Flora and vegetation of the Eastern Goldfields Ranges: Part 7. Middle and South Ironcap, Digger Rock and Hatter Hill

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Abstract

A study of the flora and plant communities of part of Forrestania greenstone belt between Middle Ironcap and Hatter Hill (some 80 km ESE of Hyden), recorded a total flora of 345 taxa of which 342 were native and three were introduced. Three species of threatened flora and 29 taxa being considered for listing were found. Ten species are considered to be endemic to the range and a further eight species are restricted to similar landforms within 100 km of the range. A new species of *Stenanthemum* is only known from two populations. Despite considerable mining and exploration activity in the area, the flora and vegetation remain poorly known. Thirty-eight quadrats were established along the range system and data from these quadrats were used to define four community types. Differences in these community types were strongly related to edaphic gradients. Very little of the Forrestania vegetation system is reserved and the results of this survey support recommendations for the establishment of nature reserves to conserve this vegetation system.

Keywords: flora, vegetation, Goldfields, Ironcap, Hatter Hill, Digger Rock, Western Australia, greenstone

Introduction

The Forrestania greenstone belt extends from Mt Holland south to Hatter Hill, a distance of some 70 km, and lies 80 km east of Hyden. This narrow greenstone belt is composed of an undulating plain of mafic and ultramafic lithologies and abrupt ridges of banded ironstones, and forms part of the western most greenstone series (Chin *et al.* 1984). These belts are common landforms of the Eastern Goldfields and have been heavily exploited for mineral exploration and mining for over 100 years. Despite this, a detailed knowledge of the flora and vegetation of individual ranges is still lacking although broad scale structural vegetation mapping (Beard 1972) and regional surveys are available (Newbey & Hnatiuk (1988).

The aim of this series of papers is to report on detailed floristic studies on some of these ranges to address this deficiency (Gibson *et al.* 1997; Gibson & Lyons 1998a,b; Gibson & Lyons 2001a,b). This work has highlighted the high biodiversity values of these ranges as centres of endemism and restricted vegetation assemblages within the subdued landscapes of the eastern goldfields.

Study Locality

The study area lies ca 80 km ESE of Hyden and covers the section of the Forrestania greenstone belt between Middle Ironcap and Hatter Hill (Fig 1). The northern portion of this belt was burnt by a large, extremely hot, wildfire in summer of 1993 that consumed almost all vegetation between Mt Holland and Middle Ironcap. The northern section of the belt runs roughly north–south then swings north west–south east near South Ironcap.

The regional geology of the study area has been mapped and described in the Hyden 1: 250000 sheet (Chin *et al.* 1984) and the geology and landforms have also been summarized by Newbey (1988). The study area has been tectonically stable since the Proterozoic (600–2500 My go). The major landscape features are controlled by the Archaean (2500–3700 My old) granites that underlie most of the study area, and have weathered into gently undulating plains and broad valleys covered by Tertiary soils (< 65 My old). The narrow Forrestania greenstone (Archaean mafic and ultramafic lithologies) belt has several banded ironstone units (formed from lacustrine deposits of iron oxides and quartz sand) up to 30 m thick which form the abrupt ridges of North, Middle and South Ironcap. Some areas of Tertiary laterite were also found associated with the greenstone belt (Chin *et al.* 1984). Gold was first discovered in the Forrestania area in 1915 and there has been a long history of mineral exploration and mining along this belt. There are presently three large mines operating in the area; at Forrestania, Middle Ironcap, and Digger Rocks.

The climate of the region is warm dry mediterranean with warm winters and hot summers. Mean annual rainfall at Hyden is 336 mm, with moderate seasonal variation. The driest year on record was 1972 with 159 mm, and the wettest was 1942 with 572 mm. Most rain falls in winter, generally associated with frontal activity from May through August. Summer rainfall (to 50 mm) is highly erratic and results from thunderstorms. The

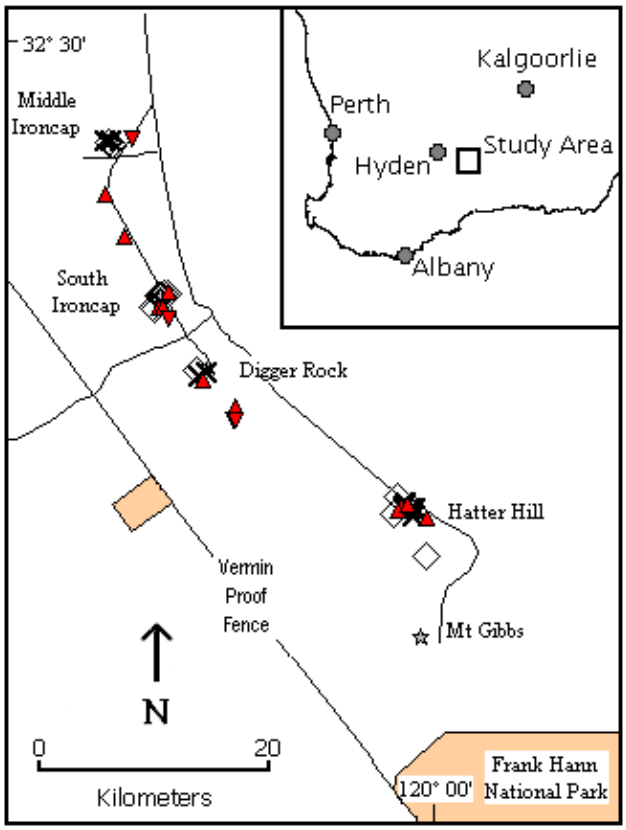

Figure 1. Location of the study area and the distribution of the four communities describes from the southern Forrestania greenstone belt (Middle Ironcap to Hatter Hill). Type 1, open diamond; type 2, solid cross; type 3, solid triangle; type 4 solid inverted triangle.

heaviest rainfalls (to 160 mm) are associated with rain-bearing depressions forming from tropical depressions (Newbey 1988, Anon 1988). The temperature data from Hyden show mean maximum temperature is highest in January (33.4 °C) with December through April all recording mean annual temperatures above 30 °C. Lowest mean minimum temperatures of below 5 °C are recorded in July and August.

The Forrestania greenstone belt lies within the Roe Botanical District, an area characterized by mallee vegetation with some eucalypt woodland in lower valleys and scrub heath and *Allocasuarina* thicket on the residual plateau soils (Beard 1990). Beard (1972) first described the major structural formations of this area and grouped them into vegetation systems. Beard (1972) defined the vegetation of the greenstone belt stretching from Mt Holland to Hatter Hill as the Forrestania system. This system also included granites, quartzites, and banded ironstones that formed prominent rocky ridges. Beard described sclerophyll woodlands of *Eucalyptus salmonophloia* and *E. longicornis* but noted that these areas had been extensively cut and burnt over and were in poor condition. Very few areas of this vegetation type were encountered during the current survey.

