, Mn, Ni) as well as a higher Ca level attributed to the presence of calcareous soils. The other communities exhibited more moderate concentrations of trace elements. The most noticeable significant environmental differences occurred between community type 4 (widespread locations with ubiquitous taxa—*A. aneura*, *E. latrobei* and *P. schwartzii*) and community type 6 (mid- to lower slopes with ubiquitous taxa). Higher concentrations of chemical elements, except Fe and S, were linked to community type 6.

Conservation Significance

The Montague Range has a long history of grazing, mineral exploration and mining. Evidence of the impact of these activities was apparent on the range, in particular the presence of livestock, extensive gridline tracks, drill holes and open cut mining. 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 had lower levels of species richness than other BIF ranges in the Yilgarn, the range is still an important repository of taxa of conservation significance and taxonomic uncertainty. This is similar to other areas on the BIF ranges of the Yilgarn (Gibson 2004 a, 2004b; Gibson & Lyons 1998a, 1998b, 2001a, 2001b; Gibson et al. 1997; Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c). The south-east portion of the range occurs on land managed by the Department of Environment and Conservation, but remains unclassified within the conservation estate. At present, there are no BIF ranges designated within Class A Nature Reserves.

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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, BA, 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, Wyche S, Doyle MG (2006) *Youno Downs, Western Australia. Western Australian Geological Survey 1:100,000 Geological Series Sheet 2743.* Geological Survey of Western Australia, 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. Mineral Resource Bulletin 7, Geological Survey of Western Australia, 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.

Department of Mines and Petroleum (2009) *Tengraph*® Online. Available at: http://www.dmp.wa.gov.au/3980.aspx [Accessed May 2009].

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

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. Geological Survey of Western Australia, Perth, Bulletin 34.

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, Memoir 3* (eds AF Trendall, JS Myers, RM Hocking), pp. 60–77. 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, KA 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. Agriculture Western Australia, Technical Bulletin No. 90, 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 and 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, van Vreeswyk AME (1994) Land Systems. In *An Inventory and Condition Survey of the North-Eastern Goldfields, Western Australia* (eds. HJR Pringle, AME Van Vreeswyk, SA Gilligan), pp. 171–292. Technical Bulletin No. 87, Department of 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, VIC.

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 (2011a) Flora and vegetation of banded iron formations of the Yilgarn Craton: the Lake Mason Zone of the Gum Creek Greenstone Belt. *Conservation Science Western Australia* **8**, 77–94.

Thompson WA, Sheehy NB (2011b) Flora and vegetation of banded iron formations of the Yilgarn Craton: the Lee Steere Range. *Conservation Science Western Australia* **8**, 61–76.

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

Western Australian Herbarium (1998–) *Florabase—The Western Australian Flora*. Department of Environment and Conservation. Available at http://florabase.dec.wa.gov.au/ [Accessed May 2009].

Wyche S, Doyle MG (2006) *Montagu, Western Australia. Western Australian Geological Survey 1:100 000 Geological Series Sheet 2843*. 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 Montague Range Zone of the Gum Creek Greenstone Belt, including collections made outside of the survey quadrat boundaries. Nomenclature follows Packowska and Chapman (2000).

Acanthaceae
- *Harnieria kempeana* subsp. *muelleri*

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

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

Asclepiadaceae
- *Marsdenia australis*
- *Sarcostemma viminale* subsp. *australe*

Asteraceae
- *Olearia humilis*

Brassicaceae
- *Lepidium platypetalum*

Caesalpiniaceae
- *Senna artemisioides* subsp. *filifolia*
- *Senna artemisioides* subsp. *helmsii*
- *Senna artemisioides* subsp. *petiolaris*
- *Senna artemisioides* subsp. x *artemisioides*
- *Senna artemisioides* subsp. x *sturtii*
- *Senna glaucifolia*
- *Senna glaucifolia* x *artemisioides* subsp. x *sturtii*
- *Senna* sp. Meekatharra (E Bailey 1–26)

Chenopodiaceae
- *Enchylaena tomentosa* var. *tomentosa*
- *Maireana convexa*
- *Maireana georgei*
- *Maireana georgei* x *Enchylaena tomentosa*
- *Maireana thesioides*
- *Maireana triptera*
- *Rhagodia drummondii*
- *Sclerolaena fusiformis*

Convolvulaceae
- *Duperreya sericea*

Cupressaceae
- *Callitris columellaris*

Dilleniaceae
- *Hibbertia arcuata*

Euphorbiaceae
- *Sauropus ramosissimus* P3

Frankeniaceae
- *Frankenia pauciflora*

Goodeniaceae
- *Goodenia macroplectra*
- *Scaevola spinescens*

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

Loranthaceae
- *Amyema preissii*

Malvaceae
- *Sida ectogama*
- *Sida* sp. Excedentifolia (JL Egan 1925)
- *Sida* sp. golden calyces glabrous (HN Foote 32)
- *Sida* sp. verrucose glands (FH Mollemans 2423)

Mimosaceae
- *Acacia* aff. *coolgardiensis*
- *Acacia aneura* aff. *argentea* (transluscent aging to opaque resin)
- *Acacia aneura* var. *alata* (narrow phyllode variant) BRM 9058
- *Acacia aneura* var. *argentea*
- *Acacia aneura* var. *argentea* (narrow phyllode variant) BRM 9745
- *Acacia aneura* var. *conifera*
- *Acacia aneura* var. *microcarpa*
- *Acacia aneura* var. *microcarpa* (broad, incurved phyllode variant) BRM 9929
- *Acacia aneura* var. *tenuis* (grey) BRM 9191C
- *Acacia burrowsiana* P1
- *Acacia cockertoniana*
- *Acacia craspedocarpa*
- *Acacia effusifolia*
- *Acacia masliniana*
- *Acacia minyura*
- *Acacia paraneura*
- *Acacia pruinocarpa*
- *Acacia quadrimarginea*
- *Acacia ramulosa* var. *linophylla*
- *Acacia rhodophloia*
- *Acacia sibirica*
- *Acacia tetragonophylla*
- *Acacia xanthocarpa*

Myoporaceae
- *Eremophila conglomerata*
- *Eremophila exilifolia*
- *Eremophila forrestii*
- *Eremophila galeata*
- *Eremophila jucunda*
- *Eremophila latrobei* subsp. *latrobei*
- *Eremophila longifolia*
- *Eremophila oppositifolia* subsp. *angustifolia*
- *Eremophila pantonii*
- *Eremophila punctata*

Myrtaceae
- *Aluta maisonneuvei* subsp. *auriculata*
- *Baeckea* sp. Melita Station (H Pringle 2738) P3
- *Calytrix desolata*
- *Calytrix praecipua* P3
- *Eucalyptus carnei*
- *Eucalyptus kingsmillii* subsp. *kingsmillii*
- *Eucalyptus lucasii*
- *Micromyrtus sulphurea*

Papilionaceae
- *Mirbelia rhagodioides*

Poaceae
- *Eragrostis eriopoda/xerophila/setifolia* complex
- *Eriachne helmsii*
- *Eriachne mucronata*
- *Eriachne pulchella* subsp. *pulchella*
- *Paspalidium basicladum*

Proteaceae
- *Grevillea berryana*
- *Hakea preissii*

Rhamnaceae
- *Stenanthemum mediale* P1

Rubiaceae
- *Psydrax latifolia*
- *Psydrax rigidula*
- *Psydrax suaveolens*

Santalaceae
- *Exocarpos aphyllus*
- *Santalum spicatum*

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

Solanaceae
- *Solanum ashbyii*/*lasiophyllum* complex
- *Solanum orbiculatum* subsp. *orbiculatum*

Sterculiaceae
- *Brachychiton gregorii*

Stylidiaceae
- *Stylidium induratum*

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

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ABSTRACT

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

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

INTRODUCTION

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

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

SURVEY AREA

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

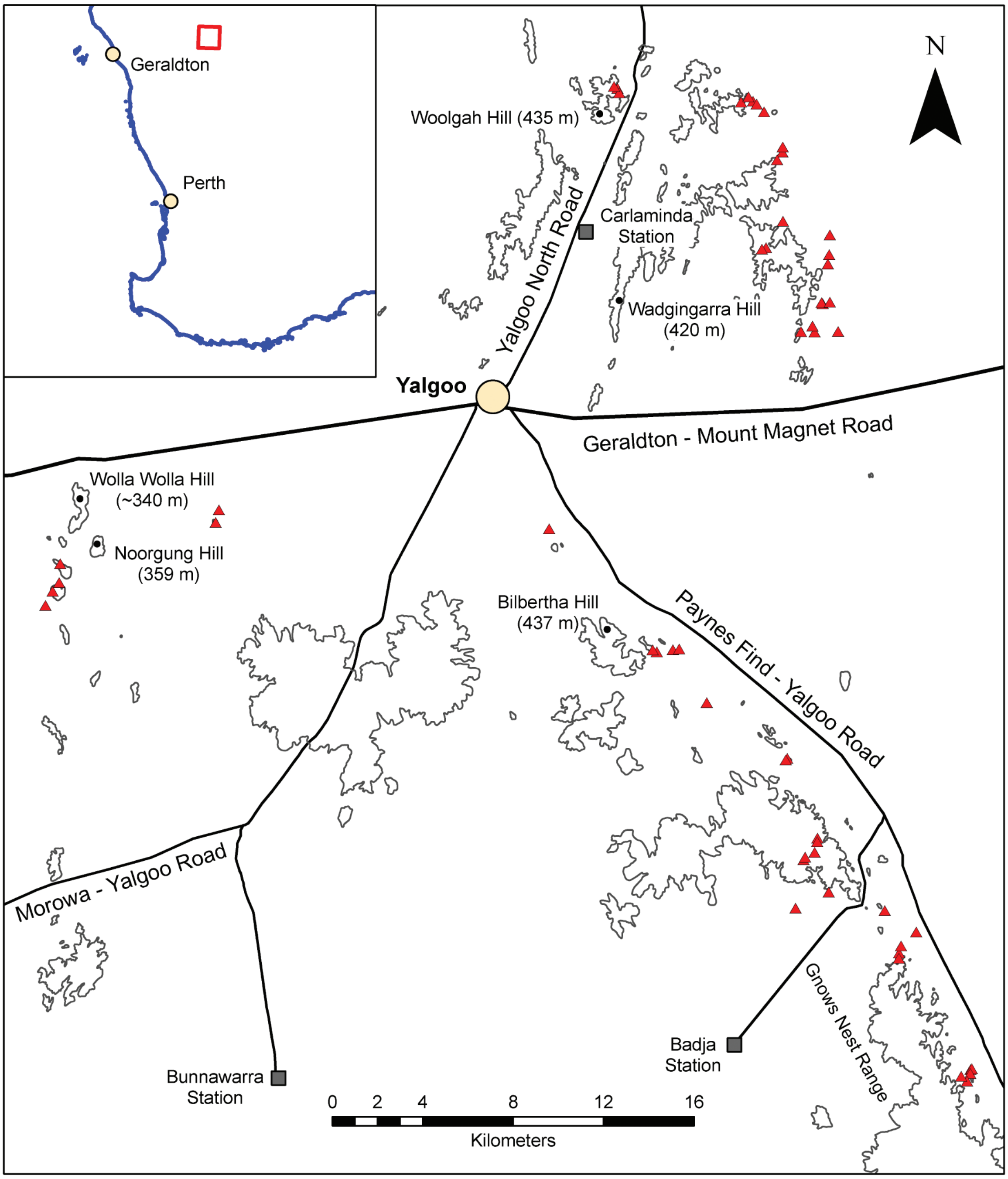

Figure 1. Map showing the location of the of the Yalgoo region relative to major centres in the Yilgarn region of Western Australia (insert), and location of the specific ranges, landforms and landmarks within the Yalgoo survey area. Locations of the 55 floristic quadrats are marked by triangles (▲),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

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

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

Land Use History

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

Climate

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

Geology, Landform and Soils

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

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

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

Vegetation

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

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

METHODS

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

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

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

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

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

RESULTS

Flora

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

Priority taxa

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

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

Notable taxa

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

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

Range extensions

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

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[2] Bruce Maslin, Senior Principal Research Scientist. Western Australian Department of Environment and Conservation, Western Australian Herbarium, Kensington.

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

Floristic Communities

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

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

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

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

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

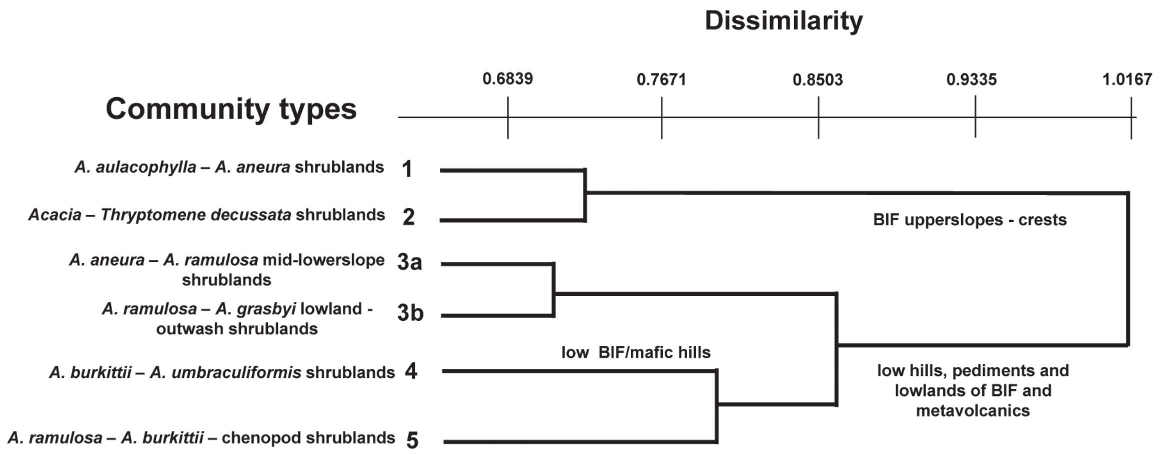

Figure 2. Summary dendrogram of floristic community types and subtypes of the Yalgoo survey region. Groups were resolved from classification analysis of a presence/absence dataset of 214 perennial taxa from 55 quadrats, using flexible UPGMA (dilated using $\beta = -0.1$) and the Bray–Curtis measure of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

Table 1

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

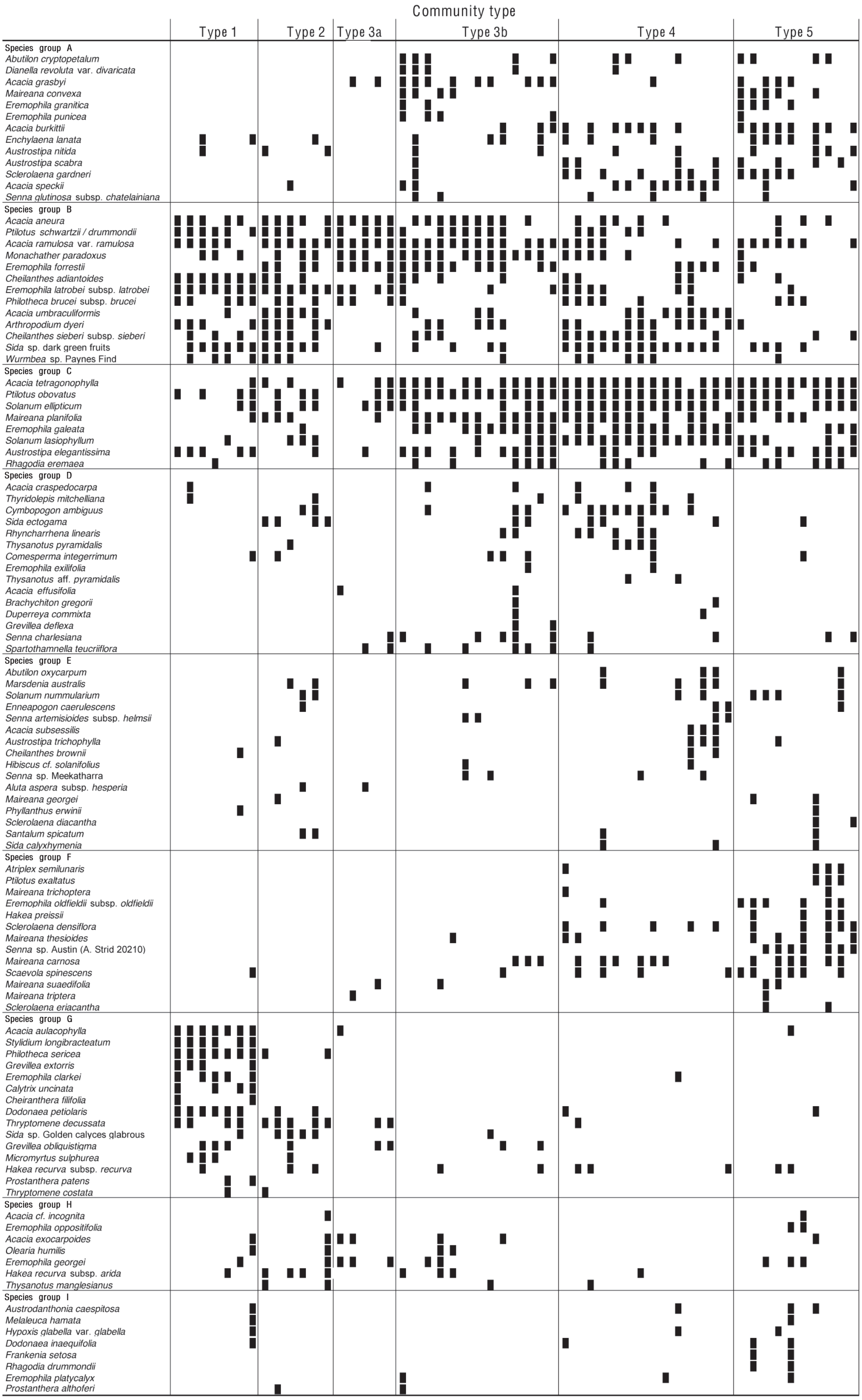

Table 2

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

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

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

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

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

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

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

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

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

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

Table 3

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

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

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

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

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

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

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

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

Physical Environment

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

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

Univariate analyses

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

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

SSH MDS ordination

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

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

DISCUSSION

Flora

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

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

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

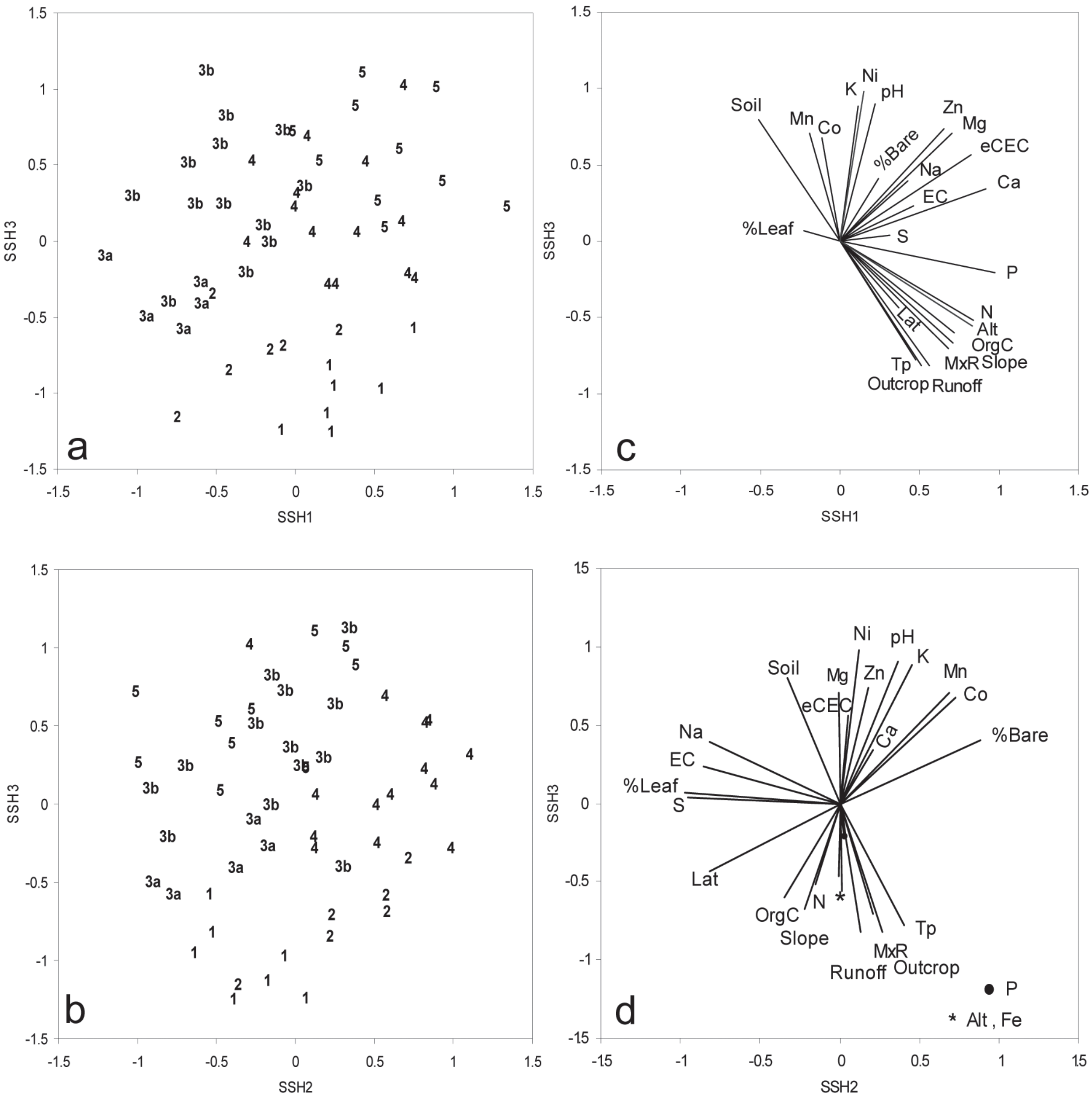

Figure 3. 3D SSH MDS ordination of sites for the Yalgoo survey area, based on dissimilarities in floristic composition from a presence/absence data matrix of 108 perennial taxa from 55 quadrats: (a) SSH axis 1 vs 3; and (b) SSH axis 2 vs 3 (both from three dimensional solution). Stress = 0.20. Sites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

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

Taxa of conservation significance

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

Table 4

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

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

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

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

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

Vegetation Communities

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

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

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

Table 5

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

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

Table 6

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

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

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

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

Species Turnover among Ranges

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

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

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

Physical Environment and Community Associations

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

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

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

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

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

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

Conservation

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

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

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REFERENCES

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.

Angiosperm Phylogeny Group (2003) An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG II. *Botanical Journal of the Linnaean Society* **141**, 399–436.

Beard JS (1976a) *Murchison, 1:1,000,000 Vegetation Series: The Vegetation of the Murchison Region.* University of Western Australia Press, Perth.

Beard JS (1976b) *The Vegetation of the Perenjori Area, Western Australia: Map and Explanatory Memoir, 1:250,000 series.* Vegmap Publications, Perth.

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

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

Belbin L (1991) Semi-strong hybrid scaling, a new ordination algorithmn. *Journal of Vegetation Science* **2**, 491–496.

Belbin L, Faith D, Milligan GW (1992) A comparison of two approaches to beta-flexible clustering. *Multivariate Behavioral Research* **27**, 417–433

Ben-Shahar R (1990) Soil nutrients distribution and moisture dynamics on upper catena in a semi-arid nature reserve. *Vegetatio* **89**, 69–77.

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

Brittan NH (1987) Thysanotus. In *Flora of Australia*: *Volume 45. Hydatellaceae to Liliaceae.* (ed AS George), pp 308–344. Australian Government Publishing Service, Canberra.

Bureau of Meteorology (1908–2007) Climate Statistics for Australian Locations. Available at http://www.bom.gov.au/climate/averages/. [Accessed May 2008].

Butcher R, Byrne M, Crayn D (2007) Evidence for convergent evolution among phylogenetically distant rare species of *Tetratheca* (Eleocarpaceae, formerly Tremandraceae) from Western Australia. *Australian Systematic Botany* **20**, 139–160.

CALM (2004) *2003–2004 Annual Report*. Department of Conservation and Land Management, Perth, W.A.

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

Chalwell ST (2003) 'Plant Communities of Greenstone Hills of the Eastern Goldfields of Western Australia as Analogues for the Rehabilitation of Rocky Waste Dumps'. Unpublished PhD thesis, Murdoch University, Western Australia.

Champion DC, Smithies RH (2001) Archaean granites of the Yilgarn and Pilbara cratons, Western Australia. In *4th International Archaean Symposium 2002, Extended Abstracts*. (eds KF Casidy, JM Dunphy & MJ Van Kranendonk), pp. 134–136. AGSO-Geoscience Australia, Record 2001/37.

Cole MM (1973) Geobotanical and biogeochemical investigations in the sclerophyllous woodland and shrub associations of the eastern goldfields area of Western Australia, with particular reference to the role of *Hybanthus floribundus* (Lindl.) F. Muell. as a nickel indicator and accumulator plant. *The Journal of Applied Ecology* **10**, 269–320.

Conn JS, Snyder-Conn EK (1981) The relationship of the rock outcrop microhabitat to germination, water relations, and phenology of *Erythrina flabelliformis* (Fabaceae) in southern Arizona. *The Southwestern Naturalist* **25**, 443–451.

Cornelius M, Robertson IDM, Cornelius AJ, Morris PA (2007) *Laterite Geochemical Database for the Western Yilgarn Craton, Western Australia.* Record 2007/9, Geological Survey of Western Australia, Perth.

Clarke, KR (1993). Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* **18,** 117–143.

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

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

Department of Conservation and Land Management see CALM.

Department of Environment and Conservation (2007) Banded ironstone formation ranges of the Midwest and Goldfields. In *Strategic Review of the Conservation and Resource Values of the Banded Iron Formation of the Yilgarn Craton.* Government of Western Australia, Perth.

Department of Environment and Water Resources (2007) IBRA Version 6.1. www.environment.gov.au/parks.nrs/ibra/version 6-1/. Updated 6th February [accessed June 2008].

Department of Industry and Resources (2007) Strategic review of an iron ore industry in the Yilgarn Region (with a focus on the Midwest). In *Strategic Review of the Conservation and Resource Values of the Banded Iron Formation of the Yilgarn Craton.* Government of Western Australia, Perth.

Department of Water (2010) *Yalgoo Water Reserve. Drinking Water Source Protection Plan.* Water Resource Protection Series. Report WRP 118. Department of Water, Perth.

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

Edwards AB (1955) *The Petrology of the Bauxites of Tasmania (Mimeo).* CSIRO Mineragraphic Investigations, Melbourne.

Facelli JM, Brock DJ (2000) Patch dynamics in arid lands: localized effects of *Acacia papyrocarpa* on soils and vegetation in open woodlands of South Australia. *Ecography* **23**, 479–491.

Faith DP, Norris RH (1989) Correlation of environmental variables and patterns of distribution and abundance of common and rare freshwater macroinvertebrates. *Biological Conservation* **50**, 77–98.

Foulds, W (1993) Nutrient concentrations of foliage and soil in south-western Australia. *New Phytologist* **125**, 529–546.

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

Gibson N, Lyons MN (1998) 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 M (2001a) 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 (2001b) Flora and vegetation of the Eastern Goldfields ranges: Part 4: Highclere Hills. *Journal of the Royal Society of Western Australia* **84,** 71–81.

Gray JM, Humphreys GS (2004) Patterns of global soil distribution as revealed by two major soil databases. In *Supersoil 2004. Proceedings of the 3rd Australian and New Zealand Soils Conference*, University of Sydney, 5–9 December 2004.

Gray JM, Murphy BW (2002) Parent material and soil distribution. *The Journal of the Australian Association of Natural Resource Management* **5,** 2–12.

Jacobi CM, do Carmo FF, Vincent RC, Stehmann JR (2007) Plant communities on ironstone outcrops: a diverse and endangered Brazilian ecosystem. *Biodiversity and Conservation* **16,** 2185–2200.

Johnson SL (1998) Geology and hydrology. 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 39–48. Technical Bulletin No. 90, Agriculture Western Australia, South Perth.

Harrison S (1997) How natural habitat patchiness affects the distribution of diversity in Californian serpentine chaparral. *Ecology* **78**, 1898–1906.

Hennig P (1998a) A brief land use history. 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 11–17. Technical Bulletin No. 90, Agriculture Western Australia, South Perth.

Hennig P (1998b) Soils. 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 95–118. Technical Bulletin No. 90, Agriculture Western Australia, South Perth.

Hopper SD, Brown AP, Marchant NG (1997) Plants of Western Australian granite outcrops. *Journal of the Royal Society of Western Australia* **80**, 141–158.

Hopper SD, Gioia P (2004) The southwest Australian floristic region: evolution and conservation of a global hot spot of biodiversity. *Annual Review of Ecology, Evolution and Systematics* **35**, 623–650.

Leighton K (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.

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. Australian Collaborative Land Evaluation Program, Canberra, Australia.

Markey AS, Dillon SJ (2008a) Flora and vegetation of the banded iron formations of the Yilgarn Craton: 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, 153–178.

Markey AS, Dillon SJ (2009) Flora and Vegetation of the banded iron formations of the Yilgarn Craton: Herbert Lukin Ridge (Wiluna). *Conservation Science Western Australia* 7, 391–412.

Markey AS, Dillon SJ (2010a) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Gullewa. *Conservation Science Western Australia* 7, 531–556.

Markey AS, Dillon SJ (2010b) Flora and vegetation of the banded iron formations of the Yilgarn Craton: the Booylgoo Range. *Conservation Science Western Australia* 7, 503–529.

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

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

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

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

Meissner RM, Bayliss B, Owen G (2010a) Flora and vegetation of the banded iron formations of the Yilgarn

Craton: Mount Forrest – Mount Richardson Range. *Conservation Science Western Australia* 7, 377–389.

Meissner RM, Bayliss B, Owen G (2010b) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Cashmere Downs Range. *Conservation Science Western Australia* 7, 349–361.

Meissner RM, Bayliss B, Owen G (2010c) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Robinson Ranges and Mt Gould. *Conservation Science Western Australia* 7, 363–376.

Mott JJ (1972) Germination studies on some annual species from an arid region of Western Australia. *Journal of Ecology* **60**, 293–304.

Mott JJ (1973) Temporal and spatial distribution of an annual flora in an arid region of Western Australia. *Tropical Grasslands* 7, 89–97.

Muling PC, Low GH (1977) *Yalgoo, Western Australia, 1:250,000 Geological Series – Explanatory Notes, Sheet SH/50-2,* Geological Survey of Western Australia, Perth.

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

Payne AL, Pringle HJR (1998) Geomorphology. 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 79–118. Technical Bulletin No. 90, Agriculture Western Australia, South 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.

Pedley L (2001) *Acacia aneura* and relatives. In *Flora of Australia 11B, Mimosaceae, Acacia, Part 1* (eds AE Orchard, AJG Wilson), pp 309–328. Australian Biological Resources Study, Canberra, and CSIRO Publishing, Melbourne.

Porembski S, Martinelli G, Ohlemuller R, Barthlott W (1998) Diversity and ecology of saxicolous vegetation mats on inselbergs. *Diversity and Distributions* **4**, 107–119.

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.

Shaw RJ (1999) Soil salinity – electrical conductivity and chloride. In *Soil Analysis: An Interpretation Manual* (eds KI Peverill, LA Sparrow, DJ Reuter), pp 129–145. CSIRO Publishing, Melbourne.

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

Smith MG (2010) 'Declared Rare and Priority Flora List for Western Australia, 16th September 2010'. Department of Environment and Conservation, Perth.

Sneath PHA, Sokal RR (1973) *Numerical Taxonomy: The Principles and Practice of Numerical Classification.* Freeman, San Francisco.

Specht R, Batianoff GN, Reeves RD (2006) Vegetation structure and biodiversity along the eucalypt forest to rainforest continuum on the serpentine soil catena in a subhumid area of central Queensland, Australia. *Austral Ecology* **32**, 394–407.

Soil and Plant Council Inc. (1999) *Soil Analysis – Handbook of Reference Methods.* CRC Press, Boca Raton.

Tiller KG (1962) Weathering and soil formation on dolerite in Tasmania with particular reference to several trace elements. *Australian Journal of Soil Research* **1**, 75–90.

van Etten EJB, Fox JED (2004) Vegetation classification and ordination of the central Hamersley Ranges, Western Australia. *Journal of the Royal Society of Western Australia* **87**, 63–79.

Walton K, Allen D (2004) Mehlich no. 3 soil test – the Western Australian experience. In *Abstracts, Supersoil 2004: 3rd Australian New Zealand Soils Conference*, University of Sydney, Australia, December 5–9, 2004.

