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Flora and vegetation of banded iron formations of the Yilgarn Craton: Jack Hills

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ABSTRACT

A study of the flora and plant communities of Jack Hills, 140 km WNW of Meekatharra, found 208 taxa, with 205 native and 3 weeds. Two priority taxon was found and two new species identified. Fifty quadrats were established to cover the major geographical, geomorphologic and floristic variation across the hills. Data from these quadrats were used to define six community types. Differences in communities were strongly correlated with altitude and soil fertility. Several communities had restricted distributions. None of the plant communities found on the Jack Hills is reserved in conservation estate.

INTRODUCTION

Banded iron formation ranges within the Yilgarn Craton are highly prospective for iron ore exploration and mining. Previous studies on greenstone and banded ironstone ranges in the Goldfield have found high plant endemicity and restricted vegetation types. It is hypothesised that these patterns may also be found on the ironstone ranges in the Yilgarn (Gibson et al. 1997; Gibson & Lyons 1998a,b; Gibson & Lyons 2001a,b; Gibson 2004a,b). The current knowledge of the flora and vegetation that occur on these ranges is poor and based primarily on the structural description of the dominant vegetation (Speck 1963; Beard 1976; Curry et al. 1994) rather than the community composition.

The study area is located approximately 140 km WNW of Meekatharra and covers the major extent of Jack Hills, approximately 40 km from the Berringarra-Cue Road to Mount Taylor. The range runs in a prominent NE-SW direction (Figure 1). The south west part of the range extends across Berringarra-Cue Road, but this area was not surveyed.

The climate of the region is arid with mild winters and hot summers. Mean annual rainfall at Meekatharra is 235.9 mm, with much variation in rainfall (112.9mm 1st decile; 368.9 9th decile; recorded 1994 to 2004). Annual rainfall has a bimodal distribution with summer and winter rainfall. Summer rainfall, peaking in January and February, is influenced by cyclonic activity off the Pilbara coast of Western Australia. Cyclones that cross the coast dissipate and develop into rain bearing depressions which may bring rain inland. In addition, thunderstorm may develop from convectional activity (Curry et al. 1994). Winter rainfall is often the result of cold frontal activity associated with low pressure systems in the south west of Western Australia. These systems often weaken as they move inland and result in isolated showers and strong winds (Curry et al. 1994). The highest maximum temperatures occur during summer, with the January as hottest month (mean maximum temperature 38.9 °C and mean 11.3 days above 40 °C). Winters are mild with lowest mean maximum temperatures recorded for July of 18.9 °C. Temperatures rarely fall below 2 °C in winter, with mean minimum of 7.4°C in July.

Jack Hills is located in the Murchison geological province in the northwest part of the Yilgarn Craton. It differs locally from the Weld Range, 90 km south, although formed during the same tectonic phase, as it mainly contains metasedimentary rock rather than the metavolcanics of the Weld Range (Elias 1982). Jack Hills is dominated by pelitic and psammitic metasediments such as quartz-mica schists, banded iron formations and chert. The latter two form units several centimetres to several hundred metres thick as prominent strike ridges within the range (Elias 1982).

The area surrounding Jack Hills is topographically flat, with the more erosion resistant range of Banded Ironstone prominent in the landscape. Colluvial deposits are present in a valley between a divide in the range, resulting in deeper sandier soils, than the colluvial deposits exterior to the range. This is probably a result of sheetwash across a larger area exterior to the hills, rather than the smaller constricted area between two ridges. Skeletal soils are found on the crests and hill slopes of the range. The shallow soils are formed when erosion is greater than the weathering process resulting in relatively thin soil profile and extensive rock outcrop (Gray & Murphy 2002)

Jack Hills occurs in the Murchison IBRA region, which is characterised by open mulga (*Acacia aneura*) woodlands and a rich diversity in ephemerals (Environment Australia 2000). Beard (1976) describes the dominant cover of *Acacia aneura* and *A. grasbyi*.

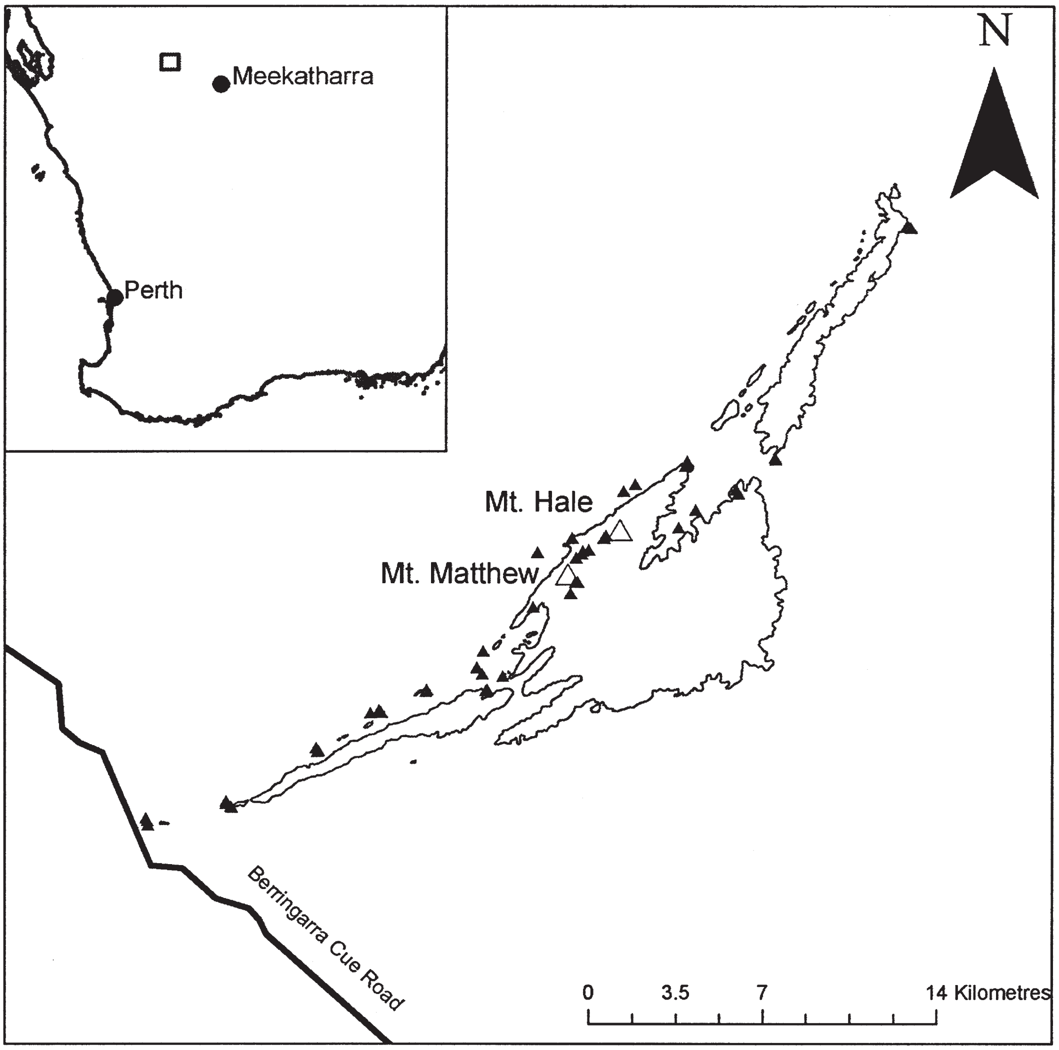

Figure 1. Location of the study area and distribution of the 50 quadrats (▲) along the Jack Hills. Mount Matthew and Mount Hale are the highest peaks (Δ) on the range. The 340m contour is shown.