A peculiar feature of the Forrestania system was the ridges of banded ironstone (Beard 1972), with Mt Holland being covered by a dense thicket whose dominants included *Allocasuarina campestris, Calothamnus asper, Hakea* sp, *Dryandra* sp, and *Callitris preissii* subsp *verrucosa* (syn *C. tuberculata*). Further south at South Ironcap the vegetation was a heath with occasional scattered *E. falcata* (syn *E. rugulata*). Shrubs recorded included *Banksia sphaerocarpa, Allocasuarina ?dielsiana, Isopogon gardneri, Melaleuca ?cardiophylla, Grevillea insignis, Adenanthos viridiflorus, Isopogon teretifolius, Callitris roei, Calothamnus quadrifidus, Lysinema ciliatum, Lasiopetalum* sp and *Dryandra viscida.* At Hatter Hill, a further 25 km south-east, the rocky greenstone ridges were covered with thickets of *Allocasuarina ?dielsiana,* and *Eucalyptus loxophleba* with *Cassia chatelainiana, Dodonaea stenozyga, Melaleuca acuminata, Calothamnus quadrifidus, Boronia inornata* and *Westringia dampieri.*

Following Beard's work in the area a series of regional surveys were undertaken across the eastern goldfields. In the report covering the Lake Johnson–Hyden area, Newbey & Hnatiuk (1988) detail the regional vegetation patterns following a land system approach. They note that the three Ironcaps (North, Middle and South) vary slightly in their fine grain mosaic of vegetation structure and more so in species composition. They further note that the vegetation and flora of these ironstones differ widely from the nearest other banded ironstone formation. The major vegetation type of the greenstone belt from Mt Holland to Hatter Hill is *Eucalyptus flocktoniae* (syn *E. urna*) low woodland which differs from the Parker Range and Highclere Hills to the north (Newbey & Hnatiuk 1988). Growing in the *E. flocktoniae* low woodlands were other low trees of *E. salubris,* and *E. annulata,* with tall shrubs of *Exocarpos aphyllus, Melaleuca cucullata* and *Melaleuca pauperiflora*. Breakaways, a common component of goldfield ranges, were only recorded once but mallees of *Eucalyptus* aff *wandoo* (syn *Eucalyptus livida*) were usually present in small partially laterized areas. Both Beard's survey and the later biological survey of the eastern goldfields were undertaken to provide regional overviews. Consequently the individual ranges were not sampled extensively.

The aim of the present work was to undertake a detailed floristic survey of the Forrestania greenstone belt form Middle Ironcap to Hatter Hill. This involved the compilation of a detailed flora list, and the description of the vegetation patterning of the area based on a series of permanently located quadrats.

Methods

Thirty-eight 20 m x 20 m quadrats were established on the southern half of the Forrestania greenstone belt from Middle Ironcap south to Hatter Hill (Fig 1). These quadrats attempted to cover the major geographical, geomorphological and floristic variation found in the study area. Care was taken to locate quadrats in the least disturbed vegetation available in the area being sampled.

Within each quadrat all vascular plants were recorded. Quadrats were sampled in early September 1996. Data on topographical position, slope, aspect, percentage litter, percentage bare ground, percentage surface rock (bedrock and surfical deposits), and vegetation structure were collected from each quadrat. Topographical position was scored on a subjective six point scale (ridge tops = 1, upper slopes = 2, midslopes = 3, lower slopes = 4, valley

flats =5, small rise in valley =6). Slope was scored on a one to three scale from flat to medium, to steep. Aspect was recorded as one of 16 cardinal directions. Altitude was taken from 1:100000 series topographical map to nearest 10 m. Vegetation structure was recorded using Muir's (1977) classification. All quadrats were permanently marked with four steel fence droppers and their positions fixed using a GPS unit.

Quadrats were classified according to similarities in species composition. In these analyses only perennial species were used to facilitate comparisons with classifications from other ranges (Gibson *et al.* 1997; Gibson & Lyons 1998a,b; Gibson & Lyons 2001a,b). The quadrat and species classifications undertaken used the Czekanowski similarity coefficient and "unweighted pair-group mean average" fusion method (UPGMA module in PATN, Belbin 1995, beta value -0.1, Sneath & Sokal, 1973). Semi-strong hybrid (SSH in PATN) ordination of the quadrat data was undertaken to show spatial relationships between quadrat groups (here referred to as community types) and to elucidate possible environmental correlates with the classification (Belbin 1991). Methods of Dufrene & Legendre (1997) were used to determine best indicator taxa for each group (from PC-ORD v 4.24, McCune & Mefford 1999).

Climate estimates (mean annual temperature, annual temperature range, mean annual rainfall, rainfall coefficient of variation) were obtained from BIOCLIM (Busby 1986), a prediction system that uses mathematical surfaces fitted to long term climate data. Relationships among and between physical site parameters and climate estimates was examined using Spearman rank correlation coefficient. To reduce the probability of type I errors given the number of intercorrelations, significance differences were reported at a level of $P<0.01$. Vectors for the physical site parameters, latitude, altitude and climatic estimates were fitted to the ordination along axes of highest correlation using the principal axis correlation routine in the PATN package (Belbin 1995) (also known as rotational correlation analysis). Statistical significance of these vectors was determined using random permutations of the values of the variable among sites (Faith & Norris 1989). Statistical relationships between quadrat groups for physical site parameters and climate estimates were tested using Kruskal-Wallis non-parametric analysis of variance (Siegel 1956).

Nomenclature generally follows Paczkowska and Chapman (2000). Voucher specimens have been be lodged in the Western Australian Herbarium. Introduced taxa are indicated by a "*".

Results

Flora

A total of 343 taxa (species, subspecies, varieties) and two hybrids were recorded from the Forrestania greenstone belt. The flora list was compiled from taxa found in the 38 quadrats or the adjacent area and from collections of the Western Australian Herbarium (Appendix 1). Of these 345 taxa, 342 are native and 3 are weeds. The best represented families were the Myrtaceae (77 taxa), Proteaceae (38 taxa), Mimosaceae (25 taxa), Papilionaceae and Orchidaceae (20 taxa), Asteraceae (17 native taxa and 1 introduced taxon) and Epacridaceae (14 taxa) (Appendix 1). This pattern is typical of the flora of the South Western Botanical Province (Beard 1990). The most common genera were *Eucalyptus* (38 taxa), *Acacia* (25 taxa) and *Melaleuca* (22 taxa).

Thirty-five taxa of conservation significance were recorded from the range. This included;

- three taxa listed as threatened;
- a further 29 that are being considered for listing as threatened flora (Atkins 2001);
- 10 taxa considered endemic to the range; and
- a further eight that are regional endemics (found within 100 km) (Table 1).

One taxon (*Stenanthemum liberum*) was collected for the first time and is only known from two populations (Rye 2001).

During the current survey, new populations of *Boronia revoluta* and *Banksia sphaerocarpa* var. *dolichostyla* (both listed as threatened) were located. This was somewhat surprising given the proximity to active mines and the botanical survey work undertaken associated with their commissioning. A significant range extensions was recorded for *Bentleya diminuta.* This is a very unusual tufted perennial herb (Pittosporaceae) which has small clusters of prostrate leaves connected by thick underground rhizomes. It has previously been recorded from the Cape Arid–Ravensthorpe area.

Vegetation

In the 38 quadrats established south of Middle Ironcap, 229 taxa were recorded of which 202 were perennial. Fifty-seven perennials occurred at only one quadrat. Preliminary analyses showed these singletons had no effect on the community classification and therefore are not discussed further. As a result the final data set consisted of 145 perennial taxa in 38 quadrats. Species richness ranged from seven to 36 taxa per quadrat, with individual taxa occurring in between two and 28 of the 38 quadrats. Only material that could be identified down to species or subspecies level was included in the analysis (ca 95% of records).