Western Australian Herbarium (1998–) *Florabase – The Western Australian Flora.* Department of Environment and Conservation. Available at http://florabase.dec.wa.gov.au/ [last accessed July 2007].

Woodman Environmental Consulting Pty Ltd (2007) 'Flora and vegetation of the Karara–Mungada Project Survey Area'. Unpublished report for Gindalbie Gold NL, Perth.

Wyche S (2008) *Kalgoolie, Youanmi and Narryer Terranes of the Yilgarn Craton – A Field Guide.* Record 2008/12, Geological Society of Western Australia, Perth.

Zar J H (1984) *Biostatistical Analysis,* 2nd ed. Prentice-Hall International, New Jersey.

APPENDIX 1

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

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

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

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

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

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

Apocynaceae
- *Alyxia buxifolia*

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

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

Boraginaceae
- *Omphalolappula concava*

Boryaceae
- *Borya sphaerocephala*

Brassicaceae
- *Lepidium oxytrichum*
- *Stenopetalum anfractum*

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

Casuarinaceae
- *Allocasuarina acutivalvis*

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

Sclerolaena densiflora
Sclerolaena diacantha
Sclerolaena eriacantha
Sclerolaena gardneri

Colchicaceae
Wurmbea sp. Paynes Find (CJ French 1237)

Convolvulaceae
Duperreya commixta

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

Cuscutaceae
*Cuscuta epithymum**

Droseraceae
Drosera bulbosa subsp. *major*

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

Frankeniaceae
Frankenia setosa

Geraniaceae
*Erodium aureum**
Erodium cygnorum

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

Hypoxidaceae
Hypoxis glabella var. *glabella*

Juncaginaceae
Triglochin isingiana

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

Loranthaceae
Amyema fitzgeraldii

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

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

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

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

Papilionaceae
Mirbelia bursarioides
Swainsona oliveri

Phormiaceae
Dianella revoluta var. *divaricata*

Pittosporaceae
Cheiranthera filifolia var. *simplicifolia*

Plantaginaceae
Plantago debilis

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

Appendix 1 (cont.)

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

Polygalaceae
Comesperma integerrimum

Polygonaceae
*Emex australis**

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

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

Rubiaceae
Psydrax latifolia
Psydrax suaveolens

Rutaceae
Philotheca brucei subsp. *brucei*
Philotheca sericea

Santalaceae
Exocarpos aphyllus
Santalum spicatum

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

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

Sterculiaceae
Brachychiton gregorii
Rulingia luteiflora

Stylidiaceae
Stylidium longibracteatum

Thymelaeaceae
Pimelea forrestiana

Urticaceae
Parietaria cardiostegia

Zygophyllaceae
Zygophyllum lobulatum

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Flora and vegetation of the banded iron formations of the Yilgarn Craton: the Johnston Range, Menzies

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ABSTRACT

The Johnston Range is located in the Mt Manning Region of the Eastern Goldfields, in Western Australia. These ridges and hills of outcropping banded iron formation and mafic bedrock are associated with the Marda–Diemals greenstone belt. Fifty permanent quadrats were established on the range and adjacent ridges during the course of a vegetation and flora survey. A total of 179 taxa (176 native) were identified, including five taxa of conservation significance that were new records for the survey area. Four range extensions (>100 km) and three regional endemic taxa were reported. Notable taxa included a Western Australian variant of *Sida petrophila s.l.*, a regional endemic (*Banksia arborea*) and a new population of the declared rare and locally endemic taxon, *Ricinocarpus brevis*. Six floristic community types were described from classification analysis of a presence/absence matrix of floristic data. The communities were associated with geological substrate and a topo-edaphic gradient. Nonmetric multidimensional scaling ordination found significant correlations between soil chemical and site variables and site floristic composition, and non-parametric ANOVA found significant differences in soil chemistry and site physical attributes among community types. The entire survey area around the Johnston Range is currently tenured as pastoral lease, and the greenstone and banded iron formations are under tenement for mining and exploration. The survey area lies outside of any proposed conservation reserves and secure conservation estate. Proposed developments must take consideration of the rare and endemic taxa and communities into the planning process to reduce impacts on conservation values of the area.

Keywords: banded iron formation, conservation, flora, Marda–Diemals greenstone belt, vegetation communities, Yilgarn.

INTRODUCTION

Ranges of Archaean banded iron formation (BIF) and greenstones are a common topographic feature of the eastern region of the Yilgarn Craton. These isolated landforms harbour distinctive flora and fauna that reflects the antiquity, unique evolutionary history and individual physical characteristics of these ranges (Department of Environment and Conservation 2007; Gibson et al. 2007). However, these ranges are highly prospective for iron ore and have been targeted for exploration (Department of Industry and Resources 2007). This has lead to a series of quadrat-based surveys to document the flora and floristic communities on 25 individual BIF ranges in the Yilgarn in order to place these within a regional context and to assist with management and reservation decisions (Department of Environment and Conservation 2007; Gibson et al. 1997; Gibson & Lyons 1998a, 1998b, 2001a, 2001b; Gibson 2004; Markey & Dillon 2008a, 2008b, 2009, 2010a, 2010b, 2011; Meissner & Caruso 2008a, 2008b, 2008c, Meissner et al. 2010a, 2010b, 2010c).

The Mount Manning Region, between Southern Cross and Menzies in the Midwest region of Western Australia, is one such area that has BIF ranges under consideration for both mining and reservation (Environmental Protection Authority 2007). The Johnston Range survey area lies within the northern part of this region, which also includes the Die Hardy Range, Windarling Range, Jackson Range, Mt Manning Range, Hunt Range, Helena and Aurora Range and Highclere Hills. Over the past decade, there have been a number of vegetation surveys on BIF ranges in the wider eastern goldfields and in the Mount Manning Region (Department of Environment and Conservation 2007; Environmental Protection Authority 2007; Gibson et al. 1997; Gibson & Lyons 1998a, 1998b, 2001a, 2001b; Gibson 2004; Mattiske 2001a, 2001b). These surveys have both described floristic communities and compiled a flora list for individual ranges. A number of these ranges have been identified as being of high conservation significance because of their relatively high α species diversity, and for harbouring rare, poorly known, new and endemic species and highly

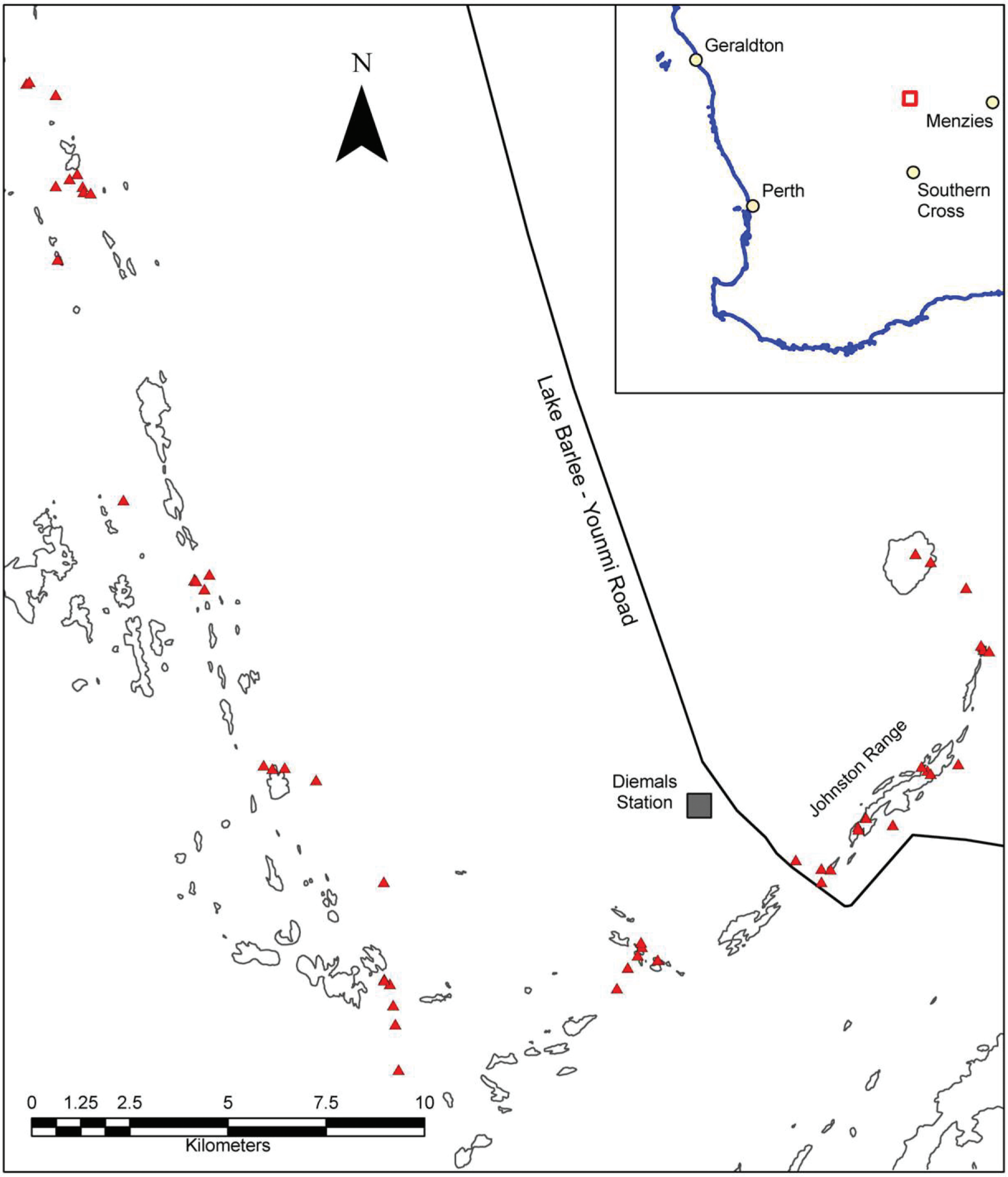

Figure 1. The location of the Johnston Range survey area, with major landforms and landmarks indicated. Areas of higher elevation (>410 m) are outlined by contour lines. The locations of the 50 permanent quadrats are marked (▲).

restricted vegetation communities (Barrett 2007; Butcher et al. 2007; Bull 2007; Department of Conservation and Environment 2007; Environmental Protection Authority 2007; Gibson et al. 2007; Mattiske 2001a, 2001b).

Recent demand from Asian markets has seen an unprecedented level of exploration and mining for iron ore deposits within the Mount Manning Region, and ranges with high conservation values are also highly prospective for minerals (Department of Environment and Conservation 2007; Environmental Protection Authority 2007; Gibson et al. 2007). For the ongoing purposes of regional conservation management and strategic planning around conflicting demands in this region, the Johnston Range was targeted as a region requiring biological survey (Department of Environment and Conservation 2007). This paper aims to describe the flora and floristic communities of this BIF landform.

STUDY AREA

The Johnston Range survey area is located 416 km northeast of Perth, some 169 km west of Menzies and 175 km north of Southern Cross (Fig. 1). All landforms are located on Diemals Station, within the Shire of Menzies. This survey targeted BIF landforms within a rectangle spanning 24.5 km east to west and 25 km north to south, between the latitudes of 29° 44' to 29° 29', and between the longitudes of 119° 24' to 119° 07'. A series of hills and ridges were visited, including the Johnston Range proper in the east and a series of unnamed hills and ridges to the south and west of Diemals homestead (Fig. 1). These BIF landforms are narrow and elongate, being only 4 km at the widest point and totalling 41 km in length. The survey area is north of a number of significant ironstone ranges, including the Die Hardy Range (28 km south), Windarling Range (42 km south), Jackson Range (80 km south), Mt Manning Range (47 km southeast), Hunt Range (83 km southeast), Helena and Aurora Range (84 km south) and Highclere Hills (119 km southwest).

Land Use History

The study area lies within the north-eastern Goldfields, on the eastern margin of the Yilgarn Mineral Field, next to the North Coolgardie Mineral Field (Walker & Blight 1983). The main industries of the wider region are pastoralism and mining for gold and base metals. These activities commenced in wider Southern Cross – Menzies region the mid to late 19th century and have persisted up to the present (Beard 1972; Faithfull 1994; Walker & Blight 1983; Wyche et al. 2001). Both active pastoral leases and mining tenements currently cover the entire extent of the study area. While most of the range and surrounds have been grazed, very little of the vegetation has been cleared for agriculture as the eastern margin of the Western Australian wheatbelt region lies some 160 km to the south of the study area. Sandalwood harvesting has occurred for over a century and continues to a limited extent on Diemals station. Whilst there are several active mines in the wider Mt Manning Region (including Windarling and Evanston), the older mines on the Johnston Range are inactive. The last period of significant activity was from 1966 to 1971, when extensive diggings for copper on eastern ridges of the survey area failed to locate profitable deposits (Wyche et al. 2001). Exploration drilling recommenced on the Johnston Range in 2007.

Climate

The climate is semi-arid Mediterranean, with hot dry summers and cool winters (Beard 1990; Milewski & Hall 1995). Rainfall is variable, with marginally more rain falling during the winter months than in summer. Southerly fronts bring winter rain, while irregular summer rainfall results from thunderstorms or the remains of northerly tropical depressions (Milewski & Hall 1995). The two closest meteorological centres to the study area are Menzies township (1896–2008) and Diemals homestead (1970–1994), where the average annual rainfall is 251 mm and 276 mm respectively (Bureau of Meteorology 1908–). The average summer daily maxima (December to February) are 35.3 °C and 34.3 °C for Diemals and Menzies respectively, with average maxima over 30 °C occurring between November and March (Bureau of Meteorology 1908–). Winter months (June to August) are coolest, with average winter minima falling below 7 °C and periods of overnight frosts (Bureau of Meteorology 1908–; Milewski & Hall 1995).

Geology and Geomorphology

Around 70% of the Yilgarn Craton consists of Archaean (c. 3–2.6 Ga) granitoids and gneisses, with the remaining rocks being intrusive metamorphosed volcano-sedimentary assemblages. These rocks are known as greenstones and form extensive, north-trending belts in the north-east of the craton (Cassidy et al. 2006; Champion & Smithies 2001, 2003). The Johnston Range landforms are associated with prominent outcroppings of the northern extent of the Marda–Diemals greenstone belt, which is situated within the Southern Cross Domain of the Youanmi Terrane, a centrally-located subdivision of the Yilgarn Craton (Cassidy et al. 2006; Chen & Wyche 2003; Wyche et al. 2001).

The geology of the wider region has been described and mapped on the Barlee 1:250,000 sheet (Sheet SH/50-8; Walker & Blight 1983), and the range is a major feature on the Johnston Range 1:100,000 sheet (Wyche et al. 2001). The Marda–Diemals greenstone belt in the vicinity of the Johnston Range is composed of the lower greenstone succession (3 Ga), which consists of metamorphosed basalts, ultramafics, sedimentary rock and felsic volcanics. Metamorphosed sedimentary rocks are a substantial part this succession, and form prominent ridges of mainly BIF and chert when exposed (Wyche et al. 2001). The western ridges have substantial amounts of exposed, deeply weathered metagabbro, metamorphosed mafics and high Mg basalt in addition to extensive ridges of BIF and cherts and other metasedimentary rocks. These latter ridges are commonly flanked by deeply weathered, ferruginized metasedimentary rocks (Wyche et al. 2001). Extensive deposits of coarse talus, colluvium, sand, silts and gravel accumulate below ridges and breakaways, and sheetwash deposits accumulate further from these landforms (Wyche et al. 2001). Surrounding these exposed greenstones ranges are expanses of Cainozoic regolith. Those which overlie the Archean granitoids and gneisses were formed by prolonged, deep weathering of bedrock during the Tertiary (Wyche et al. 2001).

With the exception of ranges formed by substantial outcroppings of greenstone belts, much of the wider Mount Manning Region is a relatively low-lying, subdued landscape of undulating plains. The highest topographic features within the survey area are the Johnston Range proper and associated western ridges, which reach heights of between 30 and 60 m above the surrounding plains. The lowest elevations (c. 400 m above sea level) coincide with the playa lake systems of Lake Barlee in the Diemals area (Chen & Wyche 2003; Wyche et al. 2001).

Vegetation

The survey area spans the boundary between the Yalgoo and Murchison Interim Biogeographic Regionalisation for Australia (IBRA) bioregions, and the southern edge almost crosses into the Coolgardie IBRA bioregion (Department of Environment and Water Resources 2007). These bioregions are comparable to the Yalgoo and Barlee Subregions and South West Interzone of Beard (1976, 1990). The vegetation at this junction of three biogeographic regions has been noted to be intermediate in character and possessing both Eremaean and South Western floristic elements (Keighery et al. 1995), and occurs within the transition from southern eucalyptus woodlands to mulga (*Acacia aneura*) shrublands in the north (Beard 1976, 1990; Keighery et al. 1995).

Beard (1972, 1976) described and mapped major vegetation systems (catenary sequence of communities over a geological feature) and greenstone hill communities (based on dominant taxa and physiognomy) for the southern part of the Barlee subregion, immediately south of the Johnston and Mt Manning Ranges. Three vegetation systems were described for BIF ranges: the Highclere and Bungalbin Systems were located on the southernmost ranges of the Mt Manning Region, while the Die Hardy System was mapped for the Die Hardy Range. This latter system was assumed to also occur on the Mt Manning Range (Beard 1972, 1976), but it was not specified if the Die Hardy System also occurred on the Johnston Range. The Die Hardy System consisted of *Banksia arborea* shrublands on rocky crests, with casual occurrences of *Brachychiton gregorii*. Drier northern slopes had shrublands of *A. aneura, Acacia ramulosa* var. *linophylla*, *Acacia burkittii*, *Acacia tetragonophylla* and *Dodonaea* sp., while southern slopes were primarily shrublands of *Allocasuarina acutivalvis* and *Allocasuarina campestris*, with various *Acacia* species and mallees (*Eucalyptus oleosa* and *Eucalyptus formanii*). Vegetation on lower slopes and outwashes consisted of woodlands of *A. aneura*, with scattered *Casuarina pauper* and *Acacia ramulosa* var. *ramulosa* (Beard 1972, 1976).

The Johnston Range was included within the bounds of the regional survey of the Barlee–Menzies region by Keighery et al. (1995), but not specifically addressed as an individual landform. They described 28 structural formations for greenstone and BIF landforms, eight of these occurring on BIF landforms, eleven on greenstone landforms, and nine structural communities for broad valleys. BIF communities included tall shrublands or mallee woodlands dominated by *A. aneura, A. acutivalvis* and *B. arborea,* with *Acacia quadrimarginea* and *Eucalyptus ebbanoensis* on crest, slopes and undulating plains. Broad valleys contained low woodlands dominated by a variety of *Eucalyptus* species, *A. aneura* or *Callitris collumelaris*. Keighery et al. (1995) concluded that the Die Hardy System also existed on the Mt Manning Range, as they found patches of crest shrublands dominated by *B. arborea* and *A. acutivalvis.* Gibson (2004) failed to relocate this crest community and concluded that it was localised in small patches. This raises the possibility that elements of the Die Hardy System could occur on the Johnston Range.

METHODS

Fifty 20 x 20 m permanent quadrats were established during August 2007. The survey primarily focused on vegetation communities on ironstone geologies, but five quadrats were located on adjacent hills of greenstone to enable comparison with the ironstone communities. Quadrats were established along a toposequence from ridge crests to the colluvial deposits on lower slopes and outwash plains. This covered an elevational range from 421 m to 512 m AMSL, and sampled over the vegetation catenary sequence. This methodology has been used to survey other ranges in Western Australia (Gibson 2004; Gibson et al. 1997; Gibson & Lyons 2001a, 2001b; Markey & Dillon 2008a, 2008b). Quadrats were established only in the least disturbed vegetation in the area, heavily grazed and cleared areas were avoided. The extreme southern part of the range was regenerating from a wildfire that occurred c. 15 years prior to the survey. Some quadrats were established in this area, but only placed in relatively unburnt patches within this fire mosaic. Quadrats were marked with four steel fence droppers and their position and altitude recorded by a GPS receiver (Garmin 76, Garmin Ltd, Kansas). The presence and cover of all vascular plant species were recorded for each quadrat, and material within and adjacent to quadrats was collected for identification at the Western Australian Herbarium, where representative specimens were lodged. Geographical distributions of taxa were obtained from online records at the Western Australian Herbarium (1998–). The *Acacia aneura* complex is currently under review (Maslin & Reid 2009; Miller et al. 2002) so was resolved to three varietal morphotypes that approximate the varieties described by Pedley (2001).

For each quadrat, vegetation structure was described according to McDonald et al. (1998). All data on topographical position, aspect, slope, litter cover, bare ground cover, and rock cover classes of both surface deposits and exposed bedrock were noted according to the standard definitions outlined in McDonald et al. (1998). Leaf litter and bare ground were visual estimates of percentage cover. Both the cover classes of surface rock fragments and exposed bedrock, and maximum surface rock fragment size were coded on a semi-quantitative scale (Table 4). Twenty samples of soil were collected from the top 10 cm, then bulked and sieved, and the 2 mm fraction used for analysis at the Chemistry Centre of Western Australia. Concentrations of 16 elements (Al, B, Ca, Cd, Co, Cu, Fe , K, Mg, Mn, Mo, Na, Ni, P, S and Zn) were determined simultaneously using inductively coupled plasma atomic emission spectrometry (ICP AES), using the Mehlich No. 3 soil test procedure (Mehlich 1984; Walton & Allen 2004). The effective cation exchange capacity (eCEC) was estimated from the sum total of individual charge equivalents per kilogram of Na, Ca, K and Mg, which were calculated from their respective cation concentrations from ICP AES (Soil and Plant Council 1999; Rayment & Higginson 1992). Soil pH was determined in 0.01 M $CaCl_2$ (method S3; Rayment & Higginson 1992), and electrical conductivity ($EC_{1:5}$) was determined in a 1:5 solution of soil extract:deionised water at 25 ºC (method S2, Rayment & Higginson 1992). Soil organic carbon (%) was determined using Metson's colorimetric modification of the Walkley and Black wet oxidation method S09 (method 6A1 of Rayment & Higginson 1992). Total soil nitrogen (%) was determined from colorimetry after a modified Kjeldahl digest of samples (method S10; Rayment & Higginson 1992).

Both singleton taxa (appearing only in a single quadrat) and annual (desert ephemeral) taxa were omitted from the dataset. This allowed for comparison of data collected between seasons and years, and was consistent with previous surveys on Western Australian ironstone and greenstone ranges (Gibson 2004; Markey & Dillon 2010a, 2010b, 2011, Meissner & Caruso 2010a, 2010b). These varied resemblance matrices (Bray–Curtis measure of distance) were compared using the '2 Stage' algorithm in Primer (Clark & Gorley 2006) to determine the degree of correlation between datasets following the exclusion of taxa. Classification and ordination analysis was conducted using the statistical software package, PATN (V3.03) (Belbin 1989), using the Bray–Curtis coefficient to generate an association (resemblance) matrix. A flexible UPGMA (β = –0.1), an agglomerative, hierarchical clustering method, was used to simultaneously generate both a species and site classification (Belbin et al. 1992; Sneath & Sokal 1973). Indicator species analysis (INDVAL) was calculated using PC-Ord (McCune & Mefford 1999), using the methods of Dufrêne and Legendre (1997). INDVAL measures were calculated from species fidelity and constancy for each community, and a Monte Carlo permutation test (10 000 simulations) was used to test for the significance of these indicator species. Using PATN, semi-strong hybrid (SSH) multidimensional scaling was used to ordinate the quadrat floristic data in three dimensions, using 1000 random starts and 50 iterations (Belbin 1991). Principal Component Correlation (PCC) was used for a multiple linear regression of physical and soil variables on the site ordination (Belbin 1989; Faith & Norris 1989). A Monte-Carlo procedure (MCAO) was used in PATN to evaluate the significance of these correlation coefficients, using 1000 iterations. Differences in community averages for environmental variables were tested using Kruskal–Wallis nonparametric analysis of variance and Dunns' post-hoc multiple comparisons (Zar 1984).

RESULTS

Flora

A total of 179 taxa (species, subspecies, varieties and forms) and 4 putative hybrids were identified from collections within or adjacent to the 50 quadrats on the Johnston Range (Appendix 1). Of these, the majority of taxa (176) were native. Taxa identified were from 45 families, of which the most common were the Asteraceae (15 native taxa and one introduced taxon), Mimosaceae (*Acacia*, 16 taxa), Chenopodiaceae (15 taxa and one hybrid), Poaceae (15 native and one introduced taxon), Myoporaceae (*Eremophila*, 13 taxa), Myrtaceae (12 taxa), Lamiaceae (eight taxa and one hybrid), Malvaceae (eight taxa), Caesalpiniaceae (*Senna*, five taxa and two hybrids) and Proteaceae (seven taxa). Other common genera were *Maireana*, *Eucalyptus* and *Sida* (all with six taxa each; Appendix 1). Families were defined using the APG II system (Angiosperm Phylogeny Group 2003).

The dominant growth forms were shrubs (110 sub-shrub to tall shrub taxa, 61% of total taxa), with 6% of taxa (11 taxa) being classed as a tree or mallee, 2% (3 taxa) as perennial climbers, 5% (9 taxa) as perennial geophytes, 6% (11 taxa) as perennial grasses, 3% (5 taxa) as annual grasses and 1 species of mistletoe. There was sufficient winter rainfall to support moderate abundances of geophytes (9 taxa), perennial herbs (5 taxa) and herbaceous winter annuals (24 taxa), which together constituted 21% of the total flora (Appendix 1). Only two succulent species (both species of *Crassula*) were recorded.

Significant taxa

Five taxa of conservation significance were collected in this survey (Smith 2010; rare or poorly known taxa are assigned a numerical priority listing from 1 to 4 by the Department of Environment and Conservation). Although these five species are known from other ranges in at least the wider Mount Manning Region, these are new populations and some are species range extensions.

- The collection of the declared rare flora (DRF) species, *Ricinocarpos brevis* (Euphorbiaceae) is the first record for the Murchison IBRA bioregion. This new population is 32 km to the north of a disjunct population on the Windarling Range (Mattiske 2001a, 2001b; Western Australian Herbarium 1998–). While the Windarling Range population is restricted to massive BIF outcrops between 500 to 550 m in altitude, occurring in *Banksia arborea* – *Melaleuca leiocarpa* shrublands (Halford & Henderson 2007; Mattiske 2001b), the Johnston Range population occurs on the deep soils of the gently inclined, lower slopes and pediments. *Ricinocarpos brevis* is considered to be a regional endemic with a highly restricted distribution to BIF ranges in the northern Mount Manning Region (Environmental Protection Authority 2007).
- *Baeckea* sp. Parker Range (M Hislop & F Hort MH 2968; Myrtaceae) has a Priority 3 conservation status (Smith 2010), as it is poorly known and only represented by eight collections in the herbarium. The Johnston Range population is 18 km north of the

nearest known populations on the Die Hardy Range, and a significant (220 km) disjunction north from the Parker Range (Western Australian Herbarium 1998–). This species was found at two locations on BIF uplands at the Johnston Range, but herbarium records indicate that it has also been found on massive BIF, a sandplain with laterite gravels and low laterite ridge near BIF ranges.

- *Daviesia purpurascens* (Papilionaceae) is a Priority 4 listed taxon that has a relatively wide distribution in South West and Eremaean regions (Western Australian Herbarium 1998–), which has lead to suggestions that this taxon could be removed from listing (Environmental Protection Agency 2007). There are currently 41 records at the Western Australian Herbarium. However, further taxonomic work on the group is required since there may be several taxa under this name (M Hislop[1], pers. comm.). The northern variant collected from the Johnston Range has several characters that distinguish it from the southern variants, including numerous pungent phyllodes, and the combination of elongate, slender and intertwined branches that are distinctly non-glaucous. The same northern variant also occurs on Bungalbin Hill and the Helena and Aurora, Mt Manning, Mt Jackson and Windarling Ranges (Gibson 2004; Western Australian Herbarium 1998–). A review of this species complex is required to recognise if there is a regional variant that may be restricted to BIF landforms in the Mt Manning Region.
- Prior to the spring survey season of 2007, *Spartothamnella* sp. Helena and Aurora Range (PG Armstrong 155–109; Lamiaceae) was not known from the survey area, with the nearest population 67 km west of the Johnston Range (Western Australian Herbarium 1998–). This species has a Priority 3 conservation listing. Plants were located not only on the Johnston Range, but 80 km to the east on the northern Yerilgee greenstone belt (Markey & Dillon 2011).
- Sterile material was collected that was tentatively identified as *Austrostipa* cf. *blackii,* based on similarity with fruiting material collected from the northern Yerilgee Hills (Markey & Dillon 2011). *Austrostipa blackii* has Priority 3 conservation status, and occurs in scattered localities throughout the Avon Wheatbelt, Yalgoo and Coolgardie IBRA Bioregions. These are new records for this species for the area, the nearest collection being from the Hunt Range, 83 km to the south east. This species is not restricted to BIF landforms.
- *Banksia arborea* (Priority 4) was located in a few scattered locations on the Johnston range, with all of these populations restricted to rocky crests of weathered BIF. This species grows as a tall shrub or low tree, and is often a dominant species along these crests. Tall and sometimes senescent trees were observed in long-unburnt vegetation, while a number of vigorous and heavily flowering shrubs were observed in the burnt area at the south-western extant of the range. This species is a regional endemic that has a range less than 200 km in diameter, and is primarily restricted to BIF outcrops. Populations also occur on the Yerilgee hills, c. 80 km east of the Johnston Range (Markey & Dillon 2011) and on an unspecified range on Mt Elvire Station (collection number J Blyth s.n.), although Keighery et al. (1995) failed to located this species on the ironstone of Mt Elvire proper.

Notable taxa

Collections of *Sida petrophila s.l.* from the Johnston Range have had their identity confirmed (R Barker[2], pers. comm.). The name *Sida petrophila* has been applied to group of several entities, and the taxon in the strictest sense does not occur in Western Australia (Barker 2007). The few Western Australian collections of this entity require further examination to determine if they are different from disjunct populations in eastern Australia (R Barker[2], pers. comm.). This entity has also been collected from northern Yerilgee hills (Markey & Dillon 2011) and a few other locations in the Midwest and Goldfields. This *Sida* appears to be restricted to mafic substrates, and occurs on metabasalt hillslopes in the western part of the Johnston Range survey area.

Collections of *Austrostipa scabra* were found to include several entities, including an atypical variant within the circumscription of *Austrostipa scabra s.l.* (collection number: A Markey & S Dillon 6114) and an entity with affinities to the complex (*Austrostipa* aff. *scabra* collection number: A Markey & S Dillon 6107). This complex is currently undergoing revision, and further studies and collections are required to confirm the status of these collections. In addition to the two endemic priority listed taxa, *Eremophila* sp. Mt Jackson (GJ Keighery 4372) is considered as a regional endemic (Environmental Protection Authority 2007; Gibson 2004), with a geographical range of approximately 200 km.

Range extensions

Range extensions of 100 km or greater were noted for four other species that did not have a conservation listing (Western Australian Herbarium 1998–). The ranges of two species were extended by over 300 km. *Senna artemisioides* subsp. x *coriacea* is known from ten locations that are scattered widely throughout the entire state, the nearest population being 400 km south of Johnston Range. The collection of *Glycine peratosa* is a 350 km range extension north-west from other collections. *Acacia* sp. Wondinong (AA Mitchell 917) is widespread

[1] Michal Hislop, Senior Technical Officer, Western Australian Herbarium, Department of Environment and Conservation, Kensington.

[2] Robyn Barker, Research Associate, State Herbarium of South Australia, Department of Environment and Natural Resources, Kent Town.

throughout the Murchison IBRA, but the Johnston Range population is a range extension of c. 120 km south from the nearest known population. *Acacia obtecta* was collected 120 km east from previously known populations.

Floristic Communities

Four taxa were amalgamated into two species complexes for floristic analyses as there was some difficulty in differentiating between closely related taxa due to poor quality flowering material and intergrading characters. These two species complexes were the *Austrostipa scabra* sens. lat (atypical variant)/*A. nitida* and *Enchylaena lanata/ E. tomentosa* subsp. *tomentosa*.

The full dataset consisted of 155 taxa in 50 quadrats, of which 26 were annual taxa and 26 perennial taxa that were singletons. The average species richness per quadrat was 24.1 ± 0.8 taxa (x ± s.e.), and ranged from 14 to 36 taxa. After the omission of these annual and singleton perennial taxa, the final dataset consisted of 103 taxa from 50 quadrats (66% of total taxa), with an average of 22.4 ± 0.7 taxa per quadrat, and richness ranging from 14 to 33 taxa per quadrat. '2-Stage' comparison of resemblance matrices of the original dataset and the dataset used in the final analyses found 98.6% correlation. Preliminary classification analyses found that the omission of singletons and annuals had little effect on the site classification.