Speck (1963) and later Curry et al. (1994) mapped land systems at a similar scale. Jack Hills is in the Weld land system, which covers the Weld Range to the south. The vegetation consists of rocky hills with mixed shrubland, minor areas of stony soils with mulga mixed shrubland, and shrublands on valley floors.

The aim of this work was to undertake a detailed floristic survey of the Jack Hills and to identify the plant communities that occur on the range. This was achieved by detailed flora list, and description of plant communities based on a series of permanently established quadrats. The survey of the Jack Hills will be part of a larger regional study of flora and plant communities of banded ironstone formations of Yilgarn Craton.

METHODS

Fifty 20 x 20 m quadrats were established on Jack Hills in August 2005 (Figure 1). The location of quadrats attempted to cover the major geographical, geomorphologic and floristic variation found on the hills in the study area. Each quadrat was permanently marked with four steel fence droppers and their positions determined using a GPS unit. All vascular plants within the quadrat were recorded. Data on topographical position, disturbance, abundance, size and shape of coarse fragments on surface, the amount of exposed bedrock, cover of leaf litter and bare ground were recorded following McDonald et al. (1990). Additionally, growth form, height and cover were recorded for dominant taxa in each strata (tallest, mid- and lower).

Twenty soil samples were collected from the upper 10 cm of the soil profile within each quadrat. The soil was bulked and the 2mm fraction analysed for B, Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S and Zn using the Mehlich No. 3 procedure (Mehlich 1984). The extracted samples were then analysed using Inductively Coupled Plasma – Atomic Emission Spectrometer (ICP-AES). This procedure is an effective and cost efficient alternative to traditional methods for evaluating soil fertility and has been calibrated for Western Australian soils (Walton & Allen 2004). pH was measured in 0.01M $CaCl_2$ at soil to solution ratio of 1:5. Effective cation exchange capacity (eCEC) was calculated from the sum of exchangeable Ca, Mg, Na and K (Rengasamy & Churchman 1999). Exchangeable Ca, Mg, Na and K were obtained by multiplying the values of Ca, Mg, Na and K obtained from ICP-AES by a standard constant.

Quadrats were classified on the basis of similarity in species composition on perennial species only, to be consistent with other analyses of banded ironstone ranges (see Gibson 2004 b). Taxa identified to species level and occurring in more than one quadrat were used in the floristic analysis. Life form followed Paczknowska and Chapman (2000), where perennial is defined as a plant whose life span extends over 2 or more growing seasons.

The quadrat and species classifications were undertaken using the Bray and Curtis coefficient and Flexible UPGMA (Unweighted pair-group mean average; â = - 0.1; Belbin 1989). Indicator species and species assemblages characterising each community were determined following Dufrene and Legendre (1997) using INDVAL routine in PC-ORD (McCune & Mefford 1999). Quadrats were ordinated using SSH (semi-strong hybrid multidimensional scaling), correlations of environmental variables were determined using the PCC (Principal Component Correlation) routine and significance determined by the MCAO (monte-carlo attributes in ordination) permutation test in PATN (Belbin 1989). PCC is a routine that runs multiple linear regressions on the variables and the ordination coordinates, resulting in a vector for each variable within the ordination plot. The MCAO is a monte-carlo test determining the robustness of the PCC results by randomly assigning values of variables to objects and then running the PCC routine (Belbin 1989).

Statistical relationships between quadrat groups were tested using Kruskall-Wallis non parametric analysis of variance (Siegel 1956) followed by non-parametric comparison (Zar 1999). Correlations between environmental parameters were analysed using Spearman Rank correlation coefficient.

Nomenclature generally follows Paczkowska and Chapman (2000).

RESULTS

Flora

A total of 209 taxa, from 98 genera and 43 families as recorded from the 50 established quadrats or adjacent areas. The best represented families were Asteraceae (41 taxa), Poaceae (17), Mimosaceae (16), Malvaceae (12) and Myoporaceae (12).

Rare and Priority Flora

Two priority three (P3) species were found during the survey of Jack Hills, *Gunniopsis propinqua* and *Homalocalyx echinulatus*.

- *Gunniopsis propinqua* (P3) is a small prostrate succulent herb growing on low outwash areas or flats. Only one collection was made from an open drainage channel in a valley.
- *Homalocalyx echinulatus* (P3) is a low growing myrtaceous shrub to 1m, growing on breakaways, sandstone hills and laterite in the northern area of the Murchison IBRA region. A single collection was made from a colluvial outwash.

New taxa

Three new taxa, *Prostanthera ferricola*, *Lobelia heterophylla* subsp. Pilbara (R.Meissner & Y.Caruso 1), and *Acacia* sp. Jack Hills (R. Meissner & Y. Caruso 4) were collected during the Jack Hills survey.

- *Prostanthera ferricola* is a highly aromatic shrub to 1 m with purple mauve flowers. The shrubs are highly palatable and were heavily grazed by feral goats. Initially, the collections at Jack Hills were matched to a specimen collected by G. Byrne from Doolgunna station in 2003, approximately 100 km north of Meekatharra. Subsequent taxonomic work identified the Doolgunna specimen as a distinct new species, *P. ferricola*. Its taxonomic affinities remain unclear, but it is morphologically similar to *P. centralis*, but differs significantly by having smaller leaves and short, patent indumentum (Conn & Shepherd 2007).
- *Lobelia heterophylla* subsp. Pilbara (R.Meissner & Y.Caruso 1) was identified as a subspecies of *L. heterophylla*, previously collected in the Pilbara. This taxon is a small herb to 20 cm with bright blue flowers, and serrated leaves. It has been found growing in two localities on Jack Hills. In this survey, it was found growing abundantly on a small ironstone outcrop approximately 5 km east of the Berringarra-Cue Road. Additional collections were recorded from *Triodia* shrubland between Mount Matthew and Mount Hale. Further work and collections need to be made to determine the taxonomic rank of this herb.
- *Acacia* sp. Jack Hills (R. Meissner & Y. Caruso 4) is a multi-stemmed shrub to 2.5 m with bright green phyllodes. Initially it was thought to be *Acacia cockertoniana* on account of the generally features of its phyllodes and flowers, but it differs significantly in having elongated flowering spikes and less resinous phyllodes (Maslin 2007).

Range extensions

- *Actinobole drummondianum* is a small prostrate daisy to 10 cm with small white to cream flowers. It was collected from a valley flat growing in red sandy loam soil. It is known from the Carnarvon IBRA region, growing in creeklines and hillsides. The single collection extends its range east by approximately 200 km.
- *Calandrinia disperma* is a prostrate succulent annual

to 10 cm. It has been poorly collected with only 11 collections in the Western Australian Herbarium. This survey collected *C. disperma* from two locations, a valley flat and a small crest. The survey has extended the range by nearly 400 km eastward.

