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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

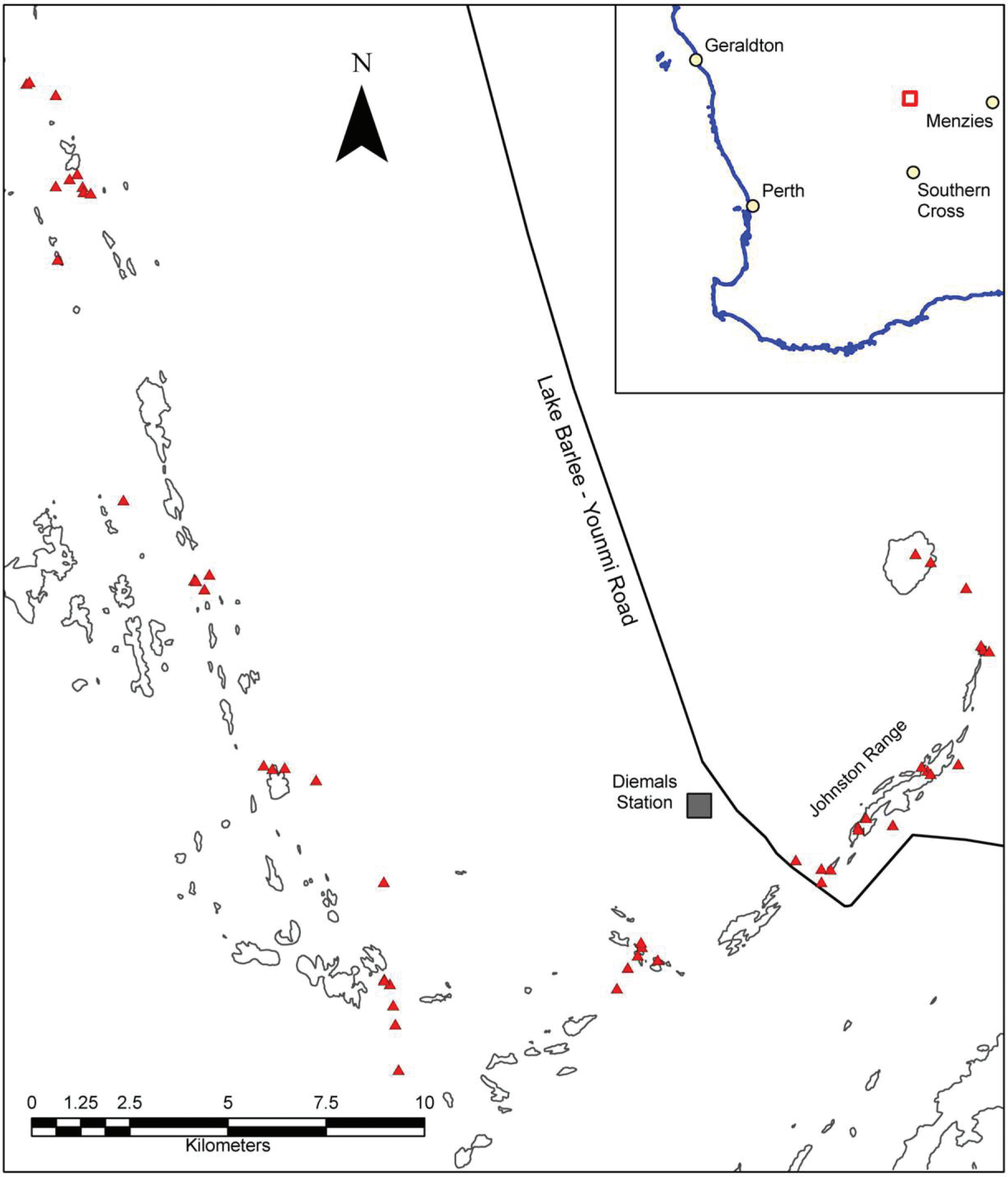

Figure 1. The location of the Johnston Range survey area, with major landforms and landmarks indicated. Areas of higher elevation (>410 m) are outlined by contour lines. The locations of the 50 permanent quadrats are marked (▲).

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 °C (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

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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