Floristic communities were resolved at two levels in the site classification: the two group level from the primary division, and the six group level (Fig. 2). The species classification of 103 taxa produced eight species groups (Table 1). The primary division in the site classification separated floristic communities on mixed BIF and metamorphosed mafic substrates (community types 1, 2 and 3) from those communities associated with predominately BIF substrates on rocky hill slopes, crests, lower slopes and colluvial flats (community types 4, 5 and 6). This primary division can be seen on the sorted two-way table (Table 1), where community types 1, 2 and 3 have high representation from species group F, more limited presentation in A to E, and a general lack of species from species group G. Conversely, the predominately BIF communities (community types 4, 5 and 6) have high and distinctive representation from groups E and F, low representation in A to D, and moderate sampling from species group G.

Community type 1: Casuarina pauper – Allocasuarina dielsiana – Eucalyptus *woodlands on lower slopes and flats*

Location: Woodlands on lower slopes, valley flats and pediments surrounding outcropping ridges and hills of BIF. Quadrats were at low altitudes and among the lowest topographic positions (Table 3).
Substrate: BIF quartz and calcrete colluvium, over BIF and mafic (occasionally some ultramafic) bedrock. This community was associated with very low cover of exposed bedrock, low runoff scores and gentle inclines (Table 3). Soils were weakly acidic to neutral, with moderate organic C, N, S and Fe concentrations, moderate to high concentrations of a range of trace elements and relatively higher salinity values (soil $EC_{1:5}$ and Na; Table 4).
Structural description: Open woodlands to occasional trees, varyingly dominated or co-dominated by *Casuarina pauper*, *Allocasuarina dielsiana* or *Eucalyptus* spp. (*E. concinna*, *E. salubris* and/or *E. oleosa* subsp. *oleosa*). The understorey consisted of a mid to dense shrub layer that included *Olearia muelleri*, *Acacia andrewsii*, *Eremophila pantonii*, *Eremophila oldfieldii* subsp. *angustifolia*, *Acacia erinacea*, *Acacia acanthoclada* subsp. *glaucescens*, *Alyxia buxifolia*, *Exocarpus aphylla* and *Senna artemisioides* subsp. *filifolia.* Chenopods (*Maireana* and *Sclerolaena* spp.) and speargrass (*Austrostipa platychaeta*) were common in the ground layer.
Species groups: Species groups C and F most consistently present, with more limited occurrences from species

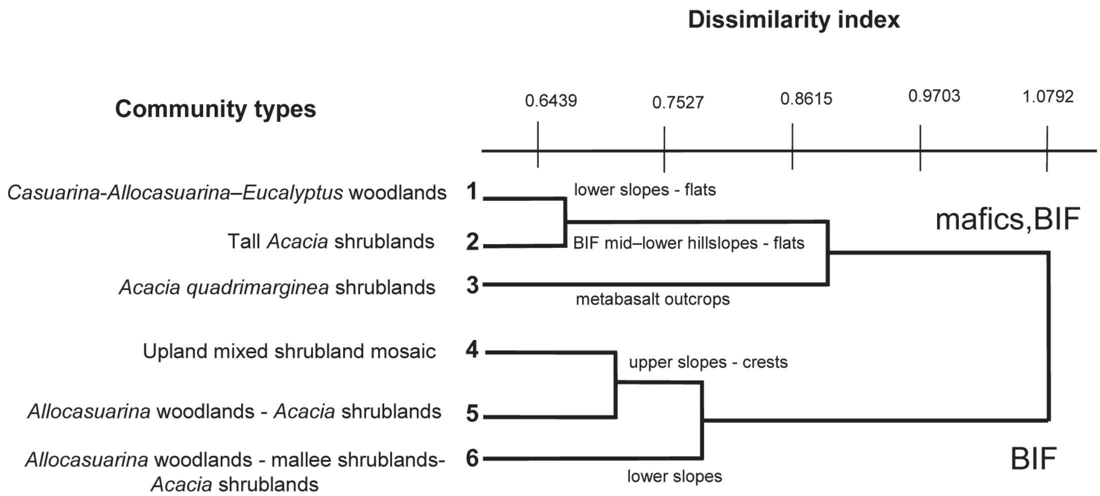

Figure 2. Summary dendrogram of floristic community types of the Johnston Range, resolved from classification analysis of a presence/absence data matrix of 103 perennial taxa from 50 quadrats, using Bray–Curtis dissimilarities and flexible UPGMA method of classification (β = –0.1). Topographic and geological attributes are superimposed on the dendrogram.

Table 1

Two-way table of quadrats and perennial taxa, sorted by the site and species classification, of the Johnston Range. Quadrats appear as columns, and species as rows, ordered by species groups and community types derived from the floristic classification of 103 taxa from 50 quadrats. The presence of a taxon within a quadrat is indicated by a rectangle.

	type 1									type 2									type 3		type 4											type 5											type 6							
Species group A																																																	
Abutilon cryptopetalum										■		■			■	■		■	■												■			■			■	■										
Solanum ellipticum										■		■			■			■	■														■								■							■	
Abutilon oxycarpum																		■	■																												
Sida petrophila																		■	■																												
Austrostipa aff. *scabra*																		■	■																			■									
Maireana planifolia																		■	■																		■	■									■
Austrostipa cf *blackei*															■				■	■												■													■					
Enneapogon caerulescens															■				■																													
Eremophila serrulata															■				■	■																												
Cheilanthes lasiophylla																		■											■		■																			
Senna artemisioides subsp. x *artemisioides*							■												■	■											■					■														
Species group B																																																	
Acacia acanthoclada subsp. *glaucescens*		■			■																																											
Pittosporum angustifolium		■			■										■																																	
Sida spodochroma					■														■																												
Austrostipa platychaeta			■		■																																										
Eremophila decipiens subsp. *decipiens*			■		■											■																															■
Casuarina pauper	■		■																																													
Eremophila alternifolia			■		■					■						■		■																			■													
Solanum nummularium					■					■			■			■	■	■																															
Species group C																																																	
Acacia andrewsii						■	■	■	■				■					■																																
Eremophila oppositifolia subsp. *angustifolia*							■	■	■									■																																
Austrodanthonia caespitosa			■	■	■			■				■	■							■															■	■													
Eremophila pantonii			■	■	■	■	■																																								
Olearia muelleri		■	■	■	■	■	■	■	■			■																																				
Eucalyptus concinna				■	■		■	■										■						■																									■
Eriochiton sclerolaenoides			■	■				■				■																																	■				
Sclerolaena fusiformis			■				■	■	■																																			■				
Acacia erinacea				■		■			■																																								
Exocarpos aphyllus			■	■					■																																								
Maireana trichoptera			■	■																																													
Alyxia buxifolia	■	■	■	■				■	■									■																																
Enchylaena lanata/tomentosa	■	■		■					■				■			■													■								■							■				■
Maireana georgei	■	■		■			■		■																																					■				■
Rhagodia drummondii		■	■						■				■				■		■																														
Species group D																																																	
Eucalyptus longissima		■										■																														■								
Senna stowardii												■	■																																			
Species group E																																																	
Acacia aneura var. cf. *argentia*	■	■																■			■	■	■	■	■			■				■		■		■			■	■	■		■			■				■
Acacia cockertoniana							■		■					■									■	■	■	■	■	■		■		■	■	■	■		■	■	■		■	■		■	■	■		■		
Eremophila latrobei																					■	■	■	■	■	■	■	■			■	■	■	■				■	■	■	■	■		■	■	■		■	■	■
Philotheca brucei subsp. *brucei*	■						■	■					■				■	■		■	■	■	■	■	■	■	■			■	■	■	■		■	■	■	■	■	■	■		■			■	■		
Eremophila georgei	■													■											■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■		■	■		
Olearia humilis								■						■							■		■	■	■			■	■			■		■			■				■	■	■	■	■	■	■	■	■	■
Cheilanthes adiantoides										■				■					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■		
Eremophila forrestii																■				■		■	■	■	■					■	■	■	■	■	■	■	■	■			■			■	■	■	■	■	■		
Cheilanthes sieberi subsp. *sieberi*	■									■					■	■		■		■	■	■	■			■		■	■	■		■		■	■	■	■	■		■		■		■	■		■	■	
Acacia aneura var. cf. *intermedia*									■							■					■	■		■		■		■		■									■	■		■	■	■	■	■	■	■	■
Monachather paradoxus	■										■	■				■						■				■	■	■	■		■			■				■				■	■	■	■	■	■	■	■	■
Austrostipa scabra		■			■	■							■		■	■	■			■			■	■	■	■	■		■	■	■			■			■	■	■	■			■	■	■	■			■	■
Comesperma integerrimum							■		■					■					■							■					■	■			■			■	■	■		■						■			■
Grevillea extorris						■		■	■														■	■	■	■				■						■	■	■	■	■									
Acacia ramulosa var. *ramulosa*							■			■	■		■	■	■	■	■	■										■				■	■	■			■	■					■	■	■	■	■	■	■	■
Dianella revoluta var. *divaricata*		■														■	■	■			■											■		■				■	■				■	■		■	■	■		■
Thysanotus manglesianus		■									■	■					■		■														■		■				■	■							■		■	■		
Amphipogon cf. *caricinus* var. *caricinus*																								■																				■		■		■		■	■
Eremophila granitica		■														■	■	■																											■	■	■		■	■
Acacia aneura var. cf. *microcarpa*																					■				■										■		■	■	■	■	■		■		■	■	■	■			
Prostanthera magnifica																					■				■			■									■		■				■								
Cryptandra connata																																						■					■		■				
Psydrax suaveolens																									■															■				■			■				
Spartothamnella teucriiflora																■						■																■			■		■		■			■	■		■	
Species group F																																																	
Acacia burkittii	■	■	■	■	■	■	■	■	■			■	■	■	■	■	■	■		■							■										■	■		■											
Senna artemisioides subsp. *filifolia*	■	■	■	■	■	■	■	■	■	■	■	■	■			■	■	■		■						■		■									■		■					■							■
Acacia tetragonophylla	■	■	■	■	■		■	■	■	■	■	■	■		■	■	■	■		■										■			■		■	■	■	■	■	■	■		■	■	■	■	■			
Scaevola spinescens	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■				■		■	■					■			■	■	■	■		■	■		■	■	■		■			
Ptilotus obovatus	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■				■	■		■	■	■	■	■		■	■	■	■	■	■	■	■		■		■				■
Austrostipa elegantissima		■	■	■	■	■	■	■	■				■	■	■	■	■	■		■					■		■				■				■		■	■		■	■		■	■	■	■	■	■	■	■
Sida sp. dark green fruits	■	■	■					■			■	■	■	■	■	■	■	■		■					■					■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■			
Solanum lasiophyllum	■		■						■	■		■	■	■	■	■	■	■	■		■				■				■	■				■	■			■	■				■	■				■
Acacia quadrimarginea							■			■	■	■	■	■					■	■	■	■			■				■	■	■	■	■	■	■	■	■	■	■	■										
Austrostipa scabra /nitida	■	■	■	■	■					■	■	■	■	■	■		■			■		■								■				■	■	■	■	■	■	■	■	■										
Dodonaea rigida			■				■					■	■	■	■				■			■	■				■	■	■				■	■	■	■	■	■	■	■	■	■	■		■					
Marsdenia australis	■	■	■	■	■				■				■		■	■						■	■			■		■				■	■	■	■	■	■		■	■	■		■								
Allocasuarina dielsiana			■									■		■	■		■	■													■	■	■	■	■	■		■		■					■	■					
Sida ectogama								■		■			■																	■	■		■		■	■	■	■		■	■	■								
Dodonaea lobulata	■			■		■	■	■		■		■	■	■	■					■											■																			
Eremophila oldfieldii subsp. *angustifolia*	■	■	■	■		■	■	■	■	■	■	■	■	■	■						■						■											■	■														
Santalum spicatum			■	■			■	■	■	■	■			■	■	■	■								■				■	■								■													
Species group G																																																	
Acacia effusifolia																								■																						■			■
Prostanthera grylloana																								■																						■			
Wrixonia prostantheroides																							■	■																						■			
Grevillea obliquistigma subsp. *obliquistigma*																								■																							■		
Bursaria occidentalis																																														■		■	
Hakea recurva subsp. *recurva*																																						■									■			
Baeckea elderiana																								■				■																							
Brachychiton gregorii																								■	■			■											■	■						■							
Leucopogon sp. Clyde Hill (M.A. Burgman 1207)																								■	■	■	■	■							■							■									
Mirbelia microphylla																							■	■	■	■		■						■																
Banksia arborea																											■	■													■										
Drosera macrantha subsp. *macrantha*																										■	■						■		■						■	■				■					
Baeckea sp. Parker Range (M. Hislop & F. Hort MH 2968)																												■							■															
Pimelea spiculigera var. *thesioides*																												■							■				■									■			
Prostanthera althoferi subsp. *althoferi*																																		■		■									■		■			
Pterostylis sp. inland (A.C. Beauglehole 11880)																									■						■			■						■							■			
Rhyncharrhena linearis		■	■																								■			■	■	■	■						■			■	■			■		■	
Species group H																																																	
Arthropodium curvipes										■																■				■	■	■	■																	
Pleurosorus rutifolius																														■	■																			
Calycopeplus paucifolius																					■				■	■	■	■	■	■	■																			
Melaleuca leiocarpa																						■			■	■	■		■	■	■			■							■									
Chamaexeros macranthera									■																■	■		■	■	■			■										■		■				■
Eremophila glutinosa																					■	■	■		■		■		■																				
Sida sp. Golden calyces glabrous (H.N. Foote 32)																					■	■	■						■	■								■										■		
Callitris columellaris																										■																									■
Olearia pimeleoides														■			■																																	■

Table 2

Significant indicator taxa of the six community types for the Johnston Range. Indicator values (%) are shown only for taxa which were significant at $p \leq 0.05$ (from Monte Carlo permutation test); levels of significance: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$). The highest indicator values per taxon (≥ 25%) are indicated by shading.

Indicator species	**Community Type 1**	**2**	**3**	**4**	**5**	**6**
*Olearia muelleri****	79	1	0	0	0	0
Senna artemisioides subsp. *filifolia****	42	25	0	1	1	3
*Acacia burkittii****	38	23	9	0	3	0
*Scaevola spinescens***	29	29	0	2	12	7
*Eremophila pantonii***	56	0	0	0	0	0
*Sclerolaena fusiformis**	35	0	0	0	0	3
*Alyxia buxifolia**	57	2	0	0	0	0
*Maireana georgei**	38	0	0	0	0	8
*Acacia andrewsii**	30	7	0	0	0	0
*Solanum nummularium**	2	46	0	0	0	0
*Abutilon oxycarpum***	0	0	100	0	0	0
*Sida petrophila***	0	0	100	0	0	0
Austrostipa aff. *scabra***	0	0	92	0	1	0
*Eremophila serrulata***	0	1	90	0	0	0
Senna artemisioides subsp. x *artemisioides***	1	0	77	1	1	0
*Acacia quadrimarginea***	0	10	33	10	22	0
*Maireana planifolia***	0	0	77	0	3	1
Austrostipa cf *blackei***	0	1	75	0	1	1
*Abutilon cryptopetalum**	0	11	55	0	7	0
*Solanum ellipticum**	0	7	61	0	2	1
*Cheilanthes lasiophylla**	0	0	37	5	0	0
*Calycopeplus paucifolius****	0	0	0	73	0	0
*Mirbelia microphylla**	0	0	0	38	2	0
*Eremophila glutinosa**	0	0	0	55	0	0
Leucopogon sp. Clyde Hill*	0	0	0	32	5	0
Sida sp. golden calyces glabrous*	0	0	0	31	1	2
*Cheilanthes adiantoides**	0	1	26	26	21	14
*Melaleuca leiocarpa**	0	0	0	49	4	0
*Dodonaea rigida****	2	13	0	9	42	1
*Eremophila georgei***	1	1	0	13	36	17
Sida sp. dark green fruits*	7	20	0	2	27	13
*Olearia humilis****	1	1	0	13	9	45
Acacia aneura var. cf. *intermedia****	1	1	0	15	2	51
*Monachather paradoxus****	1	5	0	13	3	44
Acacia ramulosa var. *ramulosa****	0	31	0	0	8	39
Amphipogon cf. *caricinus* var. *caricinus**	0	0	0	1	0	55
*Austrostipa elegantissima**	21	12	7	2	5	26
*Eremophila granitica**	1	10	0	0	0	37
Number of plots	9	9	2	11	11	8

Table 3

Summary statistics (average ± s.e.) of physical variables for floristic community types of the Johnston Range. Differences were determined using Kruskal – Wallis nonparametric analysis of variance. (* indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$), with Dunn's posthoc test (LSD $p < 0.05$, two tailed). ^{1} = non significant differences detected in multiple comparisons. Values for altitude are in metres above sea level.

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
Slope **	3.6 ± 0.5 ^{ab}	5.3 ± 1.3 ^{ab}	10.0 ± 3.0	9.0 ± 2.0 ^{b}	7.9 ± 0.9 ^{b}	2.1 ± 0.8 ^{a}
Topographic position ***	1.9 ± 0.4 ^{a}	2.9 ± 0.4 ^{ab}	4.3 ± 0.3	4.6 ± 0.2 ^{c}	4.1 ± 0.2 ^{bc}	2.0 ± 0.3 ^{a}
Surface rock ^{*1}	5.2 ± 0.3	5.1 ± 0.1	4.5 ± 0.5	4.4 ± 0.2	4.8 ± 0.3	4.3 ± 0.3
Maximum rock size ***	3.7 ± 0.2 ^{ab}	3.6 ± 0.3 ^{ab}	5.0 ± 0.0	5.2 ± 0.3 ^{b}	4.7 ± 0.3 ^{b}	2.5 ± 0.2 ^{a}
Outcrop ***	0.6 ± 0.3 ^{a}	0.3 ± 0.2 ^{a}	2.5 ± 0.5	3.9 ± 0.5 ^{b}	2.4 ± 0.6 ^{ab}	0.0 ± 0.0 ^{a}
Runoff **	2.2 ± 0.3 ^{ab}	2.1 ± 0.3 ^{ab}	3.0 ± 0.0	3.1 ± 0.2 ^{b}	2.9 ± 0.3 ^{b}	1.4 ± 0.3 ^{a}
Soil depth ***	2.5 ± 0.2 ^{bc}	2.3 ± 0.2 ^{abc}	2.0 ± 1.0	1.3 ± 0.2 ^{a}	1.9 ± 0.3 ^{ab}	3.0 ± 0.0 ^{c}
%Leaf litter ^{NS}	30.0 ± 6.8	18.3 ± 4.2	40 ± 0	24.1 ± 4.9	35.5 ± 6.8	35 ± 8.9
%Bare ground ^{NS}	85.6 ± 2.4	90.0 ± 2.5	55 ± 5	86.8 ± 2.2	79.1 ± 3.4	83.1 ± 3.4
Latitude ^{*1}	29.6089 ± 0.0259	29.628 ± 0.0249	29.5668 ± 0.0277	29.6853 ± 0.0076	29.6121 ± 0.0205	29.6548 ± 0.0224
Longitude ^{NS}	119.242 ± 0.034	119.228 ± 0.03	119.14 ± 0.008	119.295 ± 0.018	119.241 ± 0.031	119.259 ± 0.03
Altitude **	469.6 ± 9.6 ^{a}	474.7 ± 6.6 ^{ab}	496 ± 6	499.1 ± 3.5 ^{b}	478.8 ± 5 ^{ab}	458.8 ± 5.9 ^{a}
Total species /quadrat	23.9 ± 1.5	21.9 ± 0.8	31.0 ± 2.0	23.8 ± 1.9	26.2 ± 2.0	23.4 ± 1.9
Perennial species /quadrat	23.4 ± 1.4	20.4 ± 1.1	21.0 ± 1.0	21.3 ± 1.5	24.9 ± 1.8	22.8 ± 1.9
Number of quadrats	9	9	2	11	11	8

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

Percentage surface rock fragment cover class: %RF; maximum rock fragment size (MxR) and exposed bedrock outcrop cover are coded on a semi-quantitative scale.
Surface rock and outcrop % cover: 0 % cover (0); <2 % cover (1); 2–10%, (2); 10–20% (3); 20–50% (4); 50–90% (5); >90%.
Topographic position: outwash (1); lower slope (2); mid slope (3), upper slope or low, isolated ridge/hillock (4); crest (5).
Surface rock fragment and exposed bedrock cover: 0 = 0 %; 1 = <2 %; 2 = 2–10%, 3 = 10–20%; 4 = 20–50%; 5 = 50–90; 6 = >90%.
Maximum rock fragment size: 1 = 2–6 mm; 2 = 6–20 mm; 3 = 20–60 mm; 4 = 60–200 mm; 5 = 200–600 mm; 6 = 600 mm–2 m.
Runoff: 0 = no runoff; 1 = very slow; 2 = slow; 3 = moderately rapid; 4 = rapid; 5 = very rapid.
Soil depth: 1 = 0–5 cm; 2 = 5–50 cm; 3 = >50 cm.

groups B and E (Table 1). Relatively high representation from species group C (which contained a suite of chenopod subshrubs) characterised the community.
Mean perennial species richness: 23.4 ± 1.4 (SE) taxa per quadrat.

Community type 2: Tall Acacia *shrublands on BIF mid to lower hillslopes and flats*

Location: Primarily on middle to lower slopes and stony, colluvial flats, with occasional occurrences on mid to upper mafic hillslopes.
Substrate: Primarily on BIF landforms, but also occasionally found on metamorphosed mafics. Quadrats had shallow to deep colluvial deposits of BIF, quartz, mafics and calcretes with little exposed bedrock and gently to moderately inclined slopes (Table 3). Soils were weakly acidic to neutral, with moderate concentrations of organic C, N, S and Fe, and moderate to high concentrations of some trace elements (Table 4).
Structural description: Tall *Acacia* shrubland communities, often with isolated trees of *Allocasuarina dielsiana* or *Eucalyptus* (*E. concinna* or *E. longissima*). Dominant/co-dominant species in the upper stratum also included *Acacia burkittii*, *Acacia quadrimarginea*, *Acacia tetragonophylla*, *Acacia aneura*, *Acacia ramulosa* var. *ramulosa* and *E. oldfieldii* subsp. *angustifolia*. Mid-stratum shrub species include *Eremophila granitica*, *Senna artemisioides* subsp. *filifolia*, *Scaevola spinescens*, *Dodonaea lobulata*, *Ptilotus obovatus*, *Solanum nummularium* and *Sida* sp. dark green fruits (S van Leeuwen 2260; Table 2).
Species groups: Typical and consistent/frequent taxa from species group F, with more limited representation from species groups B and E (Table 1).
Mean perennial species richness: 20.4 ± 1.1 (SE) taxa per quadrat.
Comments: Community types 1 and 2 are closely allied floristically, but community type 2 has marginally lower species richness. Unlike community type 1, taxa from species group A occur in community type 2 and there is reduced representation from species group C.

Community type 3: Tall Acacia quadrimarginea *shrublands on metabasalt outcrops*

Location: Only two quadrats were classified as this community, both on the far western ridge of the Diemals greenstone belt, on upper slopes of metabasalt hills.
Substrate: Relatively steep, rocky metabasalt outcrops with high cover of exposed bedrock, large surface rocks and high runoff (Table 3). Soils were moderately acidic, with moderate concentrations of organic C and Fe and moderate to high microelement concentrations (particularly K, Mn, Ca and Co; Table 4).
Structural description: Tall shrublands dominated by *Acacia quadrimarginea*, over shorter shrubs of *Eremophila serrulata*, *Ptilotus obovatus*, *Eremophila forrestii* subsp. *forrestii* and *Solanum lasiophyllum*. Characteristic and common taxa included *Sida petrophila* and *Abutilon oxycarpum*, *Austrostipa* spp. and *Solanum ellipticum.* (Table 2)
Species groups: Distinguished by subset of species from species group A. Apart from species group F, there were few occurrences of species from the other species groups (Table 1).
Mean perennial species richness: 21.0 ± 1.0 (SE) taxa per quadrat.

Table 4

Summary statistics (average ± s.e.) of soil chemical parameters for floristic community types of the Johnston Range, using Kruskal–Wallis nonparametric analysis of variance to determine differences in community averages (* indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$), with Dunn's posthoc test (LSD $p < 0.05$, two tailed). Units for parameters: $EC_{1:5}$ = mS/m; eCEC = cmol(+)/kg; minerals = mg/kg; org C and N = % total.

	type 1	Type 2	type 3	type 4	type 5	type 6
EC **	10.7 ± 1.8 ^{b}	6.9 ± 1.3 ^{ab}	3.5 ± 0.5	5.0 ± 0.6 ^{ab}	4.8 ± 0.9 ^{a}	3.5 ± 0.4 ^{a}
pH ***	6.89 ± 0.28 ^{b}	6.4 ± 0.3 ^{b}	5.75 ± 0.05	4.35 ± 0.07 ^{a}	5.27 ± 0.27 ^{ab}	4.55 ± 0.14 ^{a}
Org C ***	1.384 ± 0.16 ^{abc}	1.088 ± 0.131 ^{ab}	1.285 ± 0.035	2.34 ± 0.285 ^{c}	1.564 ± 0.19 ^{bc}	0.799 ± 0.064 ^{a}
N **	0.101 ± 0.008 ^{ab}	0.1 ± 0.011 ^{ab}	0.125 ± 0.004	0.137 ± 0.016 ^{b}	0.107 ± 0.01 ^{b}	0.063 ± 0.004 ^{a}
B ***	1.21 ± 0.23 ^{c}	0.62 ± 0.11 ^{bc}	0.45 ± 0.25	0.31 ± 0.05 ^{ab}	0.43 ± 0.06 ^{abc}	0.19 ± 0.02 ^{a}
Ca ***	2733.3 ± 636.6 ^{b}	2054.4 ± 588.6 ^{b}	1250 ± 150	370 ± 59.8 ^{a}	828.2 ± 218.7 ^{ab}	246.3 ± 34 ^{a}
Co ***	1.488 ± 0.144 ^{bc}	2.473 ± 0.232 ^{c}	2.585 ± 0.015	0.103 ± 0.028 ^{a}	1.422 ± 0.352 ^{bc}	0.648 ± 0.242 ^{ab}
Cu ***	2.8 ± 0.34 ^{bc}	3.72 ± 0.38 ^{c}	1.95 ± 0.85	1.22 ± 0.1 ^{a}	2.16 ± 0.22 ^{abc}	1.61 ± 0.25 ^{ab}
Fe ***	48.2 ± 5.0 ^{ab}	47.9 ± 2.6 ^{ab}	68.5 ± 2.5	98.7 ± 11.7 ^{c}	53.9 ± 3.7 ^{bc}	36.1 ± 1.8 ^{a}
K ***	238.9 ± 32 ^{b}	258.9 ± 19.6 ^{b}	255.0 ± 65	125.7 ± 10.3 ^{a}	181.8 ± 15.8 ^{ab}	132 ± 13.0 ^{a}
Mg ***	297.8 ± 78.5 ^{c}	202.9 ± 50 ^{bc}	175.0 ± 15	55.0 ± 7.7 ^{a}	92.4 ± 18 ^{ab}	51.5 ± 16.2 ^{a}
Mn ***	89.1 ± 9.2 ^{bc}	139.0 ± 14.7 ^{c}	141.0 ± 59	29.7 ± 2.7 ^{a}	83 ± 16.1 ^{abc}	45.5 ± 10.1 ^{ab}
Na *	21.0 ± 4.6 ^{b}	11.4 ± 1.7 ^{ab}	10.5 ± 0.5	9.5 ± 1.0 ^{ab}	10.2 ± 1.1 ^{ab}	7.0 ± 1.2 ^{a}
Ni ***	0.9 ± 0.2 ^{bc}	1.1 ± 0.2 ^{c}	0.3 ± 0.1	0.3 ± 0 ^{a}	0.7 ± 0.1 ^{bc}	0.5 ± 0.2 ^{ab}
P ^{NS}	8.7 ± 0.9	7.1 ± 0.7	11 ± 5	14.7 ± 3.7	7.1 ± 0.7	5.3 ± 0.6
S ***	8.7 ± 1.5 ^{ab}	6.3 ± 0.7 ^{a}	6.0 ± 2.0	17.7 ± 1.5 ^{c}	9.2 ± 0.8 ^{abc}	14.6 ± 2.4 ^{bc}
Zn ^{NS}	2.56 ± 0.32	2.67 ± 0.37	6.45 ± 4.55	2.34 ± 0.36	2.79 ± 0.4	1.4 ± 0.23
ECEC ***	16.792 ± 3.627 ^{b}	12.634 ± 3.311 ^{b}	8.376 ± 0.703	2.662 ± 0.38 ^{a}	5.403 ± 1.272 ^{ab}	2.021 ± 0.315 ^{a}
No. of quadrats	9	9	2	11	11	8

Comments: *Eremophila serrulata* and *Sida petrophila* were generally restricted to these mafic upper slopes and restricted to this community type. At time of survey, these areas were among the richest in annual taxa (Table 4). Adjacent plant assemblages sampled on these metabasalt hills were classified as community type 2.

Community type 4: Upland mixed shrubland mosaic on massive and laterised BIF ridges

Location: An upland community that occurred on both steep crests and summit surfaces.
Substrate: Massive outcropping BIF and adjacent laterite deposits overlaying massive BIF. On exposed and weathered rocky BIF and laterite substrates with skeletal soils (Table 3). Soils were strongly acidic, had relatively high soil organic C, Fe and N concentrations, and low concentrations for a range of trace elements (Table 4).
Structural description: The upper stratum of tall shrubs was dominated by combinations of *Banksia arborea*, *Calycopeplus paucifolius*, *A. aneura*, *A. quadrimarginea, A. cockertoniana, A. quadrimarginea*, *Allocasuarina eriochlamys* or *A. acutivalvis* subsp. *acutivalvis*. The mid stratum commonly included *C. paucifolius*, *Philotheca brucei* subsp. *brucei*, *E. forrestii* subsp. *forrestii*, *Eremophila glutinosa*, *Melaleuca leiocarpa*, *Olearia humilis Leucopogon* sp. Clyde Hill (MA Burgman 1207) and *Grevillea extorris.* Myrtaceous and Lamiaceous low shrubs, such as *Baeckea elderiana, Mirbelia microphylla* and *Prostanthera grylloana*, are associated with the weathered laterite overlying massive BIF. Many of these dominant taxa were also significant indicator species (Table 2).
Species groups: Consistent representation from a subset of species group E and some common taxa in the community are from species group F. Taxa from species groups A to C were almost or completely absent. Taxa from species groups G and H were characteristic of this community (Table 1).
Mean perennial species richness: 21.3 ± 1.5 (SE) taxa per quadrat.
Comments: There were close florisitic affinities between this community type and community type 5 (Figure 1, Table 1)

Community type 5: Allocasuarina dielsiana *open woodlands –* Acacia *shrublands on BIF upper slopes and crests.*

Location: High in the BIF landscape, usually on steep BIF ridge crests and upper slopes and occasionally ranging down to middle hillslopes.
Substrate: On exposed massive BIF and weathered rocky BIF and laterite substrates with skeletal soils and BIF colluvial deposits. Calcrete deposits were generally absent or occasionally present. Soils were moderately acidic and with low to moderate concentrations of most trace elements and moderate concentrations of organic C, Fe and N (Table 4).
Structural description: Typically *Allocasuarina dielsiana* open woodlands or isolated trees over tall shrublands of *Acacia* (A. *quadrimarginea*, A. *cockertoniana* and/or *A. aneura*). Mid stratum dominated by shrubs of *Eremophila georgei*, *E. forrestii* subsp. *forrestii*, *Grevillea extorris*, *Dodonaea rigida*, *P. obovatus*, *P. brucei* subsp. *brucei*, *Sida ectogama* and/or *Eremophila latrobei* subsp. *latrobei*, over lower stratum of isolated plants of *Sida* sp. dark green fruits, geophytes (*Cheilanthes adiantoides*) and sods of *Austrostipa scabra/nitida*. Several of these dominant or common taxa were significant indicator species of this community type (Table 2).
Species groups: There was consistent representation of taxa from much of species groups E and F, and a very limited selection of taxa from species groups A and G. This community type was floristically allied to community type 4, but differed in that taxa from species group H were lacking and there were only a limited number of taxa from species group G (Table 1).
Mean perennial species richness: 24.9 ± 1.8 (SE) taxa per quadrat.