- *Petalostylis labicheoides* is an erect shrub to 4 m with bright yellow flowers. A single specimen was collected during the survey growing in the spinifex community between Mount Matthew and Mount Hale. This species is common in the Pilbara region and this collection extends it southern range by approximately 200km.
- *Rhodanthe polycephala* is an annual daisy with small yellow flowers to 10 cm. It was found growing on the slopes between Mount Hale and Mount Matthew, in the spinifex community. It is known mainly in the southwest of Western Australia and has been previously recorded growing on ironstone hills. The collections extend its range north east by nearly 300 km.
- *Trachymene ceratocarpa* is a small annual herb to 10 cm with white to blue flowers. A single specimen was collected during the survey from a low valley flat occurring between the two strike ranges in the main area of Jack Hills. This species is mainly known from the northern Geraldton Sandplains but has also been collected from pastoral stations within Yalgoo and Coolgardie IBRA regions. The single collection extends it range north east by approximately 300 km.
- *Triodia melvillei* is a perennial hummock grass to 0.5 m with resinous culms. It is well collected and is found growing in a range of habitats, such as sandplains, dunes and rocky hills. This a range extension of approximately 200 km based upon herbarium records. It has been previously reported by (Speck 1963 cited in Beard 1976). This species was common on the upper slopes of Mount Matthew and Mount Hale.

Taxa requiring further study

Several taxa collected during the survey are of taxonomic interest for several reasons: they could not be identified beyond genus, even with sufficient floral and fruiting material; the species was a hybrid; or the current taxonomy of the genus needs revision. Only species from the first two reasons are described below. Further taxonomic work and additional collections need to be made to determine their significance and status.

- *Abutilon* sp. (R.Meissner & Caruso 136) is a short lived perennial collected from 4 quadrats in a variety of different communities. It was collected from midslope, breakaways and rocky outcrops. The species could not be identified to species level even though floral material was present.
- *Glycine* sp. (R.Meissner & Y.Caruso 110) is a leguminous climber to 20 cm found growing in a creekline. This collection could not be determined further than genus and showed no affinity to currently known taxa.
- *Gunniopsis* aff. *divisa* (R.Meissner & Y.Caruso 125) is small succulent herb collected from a lower slope/ flat. It could not be matched to any collection but exhibits affinity to *G. divisa*. This taxon has been collected previously and misidentified under *G. divisa*. Further taxonomic work and additional collections need to be undertaken.
- *Hibiscus* sp. (R.Meissner & Y.Caruso 123) is a small short lived perennial to 20 cm with purple flowers. Two collections were made of this species from a creekline and a small ironstone crest. It was not possible to identify it beyond genus, and it did not show affinity to known species.
- *Indigofera* aff. *australis* is a small herb to 30 cm found growing on a banded ironstone outcrop. Taxonomically closest to *I. australis* but differs in leaf morphology, possessing five instead of eight leaflets.
- *Senna stricta* x *artemesioides* subsp. *petiolaris* (E.N.S. Jackson 2888) is a shrub to 1.5 m collected from sites in close proximity to each other. This hybrid was recognised as a new entity of *Senna* following collections from the Weld Range and this study. These collections were also matched to an earlier misidentified collection within the Western Australian Herbarium. Hybridisation within *Senna* is common (Randell 1989) and several other *Senna* hybrids were found within the survey.

In the survey area, the dominant acacia is *Acacia aneura* (mulga). This species shows a large amount of variation in morphology, within and between populations, readily hybridises and is a taxonomically diverse group (Miller et al. 2002). This causes a great deal of difficulty in identification in the field and the herbarium. Due to the difficulty in identification, the collections were placed in morphological groups consisting of 3 varieties; *Acacia aneura* cf. var. *aneura*, *A. aneura* cf. var. *tenuis* and *A. aneura* cf. var. *microcarpa*.

Plant Communities

Sixty perennial species, perennial taxa identified to species level and species occurring in more than one quadrat were in the final analysis. A preliminary analysis between the full and perennial data set showed a correlation of 0.63.

Community groups were separated into 6 groups, based upon clear patterning in the final dendrogram (Figure 2). The first split in the dendrogram separates Community 6 from the remaining community types, indicating that this community is distinctly different from the other plant communities found on Jack Hills. Community 6 also had a restricted distribution between Mount Hale and Mount Matthew while the other community types were more widely distributed across the range. These divisions can also be clearly seen in the sorted two-way table of the sites and species classification (Table 1).

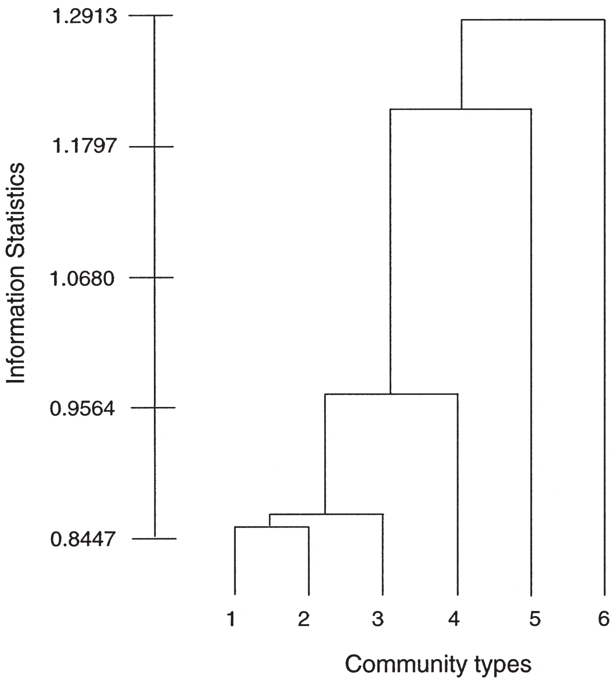

Figure 2. Dendrogram of 6 group level classification of the 50 quadrats established on Jack Hills.

Community 1 – Open woodlands and woodlands of *Acacia* spp. (dominants are *Acacia aneura cf.* var. *aneura*, *Acacia ramulosa* var. *linophylla*, *Acacia rhodophloia*) over shrublands of *Ptilotus obovatus* subsp. *obovatus* or *Eremophila* spp. This community is found along the entire range and across a variety of landscapes but mainly on creeklines and lower slopes. Mean species richness (including annual taxa) was 31.9 ±0.6 taxa per quadrat. Taxa from species group A characterise this community (Table 1). There were only two indicator species, *Enneapogon caerulescens* and *P. obovatus* subsp. *obovatus.*

Community 2 – Woodlands and shrublands and of *A. aneura* cf. var *aneura* or *A. aneura* cf. var. *tenuis* occasionally associated with *A. rhodophloia* woodlands over shrublands of *P. obovatus* subsp. *obovatus* and *Dodonaea petiolaris.* The community was found along the entire range mainly on crests and midslopes and was very similar to Community 1. However, it has lower species richness (mean taxa per quadrat 24.2 ±0.4) and *D. petiolaris* was characteristically present (Table 1).