The first major division in the dendrogram separates the quadrats on skeletal soils derived from banded ironstone and the massive laterites (community types 1 & 2) from quadrats on deeper soils derived from greenstone or decomposing laterites (community types 3 & 4; Fig 2, Appendix 2).

- Community type 1 is comprised of the species-rich shrublands or mallee shrublands. Species in species groups I and K characterize community type 1 and contain most indicator species (Appendix 2). Average species richness was 27.2 taxa plot^{-1}. This community type was restricted to the massive outcrops along the range (Middle Ironcap, South Ironcap, Digger Rock and Hatter Hill, Fig 1). Three subtypes can be recognized (Appendix 2). Type 1a occurred on all outcrops and was strongly represented by species group I and a lack of species group J which characterized

Table 1

Taxa of conservation significance from the southern Forrestania greenstone belt (Middle Ironcap to Hatter Hill). Three taxa are listed as Declared Rare Flora under Wildlife Conservation Act; 29 are being considered for listing. Ten taxa are considered to be endemic to the range and a further eight which occur on similar landforms within 100 km, are considered to be regional endemics.

Family	Taxon	Conservation status	Endemic status
Dilleniaceae	*Hibbertia axillibarba*	potentially threatened	local
	Hibbertia carinata	potentially threatened	
	Hibbertia lepidocalyx subsp *lepidocalyx*		regional
Droseraceae	*Drosera browniana*		local
Epacridaceae	*Acrotriche patula*	potentially threatened	
	Leucopogon marginatus	threatened	
	Leucopogon sp Ironcaps (N Gibson & K Brown 3070)	potentially threatened	
	Leucopogon sulcatus	potentially threatened	
	Monotoca leucantha	potentially threatened	
Loganiaceae	*Logania exilis*	potentially threatened	regional
Mimosaceae	*Acacia heterochroa* subsp *robertii*	potentially threatened	regional
	Acacia singula	potentially threatened	
	Acacia tetraneura	potentially threatened	
Myoporaceae	*Calamphoreus inflatus*	potentially threatened	
	Eremophila racemosa	potentially threatened	
Myrtaceae	*Eucalyptus exigua*	potentially threatened	
	Eucalyptus georgei subsp *fulgida*	potentially threatened	regional
	Eucalyptus rugulata		local
	Euryomyrtus leptospermoides	potentially threatened	
	Melaleuca agathosmoides	potentially threatened	local
Papilionaceae	*Eutaxia* sp Hatter Hill (KR Newbey 6532)	potentially threatened	regional
	Mirbelia densiflora	potentially threatened	
Pittosporaceae	*Bentleya diminuta*	potentially threatened	
Proteaceae	*Banksia sphaerocarpa* var *dolichostyla*	threatened	regional
	Dryandra ferruginea subsp *flavescens*	potentially threatened	
	Dryandra viscida	potentially threatened	local
	Grevillea insignis subsp *elliotii*	potentially threatened	local
	Grevillea lullfitzii	potentially threatened	local
Rhamnaceae	*Cryptandra intonsa*	potentially threatened	local
	Stenanthemum liberum	potentially threatened	local
Rutaceae	*Boronia revoluta*	threatened	local
	Microcybe pauciflora subsp *grandis*	potentially threatened	regional
	Phebalium brachycalyx	potentially threatened	
Sterculiaceae	*Lasiopetalum* sp Ironcaps (PG Wilson 7024)	potentially threatened	regional
Stylidiaceae	*Stylidium sejunctum*	potentially threatened	

the two quadrats of type 1b. Species group J contained three local and one regional endemic taxa. Type 1b was restricted to area around South Ironcap. Type 1c generally lacked taxa in species groups I and J and was found at Middle Ironcap and Hatter Hill area. Type 1c had slightly lower species richness (mean 23.6) compared with types 1a and 1b (29.1–29.5).

- Community type 2 were generally mallee shrublands or *Allocasuarina* thickets primarily found on massive laterites. Species composition varied from community type 1 by stronger representation from species groups A–D and lower representation from species groups I, J and most taxa in species group K. Indicator species for this community type occurred in species groups B and D (Appendix 2). Species richness tended to be lower than in community type 1 (20.3 taxa plot^{-1}). Distribution of this community was again closely correlated with the massive outcrops at Middle Ironcap, Digger Rock and Hatter Hill, it was not recorded from South Ironcap (Fig 1).
- Community type 3 were eucalypt woodlands dominated or co-dominated by *Eucalyptus urna* and *E. salubris* occurring on the colluvial deposits on the flats below the outcrops or on the broad flat ridges along the range generally with an understorey dominated by *Melaleuca* spp (Fig 1). Species richness was considerably lower (14.4 taxa plot^{-1}) and this community was characterized by species group E –H, with indicator species being concentrated in species group E (Appendix 2). Only one local endemic (*Melaleuca agathosmoides*) is found in these species groups, all the other local and regional endemics are restricted to community types 1 and 2.
- Community type 4 was a species poor mallee community generally dominated by *Eucalyptus calycogona* with large emergent *Eucalyptus salmonophloia* on small colluvial flats in the ranges (Fig 1). One quadrat in this group was dominated by *E. longicornis*. Species richness was low with an average 12.5 taxa plot^{-1}. Indicator species for this community type were *Eucalyptus calycogona*, *Eucalyptus salmonophloia*, and *Olearia muelleri* (Appendix 2).

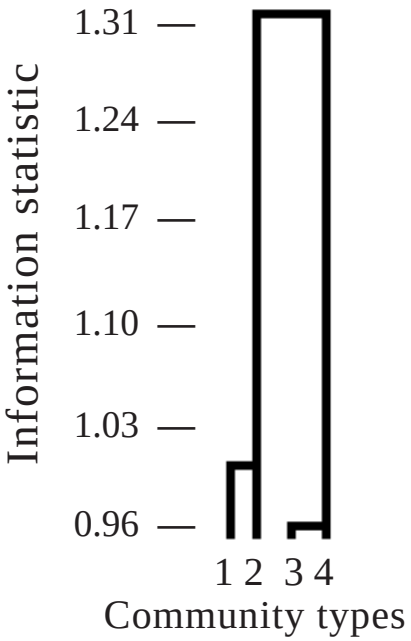

Figure 2. Dendrogram of 4 group level classification of 38 quadrats established along the southern Forrestania greenstone belt between Middle Ironcap and Hatter Hill.

Physical Correlates

The climatic estimates and latitude and altitude showed significant intercorrelations, as did slope class and aspect (Table 2). Topographic position, slope, percent surface rock and percent litter showed significance differences between the mean values of the four community types (Table 3). No significance differences were found for latitude, altitude or the climatic estimates.

Steeper slopes differentiated community types 1 and 2, from 3 and 4, as did a higher percentage of surface rock and rock type (Table 3 & Fig 3). Surfical deposits of banded ironstone and laterite (often massive) occurred at most quadrats in community types 1 and 2 but uncommon in the other community types. Altitude and topographic position scores are somewhat misleading because topographical relief along the range was subdued except near Middle and South Ironcap. The broad intervening ridges where community type 3 was common had a similar topographic position score and altitude as community types 1 and 2 that were restricted to the more pronounced hill and ridge tops. The soil profiles on these broad ridges was much deeper than on the outcrops.