Community type 6: Allocasuarina dielsiana *woodlands, mallee shrublands or tall* Acacia *shrublands on lower slopes and flats.*

Location: On mid to lower slopes, valley flats and pediments of hilly, undulating BIF terrain.
Substrate: Mainly BIF, laterite and weathered BIF colluvial deposits, on deep (>50 cm) red sandy loams or clay loams, with no exposed bedrock and minimal runoff (Table 3). Soils were moderately to highly acidic, with relatively low concentrations of organic C, N and Fe and microelements (particularly B, Ca, K, Mg, Mn; Table 4).
Structural description: Woodlands, mallee shrublands or tall *Acacia* shrublands. Tall shrublands were commonly dominated by *A. aneura* and *A. ramulosa* var. *ramulosa*, and sometimes *A. cockertoniana*. Woodlands were usually dominated by *A. dielsiana*, while the most common mallee species were *Eucalyptus ewartiana* or *Eucalyptus concinna. Callitris columellaris* was an occasional emergent in the southern regions. The understorey shrub stratum included *Olearia humilis*, *Senna artemisioides* subsp *filifolia*, *Cryptandra connata*, *Eremophila granitica*, *Bursaria occidentalis*, *Eremophila forrestii* subsp. *forrestii and Eremophila georgei.* The sparse ground stratum included species of *Austrostipa, Monachather paradoxus, Cheilanthes sieberi* subsp. *sieberi* and *Chamaexeros macranthera*. Significant indicator species included *A. aneura* var. *intermedia*, *A. ramulosa* var. *ramulosa*, *E. granitica* and several grass taxa (Table 2).
Species groups: There was high representation across all taxa from species group E, high representation from about half of the taxa in species group F, and a limited number of taxa from species group G. As with community types 4 and 5, there was an almost complete absence of taxa from species groups A to C (Table 1).
Mean perennial species richness: 22.8 ± 1.9 (SE) taxa per quadrat.

Comments: Some floristic affinities with community type 5 (species groups E and F), which is an adjacent community upslope of community type 6.

Environmental Parameters

The soils of the Johnston Range survey area were generally red-brown sandy clay loams or sandy loams that were shallow (average depth class was 5–50 cm), moderately acidic (average pH 5.47 ± 0.17), and with generally low concentrations of organic carbon (1.48 ± 0.11%) and nitrogen (0.10 + 0.01%). The leaf litter cover on the ground was sparse to moderate (29 ± 2.8%), and quadrats were generally bare and clear of vegetation (83.6 ± 1.5%).

Three elements (Al, Mo, Cd) were at levels below the limits of detection in most of the soil samples. The majority of inter-correlations found among the remaining soil variables and physical parameters were moderate (54% of significant correlations) or strong (37% of significant correlations; Table 5). Soil pH was strongly positively correlated with many trace elements, and a set of these trace elements (Mg, Ca, Co, K, Cu, Mn) were strongly positively inter-correlated (Table 5). Soil organic C, N and Fe were strongly to very strongly inter-correlated. Autocorrelation of Na, Ca, K and Mg with eCEC was expected, since the latter is derived from combinations of the former elemental concentrations. Moderate to strong correlations occurred among the physical parameters, particular among topographic position, slope, altitude, runoff, and bedrock cover. These were moderately to strongly negatively correlated with soil depth. Spatial autocorrelation probably accounted for some inter-correlation among physical variables such as runoff, slope and topographic position. There were few significant correlations between physical parameters and soil chemical parameters. Soil Fe, organic C and N were moderately to strongly correlated with a suite of physical parameters (topographic position, slope, rock size and outcrop cover, runoff and soil depth; Table 5).

Univariate analyses

Community type 3 was excluded from the univariate analysis owing to small sample size. Among the remaining community types, nonparametric analysis of variances (Kruskal–Wallis AOV) found significant differences between community types for the majority of environmental variables (Tables 2 and 3).

Both community types 4 and 5 were characteristic of steep upland sites, while community types 1 and 6 occupied sites at the lowest, least-inclined topographical positions and altitudes (Table 3). On average, community types 4 and 6 each occupied, respectively, the upper and lower extremes of topographic locations and elevations. Both community types 4 and 5 were located at significantly higher topographic positions than community types 1 and 6. Only community type 4 occupied significantly higher positions than community type 2 (Table 3). Community type 4 also occurred at significantly higher altitudes than community types 1 and 6. Average slope and runoff scores were high for community types 4 and 5, both of which were significantly steeper and more drained than community type 6 but not significantly different to community types 1 and 2.

Average values for outcropping bedrock cover were high for community types 4 and 5, with type 4 having significantly more exposed bedrock than community types 1, 2 and 6 (Table 3). Community type 6 had no exposed bedrock. There were no significant differences between communities for surface rock cover. Soils were significantly shallower in community types 4 and 5 than community type 6, and soils from community type 4 were also significantly shallower than community type 1. Both community types 4 and 5 had large size classes of surface rocks (Table 3). Community types 4 and 5 also had significantly higher maximum rock sizes than community type 6, which had among the smallest average size classes. Community type 5 tended to have on average less exposed bedrock, relatively deeper soils and less acidic soils than community type 4, but these were not statistically different.

Soils from community types 5 and 4 (in particular) had high values for organic C, Fe and N, and significantly higher concentrations of these elements were found in soils from these communities than from community type 6 (Table 4). Community type 4 also had significantly higher Fe, S and organic C than community type 2, and significantly higher Fe and S concentrations than community type 1. Community type 2 also had significantly lower concentrations of S than community types 4 and 6. Community types 4 and 6 had strongly acidic soils that were significantly more acidic than soils from community types 1 and 2, which tended to neutral pH values (Table 4).

Community types 1 and 2 tended to have significantly higher trace element concentrations than community type 4 and community type 6 (Table 4). Community types 1 and 2 had statistically higher Ca, K, Mg and eCEC than both community types 4 and 6, and significantly higher Ni, Cu and Mn concentrations than community type 4 alone. Community type 2 had significantly higher B, Co, Cu, Mn and Ni than community types 4 and 6. Community type 4 had notably low values for Co, which were significantly lower than in community types 1, 2 and 5. Community type 1 had higher concentrations of B than type 6 and also higher values of Mg than community type 5. Community type 1 had high values of $EC_{1:5}$, which were significantly higher than both community types 5 and 6 (Table 4). Average soil Na concentrations in community type 1 were also relatively high and significantly higher than in community type 6, indicating relatively greater salinity in the soils of community type 1.

SSH MDS ordination

The ordination showed a reasonable separation of floristic community types based on differences in floristic compositional differences, albeit with some overlap among some groups (Fig. 3a and 3b). The stress level (0.18) indicated a fair to poor reduction of data to three

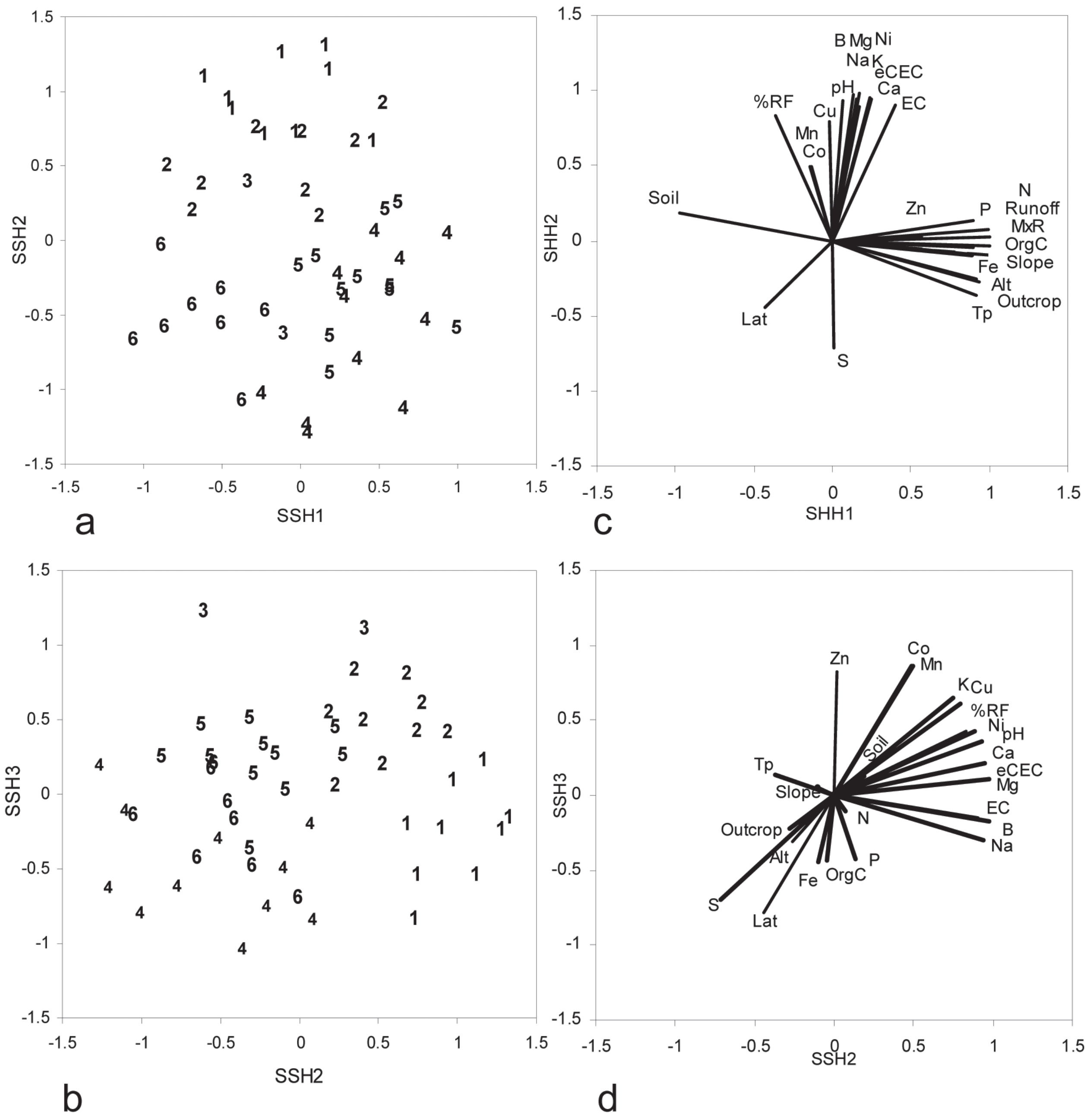

Figure 3. 3D SSH MDS site ordination for the Johnston Range survey area, based on dissimilarities in floristic composition from a presence/absence data matrix of 103 perennial taxa from 50 quadrats: (a) SSH axis 1 vs 2; (b) SSH axis 2 vs 3 (both from three dimensional solution). Quadrats are numbered by their respective floristic community types. Vectors of best fit linear correlations of physical parameters and site ordination coordinates are presented in panels c and d (only significant correlations are shown): (c) vectors for axis 1 vs 3; (d) vectors for axis 2 vs 3. Only significant vectors ($p < 0.05$) are displayed, as determined from Monte Carlo permutation tests. Most correlations are highly significant ($p < 0.001$), except for soil, alt, slope and Zn ($p < 0.01$) and %RF and lat ($p < 0.05$).

dimensions. The greatest separation in the ordination is between the communities on mafic-influenced soils on lower slopes and colluvial flats (community types 1 and 2) and the BIF crest community (community type 4).

The association between environmental factors and community type was further evaluated using PCC (Fig. 3c and 3d). Most of the significant correlations were highly significant ($p < 0.001$), except for soil depth, Zn, altitude and slope ($p < 0.01$) and surface rock fragments and latitude ($p < 0.05$). There were two main environmental gradients associated with the site ordination that were orthogonal to one another: a soil trace element gradient and topographic gradient (Fig. 3c). Vectors for soil Fe, organic C and N ran nearly co-linear with this topographic

Table 5

Matrix of Spearman rank correlation coefficients for environmental variables collated from 50 quadrats established on the Johnston Range. Only correlations significant at $p < 0.01$ are shown. Full details of environmental parameter codes are given in the methods section. Parameter codes are as follows: topographical position (Tp); litter ground cover (%litter); bare ground cover (%bare); maximum surface rock fragment size (MxR); surface rock cover (%RF); and exposed rock cover (outcrop). Full details of other environmental parameters are given in the methods section and codes given in Table 3.

	EC	pH	OrgC	N	B	Ca	Co	Cu	Fe	K	Mg	Mn	Na	Ni	P	S	Zn	eCEC	Slope	Tp	%RF	MxR	Outcrop	Runoff	Soil	%litter	%bare	Lat	Long
Soil Chemical Parameters																													
EC																													
pH	0.514																												
OrgC	.	.																											
N	0.417	.	0.906																										
B	0.680	0.776	.	.																									
Ca	0.656	0.929	.	.	0.813																								
Co	.	0.766	.	.	0.483	0.681																							
Cu	.	0.755	.	.	0.497	0.698	0.829																						
Fe	.	.	0.759	0.728	.	.	.	.																					
K	0.543	0.769	.	.	0.707	0.813	0.723	0.735	.																				
Mg	0.596	0.911	.	.	0.783	0.952	0.716	0.761	.	0.800																			
Mn	.	0.721	.	.	0.511	0.659	0.860	0.730	.	0.678	0.646																		
Na	0.666	0.469	.	0.411	0.654	0.585	.	0.439	.	0.596	0.645	.																	
Ni	0.438	0.748	.	.	0.555	0.698	0.731	0.816	.	0.643	0.735	0.538	0.444																
P	.	.	0.504	0.643	.	.	.	.	.	0.385	.	.	.	.															
S	.	-0.666	.	.	-0.382	-0.586	-0.731	-0.653	.	-0.477	-0.607	-0.735	.	-0.533	.														
Zn	.	.	0.468	0.606	0.405	0.397	.	.	0.385	0.500	0.397	0.418	.	.	0.449	.													
eCEC	0.650	0.934	.	.	0.825	0.996	0.695	0.718	.	0.829	0.967	0.665	0.607	0.707	.	-0.587	0.409												
Physical Parameters																													
Slope	.	.	0.654	0.668	.	.	.	.	0.672	.	.	.	.	.	.	.	0.525	.											
Tp	.	.	0.680	0.624	.	.	.	-0.388	0.738	.	.	.	.	.	.	.	.	.	0.563										
%RF	.	0.443	.	.	.	.	0.413	0.408	.	.	0.398	.	.	0.512	.	.	.	.	.	.									
MxR	.	.	0.819	0.826	.	.	.	.	0.833	.	.	.	.	.	0.464	.	0.509	.	0.747	0.802	.								
Outcrop	.	.	0.717	0.715	.	.	.	.	0.768	.	.	.	.	.	0.486	.	.	.	0.551	0.790	.	0.852							
Runoff	.	.	0.630	0.631	.	.	.	.	0.729	.	.	.	.	.	.	.	0.518	.	0.715	0.617	.	0.826	0.662						
Soil	.	.	-0.641	-0.617	.	.	.	.	-0.709	.	.	.	.	.	-0.424	.	.	.	-0.569	-0.751	.	-0.790	-0.896	-0.661					
%litter	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.				
%bare	.	.	.	.	.	.	.	.	.	.	.	.	0.381	.	.	.	.	.	.	.	.	.	.	.	.	-0.395			
Lat	.	.	.	.	.	-0.376	-0.414	.	.	-0.398	-0.388	.	.	-0.434	.	.	.	-0.388	.	.	.	.	.	.	.	.	.		
Long	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.444	
Altitude	.	.	0.583	0.438	.	.	.	.	0.599	.	.	.	.	.	.	.	.	.	0.467	0.483	.	0.514	0.419	0.496	-0.473	.	.	.	.

gradient (Fig. 3c). Community types 4 and 5 were associated with the high extremes of this gradient (i.e. were located high in the landscape, with associated steep, rocky terrain, shallow soils and elevated concentrations of Fe, C and N), while community types 1, 6 and 2 roughly coincided with the lower extremes of this gradient.

The main soil chemical gradient was composed of roughly co-linear vectors for a suite of variables (K, Cu, Ca, Mg, Ni, eCEC and pH; Fig. 3c and 3d). Quadrats classified as community types 1, 2 and 3 coincided with the upper extremes of this gradient (high microelement concentrations, relatively higher pH), while quadrats of community types 4 and 6 were correlated with the lower end of this gradient (Fig. 3b and 3d). Community type 1 also was associated with the higher values along a soil salinity gradient ($EC_{1:5}$, Na) and for B, while community type 2 was associated with lower S and higher Mn and Co concentrations (Fig. 3b and 3d). Latitude also was significantly correlated with the ordination, where community types 3 and 5 were associated with relatively lower latitudes, while community type 4 was associated with comparatively higher latitudes (Fig. 3b and 3d).

DISCUSSION

Flora

The Johnston Range flora was dominated by shrubs and trees, including sclerophyllous and chenopod taxa. Perennial grasses or herbs can form an appreciable ground layer in some outcrop communities (Butler & Fensham 2008; Hopper et al. 1997; Markey & Dillon 2009; Norris & Thomas 1991; van Etten & Fox 2004), but perennial grasses accounted for only 6% of taxa on the Johnston Range, and these had very low values for cover. Geophytes and herbaceous taxa accounted for a fifth of taxa on the Johnston Range, although the majority of these were widespread semi-arid or arid annuals and few were restricted to rocky landforms (e.g. *Pleurosorus rutifolius*, *Pterostylis* sp. inland; AC Beauglehole 11880). The proportion of annuals appearing in BIF and greenstone floras after a single season's survey will be a function of winter rainfall, and vary from 20 to 40% (Meissner et al. 2010a).

A total of 176 native taxa were reported for the Johnston Range, which was greater than on BIF landforms c 100 km to the north (113–142 native taxa per range; Meissner et al. 2010a, 2010b) and within the range of floristic richness (131–303 native taxa per range) reported from similar surveys of BIF landforms in the Mount Manning Region (Markey & Dillon 2011; Gibson et al. 1997; Gibson & Lyons 2001a, 2001b; Gibson 2004; Environmental Protection Authority 2007; Mattiske 2001a). A pair-wise comparison of perennial floras between the Johnston Range and adjacent ranges of the Mount Manning Region showed a similarity of between 30 and 54% in perennial species (Table 6). The ironstone floras of the Yilgarn have been noted for their high β-diversity (Gibson & Lyons 2001a; Gibson et al. 2007), and significant species turnover occurs over distances of less than 100 km between ranges in the Mount Manning Region (Mattiske 2001b). Species turnover in the region and among rock outcrops in a south-west to north-east direction has been attributed, in part, to a gradient of increasing aridity and a change from calcareous to siliceous hardpan soils (Beard 1972, 1976; Keighery et al. 1995; Hopper et al. 1997).

Although the Mount Manning Range is closer to the Johnston Range, the northern Yerilgee Hills are floristically more similar (Table 6). Other attributes besides spatial proximity could be influencing species composition. Both of the latter two ranges have similarly subdued geomorphologies while the Mount Manning Range reaches greater elevations (500–560 m ASL; Gibson 2004), and has significant outcrops of massive BIF. Some of the southern ranges of the Mount Manning Region can reach elevations of up to 640 m (Wyche et al. 2001), and the greater habitat heterogeneity may support a different or more diverse suite of species and communities (Environmental Protection Authority 2007; Gibson & Lyons 2001b). The species composition of individual ranges also presumably reflects range-specific geology and soils. Other factors have been suggested to account for floristic differences among isolated ranges, such as Pleistocene climatic fluctuations, the unique evolutionary

Table 6

Species counts of some of the ranges within the Mt Manning region, and percentage of perennial taxa in common with the Johnston Range. Floras have been compiled from quadrat-based surveys, with some additions from herbarium records (except for this study and Markey & Dillon 2011). Distances between ranges were taken at the survey area mid-points.

Range	No. native taxa	Distance from Johnston Range	Shared taxa (total taxa)	Source
Mt Manning Range	234	47 km SE	30 % (247)	Gibson 2004
northern Yerilgee Hills	182	53 km E	54% (200)	Markey & Dillon 2011
Hunt Range, Yendilberin & Watt Hills	273	83–125 km SE	27% (267)	Gibson & Lyons 2001a
Helena & Aurora Range	303	84 km SSE	27% (282)	Gibson et al. 1997
Highclere Hills	217	119 km SSW	22 % (232)	Gibson & Lyons 2001b

histories of the range floras and stochasticity in the colonisation of and extinctions within these isolated patches of habitat and mesic refugia (Butcher et al. 2007; Butler & Fensham 2008; Gibson et al 2007; Harrison 1997; Hopper & Gioia 2004; Porembski et al. 1998).

The Johnston Range is located near the junction of three biogeographic regions. The dominant families recorded were typical of the Yalgoo and Coolgardie bioregion flora (the South West Interzone), which are intermediate in character between the mesic South West and the arid Eremaean Provinces (Beard 1972, 1976, 1990; Department of Environment and Water Resources 2007). The flora is a mixture of primarily Eremaean (e.g. *Eremophila, Senna, Acacia aneura, Acacia murrayana*), interzonal taxa (e.g. *Grevillea erectiloba, Grevillea paradoxa*), with some south-western taxa (e.g. *Pterostylis* sp. inland; AC Beauglehole 11880). This was also noted for the adjacent Mt Manning range flora, where Keighery et al. (1995) commented on the sandplain (kwongan) elements on upland laterites. Some taxa are at their northern limits, including *Banksia arborea*, which changes from being dominant on the southern ranges of the Mount Manning Region to being restricted to small, isolated populations in the northern ranges (Beard 1972, 1976; Gibson et al. 1997; Gibson 2004; Keighery et al. 1995; Mattiske 2001b; Markey & Dillon 2011). Characteristic south-western families (e.g. Epacridaceae, Stylidiaceae, Sterculiaceae, Cyperaceae, Orchidaceae) were poorly represented or absent. Some notable south-west genera (*Lepidosperma, Tetratheca*) were absent, even though representative species occured on the adjacent Windarling, Die Hardy and/or Jackson ranges (Barrett 2007; Butcher et al. 2007). Only six species of *Eucalyptus* were recorded from the Johnston Range, as opposed to the 17 to 30 species found on more southern ranges (Gibson 2004; Gibson & Lyons 2001b). The flora of the Johnston Range tends to more be Eremaean in character than more southern ranges in the Mount Manning Region.

Vegetation Communities

This is the first time that the Johnston Range has been surveyed as an individual landform, and six floristic communities were described for this unit. These communities have some broad similarities to both Beard's (1976) description of the southern extent of the Barlee subregion, and the general communities described by Beard (1972, 1976) for the Die Hardy System. Keighery et al. (1995) considered the Mount Manning Range to be part of Beard's Die Hardy System, although Gibson (2004) could not find key components of this system in the upland communities. The current study notes that, like the Mount Manning Range, species which dominate the Die Hardy System upland communities (Beard 1972, 1976) are infrequent or absent on the Johnston Range (e.g. *Banksia arborea, Eucalyptus oleosa* and *Eucalyptus formanii*).

The Johnston Range is located near where Beard (1976, 1990) demarcated the boundary between the South West Interzone (Yalgoo and Coolgardie bioregions) and Murchison bioregion, based on the replacement of *Eucalyptus* woodlands by *A. aneura* woodlands or shrublands on the lower slopes and plains. The communities are characteristic of the South West Interzone, as *Eucalyptus*, *Callitris, Casuarina* and *Allocasuarina* woodlands dominate the lower slopes, valleys and pediments of the Johnston Range, while *Acacia aneura* is only dominant in upland shrublands. However, *Eucalyptus salubris* – *E. salmonophloia* woodlands were not encountered on the Johnston Range, despite being a distinctive and common community on valleys flats and plains in the northern Yerilgee Hills (Markey & Dillon 2011) and around other ranges in the Mount Manning Region (Gibson & Lyons 2001a, 2001b; Gibson et al. 1997; Keighery et al. 1995; Mattiske 2001b). Climatic or soil variables may account for the absence of *Eucalyptus salmonophloia* woodlands on the Johnston Range, as the range is located near the north-eastern limit of the species (Western Australian Herbarium 1998–), and deeper calcareous soils associated with these woodlands (Beard 1972, 1976, 1990; Gibson & Lyons 2001b; Markey & Dillon 2011) may be absent from the range.

The transition in species across the Mount Manning Region has implications for floristic community composition among different ranges. Communities described for ranges adjacent to the Johnston Range share some of the same dominant taxa as on the Johnston Range, including upland BIF crest communities dominated by *B. arborea*, *Calycopeplus paucifolius*, *Allocasuarina acutivalvis* and *Acacia quadrimarginea*, and among the lower slope *Acacia* shrubland and *Eucalyptus* woodlands (Gibson 2004; Markey & Dillon 2011; Environmental Protection Authority 2007; Mattiske 2001b). However, meta-analysis of quadrat-based survey data has shown significant differences between the floristic communities on the Die Hardy, Koolyanobbing, Helena and Aurora, Windarling, Jackson and Mt Manning Ranges, including distinctive floristic assemblages that are restricted to a single range (Mattsike 2001b). Similar meta-analyses will verify the distinctiveness of the floristic communities on the Johnston Range within a wider regional context.

Priority Taxa

One rare (DRF) and four priority taxa were recorded for the Johnston Range, which was comparable to the northern Yerilgee Hills (three priority taxa), the Hunt Range – Watt Hill area (five priority taxa) and Mount Manning Range (five priority taxa; Gibson et al. 2007; Gibson 2004; Gibson & Lyons 2001a; Mattiske 2001a). These four areas have no range-specific endemic taxa but do host regional endemics. Other ranges in the wider Mount Manning Region have far higher numbers of significant taxa, notably the Helena and Aurora Range (two DRF, 12 priority and five endemic taxa), the Die Hardy ranges (one endemic and seven priority taxa) and the Windarling Range (two DRF, two priority taxa and one endemic) and Jackson Range (two DRF, two priority taxa and four endemics; Department of Environment and Conservation 2007; Gibson et al. 2007; Gibson 2004; Gibson & Lyons 2001a;

Mattiske 2001). Factors accounting for endemism and/or rarity on these isolated ranges are not always obvious (Gibson & Lyons 2001a; Gibson et al. 2007), but these could include species richness of the surrounding region, substrate and geomorphology, climate and range-specific evolutionary history (Butler & Fensham 2008; Gibson et al. 2007; Hopper & Goia 2004; Hopper et al. 1997; Jacobi et al. 2007).

A set of uncommon taxa are known from the Mt Manning, Windarling and/or Die Hardy Ranges that have not been found on the Johnston Range, including *Pseudactinia* sp. Bungalbin Hill (FH & MP Mollemans 3069; Priority 3), *Grevillea georgeana* (Priority 3), *Mirbelia* sp. Helena Aurora (BJL 2003; Priority 3), *Beyeria rostellata* (R Cranfield & P Spencer 7751; Priority 1), *Lepidosperma ferricola* (Priority 1; Barrett 2007), *Neurachne annularis* (Priority 3; MacFarlane 2007), *Stenanthemum newbyi* (Priority 3) and two rare subspecies of *Tetratheca paynterae* (Butcher et al. 2007). Some of these taxa occupy specific niches, particularly those specialists that occur on steep, massive BIF outcrops. Such specific habitats are absent from the Johnston Range, which lacks substantial elevation and BIF massifs. It is surprising that *Ricinocarpos brevis* was located on lower slope colluvial deposits on the Johnston Range, since the other known population on the Windarling Range grows in very different habitat on upland BIF massif (Mattiske 2001b). This raises the possibility that some other species may also occupy broader niches than expected.

Environmental Parameters

Communities were associated with an edapho-topographic gradient, which has been commonly documented in this series of Yilgarn BIF surveys (Gibson 2004; Gibson & Lyons 1998, 2001a; Gibson et al. 1997; Markey & Dillon 2008a, 2008b, 2009, 2010a, 2010b, 2011; Meissner & Caruso 2008a, 2008b, 2008c), although this association is not as distinct in landforms with subdued topography (e.g. Gibson & Lyons 2001b; Meissner et al. 2010a). Geological substrate was also a segregating factor among the Johnston Range communities, as it has been in the other Yilgarn BIF surveys. The greatest floristic differences lay at the extremes of these geomorphological and edaphic gradients, namely between the upland, BIF communities from communities on lower slopes and flats with mafic, relatively calcareous soils.

At the upper extreme of the edapho-topographic gradient, community type 4 was associated with BIF crests and lateritic duricrusts overlaying BIF bedrock on ridges, with skeletal soils overtopping the greatest extent of steep, outcropping bedrock and large surface rocks. Many characteristic or common species (species groups E, G and H) were species with the capacity for rooting in rock fissures, such as shrubs (e.g. *Melaleuca leiocarpa*, *Calycopeplus paucifloru*s, *Banksia arborea*), rock ferns (*Cheilanthes adiantoides*, *Pleurosorus rutifolius*) and geophytes (*Chaemaexeros macranthera*). Many of the shrubs associated with the upland lateritic soils (e.g. *Prostanthera grylloana, Baeckea elderiana*) were what Keighery et al. (1995) referred to as sandplain taxa. All these taxa would have to cope with relatively phosphorus deficient soils. These upland soils were developed in situ from prolonged weathering of the bedrock, and the relatively low trace element concentrations indicated leaching, particularly of the mobile ions Ca, Mg, Mn, K (Britt et al. 2001; Cole 1973; Gray & Murphy 2002; Gray & Humphreys 2004). The soils of community type 4 were relatively enriched in N and organic C, presumably being derived from leaf litter trapped in rock crevices (Facelli & Brock 2000; Foulds 1993). Although enriched in macronutrients, these skeletal soils only developed in small pockets among exposed, fractured bedrock. Soil trace element concentrations were still low in community type 5, and the higher Fe and S levels in community types 4 and 5 were indicative of both heavily weathered soils and BIF bedrock composition (Foulds 1993). Such heavy weathering and bedrock sulfides could account for the strongly acidic soils.

Lower slopes, flats and outwashes are depositional areas with little exposed bedrock and deeper, more fertile soils that receive colluvium and mobile leachates from higher in the landform (Britt et al. 2001; Jacobi et al. 2007). Both community types 1 and 2 were located on lower slopes and valley floors in association with BIF and mafic substrates and some calcereous deposits. These calcretes and other carbonates are likely to be derived from weathered mafics (Anand et al. 1997). High microelemental concentrations (particularly in soils from community type 1) could be attributed to this geological substrate as well as from the colluvial inputs and leachates (Anand et al. 1997; Britt et al. 2001; Gray & Murphy 2002; Gray & Humphreys 2004).

The relatively higher eCEC and significantly reduced soil acidity in community types 1 and 2 were probably due to the buffering capacity of leached cations (Gray & Murphy 2002). While the soils of community types 1 and 2 had elevated Ca concentrations (indicative of calcareous soils), the soils were only weakly acidic to neutral, and not as basic (>pH 8) as has been reported in other more calcareous and leachate-enriched soils on lower slope and outwashes around greenstones (Gibson & Lyons 1998a, 1998b, 2001a, 2001b). Comparatively higher values for soil salinity (Na, $EC_{1:5}$) were also recorded in community type 1, suggesting that the weathered mafic and ultramafics may be the source of these salts (Gray & Murphy 2002). These salinity values would still be classed as very low to low (Shaw 1999), and are very low relative to the range of soil salinity values recorded in Western Australian wheatbelt communities (Gibson et al. 2004). Community type 1 was distinguished by a suite of taxa that are known to grow on relatively more saline, alkaline and calcareous soils (species group C), including a suite of chenopod shrubs and species of *Eremophila.* Some of these species were found to be characteristic of communities growing on similar soils in other Yilgarn BIF surveys (Gibson & Lyons 2001b; Gibson 2004; Markey & Dillon 2008a, 2011; Meissner et al. 2010a). Gibson et al. (2004), Keighery et al. (1995) and Beard (1990) all found an association between broombush

(*Eremophila*) and chenopod shrub understoreys with alkaline, slightly saline and/or calcareous soils.

Soil microelement concentrations, Ca concentrations, salinity values and pH in the other lower slope – pediment community (type 6), were significantly lower than in community type 1, presumably because these soils were derived primarily from BIF substrates and had reduced inputs from mafic subtrates. Chenopod richness was relatively low in this community, a feature that Beard (1990) associated with acidic, less saline and non-calcareous soils.

Although not measured, it is inferred that there is a soil moisture gradient across the BIF landform that affects species distributions. Greenstone outcrops are considered to be particularly xeric (Cole 1973; Jacobi et al. 2007; Specht et al. 2006), and upland skeletal soils have poor capacity overall to retain water whereas lower slopes, valleys and outwashes receive runoff and overlie groundwater sources. Presumably the dominant trees and shrub species of lower slope, valley and outwash communities on the Johnston Range are deeply rooted enough to access groundwater reserves and/or soil moisture in order to avoid drought stress (Chalwell 2003). Shallow-rooted shrub species on greenstone ridges in the eastern goldfields show drought tolerance (Chalwell 2003), and it is assumed that the dominant shrubs of community types 4 and 5 also tolerate such xeric conditions, although chronic drought appeared to be affecting some species (e.g. *Baeckea elderiana*). Further research into ecophysiological adaptations to the skeletal, metal-rich soils, xeric conditions and microtopography on ironstone outcrops would provide greater insights into factors that affect community composition.