Community 3 – Open woodlands, woodlands and shrublands of *A. aneura* cf. var. *aneura* and *Acacia citrinoviridis* over *P. obovatus* subsp. *obovatus.* This community was found on crests and midslopes of rocky outcrops on the entire range. Its main species are from Species Group A and species richness was similar to community 2 (mean 25.6 ±0.6 taxa per quadrat) (Table 1). Indicator species for this community are *A. citrinoviridis*, *Cheilanthes brownii*, *E. caerulescens*, *Neurachne minor* and *Sida chrysocalyx.*

Community 4 – Isolated trees of *Acacia stowardii* or woodlands of *A. aneura* cf. var. *tenuis*, *A. stowardii* and *Acacia kempeana* over sparse shrublands. This community was represented by only 2 quadrats, one on colluvial outwash and the other on a small ironstone crest, respectively. Both quadrats are low in perennial species and are represented by taxa in Species Group C and D (Table 1). The quadrats had low species richness of 23.0 ± 1.0 taxa per quadrat. The low number of species, the absence of species in Group A and the few species in common likely resulted in the quadrats grouping together. Indicator species were *A. kempeana*, *A. stowardii*, *Maireana villosa* and *Senna glaucifolia.*

Community 5 – Open woodlands, woodlands and isolated trees of *A. aneura cf.* var. *aneura* over shrublands of *Eremophila* spp. The community consisted of 5 quadrats of species poor (mean richness 20.8 ± 0.9 taxa per quadrat) colluvial outwashes and one low crest in the south west end of the range. The community was characterised by species from Group G and two indicator species, *A. aneura* cf. var. *aneura* and *Eremophila macmillaniana* (Table 1).

Community 6 – Shrublands of *Acacia* sp. Jack Hills (R. Meissner & Y. Caruso 4), *Philotheca brucei* subsp. *cinerea*, *Eremophila* spp. over hummock grasslands of *T. melvillei.* Occasionally present in the community are isolated trees of *A. citrinoviridis, Acacia pruinocarpa* and *Grevillea berryana*. This community is found on the slopes of Mount Matthew and Mount Hale. It had one of the highest species richness of all the communities (mean of 30.4 ± 0.6 taxa per quadrat), and is especially rich in perennial species. It is characterised by species in group H (Table 1). Indicator species were *A.* sp. Jack Hills (R. Meissner & Y. Caruso 4), *Cheilanthes sieberi* subsp *sieberi*, *Eremophila exilifolia*, *Eremophila jucunda* subsp. *jucunda*, *G. berryana*, *Halgania gustafsenii* var. *gustafsenii*, *Hibiscus sturtii* var. *sturtii*, *P. brucei* subsp. *cinerea, Thysanotus manglesianus* and *T. melvillei.*

Physical Parameters

The soil parameters showed significant intercorrelations ($P < 0.05$). Iron showed significant positive correlations with all physical site characters except aspect and leaf litter cover ($P < 0.05$). Altitude was strongly correlated with all physical site character except aspect and runoff. Slope also correlated strongly with most of the physical site characters apart from aspect, rock outcrop abundance and % bare ground (Table 2).

Community 2 and 6 were lower in pH than Community 1 but similar to Community 3 and 5. However, Community 6 has significantly higher levels of iron than Community 2 (Table 3). Communities 1, 2 and 3 had the highest levels of phosphorus and differed significantly from Community 5, with the lowest phosphorus values (Table 3). Community 5 also differed from Community 3 and 6 in higher nickel levels but had lower sulphur levels than Community 3 (Table 3). Community 4 was excluded from the post-hoc analysis due to low sample size (2 quadrats).

Altitude separates Community 6 from Communities 1, 2 and 5, which all occur lower in the landscape (Table 4). Community 3 is the only community similar in altitude to Community 6, while Community 5 is the lowest in the landscape (Table 4). Community 5 had occurred on sites with gentle inclines, located on lower slopes and creeklines. Community 2 and 6 have higher coarse fragment abundance than Community 1, but similar to Community 3 and 5 (Table 4).

The three dimensional ordination (stress = 0.21) clearly separated the spinifex community (Community 6) from the other 5 communities. Community 6 sites plot in the lower left quadrant ordination (Figure 3). The species poor communities 4 and 5 are spread across the ordination indicating large variability in species composition between the quadrats, a result of low numbers of perennial species. Sites from the most common plant communities (1 and 2) across Jack Hills occur on the upper and lower right quadrants respectively, and overlay each other slightly with Community 3 occupying the centre of the ordination.

Altitude was strongly correlated with the communities ($P < 0.01$; Figure 3). Community 6 occurred higher in the landscape on the slopes and gullies between the highest peaks of the range, while at the opposite end of the gradient, Community 1 was found mainly on lower slopes and outwashes of the range. Magnesium and pH were strongly correlated in the ordination ($P<0.01$), with Community 1 having higher pH and magnesium than Communities 2 and 6, while Communities 3 and 5 showed intermediate values. Although significant in the post-hoc analysis, phosphorus was not correlated with the position of the sites in the ordination as the relationship was non-linear.

DISCUSSION

Flora

The number of taxa recorded was lower at Jack Hills, as was the occurrence of the Myrtaceae, when compared to