The three dimensional ordination (stress = 0.17) of the 38 quadrats showed clear separation between communities (1 and 2) found on the outcrops and the eucalypt woodlands of the broad ridges and colluvial deposits. The shrublands and mallee shrublands of community type 1 occur in the lower left quadrant, the mallee shrublands and thickets of community type 2 occur in the centre and the woodlands of community type 3 and 4 in the upper right quadrant with segregation between these units (Fig 4). Good separation of the subtypes of community type 1 was found on the third axis (not shown). Of the site parameters only percentage surface rock was significantly correlated with the ordination, correlations could not be improved by standard data transformations, implying no simple non-linear response in the data.

Discussion

The southern Forrestania belt has a similar floral richness to the other goldfields ranges for which detailed information exists but is much richer in local endemics (Gibson *et al.* 1997; Gibson & Lyons 1998a,b; Gibson & Lyons 2001a,b; Gibson unpublished data; Table 4). The reasons for this high level of local endemism is not clear; topographically and geologically the range between Middle Ironcap and Hatter Hill is no more diverse than other goldfields ranges nor is the current climatic gradients unusual. The range does form part of the western most greenstone belt, but so to do the Highclere Hills which have no local endemic taxa (Table 4).

The significance of the flora of this area has long been recognized and it is one of the best collected ranges in the goldfields, yet the flora of the range is still poorly known as indicated by the number of taxa requiring further survey to an assessment of their threat status (Table 1) and that the current survey (that was restricted to the existing track network) located new populations of

Table 2

Matrix of Spearman rank correlation coefficients between site physical parameters and climate estimates. Correlation significant at P < 0.01 shown in bold. See methods for parameter codes.

	Position	**Slope**	**Aspect**	**% rock**	**% litter**	**% bare**	**Latitude**	**Altitude**	**Tann**	**Trange**	**Rann**	**Rcv**
Position	1.00											
Slope	0.25	1.00										
Aspect	0.22	**0.74**	1.00									
% rock	0.06	0.41	0.17	1.00								
% litter	-0.14	-0.11	-0.03	-0.40	1.00							
% bare	0.04	0.01	0.13	-0.09	-0.12	1.00						
Latitude	0.18	0.15	0.00	0.28	-0.19	0.24	1.00					
Altitude	-0.08	0.04	-0.28	0.36	-0.03	0.09	**0.68**	1.00				
Tann	0.32	0.11	0.39	-0.17	0.05	0.34	**0.44**	-0.26	1.00			
Trange	0.15	0.14	-0.02	0.35	-0.13	0.25	**0.96**	**0.75**	0.36	1.00		
Rann	0.17	-0.01	0.35	-0.30	-0.01	-0.03	**-0.43**	**-0.93**	**0.50**	**-0.51**	1.00	
Rcv	0.30	0.17	0.13	0.21	-0.13	0.26	**0.89**	**0.42**	**0.69**	**0.86**	-0.11	1.00

Table 3

Plant community mean values for topographic position (1 – ridge top to 6 – rises in valley), slope (1 – flat to 3 – steep), aspect (16 cardinal directions), percent exposed rock, percent litter, percent bare ground, latitude, altitude (m), mean annual temperature (°C), annual temperature range (°C), mean annual rainfall (mm), rainfall coefficient of variation (%). Differences between means tested using Kruskal – Wallis non parametric analysis of variance (ns indicates not significant, * indicates P<0.05, ** indicates P < 0.01)

	Type 1	Type 2	Type 3	Type 4
Physical site parameters				
Position*	2.9	2.1	2.3	5.5
Slope*	2.1	2.0	1.5	1.5
Aspect^{ns}	3.9	4.1	2.4	2.0
% rock**	63.2	57.8	19.1	28.8
% litter*	38.6	47.8	68.2	46.3
% bare^{ns}	22.9	12.2	13.6	26.3
Latitude^{ns}	32.7132	32.7506	32.7370	32.6996
Altitude^{ns}	431.4	413.3	414.5	405.0
Climate estimates				
Tann^{ns}	16.2	16.2	16.2	16.3
Trange^{ns}	27.1	27.0	27.0	27.1
Rann^{ns}	284.2	287.2	287.5	290.5
Rcv^{ns}	40.7	39.8	40.4	41.2
Species richness	27.2	20.3	14.4	12.5
No quadrats	14	9	11	4

threatened flora and a previously uncollected species (Rye 2001).

In biogeographical terms the range was most similar to the Bremer and Parker Ranges with high diversity of eucalypts, acacias and melaleucas, and low richness of *Eremophila* spp. compared to the more northern ranges (Table 4). Another unusual feature of the Forrestania belt is the high richness (9 taxa) of *Hibbertia* spp, a number of which have been recently been named from the range (Wheeler 2000).

Newbey & Hnatiuk (1988) suggested that the three Ironcaps (North, Middle and South) vary in species composition, and while the recent burn precluded sampling of North Ironcap during the present survey the results only partially support this finding. The community types of the banded ironstone and laterite outcrops (types 1 and 2) were not found to be restricted to particular outcrops but were widespread between Middle Ironcap and Hatter Hill (Fig 1), however community type 2 was not recorded from South Ironcap and the two quadrats comprising subtype 1b were restricted to this outcrop.

The current survey does support Newbey & Hnatiuk's (1988) observation that the vegetation and flora of these ironstones differ widely from the nearest other banded ironstone formation, indeed one of the subtypes of community 1 is characterized by a number of locally endemic species (Appendix 2) and nine of the ten local