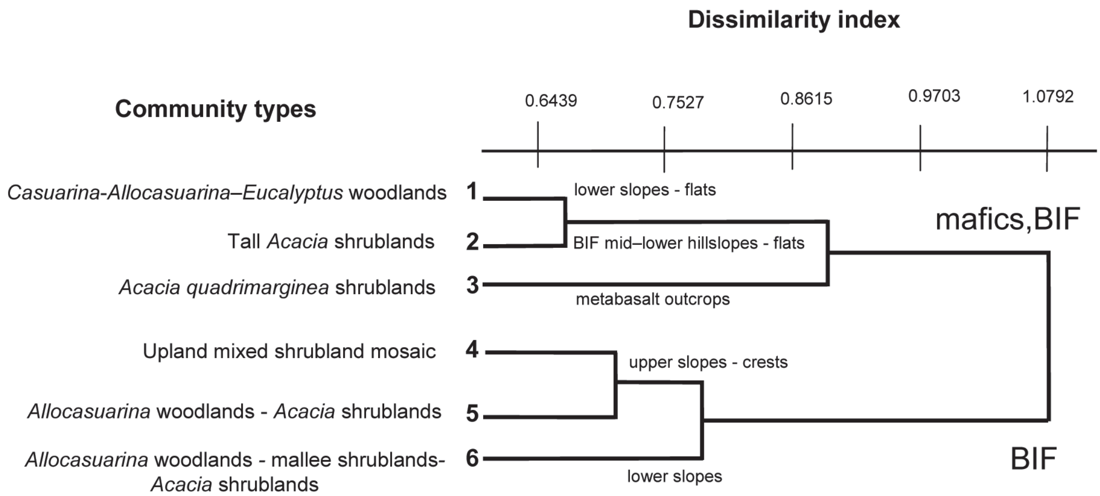

Figure 2. Summary dendrogram of floristic community types of the Johnston Range, resolved from classification analysis of a presence/absence data matrix of 103 perennial taxa from 50 quadrats, using Bray–Curtis dissimilarities and flexible UPGMA method of classification (β = –0.1). Topographic and geological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

	Community Type					
Indicator species	**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

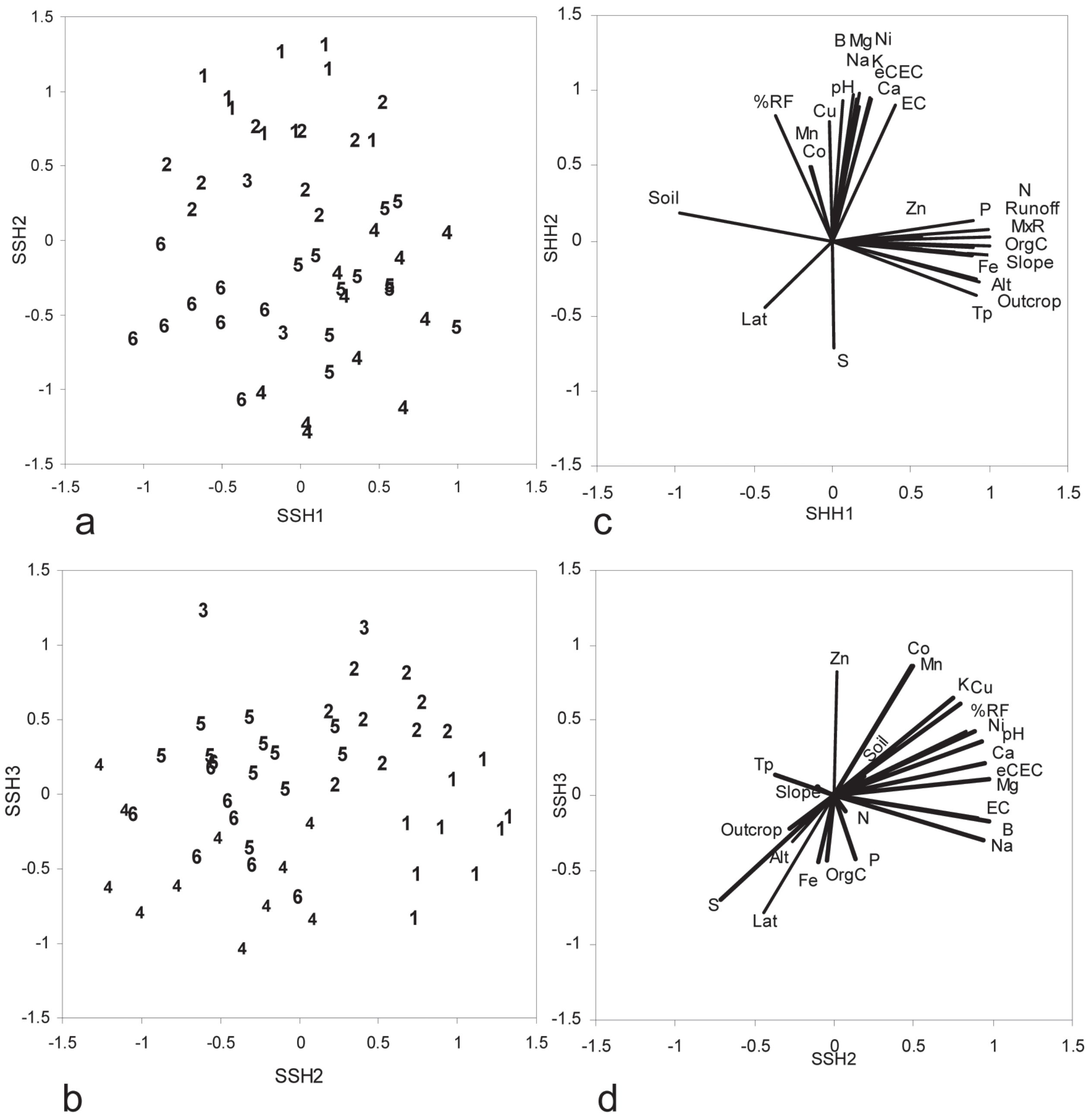

Figure 3. 3D SSH MDS site ordination for the Johnston Range survey area, based on dissimilarities in floristic composition from a presence/absence data matrix of 103 perennial taxa from 50 quadrats: (a) SSH axis 1 vs 2; (b) SSH axis 2 vs 3 (both from three dimensional solution). Quadrats are numbered 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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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*