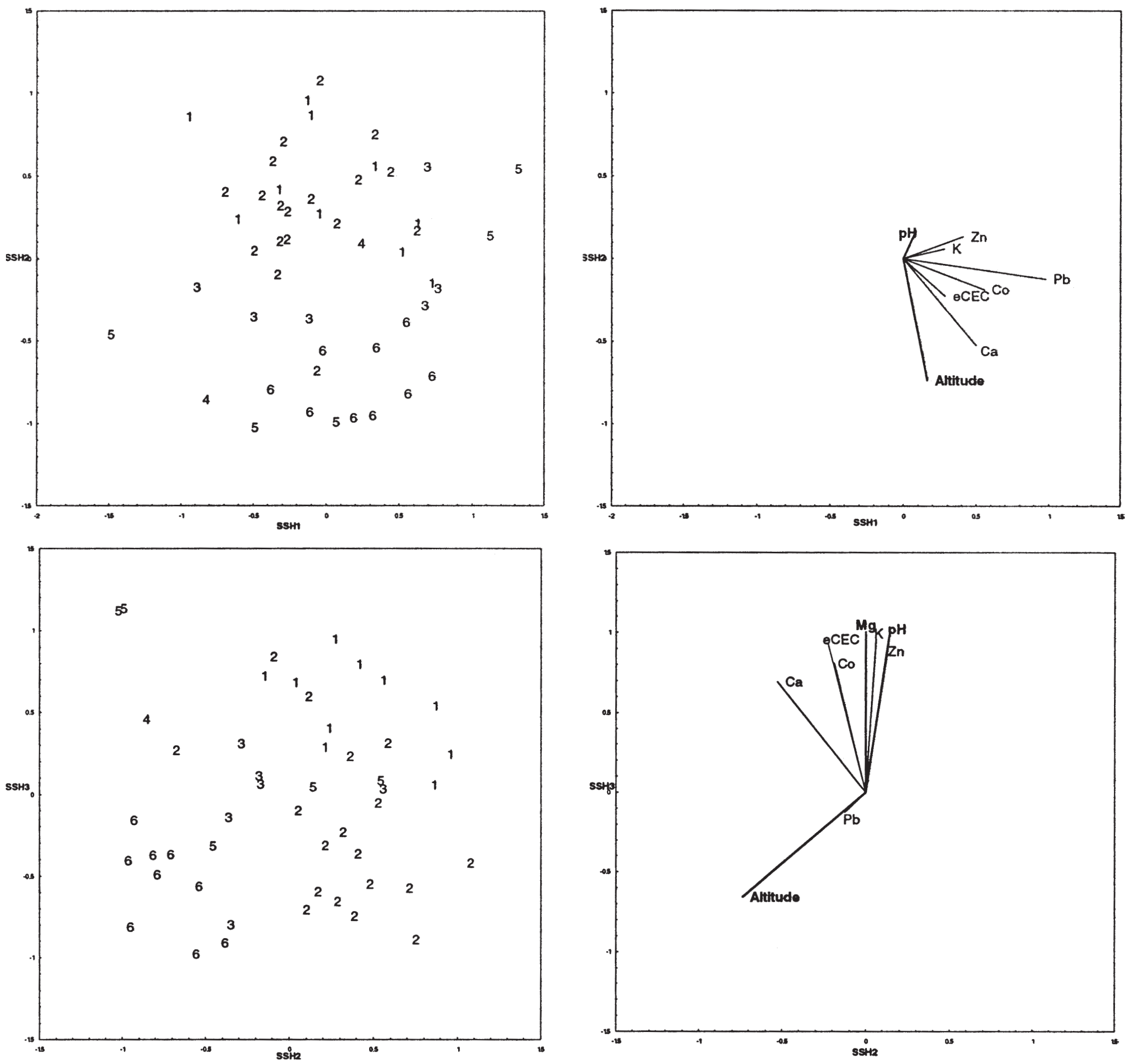

Figure 3. Three dimensional ordination showing Axis 1, 2 and 3 of the 50 quadrats established on Jack Hills and represented by community type. Lines represent the strength and direction of the best fit linear correlated variables. Bold and plain lines represent significance at P < 0.01 and P < 0.05 respectively.

studies on ranges in the eastern Goldfields (see Gibson et al. 2004b). The concurrent survey of the banded iron communities at Weld Range found 243 taxa (*cf.* 209 at Jack Hills) and similar patterns in dominant perennial families (Markey & Dillon, 2008). The shift in dominance of the perennial families from Myrtaceae in the goldfields to Mimosaceae and Myoporaceae reflects the greater aridity of Jack Hills (Beard 1976).

Annuals were a large component of the flora of Jack Hills, comprising over 50% of the species recorded, and this is similar to composition found at the Weld Range (Markey & Dillon, 2008). The season was good due to early rainfall, which encouraged the abundance of ephemeral species, indicated by the dominance of Asteraceae (41 taxa).

In the Jack Hills region, rainfall is bimodal resulting in different annual communities, grasses predominating following summer rainfall, and Asteraceae dominate the annuals following winter rain (Mott 1972). At any given time, perennials will always be present, but the abundance and composition of annuals will differ between years. Annuals were a significant component of the 2005 season because of above average rainfall and showed a different pattern from the perennial dataset.

Three new taxa were identified during the survey, a small herb, *L. heterophylla* subsp. Pilbara (R.Meissner & Y.Caruso 1), an aromatic shrub, *P. ferricola* and *A.* sp. Jack Hills (R. Meissner & Y. Caruso 4), with the latter found only on Jack Hills. *Lobelia heterophylla* subsp. Pilbara (R.Meissner & Y.Caruso 1) is found at several sites in the Pilbara and this complex is currently being reviewed. *Prostanthera ferricola* appears to be restricted to a smaller area from Weld Range to Doolgunna station. The current mining proposal would impact on several populations of these taxa.

Acacia sp. Jack Hills (R. Meissner & Y. Caruso 4) was the only endemic taxon to Jack Hills. This taxon was mainly found growing on ironstone in the spinifex community between Mount Matthew and Mount Hale (Community 6) and is currently known from only a few flowering specimens. Further taxonomic and genetic work needs to be undertaken to determine the relationship with *Acacia cockertoniana*, an ironstone endemic and its closest relative.

Plant Communities

Altitude appears to be the strongest environmental variable correlated with the distribution of the communities on the Jack Hills. Communities 1, 2 and 5 were all lower in the landscape. Community 1 occurred mainly on lower slopes and creeklines on soils of intermediate fertility, while Community 5 was found on colluvial outwashes of Jack Hills on lower phosphorus soils. Community 2 occurred, on crests and midslopes slightly higher in the landscape than 1 and 5. Community 3 was found at a higher altitude than Community 1, 2 and 5. This community was found mainly on the crests and midslopes sites, with high cover of surficial rock.

Altitude is possibly a correlate for other variables not recorded or recognised in the survey, such as soil depth and rock type. Skeletal soils and poor nutrients have previously been correlated with at higher elevations and topographic class (ie. crests and upper slopes) (Gibson & Lyons 1998a, 1998b). The presence of the communities (3 and 6) on the upper slopes and crests, and associated with higher surficial rock, may be related to the nutrient poorer soils, as indicated on the ordination (Figure 3).

Community 6, the species rich spinifex community, was restricted to higher elevations in the range, between Mount Matthew and Mount Hale. This community had the highest perennial species richness of all the communities found on the range. In addition, a number of species found in this community were not recorded elsewhere on the range. The community has a lower pH and nickel, but these values were not significantly different to several of the other communities. *Triodia* grasslands are the dominant vegetation in arid regions, occurring across the landscape in the Pilbara region to the north and in the eastern parts of the Murchison on sandplains (Beard 1976). Recent preliminary surveys have found spinifex communities on the upper slopes of Mount Gould and Robinson Ranges. All these communities are dominated by *T. melvillei*, but have different suites of perennial species e.g. *Acacia* sp. Jack Hills (R.Meissner & Y.Caruso 4) and *Halgania gustafsenni* occur only in the Jack Hills community (R. Meissner, unpublished data). Further surveys are needed to clarify their relationships to Community 6 on Jack Hills.

Early vegetation mapping in the Murchison region described the vegetation at a broad scale. Beard (1976) mapped the Weld Range and Jack Hills as the same vegetation unit, while Speck (1963) and Curry et al. (1994) mapped the ranges within the same landsystem. Vegetation on the Weld Range is quite distinct from Jack Hills with only 57% of the taxa recorded on Jack Hills found on the Weld Range, and the majority of the common taxa were annuals (Markey & Dillon, 2008). The landforms are morphologically similar, but geologically different, with the Weld Range dominated more by basalt.