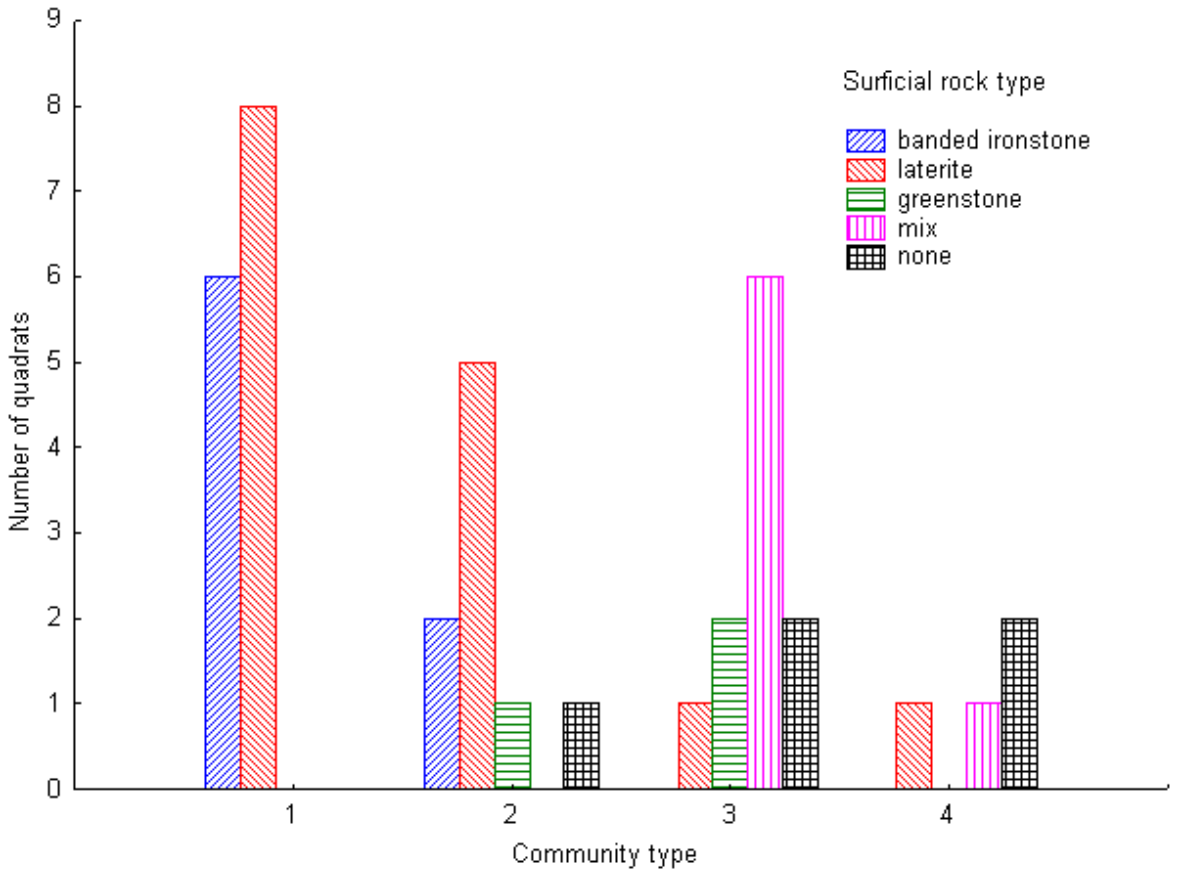

Figure 3. Type of rock seen at the surface in each of the quadrats arranged into the four community types derived from the classification of the perennial plants. The rock material could either be loose or massive, the mix category were loose material to 5 cm diameter and included in all three of the main rock types of the area.

Table 4

Comparison of the floras of the southern Forrestania greenstone belt (Middle Ironcap to Hatter Hill), the Parker Range, the Bremer Range, the Highclere Hills, the Jaurdi uplands, the Helena and Aurora Range, and the Mt Manning Range. Note data from Bremer and Parker Ranges were collect in a dry year and underestimate the annual floras (data from Gibson *et al.* 1997; Gibson & Lyons 1998a,b; Gibson & Lyons 2001a,b; Gibson unpublished data).

	Southern Forrestania belt	Parker Range	Bremer Range	Highclere Hills	Jaudi uplands	Helena & Aurora Range	Mt Manning Range
Flora	345	254	267	242	288	324	238
Weeds	3	10	8	25	15	21	4
Local endemic taxa	10	5	3	–	–	4	–
Taxa – first collections	1	2	2	–	–	1	–
Eucalyptus spp	38	29	30	12	20	19	17
Acacia spp	25	20	17	9	15	17	10
Melaleuca spp	22	14	19	2	4	5	5
Eremophila spp	5	7	11	8	16	14	11

endemics are in fact restricted to the banded ironstone and laterite outcrops of the range.

Mining and exploration has been and continues to be extremely active in the study area and rehabilitation has generally been poor. There is an urgent need for the adoption of high standard environmental management of both exploration and mining operations. Almost none of the Forrestania greenstone belt is currently in the conservation reserve system. Work outlined here and previously reported by Beard (1972) and Newbey & Hnatiuk (1988) indicate a number of plant communities and at least 10 species are restricted to this area. The small Lake Cronin Nature Reserve (1016 ha) which lies between Middle Ironcap and Mt Holland is the only reserve covering the Forrestania vegetation system. None of the banded ironstone or associated lateritic areas are currently reserved. There is an urgent need for a series of nature reserves along the Forrestania belt.

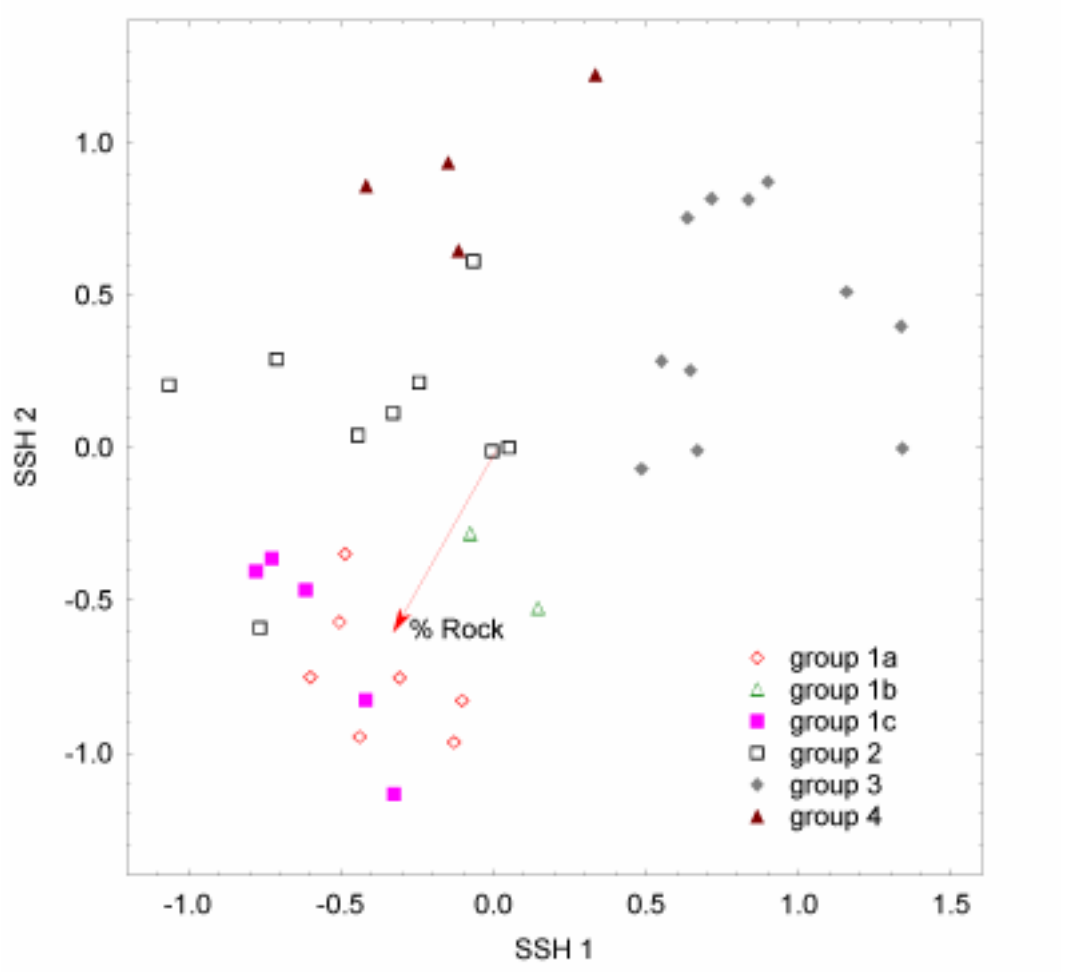

Figure 4. Ordination of the 38 quadrats coded by community type. Arrow shows the direction of the best fit linear correlation with percent surface rock. No other site parameter showed a significant correlation with the ordination.