There was some suggestion from the ordination that community types 3 and 5 occurred in more northern parts of the survey area, while community type 4 was more southern in distribution. Community type 4 was absent from the extreme north-west of the range, presumably because the BIF landforms there lacked the massive outcroppings of BIF found on the Johnston Range proper. Instead, community type 5 dominated the tops of the north-western BIF ridges. These north-western ridges were relatively inaccessible, and the possibility remains that community type 4 may occur in the unsurveyed areas. Community type 3 was restricted to the basalt ridges found in the north and west of the survey area. These are extensive formations that were under-sampled owing to time constraints, and this community appears to be widespread on these basalt ridges. There was no suggestion from the analyses and field observations that the other community types had restricted distributions.

Conservation

The vegetation of the Johnston Range was found to be in reasonable condition, although grazing was evident in all floristic communities. Areas closest to the few watering points were the most impacted by cattle. Rabbits were also common in the area, but there was little evidence of feral goats. The few weed species encountered were annual grasses, and these were not abundant. Sandalwood harvesting continues in the area, particularly along the eastern flanks of the Johnston Range. The impacts of this activity must continue to be monitored, as it has the potential to cause significant localised damage.

The survey area has a long history of mining and exploration, and there has been little effort to rehabilitate the numerous exploration tracks, older drill holes and test diggings. This is most noticeable in the mafic and basalt hills in the western part of the survey area, where damage from base metal exploration has lasted decades. Efforts have been made to reduce the impact of more recent drilling activities.

The Johnston Range lies immediately outside the areas proposed for reservation within the Mount Manning Region (Environmental Protection Authority 2007). To the immediate south are the Die Hardy, Windarling and Yokradine Hills, which are currently undergoing mining and exploration despite recommendations for their inclusion in the proposed Die Hardy – Jackson – Windarling Ranges Nature Reserve (Environmental Protection Authority 2007). The Johnston Range harbours endemic and rare species, and possibly geographically restricted floristic communities that are likely to be floristically different to the southern ranges. Proposed developments must consider endemic communities and taxa of conservation significance in the planning process to reduce impacts on the conservation values of the Johnston Range and wider Mount Manning Region. Future reserve planning should take into account the reservation of areas representative of the diversity of the Mount Manning Region biota.

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REFERENCES

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.

Angiosperm Phylogeny Group (2003) An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG II. *Botanical Journal of the Linnaean Society* **141**, 399–436.

Barker RM (2007) Two newly described species and a draft key to *Sida* s. lat. from Western Australia. *Nuytsia* **17**, 13–30.

Barrett RL (2007) New species of *Lepidosperma* (Cyperaceae) associated with banded ironstone in southern Western Australia. *Nuytsia* **17**, 37–60.

Beard JS (1972) *Vegetation Survey of Western Australia: The Vegetation of the Jackson Area, Western Australia. Map and Explanatory Memoir. 1:250,000 Series.* Vegmap Publications, Sydney.

Beard JS (1976) *Murchison, 1:1,000,000 Vegetation Series: The Vegetation of the Murchison Region.* 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, Lyneham, ACT.

Belbin L (1991) Semi-strong hybrid scaling, a new ordination algorithm. *Journal of Vegetation Science* **2**, 491–496.

Belbin, L, Faith D, Milligan, GW (1992) A comparison of two approaches to beta-flexible clustering. *Multivariate Behavioural Research* **27**, 417–433.

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

Bull JP (2007) *Tetratheca erubescens* (Elaeocarpaceae), a new and geographically restricted species from the Coolgardie Biogeographic Region of south-western Australia. *Nuytsia* **17**, 87–96.

Bureau of Meteorology (1908–) *Climate Statistics for Australian Locations*. Available at http://www.bom.gov.au/climate/averages/. [Accessed May 2008].

Butcher R, Byrne M, Crayn D (2007) Evidence for convergent evolution among phylogenetically distant rare species of *Tetratheca* (Eleocarpaceae, formerly Tremandraceae) from Western Australia. *Australian Systematic Botany* **20**, 139–160.

Butler DW, Fensham RJ (2008) Lose the plot: cost-effective survey of the Peak Range, central Queensland. *Cunninghamia* **10**, 522–538.

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

Chalwell ST (2003) 'Plant Communities of Greenstone Hills of the Eastern Goldfields of Western Australia as Analogues for the Rehabilitation of Rocky Waste Dumps'. Unpublished PhD thesis, Murdoch University, Western Australia.

Champion DC, Smithies RH (2001) Archaean granites of the Yilgarn and Pilbara cratons, Western Australia. In *4th International Archaean Symposium 2002, extended abstracts.* (eds KF Casidy, JM Dunphy, MJ Van Kranendonk), pp 134–136. Geoscience Australia, Record 2001/37, Canberra, Australian Capital Territory

Champion DC, Smithies RH (2003) Archaean Granites. In *Magmas to Mineralisation: The Ishihara Symposium on Granites and Related Metallogenesis.* (eds P Belvin, M Jones, B Chappell), pp 13–17. Geoscience Australia, Record 2003/14, Canberra.

Chen SF, Wyche S (2003) *Geology of the Bungalbin 1:100,000 Sheet. 1:100,000 Geological Series Explanatory Notes.* Geological Survey Western Australia, Perth.

Clark KR, Gorley RN (2006) *Primer v6: User Manual/Tutorial.* PRIMER–E Ltd, Plymouth.

Cole MM (1973) Geobotanical and biogeochemical investigations in the sclerophyllous woodland and shrub associations of the eastern goldfields area of Western Australia, with particular reference to the role of *Hybanthus floribundus* (Lindl.) F. Muell. as a nickel indicator and accumulator plant. *The Journal of Applied Ecology* **10**, 269–320.

Department of Environment and Conservation (2007) Banded Ironstone Formation Ranges of the Midwest and Goldfields. In *Strategic Review of the Conservation and Resource Values of the Banded Iron Formation of the Yilgarn Craton.* Government of Western Australia, Perth.

Department of Environment and Water Resources (2007) IBRA Version 6.1. Available at www.environment.gov.au/parks.nrs/ibra/version 6-1/. Updated 6th February [accessed June 2008].

Department of Industry and Resources (2007) Strategic review of an iron ore industry in the Yilgarn Region (with a focus on the Midwest). In *Strategic Review of the Conservation and Resource Values of the Banded Iron Formation of the Yilgarn Craton.* Government of Western Australia, Perth.

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

Environmental Protection Authority (2007) 'Advice on areas of the highest conservation value in the proposed extensions to Mount Manning Nature Reserve'.

Unpublished report to the Minister for the Environment, Perth, Western Australia.

Facelli JM, Brock DJ (2000) Patch dynamics in arid lands: localized effects of *Acacia papyrocarpa* on soils and vegetation in open woodlands of South Australia. *Ecography* **23**, 479–491.

Faith DP, Norris RH (1989) Correlation of environmental variables and patterns of distribution and abundance of common and rare freshwater macroinvertebrates. *Biological Conservation* **50**, 77–98.

Faithful E (1994) Land use history. In *An Inventory and Condition Survey of the North-Eastern Goldfields, Western Australia.* Technical Bulletin No. 90 (eds AL Payne, AME Van Vreeswyk, HJR Pringle, KA Leighton, P Hennig), pp 11–14. Department of Agriculture Western Australia, South Perth.

Foulds, W (1993) Nutrient concentrations of foliage and soil in south-western Australia. *New Phytologist* **125**, 529–546.

Gibson N (2004) 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, 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, Keighery GJ, Lyons MN and Webb A (2004) Terrestrial flora and vegetation of the Western Australian wheatbelt. *Records of the Western Australian Museum* Supplement **67,** 139–189.

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 M (2001a) 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 (2001b) 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 MN, Lepschi BJ (1997) Flora and vegetation of the eastern goldfields ranges, Part 1: Helena and Aurora Range. *CALMScience* **2**, 231–246.

Gray JM, Humphreys GS (2004) Patterns of global soil distribution as revealed by two major soil databases. *Supersoil 2004. Proceedings of the 3rd Australian and New Zealand Soils Conference* (ed B Singh et al.), University of Sydney, 5–9 December 2004. The Regional Institute, Gosford, New South Wales. http://www.regional.org.au/au/asssi/supersoil2004/s8/oral/1697_grayjg.htm [accessed November 2011].

Gray JM, Murphy BW (2002) Parent material and soil distribution. *The Journal of the Australian Association of Natural Resource Management* **5,** 2–12.

Halford DA, Henderson RJF (2007) A taxonomic revision of *Ricinocarpus* Desf. (Euphorbiaceae: Ricinocarpeae, Ricinocarpinae). *Austrobaileya* 7, 387–449.

Harrison S (1997) How natural habitat patchiness affects the distribution of diversity in Californian serpentine chaparral. *Ecology* **78,** 1898–1906.

Hopper SD, Brown AP, Marchant NG (1997) Plants of Western Australian granite outcrops. *Journal of the Royal Society of Western Australia* **80**, 141–158.

Hopper SD, Gioia P (2004) The southwest Australian floristic region: evolution and conservation of a global hot spot of biodiversity. *Annual Review of Ecology, Evolution and Systematics* **35**, 623–650.

Jacobi CM, do Carmo FF, Vincent RC, Stehmann JR (2007) Plant communities on ironstone outcrops: a diverse and endangered Brazilian ecosystem. *Biodiversity Conservation* **16,** 2185–2200.

Keighery, GJ, Milewski AV, Hall NJ (1995) Vegetation and flora. In *The Biological Survey of the Eastern Goldfields of Western Australia: Part 12, Barlee–Menzies Study Area* (eds GJ Keighery, NL McKenzie, NJ Hall). *Records of the Western Australian Museum* Supplement **49**, 183–207.

McCune B, and 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. Australian Collaborative Land Evaluation Program, Canberra.

MacFarlane (2007) A new species of *Neurachne* (Poaceae) from Western Australia. *Nuytsia* **17**, 215–222.

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, 153–178.

Markey AS, Dillon SJ (2009) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Herbert Lukin Ridge (Wiluna). *Conservation Science Western Australia* 7, 391–412.

Markey AS, Dillon SJ (2010a) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Gullewa. *Conservation Science Western Australia* 7, 531–556.

Markey AS, Dillon SJ (2010b) Flora and vegetation of the banded iron formations of the Yilgarn Craton: the Booylgoo Range. *Conservation Science Western Australia* 7, 503–529.

Markey AS, Dillon SJ (2011) Flora and vegetation of the banded iron formations of the Yilgarn Craton: the northern Yerilgee Hills. *Conservation Science Western Australia* **8**, 163–186.

Mattiske Consulting Pty Ltd (2001a) 'Review of the Flora on Portman Iron Ore Expansion Areas'. Unpublished report commission by Portman Iron Ore.

Mattiske Consulting Pty Ltd (2001b) 'Review of the Vegetation on Portman Iron Ore Expansion Areas'. Unpublished report commission by Portman Iron Ore.

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

Maslin B, Reid J (2009) 'Understanding mulga'. Department of Environment and Conservation, Western Australia, Science Division, Information Sheet 25/2009. Available at http://www.dec.wa.gov.au/images/stories/nature/science/sdis/sdis025.pdf. [Accessed June 2010].

Department of Environment and Water Resources (2007) IBRA Version 6.1. Available at www.environment.gov.au/parks.nrs/ibra/version 6-1/. Updated 6th February [accessed June 2008].

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

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

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

Meissner RM, Bayliss B, Owen G (2010a) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Cashmere Downs Range. *Conservation Science Western Australia* 7, 349–361.

Meissner RM, Bayliss B, Owen G (2010b) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Mount Forrest – Mount Richardson Range. *Conservation Science Western Australia* 7, 377–389.

Meissner RM, Bayliss B, Owen G (2010c) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Robinson Ranges and Mt Gould. *Conservation Science Western Australia* 7, 363–376.

Milewski AV, Hall NJ (1995) Physical Environment. In *The Biological Survey of the Eastern Goldfields of Western Australia. Part 12: Barlee – Menzies Study Area* (eds GJ Keighery, NL McKenzie, NJ Hall). *Records of the Western Australian Museum* Supplement **49**, 174–182.

Miller JT, Andrew RA, Maslin BR (2002) Towards an understanding of variation in the Mulga complex (*Acacia aneura* and relatives). *Conservation Science Western Australia* **4**, 19–35.

Norris EH, Thomas J (1991) Vegetation on rocky outcrops and ranges in central and south-western New South Wales. *Cunninghamia* **2**, 411–441.

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

Pedley L (2001) *Acacia aneura* and relatives. In *Flora of Australia 11B, Mimosaceae, Acacia part 1.* (eds AE Orchard, AJG Wilson), pp. 309–328. Australian Biological Resources Study, Canberra, and CSIRO Publishing, Melbourne.

Porembski S, Martinelli G, Ohlemuller R, Bathlott W (1998) Diversity and ecology of saxicolous vegetation mats on inselbergs. *Journal of Biogeography* **4**, 107–119.

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

Shaw RJ (1999) Soil salinity – electrical conductivity and chloride. In *Soil Analysis, An Interpretation Manual* (eds KI Peverill, LA Sparrow, DJ Reuter), pp 129–145. CSIRO Publishing, Melbourne.

Smith MG (2010) 'Declared Rare and Priority Flora List for Western Australia', 16th September 2010, Department of Environment and Conservation, Perth.

Sneath PHA, Sokal RR (1973) *Numerical Taxonomy: The Principles and Practice of Numerical Classification.* Freeman, San Francisco.

Specht R, Batianoff GN, Reeves RD (2006) Vegetation structure and biodiversity along the eucalypt forest to rainforest continuum on the serpentine soil catena in a subhumid area of central Queensland, Australia. *Austral Ecology* **32**, 394–407.

Soil and Plant Council Inc. (1999) *Soil Analysis – Handbook of Reference Methods.* CRC Press, Boca Raton.

van Etten EJB, Fox JED (2004) Vegetation classification of central Hamersley Range, Western Australia. *Journal of the Royal Society of Western Australia* **87**, 63–79.

Walker IW, Blight, DF (1983). *Barlee, Western Australia. Sheet SH/50-8.1:250,000 Geological Series Explanatory Notes.* Geological Survey of Western Australia, Perth.

Walton K, Allen D (2004) 'Mehlich no. 3 soil test – the Western Australian experience'. In *Supersoil 2004. Proceedings of the 3rd Australian and New Zealand Soils Conference* (ed B Singh et al.), University of

Sydney, 5–9 December 2004. The Regional Institute, Gosford, New South Wales. http://www.regional.org.au/au/asssi/supersoil2004/s8/oral/1697_grayjg.htm) [accessed November 2011].

Western Australian Herbarium (1998–) *Florabase – The Western Australian Flora*. Department of Environment and Conservation. Available at http://florabase.dec.wa.gov.au/ [last accessed July 2007].

Wyche S, Chen SF, Greenfield JE, Riganti A (2001) *Geology of the Johnston Range 1:100,000 Sheet. 1:100,000 Geological Series Explanatory Notes*. Geological Survey of Western Australia, Perth.

Zar J H (1984) *Biostatistical Analysis*, 2nd ed. Prentice-Hall International, New Jersey.

APPENDIX 1

Flora list for the Johnston Range. Nomenclature follows Packowska & Chapman (2000), except for recent changes which are listed in the Census of Western Australian Flora (Western Australian Herbarium 1998–). Naturalised species are denoted by an asterisk. Refrerence collection numbers for informally (phrase) named taxa and collection numbers for putatively new (unnamed) taxa are given in parentheses. Family taxonomy follows the APG II system (Angiosperm Phylogeny Group 2003), which was current at time of flora list compilation.

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

Amaranthaceae
Ptilotus exaltatus
Ptilotus helipteroides
Ptilotus obovatus

Anthericaceae
Arthropodium curvipes
Thysanotus manglesianus

Apiaceae
Daucus glochidiatus
Trachymene ornata

Apocynaceae
Alyxia buxifolia

Asclepiadaceae
Marsdenia australis
Rhyncharrhena linearis

Aspleniaceae
Pleurosorus rutifolius

Asteraceae
Cephalipterum drummondii
Chthonocephalus pseudevax
*Hypochaeris glabra**
Lemooria burkittii
Myriocephalus guerinae
Olearia humilis
Olearia muelleri
Olearia pimeleoides
Olearia stuartii
Podolepis canescens
Podolepis lessonii
Rhodanthe battii
Rhodanthe laevis
Rhodanthe maryonii
Schoenia cassiniana
Vittadinia humerata

Brassicaceae
Stenopetalum filifolium

Caesalpiniaceae
Senna artemisioides subsp. *filifolia*
Senna artemisioides subsp. *helmsii* x *glaucifolia*
Senna artemisioides subsp. *x artemisioides*
Senna artemisioides subsp. *x coriacea*
Senna glutinosa subsp. *chatelainiana* x *charlesiana*
Senna sp. Austin (A Strid 20210)
Senna stowardii

Casuarinaceae
Allocasuarina acutivalvis subsp. *acutivalvis*
Allocasuarina dielsiana
Allocasuarina eriochlamys subsp. *eriochlamys*
Casuarina pauper

Chenopodiaceae
Atriplex bunburyana
Atriplex nummularia
Enchylaena lanata
Enchylaena tomentosa var. *tomentosa*
Eriochiton sclerolaenoides
Maireana georgei
Maireana pentatropis
Maireana planifolia
Maireana planifolia x *villosa*
Maireana trichoptera
Maireana triptera
Rhagodia drummondii
Rhagodia preissii subsp. *preissii*
Sclerolaena diacantha
Sclerolaena fusiformis
Sclerolaena obliquicuspis

Crassulaceae
Crassula colorata var. *acuminata*
Crassula tetramera

Cupressaceae
Callitris columellaris

Cuscutaceae
Cuscuta cf. *epithymum**

Dasypogonaceae
Chamaexeros macranthera

Droseraceae
Drosera macrantha subsp. *macrantha*

Epacridaceae
Leucopogon sp. Clyde Hill (MA Burgman 1207)

Euphorbiaceae
Calycopeplus paucifolius
Ricinocarpos brevis

Geraniaceae
Erodium cygnorum

Goodeniaceae
Dampiera lavandulacea
Goodenia cf. *mimuloides*
Goodenia havilandii
Scaevola spinescens

Lamiaceae
Prostanthera althoferi subsp. *althoferi*
Prostanthera althoferi subsp. *althoferi* x *campbellii*
Prostanthera grylloana
Prostanthera magnifica
Spartothamnella sp. Helena & Aurora Range (PG Armstrong 155–109)
Spartothamnella teucriiflora
Westringia cephalantha
Wrixonia prostantheroides

Loranthaceae
Lysiana casuarinae

Malvaceae
- *Abutilon cryptopetalum*
- *Abutilon oxycarpum*
- *Sida petrophila s.l.*
- *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)
- *Sida spodochroma*

Mimosaceae
- *Acacia acanthoclada* subsp. *glaucescens*
- *Acacia andrewsii*
- *Acacia aneura* var. cf. *argentia*
- *Acacia aneura* var. cf. *intermedia*
- *Acacia aneura* var. cf. *microcarpa*
- *Acacia burkittii*
- *Acacia cockertoniana*
- *Acacia colletioides*
- *Acacia effusifolia*
- *Acacia erinacea*
- *Acacia murrayana*
- *Acacia obtecta*
- *Acacia quadrimarginea*
- *Acacia ramulosa* var. *ramulosa*
- *Acacia* sp. Wondinong (AA Mitchell 917)
- *Acacia tetragonophylla*

Myoporaceae
- *Eremophila alternifolia*
- *Eremophila decipiens* subsp. *decipiens*
- *Eremophila forrestii* subsp. *forrestii*
- *Eremophila georgei*
- *Eremophila glabra* subsp. *albicans*
- *Eremophila glutinosa*
- *Eremophila granitica*
- *Eremophila latrobei* subsp. *latrobei*
- *Eremophila oldfieldii* subsp. *angustifolia*
- *Eremophila oppositifolia* subsp. *angustifolia*
- *Eremophila pantonii*
- *Eremophila serrulata*
- *Eremophila* sp. Mt Jackson (GJ Keighery 4372)

Myrtaceae
- *Aluta aspera* subsp. *aspera*
- *Baeckea elderiana*
- *Baeckea* sp. Parker Range (M Hislop & F Hort MH 2968)
- *Eucalyptus clelandii*
- *Eucalyptus concinna*
- *Eucalyptus ewartiana*
- *Eucalyptus longissima*
- *Eucalyptus oleosa* subsp. *oleosa*
- *Eucalyptus salubris*
- *Euryomyrtus maidenii*
- *Melaleuca eleuterostachya*
- *Melaleuca leiocarpa*

Orchidaceae
- *Pterostylis* sp. inland (AC Beauglehole 11880)

Papilionaceae
- *Bossiaea walkeri*
- *Daviesia purpurascens*
- *Glycine peratosa*
- *Mirbelia microphylla*

Phormiaceae
- *Dianella revoluta* var. *divaricata*

Pittosporaceae
- *Bursaria occidentalis*
- *Pittosporum angustifolium*

Poaceae
- *Amphipogon* cf. *caricinus* var. *caricinus*
- *Aristida contorta*
- *Austrodanthonia caespitosa*
- *Austrostipa elegantissima*
- *Austrostipa nitida*
- *Austrostipa* cf. *blackii*
- *Austrostipa platychaeta*
- *Austrostipa scabra s.l*
- *Austrostipa scabra* (atypical variant) (A Markey & S Dillon 6114)
- *Austrostipa* aff. *scabra* (A Markey & S Dillon 6107)
- *Enneapogon caerulescens*
- *Eriachne pulchella* subsp. *pulchella*
- *Monachather paradoxus*
- *Paspalidium basicladum*
- *Pentaschistis airoides**
- *Tripogon loliiformis*

Polygalaceae
- *Comesperma integerrimum*

Proteaceae
- *Banksia arborea*
- *Grevillea extorris*
- *Grevillea nematophylla* subsp. *supraplana*
- *Grevillea obliquistigma* subsp. *obliquistigma*
- *Grevillea paradoxa*
- *Hakea minyma*
- *Hakea recurva* subsp. *recurva*

Rhamnaceae
- *Cryptandra connata*

Rubiaceae
- *Psydrax suaveolens*

Rutaceae
- *Philotheca brucei* subsp. *brucei*
- *Philotheca tomentella*

Santalaceae
- *Exocarpos aphyllus*
- *Santalum spicatum*

Sapindaceae
- *Dodonaea lobulata*
- *Dodonaea rigida*
- *Dodonaea viscosa* subsp. *spatulata*

Solanaceae
- *Duboisia hopwoodii*
- *Solanum ellipticum*
- *Solanum lasiophyllum*
- *Solanum nummularium*

Sterculiaceae
- *Brachychiton gregorii*
- *Keraudrenia velutina* subsp. *velutina*

Thymelaeaceae
- *Pimelea spiculigera* var. *thesioides*

Urticaceae
- *Parietaria cardiostegia*

Violaceae
- *Hybanthus floribundus* subsp. *curvifolius*

Zygophyllaceae
- *Zygophyllum apiculatum*
- *Zygophyllum* cf. *eremaeum*

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Flora and vegetation of the banded iron formations of the Yilgarn Craton: the northern Yerilgee Hills, Menzies

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ABSTRACT

A survey was undertaken on the flora and plant communities associated with the northern Yerilgee Hills, located some 110 km west of Menzies and in the Yilgarn region of Western Australia. The hills are the formed by the exposure of the northern Yerilgee greenstone belt, and consist of seams of banded iron formation and mafic volcanics. A total of 183 taxa (182 native) were recorded from 51 quadrats and opportunistic collections. Four taxa were of conservation significance, two of these being new records for the survey area. At least three potentially new taxa, two regional endemics and one near-endemic taxon were also located. No range-restricted endemic taxa were reported. Six floristic community types were derived from numerical classification analysis of a presence/absence dataset of perennial species. Nonparametric ANOVA found significant differences between community types in site physical and soil chemical parameters. Ordination (nonmetric multidimensional scaling) analyses indicated generally highly significant ($p \leq 0.001$) correlations between floristic composition and topographic position, substrate and edaphic factors. These outcropping landforms are currently unreserved and occur on unallocated crown land and mining tenements cover the entire area. Exploration activities are the most immediate threat to the Yerilgee communities, while mining is a future potential threat.

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

INTRODUCTION

The Yilgarn Craton is the basement rock underlying much of southern Western Australia, much of which has been weathered into gently undulating plains that are overlain by deeply weathered regolith (Cornelius et al. 2007). Greenstone belts of mafic volcanics and banded iron formation (BIF) are common in the northern and eastern parts of the Yilgarn Craton (Chen & Wyche 2003; Greenfield 2001), and outcrop as discrete, prominent hills and elongate ridges in an otherwise flat landscape. These are isolated landforms in a semi-arid–arid landscape, which have been identified as being of high conservation value since they harbour both endemic and rare flora and fauna. The ranges also support geographically restricted vegetation communities and exhibit high between-range β-diversity (Department of Environment and Conservation 2007; Environmental Protection Authority 2007; Gibson et al. 2007; Mattiske 2001a, 2001b). Greenstone belts are also rich in mineral deposits, hence they are currently subject to considerable exploration and mining interests. Therefore, conservation management and planning decisions require detailed information on the biota of these ironstone formations.

This paper is part of a series of surveys that describe the flora and communities on approximately 25 individual ranges in the northern Yilgarn region, and aim to place these ranges within a regional context (Gibson et al. 1997, 2007; Gibson & Lyons 1998, 2001a, 2001b; Gibson 2004; Markey & Dillon 2008a, 2008b, 2009, 2010a, 2011; Meissner & Caruso 2008a, 2008b, 2008c; Meissner et al. 2010a, 2010b). The northern Yerilgee Hills have been identified as an area requiring detailed survey (Department of Environment and Conservation 2007), and this survey aims to provide a detailed description of the flora and communities for this landform and highlight the significance of the range within the Eastern Goldfields and wider Yilgarn region.

STUDY SITE

This survey targeted vegetation on the upland areas of banded iron formation on the northern Yerilgee Greenstone Belt, which is referred to in this study as the northern Yerilgee Hills. The survey area is located in the Eastern Goldfields, c. 460 km north-east of Perth, and in

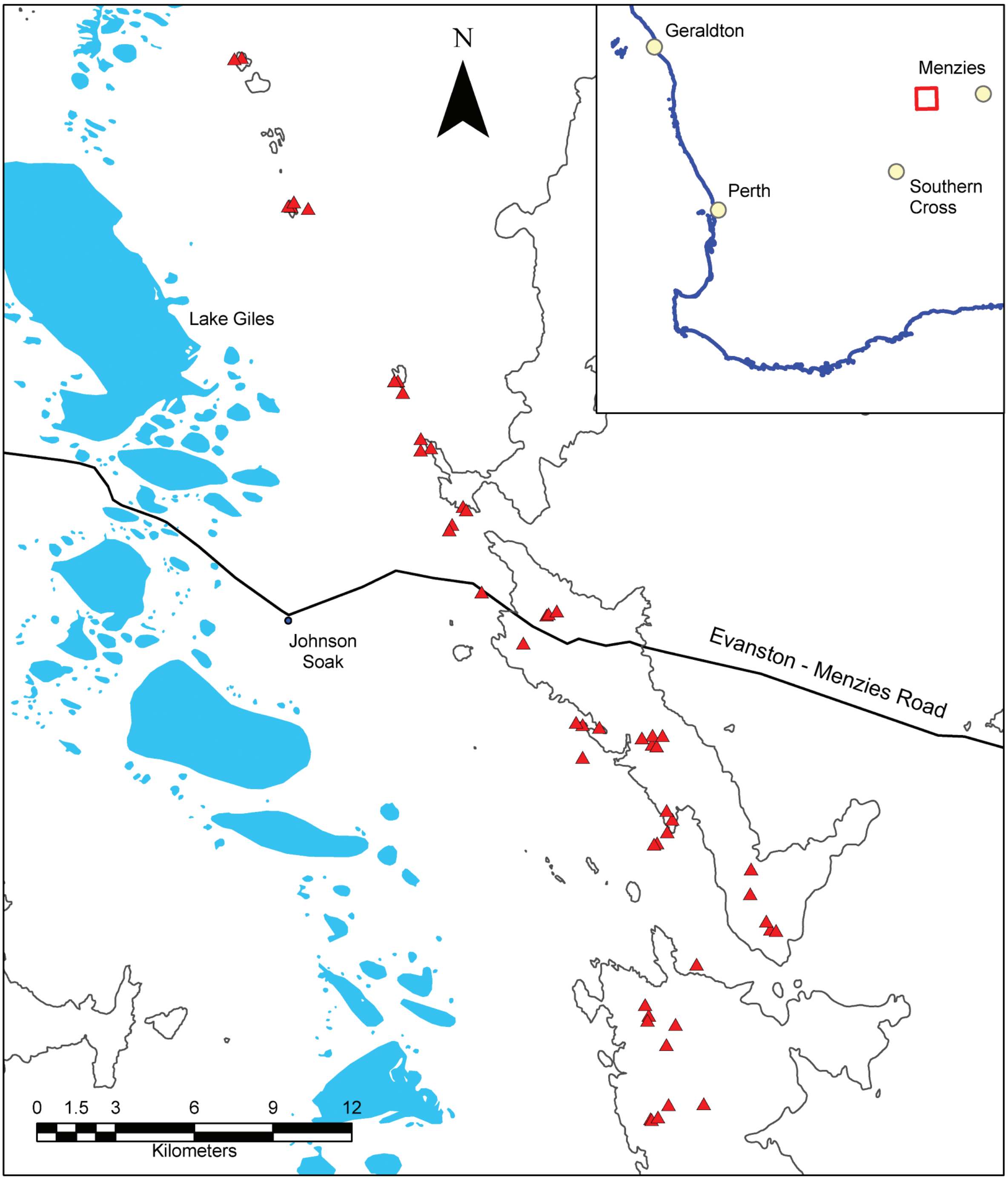

Figure 1. Map showing the location of the survey region relative to major towns in the Yilgarn region of Western Australia (insert), and the landforms and landmarks within the northern Yerilgee Hills survey area. Locations of the 51 quadrats on the Yerilgee Hills are marked (▲). The uplands of the survey area (> c. 410 m) are outlined by contour lines and playa lakes are indicated by filled areas.

an area of ironstone ranges that has been referred to as the Greater Mount Manning Region (Environmental Protection Authority 2007). The study area is located in the Shire of Menzies, 110 km west of Menzies township and c. 170 km northeast of Southern Cross (Fig. 1). The nearest homesteads are Diemals (61 km west of the survey area) and Mt Elvire (58 km north-west). The survey area is located over a latitudinal range of 29° 36' 20' to 29° 58' 31', and longitudinal extent from 119° 47' 50" to 120° 1' 21", and covers a rectangular area, 40 km north–south and 21 km east–west. The length of the range associated with the Yerilgee greenstone belt is c. 94 km and c.10 km wide, and the surveyed extent is c. 44 km long (north–south) by c. 8 km wide at its widest point (east–west).

Land Use History

Pastoralism and mining have been the main industries in the wider Mount Manning Region since the late 19th century, and very little vegetation has been cleared for agriculture (Beard 1972; Faithfull 1994). The northern Yerilgee Hills study area occurs primarily on unallocated crown land (UCL), with some sites located in the northern part of the Mt Manning Nature Reserve and others on Mt Elvire Station, a former pastoral lease acquired as a sandalwood reserve in 1991 by the Department of Conservation and Land Management (Department of Conservation and Land Management 1994). The station was de-stocked after purchase and reserved as a nature reserve and state forest in 2001, and has been proposed as a conservation reserve (Environmental Protection Agency 2007). Sandalwood harvesting continues over the study area, particularly north of the Evanston–Diemals road (Fig. 1). There is no evidence of historical livestock grazing in the northern Yerilgee Hills, but there are several active or retired pastoral leases adjoining the survey area (including Credo, Walling Rock and Mt Elvire stations.)

The survey area is located in far north-west corner of the Ularring District of the North Coolgardie Mineral Field, and abuts the south-eastern edge of the Yilgarn Mineral Field (Greenfield 2001; Walker & Blight 1983). Extensive gold mining and settlement throughout these mineral fields commenced in the late 19th century (Beard 1972; Faithfull 1994; Matheson & Miles 1947). Mining of iron ore deposits in the wider Mount Manning Region commenced in the 1960s (Beard 1972; Greenfield 2001), and extensive exploration for gold, iron ore and, to a lesser extent, nickel has been carried since the 1970s (Chen & Wyche 2003; Greenfield 2001). Renewed global interest has caused a resurgence of mining interest in the region (Greenfield 2001), and high prices and demand for steel has made the small deposits of iron ore in Yilgarn BIF ranges economically viable. Although the northern Yerilgee Hills have not been mined, a new round of iron ore exploration commenced in 2007.