The Weld Range had a higher number of perennial species and greater species richness than Jack Hills. There were no communities in common between the two ranges (Markey & Dillon, 2008). Both ranges are dominated by mulga (*Acacia aneura*) communities; however, the associated dominant species were different. For example, the dominant community (1b) on Weld range was characterised by *A. aneura*, *Acacia* sp. P129 and *G. berryana* over a shrub layer of *Eremophila* spp. (Markey & Dillon, 2008). Notably, *Acacia* sp. 129 and *Eremophila georgei* were not recorded on Jack Hills.

Mining exploration is continuing in the Jack Hills area. This is focussed especially in the area where the restricted upland spinifex community is found. If the current mining proposal proceeds approximately 20% of this community will be removed (Mattiske 2005). There is an urgent need to fully document the plant variation within this community. None of the communities identified in this survey is currently in a conservation reserve.

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Table 1

Sorted two-way table of quadrats established Jack Hills showing species by community type. Taxa shaded grey within a community are indicator species identified by INDVAL (Dufrene & Legendre 1997) at the 6 group level (* P< 0.05; ** P<0.01; statistical significance tested by randomisation procedures).

		Community Type 1	2	3	4	5	6
	SPECIES GROUP A						
*	*Abutilon oxycarpum*	•		••• (shaded)			
*	*Enneapogon caerulescens*	•••••• (shaded)	•	••			
**	*Acacia citrinoviridis*		••	•••••• (shaded)			•••
	Monachather paradoxus	••••	•••••••••	••••	•		
**	*Neurachne minor*	•	••	••••• (shaded)			
**	*Sida chrysocalyx* ms	••	•••••	•••••• (shaded)	•		•
*	*Cheilanthes brownii*	•	••••	••• (shaded)			
**	*Acacia aneura* cf. var. *aneura*	•••••	••••••••	••		••••• (shaded)	•
**	*Dodonaea petiolaris*	•••	•••••••••••••••• (shaded)				•
	Ptilotus schwartzii		•••••••••••	•••			••••
**	*Ptilotus obovatus* var. *obovatus*	•••••••••• (shaded)	••••••••••••••••• (shaded)	•••••• (shaded)	•		•••••••• (shaded)
	Solanum ashybii/lasiopetalum complex	••••••••	••••••••••••	••••	•	•	••
	Sida atrovirens	•••	•••••••••	•			•••••
	Acacia rhodophloia	••	••••••••		•	•	•
	SPECIES GROUP B						
	Corchorus crozophorifolius	•	•••				
	Eragrostis lanipes	•	•				
	SPECIES GROUP C						
	Acacia aneura cf. var. *tenuis*		•••		•	••	•
	Eremophila glutinosa	•			•	•	
*	*Maireana villosa*		•		• (shaded)		
	SPECIES GROUP D						
*	*Acacia kempeana*		••		• (shaded)		
	Maireana georgei		••				
	Acacia tetragonophylla	•••	•				
	Eragrostis eriopoda	•	•••••			•	
	SPECIES GROUP E						
**	*Acacia stowardii*		••		•• (shaded)		•
	Sclerolaena eurotioides	••••	•		•	•	
	Senna artemisioides subsp. *helmsii*	••			•		
**	*Senna glaucifolia*	••			•• (shaded)		
	SPECIES GROUP F						
	Acacia pruinocarpa	•					•
	Sida ectogma	•					•
	Acacia ramulosa var. *linophylla*	••••		••		•	
	Sida aff. *intricata* (R.Meissner & Y.Caruso 119)	••					
	SPECIES GROUP G						
	Cymbopogon ambiguus		•	•		•	•
	Tribulus suberosus		••		•	•	
	Maireana melanocoma		•			•	
	Thysanotus speckii		•			•	
*	*Eremophila macmillaniana*	••				•••• (shaded)	
	Eremophila phyllopoda subsp. *phyllopoda*	•				••	
	Maireana triptera	•				•	
	Sclerolaena eriacantha	••	•			••	
	Senna stricta x artemesioides subsp. *petiloaris* (E.N.S. Jackson 2888)					••	
	Senna sp. Meekatharra (E. Bailey 1-26)		•			••	
	SPECIES GROUP H						
	Acacia aneura cf. var. *microcarpa*	•	•••				••
	Aluta aspera subsp. *hesperia*						••
	Mirbelia rhagodioides		••				•••
*	*Acacia* sp. Jack Hills (R. Meissner & Y. Caruso 4)		•	•			••••• (shaded)
	Thryptomene decussata		•••••	•			••••
	Eremophila latrobei subsp. *latrobei*	•••	••	••		•	••••
*	*Cheilanthes sieberi* subsp. *sieberi*		••	•		•	•••••• (shaded)
*	*Thysanotus manglesianus*		•	••			••••••• (shaded)
*	*Halgania gustafsenii* var. *gustafsenii*		••••	•			••••••• (shaded)
**	*Hibiscus sturtii* var. *forrestii*		••				•••••••• (shaded)
**	*Triodia melvillei*						••••••••• (shaded)
*	*Philotheca brucei* subsp. *cinerea*						••••• (shaded)
*	*Eremophila jucunda* subsp. *jucunda*		•				••••• (shaded)
*	*Grevillea berryana*	•			•		•••••• (shaded)
*	*Eremophila exilifolia*						•••• (shaded)
	Prostanthera sp. Murchison (G.Byme 239)						•••
	Psydrax latifolia						••
	Wurmbea inframediana						••

Table 2

Spearman's rank correlation for soil chemistry and physical site parameters. Numbers show indicate strong correlation between variables (P < 0.05).

	ECEC	pH	B	Ca	Cd	Co	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Pb	S	Zn	Altitude	Aspect	Slope	CF Abundance	Max size
ECEC																							
pH	0.72																						
B																							
Ca	0.90	0.69																					
Cd																							
Co	0.64	0.66		0.55	0.32																		
Cu	0.31				0.41																		
Fe	0.47			0.55																			
K	0.62	0.32		0.43			0.30	0.37															
Mg	0.88	0.68		0.68		0.74			0.48														
Mn	0.60	0.64		0.53		0.83	0.37			0.63													
Mo			0.56																				
Na	0.62		-0.29	0.45			0.36	0.36	0.62	0.52		-0.31											
Ni	0.50	0.43		0.37		0.79				0.68	0.47												
P						-0.33		0.47	0.58														
Pb						0.28					0.30		0.36		-0.30								
S		-0.42				-0.39	0.36		0.29				0.43	-0.37	0.30								
Zn	0.69	0.48		0.59		0.43		0.43	0.66	0.54	0.45	-0.30	0.40	0.31	0.38								
Altitude		-0.46				-0.35		0.39		-0.36				-0.38			0.59						
Aspect	0.33			0.32																			
Slope								0.52	0.39								0.29	0.33	0.46				
CF Abundance								0.29											0.35		0.52		
Max size								0.48	0.46						0.61		0.30	0.45	0.39		0.66	0.37	
RO_Abundance		-0.29				-0.40		0.42						-0.30	0.52		0.52		0.39				0.42
Runoff	0.34			0.43				0.44													0.48	0.41	
%LeafLitter																			-0.34		-0.31		-0.34
%Bare Ground								0.29											0.40				

Table 3

Plant community mean values for soil chemistry parameters (measured in mg/kg except eCEC and pH). Differences between ranked values tested using Kruskall –Wallis non-parametric analysis of variance. Community 4 was excluded from analysis due to small sample size. Standard error in parentheses. a,b denote significant difference between groups by post hoc test (P < 0.05). (P = probability, n = number of quadrats, ns = not significant).