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Appendix 1

Flora list for southern Forrestania greenstone belt between Middle Ironcap and Hatter Hill, includes all taxa from the sampling quadrats and adjacent areas and collections lodged in the Western Australian Herbarium. Nomenclature generally follows Paczkowska and Chapman (2000), * indicates an introduced taxon.

Amaranthaceae
- *Ptilotus holosericeus*

Anthericaceae
- *Thysanotus patersonii*

Apiaceae
- *Daucus glochidiatus*
- *Hydrocotyle rugulosa*
- *Platysace maxwellii*
- *Trachymene ornata*

Apocynaceae
- *Alyxia buxifolia*

Asteraceae
- *Angianthus tomentosus*
- *Asteridea athrixioides*
- *Blennospora drummondii*
- *Brachyscome perpusilla*
- *Hyalosperma demissum*
- * *Hypochaeris glabra*
- *Isoetopsis graminifolia*
- *Millotia tenuifolia*
- *Olearia dampieri* subsp *eremicola*
- *Olearia muelleri*
- *Olearia ramosissima*
- *Podolepis lessonii*
- *Podolepis tepperi*
- *Rhodanthe laevis*
- *Rhodanthe pygmaea*
- *Senecio glossanthus*
- *Senecio hispidulus*
- *Senecio quadridentatus*

Boraginaceae
- *Halgania andromedifolia*
- *Halgania integerrima*
- *Halgania lavandulacea*

Boryaceae
- *Borya sphaerocephala*

Brassicaceae
- *Lepidium rotundum*

Caesalpiniaceae
- *Labichea stellata*

Casuarinaceae
- *Allocasuarina acutivalvis*
- *Allocasuarina campestris*
- *Allocasuarina thuyoides*

Celastraceae
- *Psammomoya choretroides*

Centrolepidaceae
- *Centrolepis cephaloformis* subsp *cephaloformis*

Chenopodiaceae
- *Chenopodium* sp
- *Sclerolaena diacantha*

Convolvulaceae
- *Wilsonia humilis*

Crassulaceae
- *Crassula colorata*

Cupressaceae
- *Callitris canescens*
- *Callitris roei*
- *Callitris tuberculata*

Cyperaceae
- *Lepidosperma* aff *brunonianum* (NG & KB 2509)
- *Lepidosperma* sp (NG & KB 2512)
- *Lepidosperma* sp (NG & KB 3739)
- *Schoenus nanus*

Dasypogonaceae
- *Lomandra* sp

Dilleniaceae
- *Hibbertia* aff *pungens* (NG & KB 2523)
- *Hibbertia axillibarba*
- *Hibbertia carinata*
- *Hibbertia exasperata*
- *Hibbertia gracilipes*
- *Hibbertia hemignosta*
- *Hibbertia lepidocalyx* subsp *lepidocalyx*
- *Hibbertia pungens*
- *Hibbertia rostellata*

Droseraceae
- *Drosera browniana*
- *Drosera glanduligera*
- *Drosera lowriei*
- *Drosera macrantha*

Epacridaceae
- *Acrotriche patula*
- *Astroloma serratifolium*
- *Coleanthera myrtoides*
- *Leucopogon conostephioides*
- *Leucopogon cuneifolius*
- *Leucopogon dielsianus*
- *Leucopogon fimbriatus*
- *Leucopogon marginatus*
- *Leucopogon* sp Ironcaps (NG & KB 3070)
- *Leucopogon* sp Wheatbelt (S Murray 257)
- *Leucopogon sulcatus*
- *Lysinema ciliatum*
- *Monotoca leucantha*
- *Styphelia pulchella*

Euphorbiaceae
- *Beyeria brevifolia*

Geraniaceae
- *Pelargonium havlasae*

Goodeniaceae
- *Coopernookia strophiolata*
- *Dampiera angulata*
- *Dampiera haematotricha* subsp *dura*
- *Goodenia helmsii*
- *Goodenia laevis* subsp *humifusa*
- *Goodenia pinifolia*
- *Scaevola spinescens*

Haemodoraceae
- *Conostylis argentea*

Haloragaceae
- *Glischrocaryon aureum* var *angustifolium*
- *Haloragodendron glandulosum*

Juncaceae
- *Juncus flavidus*

Juncaginaceae
- *Triglochin calcitrapa*

Lamiaceae
- *Cyanostegia lanceolata*
- *Hemigenia* sp Newdegate (E Bishop 75)
- *Hemigenia teretiuscula*
- *Hemigenia westringioides*
- *Microcorys obovata*
- *Westringia cephalantha*
- *Westringia rigida*

Lauraceae
- *Cassytha aurea*
- *Cassytha glabella*
- *Cassytha melantha*
- *Cassytha racemosa*

Lobeliaceae
- *Isotoma scapigera*

Loganiaceae
- *Logania exilis*
- *Logania flaviflora*
- *Logania judithiana*
- *Logania perryana*

Mimosaceae
- *Acacia andrewsii*
- *Acacia binata*
- *Acacia brachyclada*
- *Acacia brachyphylla* var *brachyphylla*
- *Acacia castanostegia*
- *Acacia deficiens*
- *Acacia erinacea*
- *Acacia evenulosa*
- *Acacia hemiteles*
- *Acacia heterochroa* subsp *robertii*
- *Acacia merrallii* x *poliochroa*
- *Acacia intricata*
- *Acacia lasiocalyx*
- *Acacia merrallii*
- *Acacia moirii* subsp *recurvistipula*
- *Acacia poliochroa*
- *Acacia prainii*
- *Acacia quinquenervia*
- *Acacia singula*
- *Acacia* sp Lake King (R Hnatiuk 760791)
- *Acacia sulcata* var *platyphylla*
- *Acacia tetraneura*
- *Acacia uncinella*
- *Acacia unifissilis*
- *Acacia yorkrakinensis*

Myoporaceae
- *Calamphoreus inflatus*
- *Eremophila decipiens* subsp *decipiens*
- *Eremophila densifolia* subsp *pubiflora*
- *Eremophila psilocalyx*
- *Eremophila racemosa*
- *Eremophila saligna*