Climate

The survey area is described as semi-desert Mediterranean, with cool, wet winters and hot, dry summers (Beard 1976, 1990; Milewski & Hall 1995; Newbey 1985). Rainfall is variable, with marginally more rain falling during winter months, but irregular summer rainfall also occurs (Milewski & Hall 1995). The two closest meteorological centres to the study area are Diemals Homestead and Menzies (Bureau of Meteorology 1908–). The annual rainfall for these centres is 276 mm and 251 mm respectively, with the wettest months between April and August. The average summer daily maximum (Dec–Feb) is 34.3 °C at Menzies and 35.3 °C at Diemals, with average temperatures over 40 °C occurring between December and March. The coolest period is between June and August, when average minima fall below 7 °C (Bureau of Meteorology 1908–).

Geology

The Yerilgee greenstone belt lies within the Southern Cross Domain of the Yilgarn Craton (Cassidy et al. 2006). The geology of the study region has been described and mapped on the 1:100,000 Lake Giles geological sheet (SH 50-8, 2838; Greenfield 2001), and 1:250,000 Barlee geological sheets (SH 50-8; Walker & Blight 1983). The Yilgarn Craton is composed primarily (c. 70%) of Archaean granitoids and gneisses (c. 3.6–2.63 Ga). Much of the remaining supracrustal rocks are assemblages of metamorphosed intrusive volcanics and sedimentary rocks, which are locally referred to as greenstones (Cassidy et al. 2006; Champion & Smithies 2001, 2003). These greenstone belts in the Southern Cross Domain have been aged as c. 3–2.9 Ga (Groenewald & Riganti 2004). The Yerilgee greenstone belt sequence is high-Mg basalt, with gabbro intrusions and overlain by ultramafic rocks and BIF. These are overlain with an uppermost of sequence of high-Mg basalt and sedimentary rocks (Greenfield 2001). Much of the belt is mapped as mafics, ultramafics, amphibolite and metamorphosed high-Mg basalt, with gneissic granitoids along the eastern margin and substantial seams of BIF and metasedimentary rocks.

The numerous BIF ridges provide the greatest topographic relief in the Mount Manning Region (Greenfield 2001). These ridges generally trend north–south and are <30 m in height. On the plains surrounding the ranges, a lateritic duricrust overlies granites, and this is covered by quartz sands and pisolite nodules (Greenfield 2001). Lateritic deposits also occur on the tops of the range, which have been formed by intensive weathering in the Tertiary (Greenfield 2001). The lowest elevations within the survey area are dominated by the extensive system of playa lakes associated with Lake Giles and Lake Barlee.

The lowest point within the northern Yerilgee hills survey area is c. 400 m above sea level (ASL), rising to altitudes of 500–510 m ASL at the highest points on the range (Greenfield 2001). A lateritic breakaway in the north-east of the survey area has a maximum altitude of 602 m ASL. The highest elevations and most conspicuous outcroppings of massive BIF occur immediately south of the Evanston–Menzies main road, and many of the taller ridges south of the road form a broad summit surface covered in lateritic deposits.

Vegetation

The survey area lies on the boundary of the southern edge of the Murchison and the Coolgardie IBRA bioregions, and is c. 60 km to the southeast margin of the Yalgoo Interim Biogeographic Regionalisation for Australia (IBRA) bioregion (Department of Environment and Water Resources 2007). These IBRA bioregions are derived from the Murchison and South Western Interzone botanical regions as defined by Beard (1972, 1976, 1990), and the boundary roughly coincides with the Evanston–Menzies road (Fig. 1). The southern boundary of the Murchison region is set where there is an abrupt transition from mulga (*Acacia aneura*) dominated shrublands to *Eucalyptus* woodland on lowlands, and the vegetation of this wider region is intermediate in character between the South West flora and more arid Eremaean flora (Beard 1976, 1990; Keighery et al. 1995).

The vegetation of the Yerilgee Hills has not been specifically addressed, but has been broadly covered by regional surveys. The Yerilgee Hills lie immediately north of the Jackson Area that Beard (1972) mapped and described at a scale of 1:250,000, but fall within Beard's (1976) survey of the wider Murchison Region at a scale of 1:1,000,000. In these surveys, Beard (1972, 1976) described the Bungalbin and Die Hardy Systems (i.e. a series of vegetation communities along a catenary sequence) for ironstone ranges in the Mount Manning Region. While the Die Hardy System was mapped on the Die Hardy Range and assumed to occur on the Mt Manning Range, Beard (1976) did not state if this system covered ranges north of Mt Manning (including the Yerilgee Hills).

The Yerilgee Hills were included in the Barlee–Menzies regional vegetation survey of Keighery et al. (1995), where communities were defined by structure and species composition of the upper stratum. Nearly 30 communities were described for the greenstone ranges within this region, including six communities on banded ironstone hillslopes and summits, two communities on greenstone hills slopes and summits, 11 communities on surrounding undulating plains, low ridges and colluvial flats and nine woodland communities in the broad valleys. In general, ironstone upper-slope and summit communities consisted of *Acacia aneura*, *Allocasuarina acutivalvis* or *Banksia arborea* shrublands, while *Acacia quadrimarginea* shrublands or *Eucalyptus ebbanoensis* woodlands/mallee-covered hill-slopes. Lowland communities consisted of *Eucalyptus*, *Acacia aneura* or *Casuarina pauper* woodlands, while *Eucalyptus* or *Callitris columellaris* woodlands dominated broad valleys.

More recent surveys in the Mount Manning Region have addressed several ranges on an individual basis and have used quadrat-based floristic data to describe communities (Gibson 2004; Gibson et al. 1997; Gibson & Lyons 2001a, 2001b; Mattiske 2001b). These studies have found significant differences among ranges in floristic composition and that they harbour endemic and highly restricted floristic communities (Mattiske 2001b).

METHODS

Fifty-one permanent quadrats were established on the northern half of the Yerilgee greenstone belt (Fig. 1), during the final two weeks of September 2007. Quadrats were placed strategically over the range in order to sample the topographic catena, different geologies and the greatest variation in floristic communities. This strategic placement of sites has been used to survey other ranges in the Yilgarn Craton (e.g. Gibson 2004). An effort was made to place quadrats within the least disturbed vegetation, although some disturbed sites were still sampled (i.e. sites that had been cut over for sandalwood). Quadrats were permanently marked with a steel fence picket at each corner and their location and altitude recorded by GPS (Garmin 76, Garmin Ltd, Kansas). The presence and cover class estimate of all vascular plant species (spermatophytes and pteridophytes) were recorded in each quadrat. Additional records were made adjacent to quadrats or opportunistically on the range. Vouchers were collected for species identification at the Western Australian Herbarium, where representative specimens of all taxa have been lodged. Vegetation structure and cover was described according to McDonald et al. (1998). The geographical distributions of taxa were obtained from online records at the Western Australian Herbarium (1998–). The *Acacia aneura* species complex was resolved to morphotypes that approximated the varieties described by Pedley (2001).

For each quadrat, a number of soil and site environmental parameters were determined. Topographical position, aspect, slope, litter and bare ground cover, exposed bedrock and surficial rock cover, surficial rock size, soil colour and soil texture were noted using the methods of McDonald et al. (1998). Percentage surface rock fragment cover class, maximum surface rock fragment size and exposed bedrock outcrop cover were all coded on a semi-quantitative scale (Table 3), and percentage ground and litter cover were estimated visually. Twenty soil samples from the top 10 cm were collected regularly over the quadrat, bulked and sieved. The 2 mm fraction was analysed at the Chemistry Centre of Western Australia. The concentrations of 16 elements (Al, B, Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, S and Zn) were determined using inductively coupled plasma atomic emission spectrometry (ICP AES; Mehlich 1984; Walton & Allen 2004). 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 measured calorimetrically following a modified Kjeldahl digest (method S10; Rayment & Higginson 1992). Soil pH was measured in 0.01M $CaCl_2$ (method S3, Rayment & Higginson 1992), and electrical conductivity ($EC_{1:5}$) measured in a 1:5 solution of soil extract:deionised water at 25 ºC (method S2; Rayment & Higginson 1992). Effective cation exchange capacity (eCEC) was estimated from the sum of individual charge equivalents per kilogram of Ca, Mg, Na and K, following the conversion of each element from their respective cation concentrations (from ICP AES) by dividing with 200.4, 121.6, 230, and 390 respectively (Soil and Plant Council 1999; Rayment & Higginson 1992).

Quadrats were classified according to similarities in species composition of perennial, non-singleton taxa, which is consistent with previous surveys (e.g. Gibson 2004; Markey & Dillon 2008a, 2008b; Meissner & Caruso 2008a, 2008b, 2008c). Only taxa resolved to at least species level were used in the analysis. After compiling the floristic data into quadrat by species matrices of presence/absence data, annual taxa were omitted since these desert ephemerals are seasonal in their distribution and abundance (Mott 1972, 1973). Singleton perennial taxa (appearing only in a single quadrat) were also excluded since these carry little information. The effect of these omissions was tested by comparing the results from classification analyses and from a pair-wise comparison of the matrices. Resemblance (association) matrices were generated from the site by species data matrices using the Bray–Curtis coefficient (measure of distance), and these were then compared using the '2 Stage' algorithm in Primer (Clark & Gorley 2006) to determine the degree of correlation between datasets following the exclusion of taxa.

Classification and ordination analyses on resemblance matrices were carried out using the statistical software package, PATN (V3.03; Belbin 1989). Flexible UPGMA (β = –0.1) was used to generate a species and site classification (Belbin et al. 1992). Indicator species analysis (INDVAL) was used to identify characteristic taxa for each community. INDVAL analysis was done in PC-Ord (McCune & Mefford 1999), using the methods of Dufrêne & Legendre (1997). A Monte Carlo permutation test, using 10,000 simulations, was used to test for the significance of these INDVAL values for each species ($p > 0.05$). Semi-strong hybrid (SSH) multidimensional scaling was used in the ordination of quadrats, based on floristic data, using 1000 random starts and 50 iterations in PATN (Belbin 1991). Principal Component Correlation (PCC) was used to correlate the environmental variables with the site ordination coordinates, with 10 000 iterations of a Monte Carlo procedure (MCAO) used as a bootstrap analysis to evaluate the significance of these correlation coefficients (Belbin 1989; Faith & Norris 1989). The Kruskal–Wallis nonparametric analysis of variance and Dunns post-hoc multiple comparisons were used to determine differences in community averages for individual environmental variables (Zar 1984). Univariate analyses were only conducted on groups with at least a minimum sample size ($n \geq 5$).

RESULTS

Flora

A total of 183 taxa (species, subspecies, varieties and forms) and two putative hybrids were recorded from within and adjacent to the 51 quadrats or from opportunities collections (Appendix 1). The small annual grass, *Pentaschistis airoides*, was the only naturalised species collected. Approximately 9% of taxa were annuals (ephemeral) or short-lived perennials. Taxa were from 40 families (as defined by the APG II system (Angiosperm Phylogeny Group 2003), with most from Mimosaceae (*Acacia*, 20 taxa), Chenopodiaceae (19 taxa), Myrtaceae (16 taxa), Myoporaceae (*Eremophila*, 15 taxa and one putative hybrid), Poaceae (14 native and one introduced taxon), Asteraceae (ten taxa), Proteaceae (nine taxa) and Lamiaceae (eight taxa and one hybrid). In addition to *Acacia* and *Eremophila*, the most common genera were *Eucalyptus* (12), *Maireana* (five), *Sclerolaena* (five), *Ptilotus* (five), *Sida* (five) and *Solanum* (five; Appendix 1).

The majority of taxa were perennial shrubs or trees, with less than 10% of taxa being annual or short-term perennial herbs (17 taxa). Of the remaining perennials, 39% were sub-shrubs/shrubs (71 taxa), 16% were tall shrubs/small trees (29 taxa), 10% were mallees or trees (19 taxa), 10% were chenopod sub-shrubs/shrubs (18 taxa), 7% were perennial grasses (12 taxa), 3% were perennial herbs (five taxa), 3% were geophytes (five taxa), 2% were mistletoes (four taxa) and 2% were perennial climbers (three taxa).

Priority taxa

Four taxa of conservation significance (Flora Conservation Codes as compiled by the Western Australian Department of Conservation and listed under the Western Australian Wildlife Conservation Act) were collected on the northern Yerilgee Hills, with all species regarded as data deficient or uncommon (Smith 2010).

- *Spartothamnella* sp. Helena & Aurora Range (PG Armstrong 155–109; Lamiaceae) has Priority 3 conservation status (Smith 2010). Although this species is known from several locations within the Yalgoo, Avon Wheatbelt and Coolgardie IBRA regions, this is a new record for this species from within the survey area. It was observed to be in scattered locations on the pediments and valley hillslopes of the Yerilgee Hills, and these findings are c. 60 km east of previously known collections in the Western Australian Herbarium (1998–), and c. 80 km east of new populations located on the Johnston Range (Markey & Dillon 2011). This species is considered to be a taxon with its distribution centred on BIF (Gibson et al. 2007).
- *Grevillea erectiloba* (Proteaceae) has Priority 4 conservation status (Smith 2010), and has been recorded from the area prior to this survey. It is distributed in the Coolgardie and Murchison IBRA bioregions, mostly within a range of 200 km centred around Mt Manning, but with one outlying population c. 200 km east of its main distribution (Western Australian Herbarium 1998–). Given its distribution, this species is considered to be a regional near-endemic. Within the survey area, this species was restricted to the upland laterites of the northern Yerilgee Hills. It has been recorded from a number of habitats, including lowland plains, but many collections are from upland BIF sites on ranges south of the Yerilgee Hills.
- *Austrostipa blackii* has Priority 3 conservation status, and occurs in scattered localities throughout the Avon Wheatbelt, Yalgoo and Coolgardie IBRA Bioregions. This was a new record for this species from within the survey area, although it is known from the Hunt Range 46 km to the south. Although the range of this species has been extended by previous surveys of Yilgarn ranges (Gibson & Lyons 2001a; Markey & Dillon 2008a), herbarium records indicate that this species is not restricted to BIF landforms (Western Australian Herbarium 1998–).

- *Banksia arborea* (P4) was found as a dominant tall shrub or tree growing on crests of rocky massive BIF and associated laterite. Given its distribution within a region of 200 km diameter, and restriction to crests of BIF (Western Australian Herbarium 1998–), this species is considered to be an endemic species of the Mount Manning Region (Environmental Protection Authority 2007).

Notable taxa

An entity tentatively identified as *Sida petrophila* s.l. (R Barker,[1], pers. comm.) was collected from a few locations at this study site and on the adjacent Johnston Range (c. 80 km east; collection numbers: A Markey & S Dillon 5815 and A Markey & S Dillon 5816; Markey & Dillon 2011). *Sida petrophila* s.s. is considered to be restricted to eastern Australia (Barker 2007), and the few collections from Western Australia require further examination since these populations are greatly disjunct from the eastern states. It is possible that this western variant could be a new taxon. Collections from the Diemals – Lake Giles area suggests that this species grows on colluvium overlying metabasalts, which occur in association with banded iron formation (this study; Markey & Dillon 2011).

Acacia aff. *balsamea* (collection number: A Markey & S Dillon 5212, sheet number PERTH07838611) was identified as putative new entity allied to *Acacia balsamea*, based on phyllode and seed characters being inconsistent with those of *Acacia balsamea* (B Maslin[2], pers. comm.) This entity is a putative new taxon which has a distribution greatly disjunct from the range of *Acacia balsamea* s.s. The closest population of *Acacia balsamea* s.s. is c. 200 km north of the Yerilgee Hills. According to herbarium records, *Acacia balsamea* is located in the Murchison IBRA, northwards into the Pilbara, Gibson Desert, Little Sandy Desert and Great Sandy Desert IBRA bioregions. A second novel entity of *Acacia* had affinities to *Acacia sibirica. Acacia* aff. *sibirica* (collection number A Markey & S Dillon 6092, sheet number PERTH07838654) has phyllodes and inflorescence very similar to those of *Acacia sibirica,* but is distinguished from the latter taxon by having wider pods.

Two other variants of known taxa that were considered as morphologically distinct were collected: *Grevillea* aff. *paradoxa* (collection number: A Markey & S Dillon 6097) and an atypical variant within the circumscription of *Austrostipa scabra s.l.* (collection number: A Markey & S Dillon 6114). The *A. scabra* is a complex currently under review (Alex Williams[3], pers. comm.), and further studies and collections are required to confirm the status of these collections.

Although the priority status of *Eremophila* sp. Mt Jackson (GJ Keighery 4372) had been removed in 2008, this species is still considered to be a regional endemic with a geographic range of just over 200 km and a distribution primarily centred on the foothills and flats around greenstone ranges.

Floristic Communities

The initial data matrix consisted of 153 taxa from 51 quadrats. Four pairs of taxa were amalgamated into three species complexes. These were *Austrostipa scabra* (atypical variant)/*Austrostipa nitida*, *Grevillea* aff. *paradoxa*/*Grevillea paradoxa*, *Enchylaena lanata*/*E. tomentosa* subsp. *tomentosa.* Intergrades of *Eremophila forrestii* x *latrobei* were amalgamated with the morphologically closest parental taxon. After these amalgamations and the omission of annual (14) and singleton perennial taxa (25), 114 taxa were included in the final data matrix (74% of total taxa). The correlation between original and final matrices was 98.6%. For the final dataset, species richness (taxa per quadrat) ranged from 16 to 32, and the average species richness was 22.7 ± 0.5 taxa per quadrat (mean ± SE).

Six floristic communities were identified from the classification of quadrat floristic data (Fig. 2). Floristic communities were based on the dendrogram topology, the sorted two-way table (Table 1), and from observations made during the fieldwork. The same analysis simultaneously classified the 114 taxa into nine species groups (Table 1).

The primary division separated community type 1 from the other sites (Fig. 2). This community was associated with upland summit surfaces of ridge tops. This division was evident in the two-way table (Table 1), where community type 1 was distinguished by high representation of taxa from species groups D and comparatively few taxa from species groups G, H and I. The second major division was between communities on rocky crests and mid to upper hillslopes (community types 2 and 3) and those lower in the landscape—from hill slopes, valley flats, pediments and outwashes and low plains around the BIF ridges (community types 4, 5 and 6). Taxa from species groups G and H were typically absent in these latter two upland communities, while these species groups were well represented in most of the lowland communities.

Community type 1: Mixed shrubland/mallee shrubland mosaic on upland summit surfaces

Substrate and location: Community type 1 was located on upland summit surfaces of BIF ridges, where parallel ridges and gently tilted BIF strata underlie relatively deep deposits of weathered, lateritic duricrusts. These are overlain with sandy soils and lateritic gravels. This community was located in the central to southern parts of the survey area, and was found at high elevations, on areas with low gradients and with low cover of exposed

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[2] Bruce Maslin, Western Australian Herbarium, Department of Environment and Conservation, Perth.

[3] Alex Williams, Western Australian Herbarium, Department of Environment and Conservation, Perth.

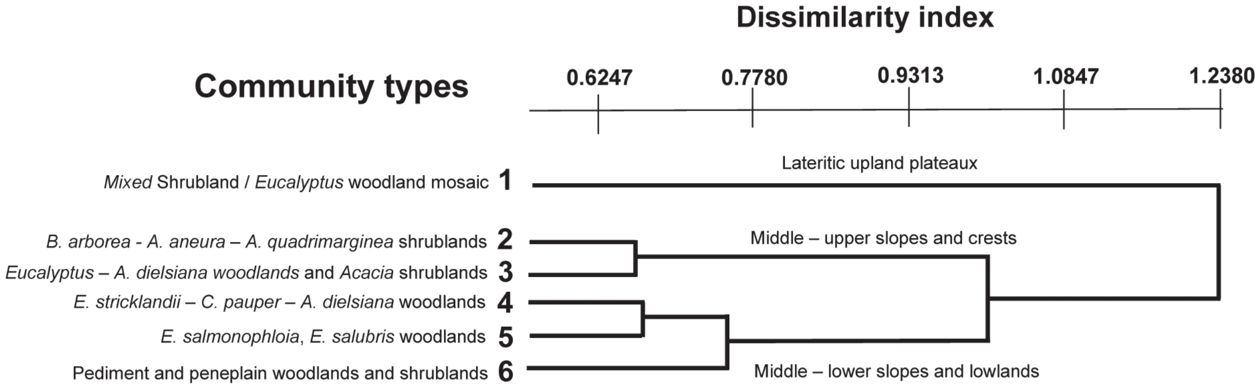

Figure 2. Summary dendrogram of the floristic community types of the northern Yerilgee Hills, resolved from classification analysis of a presence/absence data matrix of 114 perennial taxa from 51 quadrats. The classification method was flexible UPGMA (dilated using $\beta = -0.1$) using the Bray–Curtis measure of dissimilarity.

bedrock (<2%), with medium sized surface rocks and moderately shallow to deep soil depth categories (Table 3). Soils were strongly acidic (pH <4.8), and had relatively high concentrations of organic C, N and Fe (Table 4), relatively low concentrations of the most trace elements (particularly Ca, Co, K, Mg and Ni), and relatively lower average values for Na, $EC_{1:5}$ and eCEC.

Structural description: Typically a mosaic of shrublands co-dominated varyingly by *Acacia aneura*, *Allocasuarina eriochlamys* subsp. *eriochlamys*, *Banksia arborea*, *Acacia effusifolia*, or open mallee shrublands or isolated mallees of *Eucalyptus* (*E. ebbannoensis*, *E. ewartiana* and *E. horistes*). Many of the common and characteristic species come from the Proteaceae, Myrtaceae and Lamiaceae, and include *Prostanthera grylloana*, *Leucopogon* sp. Clyde Hill (MA Burgman 1207), *Olearia humilis*, *Grevillea paradoxa*, *Baeckea elderiana*, *Mirbelia microphylla*, *Prostanthera magnifica*, *Wrixonia prostantheroides*, *Grevillea oligomera*, *Baeckea elderiana* and *Aluta aspera* subsp. *aspera*. Many of these were significant indicator species (Table 2).

Species groups: Common and consistent taxa were from species group D (Table 1), and there was a moderate representation of taxa from species group F, a notable lack or complete absence of species from species groups G and H, and low representation from species group I. There were some floristic affinities to community type 2, particularly with taxa from species group E (Table 1).

Comments: Although community type 1 was a relatively heterogeneous unit, there was not enough sampling to distinguish sub-groupings among the mallee, mallee shrublands and shrublands. Perennial hummock grasses were uncommon within the survey area, however dense patches of *Triodia* cf. *scariosa* were observed in a mosaic shrubland of this community in southern parts of the survey area.

Mean perennial species richness: 20.9 ± 1.2 SE taxa per quadrat.

Community type 2: Banksia arborea – Acacia aneura – Acacia quadrimarginea *shrublands on massive BIF*

Substrate and location: Found on massive BIF outcrops on steep, rocky uplands. Located at notably high elevations and topographic locations, on steep slopes with moderate to large surface rocks, high runoff scores, a relatively high cover of exposed bedrock and notably skeletal soil depths (Table 3). Soils were strongly acidic (pH <4.8), and values for many trace elements were relatively low (Table 4).

Structural description: This community consisted of tall shrublands varyingly co-dominated by *A. aneura*, *A. quadrimarginea*, *Allocasuarina acutivalvis* and *B. arborea*. Other shrub taxa included *Melaleuca leiocarpa*, *Philotheca brucei* subsp. *brucei*, *Dodonaea rigida*, *Eremophila georgei*, *Eremophila latrobei* subsp. *latrobei* and *Ptilotus obovatus*. Common ground stratum species included both species of rock fern (*Cheilanthes* spp.) and *Sida* sp. golden calyces (HN Foote 32). Many of these characteristic shrub and geophytic species were commonly found growing out of rock fissures.

Species groups: Many of the common taxa were significant indicator species (Table 2), and occurred in species group F (Table 1). This community type has limited representation of taxa from species groups D, G and H, but notable representation of taxa from species groups E, F and I (Table 1). Two quadrats, which were located at the southern extreme of the survey area, were relatively dissimilar to the central and northern occurrence of this community type. Unlike the other sites, this pair of quadrats had characteristic representation from species group E and few taxa from species group F (Table 1). Further sampling of the range south of the survey area may identify a southern variant of this community type.

Mean perennial species richness: 21.9 ± 0.8 SE taxa per quadrat.

Table 1

Two-way table of sites and perennial species of the northern Yerilgee Hills, sorted by the site and species floristic classification of 114 taxa from 51 quadrats. Quadrats appear as columns, and species as rows, and both are ordered by group/community type. Each rectangle represents a species presence within a quadrat.

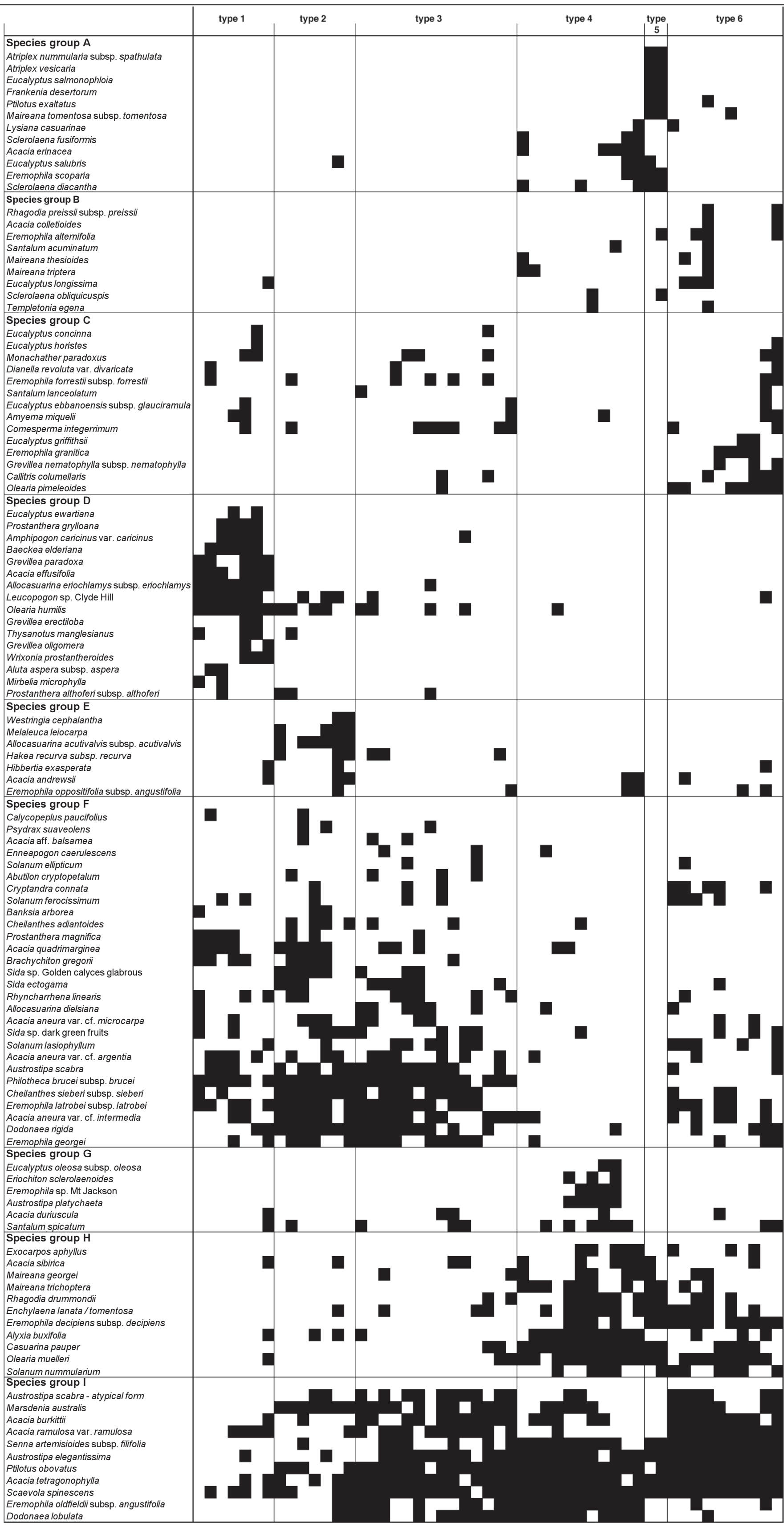

Table 2

Significant indicator species of floristic communities for the northern Yerilgee Hills. Indicator values (%) are shown only for taxa that were significant at $p \leq 0.05$ (from Monte Carlo permutation test, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$). High indicator values (>25%) per taxon are indicated by shading.

	Community type					
Indicator species	**1**	**2**	**3**	**4**	**5**	**6**
*Acacia effusifolia****	86	0	0	0	0	0
Allocasuarina eriochlamys subsp. *eriochlamys****	93	0	0	0	0	0
Amphipogon caricinus var. *caricinus***	51	0	1	0	0	0
*Baeckea elderiana***	71	0	0	0	0	0
*Grevillea paradoxa***	71	0	0	0	0	0
Leucopogon sp. Clyde Hill*	50	13	0	0	0	1
*Olearia humilis****	51	17	4	0	0	0
*Prostanthera grylloana***	57	0	0	0	0	0
*Prostanthera magnifica**	35	9	1	0	0	0
*Wrixonia prostantheroides***	43	0	0	0	0	0
Allocasuarina acutivalvis subsp. *acutivalvis****	0	86	0	0	0	0
*Cheilanthes adiantoides**	0	41	3	1	0	0
Cheilanthes sieberi subsp. *sieberi****	4	45	19	0	0	4
*Dodonaea rigida****	3	41	17	0	0	7
Hakea recurva subsp. *recurva**	0	29	7	0	0	0
*Marsdenia australis****	0	34	21	7	0	17
*Melaleuca leiocarpa***	0	57	0	0	0	0
Philotheca brucei subsp. *brucei***	26	36	31	0	0	0
Sida sp. golden calyces glabrous*	0	55	5	0	0	0
*Acacia erinacea**	0	0	0	45	0	0
*Alyxia buxifolia****	1	5	0	48	0	5
*Austrostipa platychaeta***	0	0	0	45	0	0
*Casuarina pauper***	0	0	1	39	39	6
*Dodonaea lobulata****	0	4	30	40	0	0
Eremophila oldfieldii subsp. *angustifolia****	0	4	16	49	0	2
Eremophila sp. Mt Jackson*	0	0	0	36	0	0
*Exocarpos aphyllus**	0	0	0	27	0	12
*Ptilotus obovatus**	0	8	22	25	6	25
Atriplex nummularia subsp. *spathulata****	0	0	0	0	100	0
*Atriplex vesicaria****	0	0	0	0	100	0
*Enchylaena lanata/tomentosa**	0	1	2	16	39	14
*Eremophila decipiens subsp. decipiens**	0	0	0	6	44	36
*Eremophila scoparia***	0	0	0	3	85	0
*Eucalyptus salmonophloia****	0	0	0	0	100	0
*Frankenia desertorum****	0	0	0	0	100	0
Maireana tomentosa subsp. *tomentosa***	0	0	0	0	91	1
*Maireana trichoptera***	0	0	0	22	54	2
*Olearia muelleri**	1	0	1	28	33	21
*Ptilotus exaltatus***	0	0	0	0	91	1
*Rhagodia drummondii***	0	0	1	15	50	5
*Sclerolaena diacantha***	0	0	0	6	79	0
*Sclerolaena obliquicuspis**	0	0	0	1	42	0
*Acacia burkittii***	1	1	25	9	0	33
Acacia ramulosa var. *ramulosa****	13	1	24	0	0	39
*Austrostipa elegantissima**	1	1	16	21	25	25
*Callitris columellaris**	0	0	4	0	0	29
*Cryptandra connata**	0	3	3	0	0	32
*Eremophila granitica***	0	0	0	0	0	40
*Olearia pimeleoides***	0	0	1	0	0	64
Senna artemisioides subsp. *filifolia**	0	1	5	20	30	30

Community type 3: Eucalyptus – Allocasuarina dielsiana *woodlands and* Acacia *shrublands on mid- to upper hillslopes.*

Substrate and location: Sites were generally located on middle to upper hillslopes at moderate elevations and with moderate gradients, among ridges of interbedded BIF and mafic lithologies. Sites had deposits of BIF and mafic scree, little bedrock outcrop cover, shallow soils and moderate runoff scores (Table 3). Soils were weakly acidic, had moderately low in $EC_{1:5}$ and Na values, and concentrations of trace elements in the middle range of values (Table 4).
Structural description: Tall *Acacia* shrublands usually co-dominated by *A. aneura (A. aneura* var. cf. *intermedia* or var *cf. argentia*), *Acacia ramulosa* var. *ramulosa* and/or *Acacia burkittii*, and often overtopped by isolated trees of *Allocasuarina dielsiana*. Also open woodlands dominated by *Eucalyptus* (*E. concinna* or *E. ebbanoensis* subsp. *glauciramula*) or *Allocasuarina dielsiana* (sometimes also *Casuarina pauper). Acacia* aff. *balsamea, Acacia duriuscula* or *A. quadrimarginea* were occasionally co-dominants in the upper stratum. The middle stratum of sparse shrublands often included *Scaevola spinescens*, *E. latrobei* subsp. *latrobei*, *D. rigida*, *Solanum ferocissimum*, *P. brucei* subsp. *brucei*, *E. georgei*, *Eremophila oldfieldii, Dodonaea lobulata* and *P. obovatus.* Very few indicator species characterized this community (Table 2).
Species groups: While consistent, none of the common and dominant taxa were restricted to this community (Table 2). There was a notable absence of chenopods and other taxa from species groups G and H, and there was a limited representation of taxa from species groups C, D and E. A moderately high number of taxa from across species group F were common in this community. Taxa from species group I occurred with notable constancy, and both this and a lack of taxa from group E distinguished this community from community type 2 (Table 1).
Comments: Community type 3 was most floristically allied to community type 2.
Mean perennial species richness: 21.9 ± 0.6 SE taxa per quadrat.