	Community Type						
	1	2	3	4	5	6	P
eCEC	2.1 (0.2)	1.5 (0.1)	2.0(0.4)	2.0 (0.2)	1.8 (0.2)	1.6 (0.2)	ns
pH	**5.2 (0.1)[a]**	**4.5 (0.1)[b]**	**4.6 (0.2)[ab]**	4.6 (0.1)	**4.9 (0.3)[ab]**	**4.4 (0.1)[b]**	**< 0.01**
P	**18.5 (6.8)[ab]**	**16.7 (1.5)[b]**	**21.0 (3.6)[b]**	11.5 (4.5)	**6.2 1.2)[a]**	**12.1 (2.6)[ab]**	**< 0.01**
K	160.3 (21.1)	143.2 (10.8)	186.5 (29.3)	200.0 (30.0)	103.6 (10.0)	110.1 (8.4)	ns
Mg	**77.2 (9.7)**	**54.6(4.5)**	**68.2(15.5)**	79.0(19.0)	**96.6(13.5)**	**49.7(8.9)**	**0.03**
Ca	202.6 (20.4)	132.6 (10.0)	185.3 (37.1)	145.0 (15.0)	151.0 (21.0)	177.2 (26.5)	ns
B	0.5 (0.0)	0.6 (0.1)	0.5 (0.0)	0.5 (0.0)	0.5 (0.0)	0.7 (0.1)	ns
Cd	0.01 (0.0)	0.01 (0.0)	0.01 (0.0)	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)	ns
Co	**0.7 0.1)**	**0.3 (0.1)**	**0.3 (0.1)**	1.4 (0.9)	**1.5 (0.5)**	**0.6 (0.2)**	**0.01**
Cu	**0.6 (0.0)**	**0.6 (0.0)**	**0.7 (0.0)**	0.7 (0.2)	**0.5 (0.1)**	**0.6 (0.0)**	**0.05**
Fe	**38.8 (6.1)[ab]**	**35.7 (2.1)[a]**	**45.2(4.8)[ab]**	35.5 (0.5)	**35.6 (2.0)[ab]**	**46.9 (3.3)[b]**	**0.04**
Mn	**47.2 (5.0)**	**29.7 (4.2)**	**31.8 (6.5)**	**45.5 (17.5)**	**59.0 (13.6)**	**42.8 (10.0)**	**0.03**
Mo	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)	ns
Na	12.0 (5.6)	5.1 (0.8)	11.7 (4.7)	17.0 (5.0)	5.4 (1.1)	4.4 (0.5)	ns
Ni	**0.3 (0.1)[ab]**	**0.3 (0.1)[ab]**	**0.2 (0.1)[b]**	1.0 (0.3)	**0.8 (0.1)[a]**	**0.3 (0.1)[b]**	**0.02**
Pb	0.5 (0.0)	0.4 (0.0)	0.5 (0.0)	0.6 (0.2)	0.5 (0.1)	0.5 (0.0)	ns
S	**7.9 (4.1)[a]**	**5.8 (0.6)[ab]**	**10.0 (1.9)[b]**	9.0 (4.0)	**2.6 (0.7)[a]**	**6.6 (0.4)[ab]**	**< 0.01**
Zn	2.6 (0.4)	1.8 (0.2)	2.2 (0.5)	2.3 (0.5)	1.6 (0.3)	1.7 (0.2)	ns
n=	10	18	6	2	5	9	

Table 4

Plant community mean values for physical site parameters; altitude (m above sea level); aspect (16 cardinal directions), slope (degrees), coarse fragment (CF) abundance (0 – no coarse fragments to 6 very abundant coarse fragments), Maximum size of coarse fragments (1 – fine gravely to 7 large boulders), rock outcrop (RO) abundance (0 – no bedrock exposed to 5 – rockland), runoff (0 – no runoff to 5 – very rapid), % leaf litter and bare ground (1 – >70%, 2 – 30–70%, 3 – <10% 0 – <0 % cover). Differences between ranks tested using Kruskall –Wallis non-parametric analysis of variance. Standard error in parentheses. a, b, c indicate significant difference between groups by post hoc test (P < 0.05). (n = number of quadrats, P = probability, ns = not significant). Community 4 excluded from the analysis due to small sample size.

	Community Type						
	1	2	3	4	5	6	P
Altitude	**401 (0.1)[bc]**	**418 (0.0)[bc]**	**442 (0.2)[ac]**	413 (0.0)	**389 (0.0)[b]**	**548 (0.2)[a]**	**<0.01**
Aspect	6.1 (3.2)	5.9 (5.2)	5.3 (11.8)	6.0 (12.5)	5.8 (2.3)	6.9 (16.0)	ns
Slope	**7.2 (1.2)**	**10.8 (0.4)**	**12.5 (0.3)**	1.5 (0.0)	**3.6 (1.7)**	**15.0 (1.2)**	**0.02**
CF Abundance	**3.0 (3.0)[a]**	**4.2 (1.7)[b]**	**4.0 (2.4)[ab]**	4.5 (0.5)	**3.6 (1.3)[ab]**	**4.7 (2.7)[b]**	**<0.01**
Max. Size	4.0 (0.4)	5.2 (0.2)	5.0 (0.3)	4.5 (0.5)	3.6 (0.2)	5.1 (0.2)	ns
RO Abundance	1.0 (0.5)	1.3 (0.2)	2.8 (0.6)	0.5 (0.5)	0.4 (0.9)	1.4 (0.2)	ns
Runoff	1.9 (0.4)	2.2 (0.3)	2.3 (0.5)	1.0 (0.5)	2.2 (0.4)	2.4 (0.6)	ns
%Leaf Litter	**1.4 (0.5)**	**1.1 (0.2)**	**1.0 (0.2)**	1.0 (0.0)	**1.0 (0.2)**	**1.0 (0.3)**	**0.02**
% Bare Ground	**1.2 (0.2)**	**1.0 (0.1)**	**1.3 (0.0)**	1.0 (0.0)	**1.0 (0.0)**	**1.7 (0.0)**	**<0.01**
n=	10	18	6	2	5	9	

APPENDIX 1

Flora list for Jack Hills, including all taxa from the sampling quadrats and adjacent areas. Nomenclature follows Paczkowska and Chapman (2000), * indicates introduced taxon.