Myrtaceae
- *Aluta appressa*
- *Astartea ambigua*
- *Baeckea* sp Merredin (KR Newbey 2506)
- *Beaufortia micrantha*
- *Beaufortia schaueri*
- *Calothamnus quadrifidus*
- *Calytrix breviseta* subsp *stipulosa*
- *Chamelaucium ciliatum*
- *Eremaea* sp
- *Eucalyptus* aff *calycogona*
- *Eucalyptus alipes*
- *Eucalyptus annulata*
- *Eucalyptus calycogona* subsp *calycogona*
- *Eucalyptus capillosa* subsp *polyclada*
- *Eucalyptus celastroides* subsp *virella*
- *Eucalyptus conglobata*
- *Eucalyptus cylindriflora*
- *Eucalyptus cylindrocarpa*
- *Eucalyptus dendrosheath* ms
- *Eucalyptus densa* subsp *densa*
- *Eucalyptus eremophila*
- *Eucalyptus exigua*
- *Eucalyptus georgei* subsp *fulgida*
- *Eucalyptus gratiae*
- *Eucalyptus grossa*
- *Eucalyptus kondininensis* subsp *kondininensis*
- *Eucalyptus livida*
- *Eucalyptus longicornis*
- *Eucalyptus loxophleba* subsp *lissophloia*
- *Eucalyptus myriadena* subsp *myriadena*
- *Eucalyptus olivina*
- *Eucalyptus phaenophylla* subsp *interjacens*
- *Eucalyptus phaenophylla* subsp *phaenophylla*
- *Eucalyptus phenax*
- *Eucalyptus pileata*
- *Eucalyptus protensa*
- *Eucalyptus quadrans*
- *Eucalyptus rigidula*
- *Eucalyptus rugulata*
- *Eucalyptus salmonophloia*
- *Eucalyptus salubris*
- *Eucalyptus sporadica*
- *Eucalyptus subtenuis*
- *Eucalyptus tenera*
- *Eucalyptus transcontinentalis*
- *Eucalyptus urna*
- *Eucalyptus yilgarnensis*
- *Euryomyrtus leptospermoides*
- *Leptospermum fastigiatum*
- *Leptospermum nitens*
- *Leptospermum spinescens*
- *Melaleuca acuminata* subsp *acuminata*
- *Melaleuca adnata*
- *Melaleuca agathosmoides*
- *Melaleuca cliffortioides*
- *Melaleuca cordata*
- *Melaleuca coronicarpa*
- *Melaleuca cucullata*
- *Melaleuca halmaturorum*
- *Melaleuca johnsonii*
- *Melaleuca lanceolata*
- *Melaleuca lateriflora* subsp *lateriflora*
- *Melaleuca laxiflora*
- *Melaleuca pauperiflora* subsp *pauperiflora*
- *Melaleuca pentagona*
- *Melaleuca phoidophylla*
- *Melaleuca pungens*
- *Melaleuca quadrifaria*
- *Melaleuca rigidifolia*
- *Melaleuca sapientes*
- *Melaleuca* sp Hatters Hill (NG & KB 2516)
- *Melaleuca teuthidoides*
- *Melaleuca uncinata*
- *Micromyrtus erichsenii*
- *Micromyrtus racemosa*
- *Micromyrtus triptycha* subsp *elata*
- *Thryptomene kochii*
- *Verticordia chrysantha*

Orchidaceae
- *Caladenia doutchiae*
- *Caladenia microchila*
- *Caladenia pachychila*
- *Caladenia paradoxa*
- *Caladenia saccharata*
- *Caladenia sigmoidea*
- *Cyanicula amplexans*
- *Diuris laxiflora*
- *Diuris porrifolia*
- *Eriochilus dilatatus*
- *Genoplesium nigricans*
- *Microtis media* subsp *media*
- *Oligochaetochilus muticus*
- *Oligochaetochilus sanguineus*
- *Oligochaetochilus sargentii*
- *Pterostylis* aff *aspera*
- *Pterostylis* aff *barbata*
- *Pterostylis recurva*
- *Pterostylis* sp (S Barrett 553*)*
- *Thelymitra* aff *macrophyllum*

Papilionaceae
- *Bossiaea preissii*
- *Daviesia benthamii* subsp *acanthoclona*
- *Daviesia euryloba*
- *Daviesia nematophylla*
- *Dillwynia uncinata*

Eutaxia parvifolia
Eutaxia sp Hatter Hill (KR Newbey 6532)
Gastrolobium floribundum
Gastrolobium melanocarpum
Gastrolobium nutans
Gastrolobium spinosum
Glycyrrhiza acanthocarpa
Gompholobium gompholobioides
Gompholobium viscidulum
Mirbelia densiflora
Mirbelia dilatata
Pultenaea arida
Pultenaea vestita
Templetonia battii
Templetonia sulcata

Pittosporaceae
Bentleya diminuta

Pittosporaceae
Billardiera coriacea

Plantaginaceae
Plantago aff *hispidula* (NG & KB 3179)

Poaceae
Austrodanthonia caespitosa
Austrostipa acrociliata
Austrostipa elegantissima
Austrostipa platychaeta
* *Bromus rubens*
Neurachne alopecuroidea
Triodia rigidissima

Polygalaceae
Comesperma volubile

Portulacaceae
Calandrinia sp (NG & KB 3728)

Primulaceae
* *Anagallis arvensis*

Proteaceae
Adenanthos argyreus
Banksia audax
Banksia elderiana
Banksia laevigata subsp *fuscolutea*
Banksia sphaerocarpa var *dolichostyla*
Banksia violacea
Conospermum brownii
Dryandra erythrocephala var *erythrocephala*
Dryandra ferruginea subsp *flavescens*
Dryandra pallida
Dryandra purdieana
Dryandra viscida
Grevillea acuaria
Grevillea anethifolia
Grevillea cagiana
Grevillea decipiens
Grevillea huegelii
Grevillea insignis subsp *elliotii*
Grevillea lullfitzii
Grevillea nematophylla
Grevillea pilosa subsp *pilosa*
Hakea commutata
Hakea erecta
Hakea meisneriana
Hakea multilineata
Hakea scoparia
Hakea subsulcata
Isopogon gardneri
Isopogon scabriusculus subsp. *stenophyllus*
Isopogon sp Newdegate (DB Foreman 771)
Isopogon sp Watheroo (D Foreman 477)
Persoonia helix
Persoonia saundersiana
Persoonia striata
Petrophile circinata
Petrophile glauca
Petrophile stricta
Synaphea interioris

Rhamnaceae
Cryptandra intonsa
Cryptandra minutifolia subsp *minutifolia*
Cryptandra myriantha
Cryptandra spyridioides
Cryptandra wilsonii
Spyridium mucronatum subsp *mucronatum*
Stenanthemum liberum
Trymalium myrtillus subsp *myrtillus*

Rubiaceae
Opercularia hispidula

Rutaceae
Boronia inornata subsp *inornata*
Boronia inornata subsp *leptophylla*
Boronia revoluta
Drummondita hassellii
Eriostemon sp
Microcybe albiflora
Microcybe pauciflora subsp *grandis*
Phebalium ambiguum
Phebalium brachycalyx
Phebalium filifolium
Phebalium tuberculosum x *canaliculatum*
Phebalium tuberculosum

Santalaceae
Exocarpos aphyllus
Santalum acuminatum

Sapindaceae
Dodonaea bursariifolia
Dodonaea ceratocarpa
Dodonaea glandulosa
Dodonaea pinifolia
Dodonaea ptarmicaefolia
Dodonaea stenozyga
Dodonaea viscosa subsp *angustissima*

Solanaceae
Solanum capsiciforme
Solanum simile
Symonanthus aromaticus

Stackhousiaceae
Stackhousia monogyna

Sterculiaceae
Lasiopetalum sp Ironcaps (PG Wilson 7024)

Stylidiaceae
Stylidium breviscapum
Stylidium sejunctum

Thymelaeaceae
Pimelea angustifolia

Zygophyllaceae
Zygophyllum glaucum
Zygophyllum ovatum

Appendix 2

Sorted two-way table of quadrats established between Middle Ironcap and Hatter Hill showing species occurrence by community type. Quadrats appear as columns and species as rows. Taxa in bold are indicator species identified by INDVAL (Dufrene & Legendre 1997) at four group level ($P < 0.05$), statistical significance tested by randomization procedure.