Community type 4: Eucalyptus stricklandii – Casuarina pauper – Allocasuarina dielsiana *woodlands*

Substrate and location: Distributed on middle to lower slopes of ridges, low hills, hillocks and pediments. Found on colluvial deposits of BIF and mafic rocks, often with some deposits of calcrete. Sites were located at moderate elevations, on low gradients with little bedrock outcrop, shallow soils and moderate runoff scores (Table 3). Soils were weakly acidic to neutral and average trace element concentrations and soil eCEC were relatively high, with comparatively higher salinity values (Na and $EC_{1:5}$; Table 4).
Structural description: Woodlands dominated varying by *Eucalyptus stricklandii*, *C. pauper* and/or *A. dielsiana*, over tall shrubs or *Acacia* (*A. ramulosa* subsp. *ramulosa*, *A. burkittii*, *Acacia sibirica, A. quadrimargina*). Common species included *Santalum spicatum*, *Acacia erinacea*, *Eremophila* sp. Mt Jackson (GJ Keighery 4372), *Eremophila oldfieldii*, *D. lobulata*, *Alyxia buxifolia*, *S.spinescens, Olearia muelleri* and *P. obovatus,* over isolated chenopod subshrubs (*Maireana* and *Sclerolaena*) and the perennial speargrass, *Austrostipa platychaeta*.
Species groups: Many of the common and dominant taxa were significant indicator species (Table 2), as were taxa from species group G (Table 1). Taxa from species groups G, H and I were highly represented in this community, while there was a limited but notable occurrence of taxa from species group A. Species from the remaining species groups were either severely lacking or absent.
Mean perennial species richness: 20.5 ± 0.9 SE taxa per quadrat.

Community type 5: Tall, open Eucalyptus salmonophloia – E. salubris *woodlands over halophytes and chenopods*

Substrate and location: Environmental information from the two quadrats and additional field observations suggested that this community was located at relatively low altitudes and among the lowest topographic positions. It was restricted to the deep, sandy-clay soils in the flat, wide, lowland valleys between ridges, which were associated with both colluvial and alluvial deposits (Table 3). The soil pH was relatively high and approaching neutral, with relatively little organic C and concentrations of most elements (especially Ca, Co, Cu, K, Mg, Na, Ni and P) were at the higher range of values (Table 4).
Structural description: Tall, open woodlands of *Eucalyptus salmonophloia*, *E. salubris* over very sparse halophyte and chenopod-rich shrublands. Best indicator taxa included *Eremophila decipiens* subsp. *decipiens*, *Atriplex nummularia* subsp. *spathulata*, *Rhagodia drummondii*, *Frankenia desertorum* and species of *Enchylaena, Maireana* and *Sclerolaena* (Table 2).
Species groups: There was distinctive representation of a set of taxa from species group A, many of which had high fidelity to the community type. There was high representation from species group H and part of group I. Taxa from most other species groups were absent (Table 1). Despite some floristic similarities, this community was distinguished from community type 4 by a lack of taxa from species group G.
Comments: Although under-sampled in this survey, these woodlands cover a reasonably large area of lowland valleys between ridges in the southern half of the survey area. This low sampling has resulted in a large number of significant indicator species because of inflated constancy values (Table 2).
Mean perennial species richness: relatively high, at 24.5 ± 1.5 SE taxa per quadrat.

Community type 6: Pediment and peneplain woodlands and shrublands

Substrate and location: Woodlands and shrublands on the pediments and peneplains flanking BIF ridges, on colluvial deposits of BIF, calcrete, quartz and mafic

Table 3

Summary statistics (average ± SE) of site physical variables for floristic community types of the northern Yerilgee Hills, differences were determined using Kruskal–Wallis nonparametric analysis of variance. (* indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$), with Dunn's post-hoc test (LSD $p < 0.05$). [1]: no significant group differences detected in post-hoc test.

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
Slope ***	1.4 ± 0.2 ^{ab}	9.7 ± 1.5 ^{c}	4.0 ± 1.0 ^{bc}	2.5 ± 0.7 ^{ab}	0.0 ± 0.0	0.5 ± 0.2 ^{a}
Topographic position***	4.3 ± 0.2 ^{b}	4.8 ± 0.1 ^{b}	3.4 ± 0.2 ^{b}	3.0 ± 0.4 ^{ab}	1.0 ± 0.0	1.3 ± 0.1 ^{a}
Surface fragment cover**[1]	5.1 ± 0.3	4.3 ± 0.3	4.4 ± 0.3	5.3 ± 0.2	4.5 ± 0.5	4.0 ± 0.4
Maximum rock size***	3.3 ± 0.3 ^{a}	5.3 ± 0.2 ^{b}	3.8 ± 0.4 ^{ab}	3.7 ± 0.1 ^{ab}	2.5 ± 0.5	2.5 ± 0.2 ^{a}
Bedrock cover***	0.9 ± 0.6 ^{ab}	4.7 ± 0.2 ^{c}	1.1 ± 0.5 ^{bc}	1.1 ± 0.3 ^{ab}	0.0 ± 0.0	0.0 ± 0.0 ^{a}
Runoff ***	2.6 ± 0.4 ^{ab}	4.0 ± 0.2 ^{b}	2.9 ± 0.2 ^{b}	2.5 ± 0.3 ^{ab}	0.0 ± 0.0	1.1 ± 0.2 ^{a}
Soil depth***	2.4 ± 0.2 ^{b}	1.0 ± 0.0 ^{a}	2.3 ± 0.2 ^{b}	2.0 ± 0.1 ^{ab}	3.0 ± 0.0	2.8 ± 0.1 ^{b}
% Litter cover^{NS}	49.3 ± 4.9	32.1 ± 7.9	33.9 ± 4.1	31.4 ± 5.2	12.5 ± 2.5	32.5 ± 4.7
% Bare ground^{NS}	75.7 ± 2.5	80 ± 3.5	84.6 ± 1.9	80.9 ± 1.9	87.5 ± 2.5	79 ± 3.1
Latitude^{NS}	29.8869 ± 0.020	29.8657 ± 0.030	29.7818 ± 0.026	29.8076 ± 0.037	29.8975 ± 0.020	29.8303 ± 0.030
Longitude^{NS}	119.9788 ± 0.000	119.9551 ± 0.017	119.909 ± 0.019	119.9163 ± 0.021	119.98 ± 0.009	119.9296 ± 0.017
Altitude*[1]	487.9 ± 6.2	489.1 ± 5.4	465.6 ± 6.5	467.8 ± 6.9	447.0 ± 6.0	458.3 ± 8.0
Total species	21.4 ± 1.0	23.4 ± 0.8	22.6 ± 0.7	21.1 ± 1.0	24.5 ± 1.5	25.1 ± 1.6
No. quadrats	7	6	14	11	2	10

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

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

Table 4

Summary statistics (average ± SE) of soil variables for floristic community types of the northern Yerilgee Hills, differences were determined using Kruskal–Wallis nonparametric analysis of variance (* indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$), with Dunn's post-hoc test (LSD $p < 0.05$). Units for parameters: eCEC = cmol(+)/kg, minerals = mg/kg, $EC_{1.5}$ = mS/m, organic C and N = %. pH values from $CaCl_2$ solution. Community type 5 was omitted from univariate analyses.

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
$EC_{1:5}$**	3.6 ± 0.3 ^{a}	16.7 ± 11.6 ^{ab}	5.1 ± 1.0 ^{a}	12.5 ± 2.0 ^{b}	9.5 ± 5.5	4.1 ± 0.9 ^{a}
pH***	4.73 ± 0.1 ^{a}	4.76 ± 0.2 ^{a}	5.04 ± 0.2 ^{a}	6.56 ± 0.3 ^{b}	6.75 ± 0.8	5.56 ± 0.3 ^{ab}
OrgC**	1.084 ± 0.094 ^{ab}	2.241 ± 0.174 ^{b}	1.001 ± 0.129 ^{a}	1.329 ± 0.209 ^{ab}	1.02 ± 0.05	0.762 ± 0.079 ^{a}
N***	0.070 ± 0.005 ^{a}	0.130 ± 0.01 ^{b}	0.074 ± 0.006 ^{a}	0.098 ± 0.013 ^{ab}	0.083 ± 0.01	0.058 ± 0.006 ^{a}
B **	0.40 ± 0.07 ^{a}	0.47 ± 0.11 ^{a}	0.48 ± 0.06 ^{a}	1.32 ± 0.24 ^{b}	1.15 ± 0.25	0.53 ± 0.1 ^{a}
Ca***	364.3 ± 54.9 ^{a}	560.0 ± 61.0 ^{ab}	688.6 ± 219.0 ^{ab}	2322.7 ± 537.9 ^{b}	2945 ± 2055	804 ± 139.4 ^{b}
Co***	0.316 ± 0.095 ^{a}	0.303 ± 0.059 ^{a}	1.397 ± 0.187 ^{b}	2.11 ± 0.255 ^{b}	3.075 ± 0.025	1.869 ± 0.275 ^{b}
Cu***	0.90 ± 0.12 ^{a}	1.04 ± 0.08 ^{ab}	1.84 ± 0.18 ^{ab}	3.58 ± 0.3 ^{c}	3.05 ± 0.85	2.14 ± 0.27 ^{bc}
Fe***	51.4 ± 3.2 ^{ab}	74.6 ± 5.5 ^{b}	45.6 ± 2.4 ^{a}	47.0 ± 2.9 ^{a}	44.5 ± 0.5	39.6 ± 2.5 ^{a}
K **	104.0 ± 8.2 ^{a}	123.0 ± 9.1 ^{ab}	155.7 ± 10.7 ^{ab}	257.3 ± 47.9 ^{b}	390.0 ± 150.0	158.7 ± 16.9 ^{ab}
Mg***	54.7 ± 8.5 ^{a}	108.9 ± 29.3 ^{ab}	99.6 ± 14.6 ^{ab}	326.4 ± 31.0 ^{c}	670.0 ± 290.0	146.6 ± 26.8 ^{bc}
Mn***	49.6 ± 6.6 ^{ab}	33.3 ± 3.8 ^{a}	74.4 ± 7.2 ^{bc}	102.8 ± 12.6 ^{c}	118.5 ± 41.5	97.6 ± 13.7 ^{bc}
Na***	2.6 ± 0.7 ^{a}	43.9 ± 37.7 ^{ab}	5.4 ± 1.3 ^{a}	20.6 ± 3.0 ^{b}	25.5 ± 6.5	4.2 ± 0.7 ^{a}
Ni**	0.5 ± 0.1 ^{a}	0.8 ± 0.1 ^{ab}	1.2 ± 0.2 ^{ab}	2.0 ± 0.4 ^{b}	3.8 ± 1.9	1.4 ± 0.2 ^{b}
P***	3.0 ± 0.2 ^{a}	7.3 ± 0.9 ^{b}	6.0 ± 0.7 ^{b}	8.9 ± 1.7 ^{b}	10.0 ± 1.0	5.8 ± 0.6 ^{b}
S**	15.6 ± 1.4 ^{b}	45.6 ± 32.4 ^{b}	10.3 ± 1.0 ^{ab}	11.6 ± 2.9 ^{ab}	6.5 ± 2.5	6.2 ± 0.8 ^{a}
Zn **	0.77 ± 0.05 ^{a}	1.63 ± 0.19 ^{b}	1.18 ± 0.12 ^{ab}	1.53 ± 0.15 ^{b}	1.45 ± 0.05	1.17 ± 0.15 ^{ab}
eCEC ***	2.546 ± 0.357 ^{a}	4.196 ± 0.604 ^{ab}	4.678 ± 1.204 ^{a}	15.024 ± 2.944 ^{b}	21.316 ± 13.052	5.643 ± 0.912 ^{ab}
No. quadrats	7	6	14	11	2	10

fragments. Located at the lowest points in the landform, where the gradient was low, surface rocks were small and soils were deep (Table 3). Soils were weakly acidic, with relatively low values for both soil organic C and S, and moderate or high values for many soil trace elements (Table 4).

Structural description: Predominately open woodlands co-dominated by varying combinations of *A. dielsiana*, *Eucalyptus longissima*, *Eucalyptus griffithsii*, *Callitris columellaris* and *C. pauper*. Less frequently, quadrats within this community were described as tall shrublands of *Acacia* (including *A. ramulosa* var. *ramulosa* and *A. burkittii*). Dominant lower shrub stratum taxa were *Olearia pimelioides*, *Senna artemisioides* subsp. *filifolia*, *O. muelleri*, *P. obovatus* and species of *Maireana* and *Enchylaena*. Many of these common taxa were characteristic of the community (Table 2), as were *Eremophila granitica*, *Cryptandra connata* and *Austrostipa elegantissima* (Table 2).

Species groups: There were few taxa from both species groups A and G, and notable, albeit limited, representation from species groups B, C and F. Most taxa in this community occurred in species groups H and I, where taxa from the latter group were highly constant.

Average perennial species richness: relatively speciose at 24.4 ± 1.4 SE taxa per quadrat.

Environmental Correlates

The soils of the northern Yerilgee Hills were typically red-brown sandy clay loams and sandy loams. On average, these soils were acidic (pH 5.45 ± 0.14), shallow (5–50 cm depth), with over 50% cover of surface rock, mostly bare and lacking litter and plant cover (80 ± 1.1%; Tables 2 and 3). The altitude of quadrats ranged from 420 m to 509 m ASL.

Three elements (Al, Cd and Mo) were below the limits of detection in the soil chemical analyses. The remaining soil chemical and physical parameters were found to be generally moderately inter-correlated, with some strong (>0.7) or very strong correlations (>0.9) among soil variables (Table 5). A set of trace minerals was moderately to highly positively inter-correlated (B, Mg, Ca, Mn, Co, K and Cu), and moderately to strongly correlated with eCEC. Two variables associated with salinity, Na and $EC_{1:5}$, were strongly positively correlated. Organic C and N were very strongly positively correlated, and these were moderately correlated with Fe. Some soil variables (particularly Mg and Ca) were very strongly correlated with eCEC, and autocorrelation was expected as eCEC was partially calculated from these element concentrations.

Site physical variables were mostly moderately correlated, and only a small set of these was strongly positively inter-correlated (slope, runoff, topographic position, outcrop cover, maximum rock size; Table 5). These parameters were negatively correlated with soil depth and some were moderately positively correlated with soil N, organic C and Fe, and negatively correlated with Mn concentrations. Autocorrelation among closely related topographic variables (such as slope and runoff) was expected.

Univariate analyses

There were significant differences among the community types analysed for the majority of environmental

Table 5

Matrix of Spearman rank correlation coefficients for environmental variables collated from 51 quadrats established on northern Yerilgee hills. Only correlations significant at p < 0.01 are shown. Parameter codes are as follows: topographical position (Tp), litter ground cover (%litter), bare ground cover (%bare), maximum surface rock fragment size (MxR), and surface rock cover (%RF), exposed rock cover (outcrop). Full details of other environmental parameter codes are given in the methods section.

	EC	pH	OrgC	N	B	Ca	Co	Cu	Fe	K	Mg	Mn	Na	Ni	P	S	Zn	eCEC	Slope	Tp	%RF	MxR	Outcrop	Runoff	Soil	%litter	%bare	Lat	Long
Soil Chemical Parameters																													
EC																													
pH	0.579																												
OrgC	0.418	.																											
N	0.461	.	0.921																										
B	0.614	0.732	.	.																									
Ca	0.675	0.877	.	.	0.727																								
Co	.	0.624	-0.421	.	0.445	0.606																							
Cu	.	0.639	.	.	0.656	0.714	0.780																						
Fe	.	.	0.525	0.508	.	.	.	.																					
K	.	0.407	.	.	0.515	0.576	0.650	0.756	.																				
Mg	0.573	0.788	.	.	0.733	0.910	0.655	0.725	.	0.600																			
Mn	.	0.544	.	.	0.479	0.482	0.823	0.764	-0.362	0.554	0.497																		
Na	0.720	0.500	0.376	0.435	0.746	0.645	.	0.483	.	0.398	0.730	.																	
Ni	.	0.473	.	.	0.389	0.664	0.778	0.639	.	0.678	0.691	0.560	0.362																
P	0.375	0.439	.	0.456	0.421	0.590	0.431	0.547	.	0.635	0.603	0.378	0.441	0.489															
S	.	-0.416	0.590	0.503	.	.	-0.615	.	.	.	-0.406	-0.380	.	.	.														
Zn	0.474	.	0.434	0.500	0.387	0.425	.	0.468	.	0.465	.	.	0.525	.	0.637	.													
eCEC	0.648	0.853	.	.	0.744	0.988	0.626	0.735	.	0.616	0.953	0.490	0.681	0.684	0.624	.	0.419												
Physical Parameters																													
Slope	.	-0.412	0.430	0.379	.	.	-0.459	.	0.497	.	.	-0.458	.	.	.	.	.	.											
Tp	.	-0.398	.	.	.	.	-0.488	-0.480	0.656	-0.437	.	-0.552	.	.	.	.	.	.	0.537										
%RF	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.									
MxR	.	.	0.487	0.539	.	.	.	.	0.562	.	.	-0.408	.	.	.	.	.	.	0.658	0.649	.								
Outcrop	.	.	0.547	0.575	.	.	-0.368	.	0.576	.	.	-0.492	.	.	.	.	.	.	0.550	0.700	.	0.821							
Runoff	.	-0.387	0.386	0.395	.	.	-0.393	.	0.482	.	.	-0.435	.	.	.	.	.	.	0.763	0.740	.	0.783	0.677						
Soil	.	.	-0.460	-0.522	.	.	.	.	-0.492	.	.	0.436	.	.	.	.	.	.	-0.573	-0.562	.	-0.827	-0.817	-0.679					
%litter	.	.	.	.	.	.	-0.369	.	.	.	-0.406	.	.	.	.	0.499	.	.	.	.	.	.	.	.	.				
%bare	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-0.548			
Lat	.	.	0.450	0.363	.	.	.	.	.	.	.	.	.	.	.	0.419	.	.	.	.	.	.	.	.	.	.	.		
Long	.	.	0.458	.	.	.	.	.	.	.	.	.	.	.	.	0.488	.	.	.	.	.	.	.	.	.	0.377	.	0.896	
Altitude	.	-0.459	0.518	0.419	.	.	-0.547	.	.	.	.	.	.	.	.	0.594	.	.	0.394	0.394	.	.	.	0.472	.	.	.	0.627	0.557

parameters (Tables 2 and 3). Community type 2 occupied sites that were significantly steeper and with a greater cover of exposed bedrock than community types 1, 4 and 6, and had significantly larger maximum rock sizes than community types 1 and 6 (Table 3). Soils for community type 2 were significantly shallower than for community types 1, 3 and 6. Community type 6 occupied significantly lower topographic positions than community types 1, 2 and 3, and had low values for runoff, slope and outcropping bedrock cover, all of which were significantly lower than for community types 2 and 3 (Table 3). Although differences in altitude and surface rock cover were found between the communities, post-hoc tests did not find significant pair-wise differences (Table 3).

Community type 4 had significantly higher $EC_{1:5}$ and Na values than community types 1, 3 and 6, which indicated relatively higher values for soil salinity. Trace element concentrations and eCEC values were also relatively high for community type 4. Concentrations of Cu and Mg were significantly higher than in community types 1, 2 and 3, Mn concentrations were significantly higher than in community types 1 and 2, and eCEC values were significantly higher than in community types 1 and 3 (Table 4). Both community types 4 and 6 had neutral or weakly acidic soils (pH > 5), and soil pH was significantly higher in community type 4 than in community types 1, 2 and 3. Community type 4 also had the significantly lowest levels of B among community types (Table 4).

Values for soil trace elements tended to be lowest in the community types 1 and 2. Co concentrations were significantly lower in these community types than those found in community types 3, 4 and 6 (Table 4). Community type 1 also had significantly lower Ca, Cu, Mg and Ni concentrations than community types 4 and 6, and significantly lower soil K concentrations than community type 4. Community type 2 had significantly lower Mn concentrations than community types 3, 4 and 6. Zn concentrations were notably low in community type 1, and were significantly lower than in community types 2 and 4 (Table 4).

The highest average organic C, N and Fe concentrations were found in the soils of community type 2 (Table 4). Soil organic C in community type 2 was significantly higher than in community types 3 and 6, and soil N concentrations were significantly higher than community types 1, 3 and 6. Fe concentrations in community type 2 were significantly higher than in community types 3, 4 and 6. Both community types 1 and 2 had relatively high concentrations of S, which were significantly higher than for community type 6, but not statistically different to community types 3 and 4. Community type 1 had significantly less P than all other community types (Table 4).

SSH MDS ordination

Semi-strong hybrid multidimensional scaling of the quadrat floristic data provided a three-dimensional solution to the floristic relationships between community types, of which two axes have been presented (Fig. 3a). The stress level (0.16) indicated moderate difficulty in reducing the data to three dimensions (Seber 1984). There was some segregation of sites according to community type, albeit with some overlap among some groups. Community type 4 formed a relatively close grouping of sites, while community type 1 was both the most heterogeneous group and most outlying community type. There was a notable separation of the extreme upland (community types 1 and 2) and lowland communities (community types 5 and 6), and communities were generally arranged in topographic sequence across the ordination.

There were significant correlations between a subset of the environmental variables and the site ordination (Fig. 3b). A number of other variables, such as Fe, organic C and N, were not significantly correlated with the ordination. Quadrats from community types 1 and 2 roughly coincided with high values along the fitted vectors for topographic position and runoff, with community type 2 being more closely associated with high scores of surface rock size. Community types 4, 5 and 6 correlated with the lowest extremes of the general topographic gradient (Fig. 3b).

There was an obvious gradient of soil microelement concentrations (B, Cu, Ca, Mg, Ni, Mn, Co, K), eCEC and soil pH (Fig. 3b). This gradient was roughly co-linear with the vector for topographical position, but was opposite in magnitude. The extreme high end of the gradient correlated with quadrats from community types 4 and 5, while community type 6 coincided with the gradient midpoint and both community types 2 and 1 aligned with the lower end (Fig. 3a and 3b). A vector for P was divergent to these other major gradients, and community types 1 and 4 were aligned at the lower and upper extremes of this gradient, respectively (Fig. 3a and 3b).

DISCUSSION

Flora and Vegetation

This is the first systematic survey of the flora on the northern Yerilgee Hills. Species counts from other quadrat-based surveys in the Mount Manning Region range from 131 to 303 native taxa, and from 96 to 148 perennial taxa within plots (Table 6). These broad comparisons have limitations, but numbers of shared perennial taxa between ranges decreases with distance, particularly in a north–south direction (Table 6). Decreasing floristic similarity with increasing spatial separation of ranges has been observed within the wider Mount Manning Region (Mattiske 2001b), and the wider northern Yilgarn (N Gibson[3], pers. comm.). Furthermore, the ranges that are less than c. 50 km apart may only share 30–55% of perennial taxa (Table 6; Mattiske 2001b). This spatial

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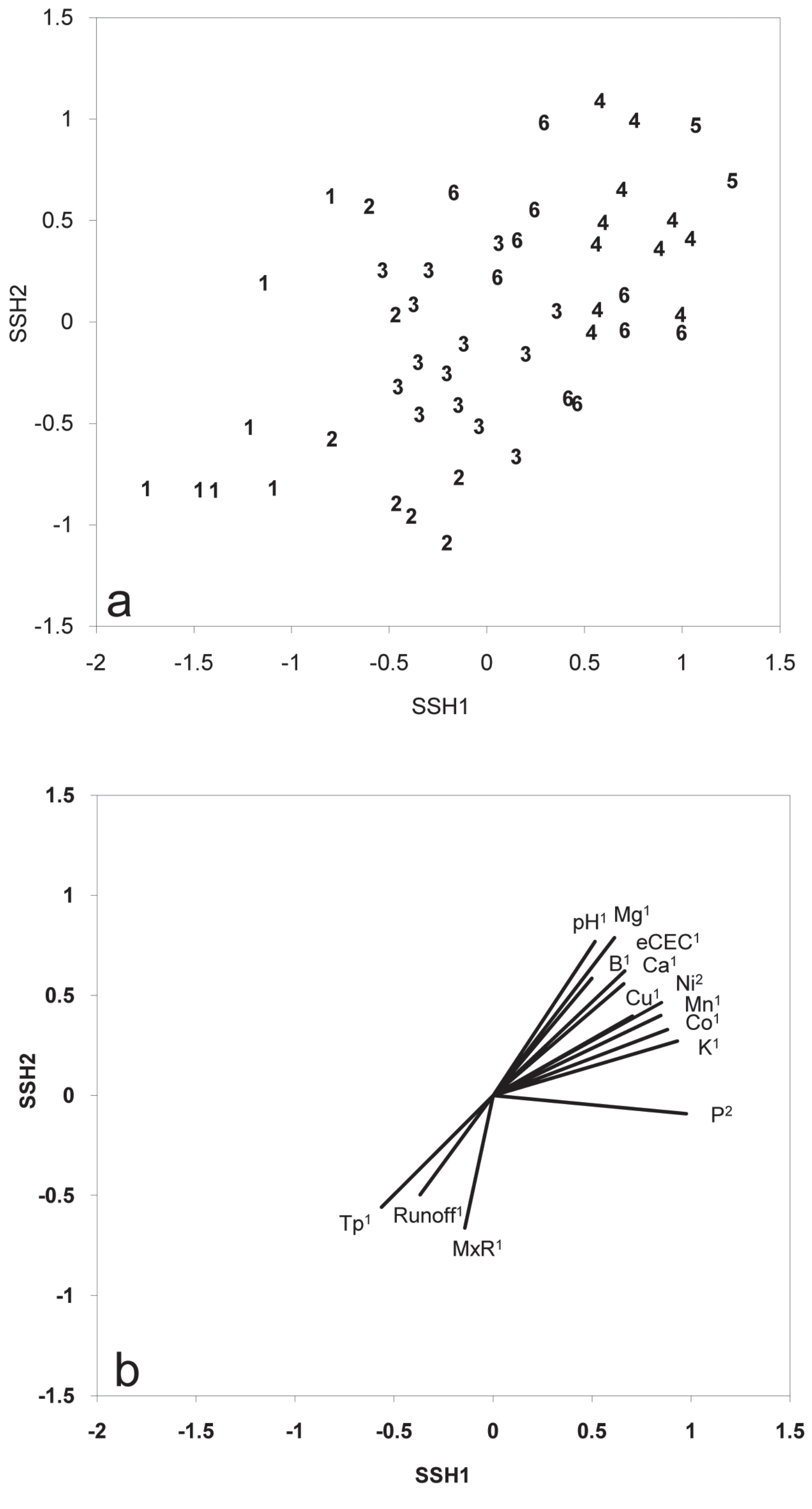

Figure 3. 3D SSH MDS site ordination for the northern Yerilgee Hills survey area, based on dissimilarities in floristic composition from Bray–Curtis dissimilarity matrix of presence/absence data of 114 perennial taxa from 51 quadrats. Sites are numbered by their respective floristic community types, and two axes (a: SSH axes 1 vs 2) of the three dimensional ordination are presented. Vectors of best fit linear correlations of site physical parameters and site ordination coordinates are illustrated in the adjacent panel (b). Vectors are illustrated in a positive direction only, and indicate strength and direction of correlation. Only significant vectors ($p < 0.05$) are displayed, as determined from Monte Carlo permutation tests. Level of significance is indicated by a superscript numeral: 1 = $p < 0.001$, 2 = $p < 0.01$; 3 = $p < 0.05$.

Table 6

Comparison of flora and shared perennial taxa on ranges adjacent to the northern Yerilgee Hills. Counts of perennial taxa or the combined total number of taxa between pairs of ranges are given in parentheses.

Range	No. native taxa (perennial)	No. taxa plots (perennial)/ no. plots	Distance from Yerilgee hills (km)	Shared perennial taxa (combined taxa)	No. taxa conservation significance	Reference
Northern Yerilgee Hills	182 (166)	156 (142) / 51	–	–	4 priority	This study
Mt Manning Range	234 (172)	197 (142) / 54	33 km SW	34% (249)	5 priority	Gibson (2004, 2007)
Johnston Range	176 (148)	157 (131) / 50	53 km E	54% (200)	1 DRF, 4 priority	Markey & Dillon (2011)
Die Hardy Range	142 (–)	–	55 km WSW	–	7 priority taxa	Gibson (2004); Mattiske (2001a)
Helena & Aurora Range	303 (209)	234 (117) / 55	68 km SSW	29% (291)	2 DRF and 12 priority taxa	Gibson et al. (1997, 2007)
Windarling Range	131 (–)	–	110 km WSW	–	2 DRF, 2 priority	Gibson (2007); Mattiske (2001a)
Hunt Range, Yendilberin and Watt hills	273 (190)	236 (148) / 53	46–88 km S	30% (269)	7 priority	Gibson & Lyons (2001a)
Highclere Hills	217 (135)	218 (96) / 45	138 km SW	23 % (240)	6 priority	Gibson & Lyons (2001b)

turnover of species could, in part, reflect increasing aridity in a north-easterly direction and a latitudinal turnover of climate and soils (Beard 1976, 1990; Keighery et al. 1995). High β-diversity among these isolated ranges could also be attributed to a number of factors, including range-specific differences in geomorphology, historical fluctuations in palaeoclimate and stochastic processes of colonisations and extinctions within and among ranges (Gibson et al. 2007; Hopper & Gioia 2004; Harrison 1997; Jacobi et al. 2007).

The northern Yerilgee Hills are on the boundary between the Coolgardie and Murchison IBRA bioregions. Both the representation of families and genera, and the vegetation communities in the survey area are typical for the Coolgardie IBRA and floras from other ironstone surveys in the Mount Manning Region (Beard 1976, 1990; Environmental Protection Authority 2007; Keighery et al. 1995; Newbey & Hnatiuk 1985; Gibson et al. 1997, Gibson & Lyons 2001a; Gibson 2004). Woodland communities on the lower slopes, valleys and plains of the northern Yerilgee Hills were still dominated by *Eucalyptus* spp., *Casuarina pauper, Callitris columellaris* and *Allocasuarina dielsiana*, while *Acacia aneura* shrublands were restricted to the hillslopes and uplands. Lowland mulga shrublands, which are indicative of the Murchison region (Beard 1976, 1990), were not observed on the pediments and peneplains of the survey area. However, the northern Yerilgee Hills have approximately half the number species of *Eucalyptus* and Myrtaceae reported for more southern ranges in the Mount Manning Region (Gibson & Lyons 2001a; Gibson et al. 1997), which reflects a transition to the Murchison bioregion.

Some of the floristic communities of the northern Yerilgee Hills have broad structural and floristic similarities to elements of the Die Hardy System of Beard (1972, 1976), formations described by Keighery et al. (1995), and communities described for individual ranges in the Mount Manning Region (Gibson 2004; Gibson et al. 1997; Gibson & Lyons 2001a; Mattiske 2001b). This includes broadly comparable lowland *Eucalyptus salmonophloia – Eucalyptus salubris* woodlands and/or *Acacia* shrublands and *Eucalyptus/Callitris/Allocasuarina* woodlands (Gibson & Lyons 2001a, Gibson 2004; Keighery et al. 1995; Mattiske 2001b, Newbey & Hnatiuk 1985). Broadly similar upland mosaic shrublands – mallee shrublands and rocky crest shrubland communities have also been described for the wider Mount Manning region (Gibson & Lyons 2001a; Gibson et al. 1997; Gibson 2004; Keighery et al 1995; Markey & Dillon 2011; Mattiske 2001b). However, many dominant or common taxa of these southern crest and lateritic upland communities are absent or restricted to southern sites on the northern Yerilgee Hills, including *Acacia cockertoniana*, *Grevillea georgeana*, *Hibbertia exasperata, Melaleuca nematophylla, Westringia cephalantha, Triodia* cf. *scariosa*, *Neurachne annularis, Grevillea arcuata* and *Hibbertia exasperata* (Gibson 2004; Gibson & Lyons 2001a; Keighery et al. 1995; MacFarlane 2007; Maslin 2007; Mattiske 2001a; Newbey & Hnatiuk 1985). There was even some suggestion of a latitudinal turnover within community type 2 over the northern Yerilgee Hills. Further survey of the southern Yerilgee Hills may find a southern variant of this community type.