Adiantaceae

Cheilanthes brownii
Cheilanthes sieberi subsp. *sieberi*

Aizoaceae

Gunniopsis aff. *divisa (*R.Meissner & Y.Caruso 125)
Gunniopsis propinqua
Tetragonia cristata
Trianthema glossostigma

Amaranthaceae

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

Anthericaceae

Thysanotus manglesianus
Thysanotus speckii

Apiaceae

Daucus glochidiatus
Trachymene ceratocarpa
Trachymene ornata
Trachymene pilbarensis
Asclepiadaceae
Marsdenia australis
Asphodelaceae
Bulbine semibarbata

Asteraceae

Actinobole drummondianum
Actinobole oldfieldianum
Actinobole uliginosum
Brachyscome cheilocarpa
Brachyscome ciliocarpa
Brachyscome iberidifolia
Calocephalus sp.
Calocephalus knappii
Calocephalus multiflorus
Calocephalus sp. Pilbara-Desert (M.E. Trudgen 11454)
Calotis hispidula
Calotis multicaulis
Cephalipterum drummondii
Chthonocephalus pseudevax
Chthonocephalus viscosus
Dielitzia tysonii
Erymophyllum ramosum subsp. *ramosum*
Gnephosis arachnoidea
Gnephosis brevifolia
Gnephosis tenuissima
Helipterum craspedioides
Hyalochlamys globifera
Lawrencella davenportii
Myriocephalus rudallii
Podolepis gardneri
Podolepis kendallii
Pogonolepis stricta
Rhodanthe battii
Rhodanthe charsleyae
Rhodanthe chlorocephala subsp. *splendida*
Rhodanthe citrina
Rhodanthe floribunda
Rhodanthe maryonii
Rhodanthe polycephala
Schoenia cassiniana
Streptoglossa liatroides
Taplinia saxatilis

Boraginaceae

Halgania gustafsenii var. *gustafsenii*
Heliotropium heteranthum
Brassicaceae
Lepidium oxytrichum
Menkea villosula
Stenopetalum anfractum
Stenopetalum filifolium

Caesalpiniaceae

Petalostylis labicheoides
Senna artemisioides subsp. *helmsii*
Senna glaucifolia
Senna glutinosa subsp. *x luerssenii*
Senna sp. Meekatharra (E. Bailey 1–26)
Senna stricta x *artemesioides* subsp. *petiolaris* (E.N.S. Jackson 2888)

Campanulaceae

Wahlenbergia tumidifructa

Caryophyllaceae

Polycarpaea corymbosa

Chenopodiaceae

Chenopodium melanocarpum
Dysphania rhadinostachya subsp. *inflata*
Dysphania rhadinostachya subsp. *rhadinostachya*
Maireana carnosa
Maireana georgei
Maireana melanocoma
Maireana triptera
Maireana villosa

Sclerolaena eriacantha
Sclerolaena eurotioides

Colchicaceae

Wurmbea densiflora
Wurmbea inframediana

Convolvulaceae

Convolvulus clementii

Crassulaceae

Crassula colorata var. *acuminata*

Cuscutaceae

**Cuscuta epithymum*
**Cuscuta planiflora*

Euphorbiaceae

Euphorbia boophthona
Euphorbia drummondii subsp. *drummondii*
Phyllanthus erwinii

Geraniaceae

Erodium cygnorum

Goodeniaceae

Brunonia australis
Goodenia berardiana
Goodenia havilandii
Goodenia occidentalis
Goodenia tenuiloba
Velleia glabrata
Velleia hispida

Haloragaceae

Haloragis trigonocarpa

Lamiaceae

Lamiaceae sp.
Prostanthera ferricola

Lobeliaceae

Lobelia heterophylla subsp. Pilbara (R. Meissner & Y. Caruso 1)

Malvaceae

Abutilon fraseri
Abutilon oxycarpum
Abutilon sp. (R.Meissner & Y.Caruso 136)
Hibiscus sp. (R.Meissner & Y.Caruso 123)
Hibiscus sturtii var. *forrestii*
Sida aff. *intricata* (R.Meissner & Y.Caruso 119)
Sida atrovirens
Sida chrysocalyx
Sida ectogama

Mimosaceae

Acacia aneura cf. var. *aneura*
Acacia aneura cf. var. *microcarpa*
Acacia aneura cf. var. *tenuis*
Acacia aneura
Acacia citrinoviridis
Acacia sp. Jack Hills (R.Meissner & Y.Caruso 4)
Acacia cuthbertsonii subsp. *cuthbertsonii*
Acacia demissa
Acacia distans
Acacia kempeana
Acacia pruinocarpa
Acacia ramulosa var. *linophylla*
Acacia rhodophloia
Acacia stowardii
Acacia synchronicia
Acacia tetragonophylla

Myoporaceae

Eremophila compacta subsp. *fecunda*
Eremophila exilifolia
Eremophila forrestii subsp. *forrestii*
Eremophila fraseri subsp. *fraseri*
Eremophila fraseri subsp. *parva*
Eremophila glutinosa
Eremophila jucunda subsp. *jucunda*
Eremophila lachnocalyx
Eremophila latrobei subsp. *latrobei*
Eremophila macmillaniana
Eremophila phyllopoda subsp. *phyllopoda*
Eremophila spathulata

Myrtaceae

Aluta aspera subsp. *hesperia*
Calytrix desolata
Homalocalyx echinulatus P3
Thryptomene decussata

Nyctaginaceae

Boerhavia coccinea

Papilionaceae

Glycine sp. (R.Meissner & Y.Caruso 110)
Indigofera australis
Mirbelia rhagodioides
Swainsona leeana
Swainsona rotunda

Plantaginaceae

Plantago aff. *hispida* (R.Meissner & Y.Caruso 112)

Poaceae

Aristida contorta
Cymbopogon ambiguus
Digitaria brownii
Enneapogon caerulescens
Eragrostis dielsii
Eragrostis eriopoda
Eragrostis lanipes
Eragrostis pergracilis
Eriachne aristidea

Eriachne helmsii
Eriachne pulchella subsp. *pulchella*
Monachather paradoxus
Neurachne minor
Paspalidium clementii
**Rostraria pumila*
Triodia melvillei
Tripogon loliiformis

Polygalaceae

Polygala isingii

Portulacaceae

Calandrinia cf. *creethae*
Calandrinia creethae
Calandrinia disperma
Calandrinia eremaea complex
Calandrinia sp. The Pink Hills (F. Obbens FO19/06)
Calandrinia polyandra
Calandrinia ptychosperma
Calandrinia remota
Calandrinia translucens
Portulaca oleracea

Proteaceae

Grevillea berryana
Hakea lorea subsp. *lorea*
Hakea preissii

Rhamnaceae

Stenanthemum petraeum

Rubiaceae

Psydrax latifolia
Psydrax suaveolens
Synaptantha tillaeacea var. *tillaeacea*

Rutaceae

Philotheca brucei subsp. *cinerea*
Philotheca sericea

Sapindaceae

Dodonaea pachyneura
Dodonaea petiolaris

Solanaceae

Nicotiana occidentalis subsp. *obliqua*
Nicotiana rosulata subsp. *rosulata*
Solanum ashbyae
Solanum lasiophyllum

Stackhousiaceae

Stackhousia muricata

Tiliaceae

Corchorus crozophorifolius

Zygophyllaceae

Tribulus aff. *adelacanthus* (R.Meissner & Y.Caruso 115)
Tribulus suberosus
Tribulus terrestris
Zygophyllum eichleri
Zygophyllum kochii
Zygophyllum simile