	Community type					
	1a	1b	1c	2	3	4
SPECIES GROUP A						
Acacia andrewsii				**		
Diuris laxiflora				**		
Stackhousia monogyna				**		
Drosera browniana	*			*		
Olearia dampieri subsp *eremicola*	*			*		
Triodia rigidissima				* *		
SPECIES GROUP B						
Acrotriche patula				****		
Callitris canescens				** *		
Eriochilus dilatatus				** *		
Austrodanthonia caespitosa				**** *		
Thysanotus patersonii	*		*	* ** *	*	*
Cryptandra wilsonii				**		
Westringia rigida		*		**	*	
Diuris porrifolia				**		
Eucalyptus livida	* *			***		
SPECIES GROUP C						
Allocasuarina acutivalvis			*	* *		
Micromyrtus erichsenii				* *		
Banksia laevigata subsp *fuscolutea*			***	*		
Hakea scoparia			* *	* *		
SPECIES GROUP D						
Beyeria brevifolia	*		*	**		
Phebalium brachycalyx	*			*		
Grevillea lullfitzii	* *			*		*
Cryptandra intonsa	*	*		**		
Westringia cephalantha				**		
Caladenia paradoxa			*	*** * *		*
Platysace maxwellii				** * **		
Melaleuca uncinata	*		*	*** **	*	
Dodonaea bursariifolia				*** **		*
Santalum acuminatum	* *		*	* * **		
Eucalyptus phenax				***	* *	*
Olearia muelleri				** **	* *	****
Eucalyptus eremophila				***	**	*
Thelymitra aff *macrophyllum*		*	* **	***** *	**	*
Pterostylis sp (S Barrett 553)		*	*	*	* **	
SPECIES GROUP E						
Acacia erinacea		*		**	**	**
Austrostipa elegantissima				* **	***	**
Grevillea huegelii				*	*	*
Eucalyptus calycogona* subsp *calycogona					* *	***
Eucalyptus salmonophloia					* *	***
Eucalyptus cylindrocarpa	*				*	*
Caladenia microchila				* *	* *	*
Caladenia sigmoidea				*	*	
Grevillea acuaria				* *	*** *	*
Boronia inornata subsp *leptophylla*				*	** *	
Melaleuca teuthidoides					*** *	
Daviesia nematophylla					* ** **	**
Melaleuca adnata				* *	*** *	**
Microtis media* subsp *media			*		*****	
Pultenaea arida					* *****	*
Dodonaea stenozyga					**** ****	*
Eucalyptus annulata					** ***	
Eucalyptus salubris					***** *	
Melaleuca cucullata					* *** ***	
Eucalyptus urna				* * *	******* *	*

	Community type					
	1a	1b	1c	2	3	4
Exocarpos aphyllus	*			* * *	* *** ** *	
Melaleuca pauperiflora* subsp *pauperiflora					** ****	
Microcybe albiflora					*** * *	
Eremophila psilocalyx				*	* *	
Oligochaetochilus muticus				** *	* ***	
SPECIES GROUP F						
Melaleuca agathosmoides					* *	
Melaleuca phoidophylla					* *	
Melaleuca coronicarpa					* * **	
SPECIES GROUP G						
Cryptandra minutifolia subsp *minutifolia*				*	*	
Trymalium myrtillus subsp *myrtillus*					* *	
Hakea commutata					* *	*
Melaleuca cliffortioides					* *	
Melaleuca lateriflora subsp *lateriflora*				*	* *	
Melaleuca pentagona				*	*	
SPECIES GROUP H						
Acacia intricata					* *	*
Austrostipa platychaeta						**
Ptilotus holosericeus					*	*
Eremophila decipiens* subsp *decipiens						* *
Templetonia sulcata						* **
Melaleuca lanceolata					**	*
Sclerolaena diacantha					**	
SPECIES GROUP I						
Acacia brachyphylla var. *brachyphylla*	**					
Leucopogon sp Ironcaps (NG & KB 3070)	* **			*		
Banksia sphaerocarpa var. *dolichostyla*	*	**				
Dampiera angulata	*	*				
Callitris roei	* *	*				
Lasiopetalum sp Ironcaps (PGW 7024)	* **	*				
***Lepidosperma* sp (NG & KB 2509)**	****	*				
Calothamnus quadrifidus	* * *	*	*	*	*	
Euryomyrtus leptospermoides	*	*	*			
Adenanthos argyreus	***	*				
Beaufortia schaueri	***	**				
Gastrolobium spinosum	****	*				
Hibbertia axillibarba	**					
Dryandra pallida	*****	**	*			
Melaleuca pungens	******	*	*	* *		
Petrophile glauca	**	**	*			
Gastrolobium nutans	* *****	*		** *		
Hibbertia aff *pungens* (NG & KB 2523)	* * *	**		* *		
SPECIES GROUP J						
Acacia castanostegia	* *	*				
Stenanthemum liberum	*	*				
Acacia heterochroa subsp *robertii*		**				
Hibbertia hemignosta		**				
Boronia revoluta	*	**				
Eucalyptus rugulata	*	**				
Oligochaetochilus sanguineus		**		* *	****	* *
Oligochaetochilus sargentii	*	**	**		*	*
Lepidosperma sp. (NG & KB 2512)		*			*	
Neurachne alopecuroidea		*				*
Pterostylis recurva		*			*	
SPECIES GROUP K						
Acacia singula	** *		*			
Hakea multilineata	* * *		* *			
Acacia uncinella	*** *		*	*		
Goodenia pinifolia	*** **	*	*			
Persoonia helix	*** **					
Isopogon gardneri	*** *	**	*			

	Community type						
	1a	1b	1c	2	3	4	
Leptospermum fastigiatum	***		**				
Dryandra viscida	*****	*					
Grevillea insignis subsp *elliotii*	** *						
Eucalyptus olivina	**		*	*			
Leucopogon cuneifolius	* **		*				
Hemigenia teretiuscula	** *				* *		
Acacia sulcata var *platyphylla*		*	*	*			
Dodonaea pinifolia			**	*			
Stylidium sejunctum			***	* *	*		
Hibbertia lepidocalyx subsp *lepidocalyx*	* **		**	* *			
Lepidosperma sp (NG & KB 3739)	* *		****	* *			
Allocasuarina campestris	*******	*	***	** * **	*		
Drosera macrantha	*******	**	****	**** **			
Melaleuca cordata	*******	**	*****	*	*		
Caladenia saccharata	*******	**	****	*********	* **	***	
Astroloma serratifolium	***** *	*	****	** *	*		
Hakea subsulcata	*** ***	**	** *	* *			
Comesperma volubile	* ***		****	***** *			
Calytrix breviseta* subsp *stipulosa	****		* **				
Verticordia chrysantha	* **		***				
Drummondita hassellii	******	*	** *	*			
Stylidium breviscapum	*****		*****	*			
Micromyrtus racemosa	*** *		*****				
Phebalium ambiguum	* ****		* * *	*	*		
Psammomoya choretroides	***		*** *	*			
SPECIES GROUP L							
Allocasuarina thuyoides	* *		** *				
Hibbertia carinata	*		**				
Beaufortia micrantha			** *				
Hibbertia rostellata			* *				
Phebalium filifolium			* *			*	
Isopogon scabriusculus subsp *stenophyllus*	*		* *				
Leucopogon sp Wheatbelt (S.Murray 257)			* *				
Hibbertia gracilipes	*	*	*				
Phebalium tuberculosum	*		* *	* *			
Thryptomene kochii	*		*				