Banksia arborea shrublands, in particular, are characteristic of the Die Hardy and Bungalbin Systems of Beard (1972, 1976), and are described for the Windarling, Jackson, Die Hardy Range and Helena and Aurora Ranges (Beard 1972, 1976; Keighery et al. 1995; Mattiske 2001b; Newbey & Hnatiuk 1985). Keighery et al. (1995) found *Banksia arborea* to be restricted to small patches on the Mt Manning Range, which Gibson (2004) could not relocate in a later survey. On the Yerilgee Hills, stands of *Banksia arborea* were only found on patches of narrow, rocky crests south of the Evanston–Menzies Road. Both these and small stands on the Johnston Range (Markey & Dillon 2011) represent the known northern limit of this species, as *Banksia arborea* shrublands are absent from the ironstones of Mt Elvire (25 km north-west of Johnson Soak; Keighery et al. 1995). Instead, *Acacia aneura* is a co-dominant with other species of *Acacia*) on the slopes on the northern Yerilgee hills, and on BIF ranges north of this area (Keighery et al. 1995).

Previous meta-analyses of quadrat-based floristic data from ranges in the Mount Manning Region have found range-specific differences in floristic composition (Mattiske 2001b). Groupings of lowland communities (supergroups of *Eucalyptus* and *Acacia* woodlands) are more widespread among ranges than the upland shrubland communities, which have considerably more restricted distributions among and within ranges (Mattiske 2001b). Changes in plant assemblages among ranges mirror trends in species turnover in the wider Coolgardie IBRA bioregion. A further meta-analysis of a larger dataset from the Mount Manning Ranges is required to determine the distinctiveness of floristic communities on the northern Yerilgee Hills. However, observations made in this study suggest that the northern Yerilgee Hills differ in floristic composition from adjacent ranges, and this may be most evident in the upland communities.

Geographical variation in floristic communities is also likely to be due to range-specific variation in soils and geomorphology, such as the relative extent and elevation of rocky crests and lateritic uplands (Gibson & Lyons 2001a). Complex BIF landforms in the Mount Manning Region support a high number of both rare and endemic taxa and unique crest communities (Environmental Protection Authority 2007). The northern Yerilgee hills are a relatively subdued landform that lack extensive massive outcroppings of BIF. The associated BIF crest communities do not appear to be as diverse as those described for the Die Hardy and Windarling Ranges by Mattiske (2001b). The northern Yerilgee Hills do support a highly distinctive community on the extensive laterities at the top of the range. This was more floristically distinct from adjacent communities than has been found within other ranges (Gibson 2004; Gibson & Lyons 2001a, 2001b).

Two regional endemics (*Banksia arborea*, *Eremophila* sp. Mt Jackson; GJ Keighery 4372) and one near endemic (*Grevillea erectiloba*) were reported for the northern Yerilgee Hills. Both *Eremophila* sp. Mt Jackson (GJ Keighery 4372) and *Grevillea erectiloba* are listed as regional or short-range endemics to the Mount Manning Region (Environmental Protection Authority 2007; Gibson 2004). Other taxa found on the Yerilgee Hills (*Banksia arborea*, *Spartothamnella* sp. Helena & Aurora Range; PG Armstrong 155–109) are recognised as having a distribution restricted to BIF (Gibson et al. 2007). Although there are fewer endemic species than reported for the other, more southern ranges in the Mount Manning Region (Environmental Protection Agency 2007; Mattiske 2001a; Gibson & Lyons 2001a; Gibson et al. 1997, 2007), other ranges can lack endemics altogether (Gibson & Lyons 2001b). Four priority taxa were located on the northern Yerilgee Hills, which is relatively low compared with some ranges in the region such as the Windarling and Die Hardy ranges, but comparable to others like the Mt Manning and Johnston Ranges (Table 6). While the number of rare or priority taxa appears to be correlated with the total number of species on BIF ranges, there is no simple association between the number of endemic taxa and overall species diversity (Gibson et al. 2007).

Many rare and endemic taxa of the Mount Manning Region tend to be BIF specialists associated with complex, elevated landforms that support a diversity of habitats, including extensive outcrops of massive BIF (Environmental Protection Authority 2007; Gibson et al. 2007; Mattiske 2001a). The northern Yerilgee Hills may not be of substantial elevation nor have the extensive BIF outcroppings to support BIF specialists like *Tetratheca paynterae* subsp. *paynterae* (Butcher et al. 2007), but they do harbour other notable BIF taxa, some of which are at their distributional limits.

Environmental Correlates

An association between floristic assemblages and topographic and/or edaphic factors have been documented for other arid ironstone ranges in the Yilgarn (for example, see Gibson 2004; Gibson & Lyons 2001a; Markey & Dillon 2008a, 2010a; Meissner & Caruso 2010a), as well as in the Pilbara (van Etten & Fox 2004), Queensland (Butler & Fensham 2008) and for Brazilian ironstones (Jacobi et al. 2007; Vincent & Meguro 2008). Distinct floristic associations were identified within the northern Yerilgee Hills that were partitioned by topographic position and substrate and correlated with environmental variables. Community differences in site physical and soil chemical parameters were most pronounced between topographic extremes, but also reflected geological substrate.

Soil attributes were typical for lithosols in the wider region (Hennig 1998), and these metalliferous, acidic, stony soils also reflected influence of parent bedrock (Gray & Murphy 2002; Vincent & Meguro 2008). Trends in soil composition and development were generally similar to those reported for other BIF ranges (Gibson 2004; Gibson et al. 1997; Gibson & Lyons 1998, 2001a; Markey & Dillon 2008a, 2008b, 2010).

Soils from the upland community types 1 and 2 were found to be strongly acidic (pH <4.8; Slattery et al. 1999), relatively infertile and lacking trace elements and heavy metals. Prolonged weathering has most likely leached the more mobile elements such as K, Ca and Mg (Britt et al. 2001; Cole 1973). The BIF crest community (community type 2) had significantly higher concentrations of Fe, presumably due to the in situ formation of soils and Fe enrichment from iron-rich bedrock (Britt et al. 2001; Cornelius et al. 2007; Foulds 1993). Relatively elevated concentrations of S in community types 1 and 2 soils could also be a results of in situ enrichment from sulfide-rich BIF bedrock, and these sulfides can lower soil pH (Britt et al. 2001; Cornelius et al. 2007; Foulds 1993). This contrasts with the lowland communities (particularly community types 5 and 6), where deep deposits of colluvium were relatively enriched with moderate to high levels of soil trace elements, heavy metals (Co, Cu and Ni), relatively lacking in S and weakly acidic to neutral (Slattery et al. 1999). Enrichment would come from leachates and colluvium (Ben-Shahar 1990; Britt et al. 2001; Cole 1973; Cornelius et al. 2007; Gray & Humphreys 2004; Gray & Murphy 2002), which contains cations (such as Ca, Mg) that can lower soil acidity and buffer soil pH (Gray & Murphy 2002).

Community types 3 and 4 were associated with moderately inclined hillslopes of mixed mafic and BIF geologies, although the latter community tended to occur on lower slopes, valleys and pediments, and with calcrete deposits. These communities were mostly separated on edaphic factors. The greater influence of mafic substrates probably accounted for relatively higher concentrations of soil microelements in community type 4, since soils from mafic substrates have comparatively higher levels of trace elements like P, Mn, K, Ca, Zn Cu and Mg (Britt et al. 2001; Cole 1973; Gray & Humphreys 2004; Gray & Murphy 2002, Jacobi et al. 2007). Calcrete deposits are often derived from mafic and ultramafic bedrock (Anand et al. 1997), and were observed to be common on the lower slopes, valleys and pediments on the northern Yerilgee Hills and in conjunction with community types 4, 5 and 6. Carbonates and mobile cations from mafics and calcrete can produce buffered, weakly acidic to neutral soils (Gray & Humphreys 2004; Gray & Murphy 2002). In addition to leachates, calcrete deposits probably also contributed to elevated soil trace element concentrations (particularly Ca) and pH values in these communities (Anand et al. 1997, Britt et al. 2001; Gray & Humphreys 2004; Gray & Murphy 2002).

The soils of community types 4 and 5 not only stand out with high concentrations of trace elements, but also for relatively high values for salinity. Community type 4 had a comparatively high Na concentration and $EC_{1:5}$, which suggested a deposition of salts derived from bedrock (Chartres 1993), although the salinity of these silty clay loam soils could be considered very low to low (Shaw 1999). The chenopod and halophyte-rich understorey of community type 5 also indicated greater relative salinity, although under-sampling of this community meant that Na, EC and Ca values were quite variable. Salinity values were also extremely variable for community type 2, and this community generally was not dominated by halophytes and chenopods. The weakly acidic to neutral soil pH values of this latter community was on a par with similar woodland communities on the Mt Manning range (Gibson 2004), but other chenopod-rich, lowland woodlands around greenstones have been reported to have more basic soils (Gibson & Lyons 2001a, 2001b)

Soils for the crest community (community type 2) were found to be significantly enriched with N and organic C, and this has been found in soils of other crest communities (Markey & Dillon 2009, 2011). Accumulations of leaf litter in crevices on rocky crests are a main source of these macronutrients in these small pockets of skeletal soil (Foulds 1993). The trend for some upland communities to have N- and C-enriched soils contradicts the generalisation that soil organic carbon is generally elevated in down-slope sites due to litter deposition and greater soil moisture (Baldock & Skjemstad 1999), and this general finding has been evident in other studies on greenstone ranges (Chalwell 2003; Gibson & Lyons 2001a, 2001b). Lower levels of organic C and N in the other communities (particularly community types 4, 5 and 6) could reflect a low overall ratio of leaf litter to soil on these deeper soils, while sampling on rocky crests was restricted to small pockets of highly enriched loamy soils.

We infer that there is a soil moisture gradient over the catena on the Yerilgee Hills, where skeletal or shallow soils, steep slopes and exposed bedrock on upland sites have a poor capacity to retain water, while lowland sites receive surface runoff and overlie groundwater sources (Cole 1973; Ben-Shahar 1990; Jacobi et al. 2007; Johnson 1998). This water deficit in upland areas can be compounded by the microclimate (high irradiance, extreme daily thermal variations and high evaporation; Jacobi et al. 2007). Ecophysiological studies have found that shallow-rooted shrubs on the rocky uplands of greenstone ranges are relatively more tolerant of xeric conditions and drought stress, while deep-rooted eucalypts avoid drought and maintain high rates of evapotranspiration by tapping into groundwater and soil moisture sources (Chalwell 2003). This would explain the limited establishment of tall woodlands and predominance of shrubs and mallee shrublands on upland summit surfaces (community type 1). Community type 2 had another suite of rock-rooted shrubs and geophytes (species group F such as *Cheilanthes, Cymbopogon*) that utilise the water and soil availability in rock fissures. Even with this relatively greater drought tolerance, dead shrubs were observed in the Yerilgee upland shrublands, most likely because of chronic drought.

Conservation

The vegetation of the northern Yerilgee Hills area is relatively free of exotic species and appears to be in good condition. We attributed this to relatively low levels of grazing, since livestock were absent and there was little evidence of feral goats. However, rabbits were causing some damage to the ground stratum in lowland woodlands. The main impact on the communities has been from sandalwood harvesting, which continues as a minor industry in the region. This harvesting has impacted the central and northern parts of the survey area, and old campsites, tracks and clearings remain decades after their establishment.

To date, almost none of the survey area is reserved on conservation estate and remains as unallocated crown land, with a small portion of the south-west area occurring within the Mt Manning Nature Reserve. Apart from this, none of the survey area is within any of the reserves proposed for the Mount Manning Region (Environmental Protection Authority 2007). Exploration or mining tenements cover the northern Yerilgee Hills, and exploration and drilling activities had commenced by August 2007. Given that mining has been proposed for all ranges within the Mount Manning Region, efforts should be made to minimise impacts on areas identified as having high conservation significance. Should mining proceed on the northern Yerilgee Hills, planning should minimise impacts on the restricted upland communities and priority taxa.

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REFERENCES

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.

Angiosperm Phylogeny Group (2003) An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG II. *Botanical Journal of the Linnaean Society* **141**, 399–436.

Baldock JA, Skjemstad JO (1999) Soil organic carbon/soil organic matter. In *Soil Analysis: An Interpretation Manual* (eds KI Peverill, LA Sparrow, DJ Reuter), pp 159–170. CSIRO Publishing, Victoria.

Barker RM (2007) Two newly described species and a draft key to *Sida s. lat.* from Western Australia. *Nuytsia* **17**, 13–30.

Beard JS (1972) *Vegetation Survey of Western Australia: The Vegetation of the Jackson Area, Western Australia. Map and Explanatory Memoir. 1:250,000 Series.* Vegmap Publications, Sydney.

Beard JS (1976) *Murchison, 1:1,000,000 Vegetation Series: The Vegetation of the Murchison Region.* 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, Lyneham, ACT.

Belbin L (1991) Semi-strong hybrid scaling, a new ordination algorithmn. *Journal of Vegetation Science* **2**, 491–496.

Belbin L, Faith D, Milligan GW (1992) A comparison of two approaches to beta-flexible clustering. *Multivariate Behavioural Research* **27**, 417–433.

Ben-Shahar R (1990) Soil nutrients distribution and moisture dynamics on upper catena in a semi-arid nature reserve. *Vegetatio* **89**, 69–77.

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 (1908–) *Climate Statistics for Australian Locations*. Available at http://www.bom.gov.au/climate/averages/. [Accessed May 2008]

Butcher R, Byrne M, Crayn D (2007) Evidence for convergent evolution among phylogenetically distant rare species of *Tetratheca* (Eleocarpaceae, formerly Tremandraceae) from Western Australia. *Australian Systematic Botany* **20**, 139–160.

Butler DW, Fensham RJ (2008) Lose the plot: cost-effective survey of the Peak Range, central Queensland. *Cunninghamia* **10,** 522–538.

Cassidy KF, Champion DC, Krapez B, Barley ME, Brown SJA, Blewett RS, Groenewald PB & Tyler IM (2006) A revised geological framework for the Yilgarn Craton, Western Australia. *Western Australian Geological Survey, Record 2006/8.* Perth, Western Australia.

Chalwell ST (2003) 'Plant communities of greenstone hills of the Eastern Goldfields of Western Australia as analogues for the rehabilitation of rocky waste dumps'. Unpublished PhD thesis, Murdoch University, Western Australia.

Champion DC, Smithies RH (2001) Archaean granites of the Yilgarn and Pilbara cratons, Western Australia. In *4th International Archaean Symposium 2002, extended abstracts*. (eds KF Casidy, JM Dunphy, MJ

Van Kranendonk), pp 134–136. Geoscience Australia, Records 2001/37, Canberra.

Champion DC, Smithies RH (2003) Archaean Granites. In *Magmas to Mineralisation: The Ishihara Symposium on Granites and Related Metallogenesis* (eds P Belvin, M Jones, B Chappell), pp 13–17. Geoscience Australia, Record 2003/14, Canberra.

Chartres CJ (1993) Sodic soils: an introduction to their formation and distribution in Australia. *Australian Journal of Soil Research* **31**, 751–760.

Chen SF, Wyche S (2003) *Geology of the Bungalbin 1:100,000 Sheet. 1:100,000 Geological Series Explanatory Notes.* Geological Survey Western Australia, Perth.

Clark KR, Gorley RN (2006) *Primer v6: User Manual/ Tutorial.* PRIMER–E Ltd, Plymouth.

Cole MM (1973) Geobotanical and biogeochemical investigations in the sclerophyllous woodland and shrub associations of the Eastern Goldfields area of Western Australia, with particular reference to the role of *Hybanthus floribundus* (Lindl.) F. Muell. As a nickel indicator and accumulator plant. *The Journal of Applied Ecology* **10**, 269–320.

Cornelius M, Robertson IDM, Cornelius AJ, Morris PA (2007) *Laterite Geochemical Database for the Western Yilgarn Craton, Western Australia.* Geological Survey of Western Australia, Record 2007/9, Perth.

Department of Conservation and Land Management (CALM) (1994) 'Goldfields Regional Management Plan 1994–2004'. Management Plan No. 27. Department of Conservation and Land Management, Western Australia, unpublished report.

Department of Environment and Conservation (2007) Banded ironstone formation ranges of the Midwest and Goldfields. In *Strategic Review of the Conservation and Resource Values of the Banded Iron Formation of the Yilgarn Craton.* Government of Western Australia, Perth.

Department of Environment and Water Resources (2007) IBRA Version 6.1. Available from www.environment.gov.au/parks.nrs/ibra/version 6-1/. Updated 6th February [accessed June 2008].

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

Environmental Protection Authority (2007) 'Advice on areas of the highest conservation value in the proposed extensions to Mount Manning Nature Reserve'. Unpublished report to the Minister for the Environment, Perth, Western Australia.

Faith DP, Norris RH (1989) Correlation of environmental variables and patterns of distribution and abundance of common and rare freshwater macroinvertebrates. *Biological Conservation* **50**, 77–98.

Faithful E (1994) Land use history. In *An Inventory and Condition Survey of the North-Eastern Goldfields, Western Australia.* Technical Bulletin No. 90 (eds AL Payne, AME Van Vreeswyk, HJR Pringle, KA Leighton, P Hennig), pp. 11–14. Department of Agriculture Western Australia, South Perth.

Foulds, W (1993) Nutrient concentrations of foliage and soil in south-western Australia. *New Phytologist* **125**, 529–546.

Gibson N (2004) 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, Lyons MN, Lepschi BJ (1997) Flora and vegetation of the Eastern Goldfields Ranges, Part 1: Helena and Aurora Range. *CALMScience* **2**, 231–246.

Gibson N, Lyons MN (1998) 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 M (2001a) 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 (2001b) 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, Coates DJ, Thiele KR (2007) Taxonomic research and the conservation status of flora in the Yilgarn Banded Iron Formation ranges. *Nuytsia* **17**, 1–12.

Gray JM, Humphreys GS (2004) Patterns of global soil distribution as revealed by two major soil databases. *Supersoil 2004. Proceedings of the 3rd Australian and New Zealand Soils Conference* (ed B Singh et al.), University of Sydney, 5–9 December 2004. The Regional Institute, Gosford, New South Wales. http:/ /www.regional.org.au/au/asssi/supersoil2004/s8/oral/ 1697_grayjg.htm) [accessed November 2011].

Gray JM, Murphy BW (2002) Parent material and soil distribution. *The Journal of the Australian Association of Natural Resource Management.* **5,** 2–12.

Greenfield JE (2001) *Geology of the Lake Giles 1:100,000 Sheet: Western Australian Geological Survey, 1:100,000 Geological Series Explanatory Notes.* Geological Survey of Western Australia, Perth.

Groenewald PB, Riganti A (2004) *East Yilgarn 1:100,000 Geological Information Series – An Explanatory Note.* Report 95, Western Australian Geological Survey, Perth.

Harrison S (1997) How natural habitat patchiness affects the distribution of diversity in Californian serpentine chaparral. *Ecology* **78,** 1898–1906.

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, KA Leighton, P Hennig), pp 95–118. Technical Bulletin No. 90, Agriculture Western Australia, South Perth.

Hopper SD, Gioia P (2004) The southwest Australian floristic region: evolution and conservation of a global hot spot of biodiversity. *Annual Review of Ecology, Evolution and Systematics* **35**, 623–650.

Jacobi CM, do Carmo FF, Vincent RC, Stehmann JR (2007) Plant communities on ironstone outcrops: a diverse and endangered Brazilian ecosystem. *Biodiversity and Conservation* **16,** 2185–2200.

Johnson SL (1998) Geology and hydrology. 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 39–48. Technical Bulletin No. 90, Agriculture Western Australia, South Perth.

Keighery, GJ, Milewski AV, Hall NJ (1995) Vegetation and flora. In *The Biological Survey of the Eastern Goldfields of Western Australia: Part 12. Barlee–Menzies Study Area* (eds GJ Keighery, NL McKenzie, NJ Hall). *Records of the Western Australian Museum* **49**, 183–207.

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. Australian Collaborative Land Evaluation Program, Canberra.

MacFarlane T (2007) A new species of *Neurachne* (Poaceae) from Western Australia. *Nuytsia* **17**, 215–222.

Markey AS, Dillon SJ (2008a) Flora and vegetation of the banded iron formations of the Yilgarn Craton: 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, 153–178.

Markey AS, Dillon SJ (2009) Flora and Vegetation of the banded iron formations of the Yilgarn Craton: Herbert Lukin Ridge (Wiluna). *Conservation Science Western Australia* **7,** 391–412.

Markey AS, Dillon SJ (2010a) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Gullewa. *Conservation Science Western Australia* 7, 531–556.

Markey AS, Dillon SJ (2011) Flora and vegetation of the banded iron formations of the Yilgarn Craton: the Johnston Range, Menzies. *Conservation Science Western Australia* **8**, 113–136.

Maslin BR (2007) *Acacia cockertoniana* (Leguminosae: Mimosoideae), a new species of Acacia from banded ironstone ranges of the south-west arid zone, Western Australia. *Nuytsia* **17**, 247–252.

Mattiske Consulting Pty Ltd (2001a) 'Review of the Flora on Portman Iron Ore Expansion Areas'. Unpublished report commission by Portman Iron Ore.

Mattiske Consulting Pty Ltd (2001b) 'Review of the Vegetation on Portman Iron Ore Expansion Areas'. Unpublished report commission by Portman Iron Ore.

Matheson RS, Miles KR (1947) *The Mining Groups of the Yilgarn Goldfield North of the Great Eastern Railway.* Western Australia Geological Survey, Bulletin 101, Perth.

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

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

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

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

Meissner RM, Bayliss B, Owen G (2010a) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Mount Forrest – Mount Richardson Range. *Conservation Science Western Australia* **7,** 377–389.

Meissner RM, Bayliss B, Owen G (2010b) Flora and vegetation of the banded iron formations of the Yilgarn Craton: Cashmere Downs Range. *Conservation Science Western Australia* **7,** 349–361.

Milewski AV, Hall NJ (1995) Physical Environment. In *The Biological Survey of the Eastern Goldfields of Western Australia. Part 12: Barlee–Menzies Study Area* (eds GJ Keighery, NL McKenzie, NJ Hall). *Records of the Western Australian Museum Supplement*, **49**, 174–182.

Mott JJ (1972) Germination studies on some annual species from an arid region of Western Australia. *Journal of Ecology* **60,** 293–304.

Mott JJ (1973) Temporal and spatial distribution of an annual flora in an arid region of Western Australia. *Tropical Grasslands* 7, 89–97.

Newbey KR (1985) Physical Environment. In *The Biological Survey of the Eastern Goldfields of Western Australia. Part 3: Jackson–Kalgoorlie Study Area* (ed J Dell). *Records of the Western Australian Museum Supplement* **23**, 5–10.

Newbey KR, Hnatiuk RJ (1985) Vegetation and flora. In *The Biological Survey of the Eastern Goldfields of Western Australia. Part 3: Jackson–Kalgoorlie Study Area* (ed J Dell). *Records of the Western Australian Museum* Supplement **23**, 11–38.

Packowska G. Chapman AR (2000) *The Western*

Australian Flora: A Descriptive Catalogue. Wildflower Society of Western Australia, Western Australian Herbarium, CALM and Botanic Gardens and Parks Authority, Perth.

Pedley L (2001) *Acacia aneura* and relatives. In *Flora of Australia 11B, Mimosaceae, Acacia part 1.* (eds AE Orchard and AJG Wilson), pp. 309–328. Australian Biological Resources Study, Canberra, and CSIRO Publishing, Melbourne.

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

Seber GAF (1984) *Multivariate Observations*. John Wiley and Sons, New York.

Shaw RJ (1999) Soil salinity – electrical conductivity and chloride. In *Soil Analysis: An Interpretation Manual* (eds KI Peverill, LA Sparrow, DJ Reuter), pp 129–145. CSIRO Publishing, Melbourne.

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

Smith MG (2010) 'Declared Rare and Priority Flora List for Western Australia, 16 September 2010'. Department of Environment and Conservation, Perth.

Sneath PHA Sokal RR (1973) *Numerical Taxonomy: The Principles and Practice of Numerical Classification*. Freeman, San Francisco.

Soil and Plant Council Inc. (1999) *Soil Analysis – Handbook of Reference Methods*. CRC Press, Boca Raton.

van Etten EJB, Fox JED (2004) Vegetation classification and ordination of the central Hamersley Ranges, Western Australia. *Journal of the Royal Society of Western Australia* **87,** 63–79.

Vincent RC, Meguro M (2008) Influence of soil properties on the abundance of plant species in ferruginous rocky soils vegetation, southeastern Brazil. *Revista Brasileira de Botânica*, **32**, 377–388.

Walker IW, Blight, DF (1983). *Barlee, Western Australia. Sheet SH/50-8.1:250,000 Geological Series Explanatory Notes.* Geological Survey of Western Australia, Perth.

Walton K Allen D (2004) Mehlich no. 3 soil test – the Western Australian experience. In *Supersoil 2004. Proceedings of the 3rd Australian and New Zealand Soils Conference* (ed. B Singh et al.), University of Sydney, 5–9 December 2004. The Regional Institute, Gosford, New South Wales http://www.regional.org.au/au/asssi/supersoil2004/s8/oral/1697_grayjg.htm) [accessed November 2011].

Western Australian Herbarium (1998–) *Florabase – The Western Australian Flora*. Department of Environment and Conservation, Available at http://florabase.dec.wa.gov.au/ [last accessed July 2007].

Zar J H (1984) *Biostatistical Analysis,* 2nd ed. Prentice-Hall International, New Jersey.

APPENDIX 1

Flora list for the northern Yerilgee Hills, compiled from collections within and adjacent to 51 quadrats. Nomenclature follows Packowska and Chapman (2000) and recent changes listed in the Census of Western Australia Flora (the Western Australian Herbarium (1998–). Family taxonomy follows the APG II system, which was current at time of compilation. Naturalised taxa are indicated by an asterisk. Reference collection numbers for informally (phrase) named taxa and for unnamed taxa are given in parentheses. Family taxonomy follows the APG II system (Angiosperm Phylogeny Group 2003), which was current at time of flora list compilation.

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

Amaranthaceae
Ptilotus aervoides
Ptilotus exaltatus
Ptilotus helipteroides
Ptilotus holosericeus
Ptilotus obovatus

Anthericaceae
Thysanotus manglesianus

Apiaceae
Trachymene ornata

Apocynaceae
Alyxia buxifolia

Asclepiadaceae
Marsdenia australis
Rhyncharrhena linearis

Asteraceae
Chrysocephalum puteale
Lawrencella rosea
Leiocarpa semicalva subsp. *semicalva*
Olearia humilis
Olearia muelleri
Olearia pimeleoides
Rhodanthe battii
Streptoglossa liatroides
Vittadinia humerata
Waitzia acuminata var. *acuminata*

Caesalpiniaceae
Senna artemisioides subsp. *filifolia*
Senna charlesiana

Casuarinaceae
Allocasuarina acutivalvis subsp. *acutivalvis*
Allocasuarina dielsiana
Allocasuarina eriochlamys subsp. *eriochlamys*
Casuarina pauper

Chenopodiaceae
Atriplex bunburyana
Atriplex nummularia subsp. *spathulata*
Atriplex vesicaria
Enchylaena lanata
Enchylaena tomentosa var. *tomentosa*
Eriochiton sclerolaenoides
Maireana georgei
Maireana thesioides
Maireana tomentosa subsp. *tomentosa*
Maireana trichoptera
Maireana triptera
Rhagodia drummondii
Rhagodia preissii subsp. *preissii*
Salsola tragus
Sclerolaena diacantha
Sclerolaena drummondii
Sclerolaena fusiformis
Sclerolaena gardneri
Sclerolaena obliquicuspis

Cupressaceae
Callitris columellaris

Dilleniaceae
Hibbertia exasperata

Epacridaceae
Leucopogon sp. Clyde Hill (MA Burgman 1207)

Euphorbiaceae
Calycopeplus paucifolius

Frankeniaceae
Frankenia desertorum

Goodeniaceae
Goodenia havilandii
Scaevola spinescens

Haloragaceae
Haloragis trigonocarpa

Lamiaceae
Physopsis viscida
Prostanthera althoferi subsp. *althoferi*
Prostanthera althoferi subsp. *althoferi x campbellii*
Prostanthera grylloana
Prostanthera magnifica
Spartothamnella sp. Helena & Aurora Range (PG Armstrong 155–109)
Spartothamnella teucriiflora
Westringia cephalantha
Wrixonia prostantheroides

Lobeliaceae
Isotoma petraea

Loganiaceae
Phyllangium sulcatum

Loranthaceae
Amyema gibberula var. *gibberula*
Amyema linophylla subsp. *linophylla*
Amyema miquelii
Lysiana casuarinae

Malvaceae
Abutilon cryptopetalum
Sida petrophila
Sida ectogama
Sida fibulifera
Sida sp. dark green fruits (S van Leeuwen 2260)
Sida sp. golden calyces glabrous (HN Foote 32)

Mimosaceae
Acacia andrewsii
Acacia aneura var. cf. *argentia*
Acacia aneura var. cf. *intermedia*
Acacia aneura var. cf. *microcarpa*

Appendix 1 (cont.)

Acacia aff. *sibirica* (A Markey & S Dillon 6092)
Acacia aff. *balsamea* (A Markey & S Dillon 5212)
Acacia assimilis subsp. *assimilis*
Acacia burkittii
Acacia colletioides
Acacia duriuscula
Acacia effusifolia
Acacia erinacea
Acacia jennerae
Acacia ligulata
Acacia murrayana
Acacia quadrimarginea
Acacia ramulosa var. *ramulosa*
Acacia sibina
Acacia sibirica
Acacia tetragonophylla

Myoporaceae
Eremophila alternifolia
Eremophila decipiens subsp. *decipiens*
Eremophila forrestii subsp. *forrestii*
Eremophila forrestii x *latrobei*
Eremophila georgei
Eremophila glabra subsp. *glabra*
Eremophila granitica
Eremophila latrobei subsp. *latrobei*
Eremophila longifolia
Eremophila oldfieldii subsp. *angustifolia*
Eremophila oppositifolia subsp. *angustifolia*
Eremophila pantonii
Eremophila pustulata
Eremophila serrulata
Eremophila sp. Mt Jackson (GJ Keighery 4372)
Eremophila subfloccosa subsp. *lanata*

Myrtaceae
Aluta aspera subsp. *aspera*
Baeckea elderiana
Eucalyptus concinna
Eucalyptus ebbanoensis subsp. *glauciramula*
Eucalyptus ewartiana
Eucalyptus griffithsii
Eucalyptus horistes
Eucalyptus leptopoda subsp. *subluta*
Eucalyptus longissima
Eucalyptus oleosa subsp. *oleosa*
Eucalyptus salmonophloia
Eucalyptus salubris
Eucalyptus stricklandii
Euryomyrtus maidenii
Melaleuca hamata
Melaleuca leiocarpa

Papilionaceae
Bossiaea walkeri
Mirbelia microphylla
Templetonia egena
Templetonia sulcata

Phormiaceae
Dianella revoluta var. *divaricata*

Pittosporaceae
Bursaria occidentalis
Pittosporum angustifolium

Poaceae
Amphipogon caricinus var. caricinus
Aristida contorta
Austrodanthonia caespitosa
Austrostipa elegantissima
Austrostipa blackii
Austrostipa platychaeta
Austrostipa scabra
Austrostipa scabra – atypical form
Austrostipa nitida
Enneapogon caerulescens
Eragrostis eriopoda
Eriachne pulchella subsp. *pulchella*
Monachather paradoxus
Paspalidium basicladum
** Pentaschistis airoides*
Triodia cf. *scariosa*

Polygalaceae
Comesperma integerrimum

Proteaceae
Banksia arborea
Grevillea acuaria
Grevillea aff. *paradoxa*
Grevillea erectiloba
Grevillea nematophylla subsp. *nematophylla*
Grevillea obliquistigma subsp. *obliquistigma*
Grevillea oligomera
Grevillea paradoxa
Hakea recurva subsp. *recurva*

Rhamnaceae
Cryptandra connata
Stenanthemum stipulosum

Rubiaceae
Psydrax suaveolens

Rutaceae
Phebalium canaliculatum
Phebalium tuberculosum
Philotheca brucei subsp. *brucei*

Santalaceae
Exocarpos aphyllus
Santalum acuminatum
Santalum lanceolatum
Santalum spicatum

Sapindaceae
Dodonaea lobulata
Dodonaea microzyga var. *acrolobata*
Dodonaea rigida
Dodonaea viscosa subsp. *angustissima*

Solanaceae
Solanum ellipticum
Solanum ferocissimum
Solanum lasiophyllum
Solanum nummularium
Solanum plicatile

Sterculiaceae
Brachychiton gregorii

Violaceae
Hybanthus floribundus subsp. *curvifolius*

Zygophyllaceae
Zygophyllum eremaeum