Flora and vegetation of calcrete palaeodrainage channels in the north eastern Goldfields

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ABSTRACT

Large salt lakes are distinctive features in the West Australian landscape and are all that remains of ancient rivers systems, in conjunction with the drainage channels that connect them. Calcrete, or calcium carbonate, forms in these palaeodrainange channels under conditions of high evaporation and low evapo-transpitation and within the calcrete are highly prospective deposits of uranium. This paper describes the flora and vegetation on eight calcrete palaeodrainage channels within the northern goldfields in the Murchison IBRA and compared four plant communities, Acacia and Melaleuca shrublands, *Casuarina* and *Eucalyptus* woodlands between each palaeochannels. The calcrete vegetation was species poor and few endemic or rare taxa were recorded. Similarities in community composition were not consistent with palaeodrainage systems but between neighbouring calcrete paleochannels suggesting that the calcrete were colonised by species from the surrounding landscape pre-adapted to high pH conditions. Low beta diversity and endemism indicate that

conflicts between resource development and conservation values are unlikely to be significant.

INTRODUCTION

The extensive network of drainage channels and large playa lakes are visible features of ancient river systems in the Western Australian arid landscape. These ancient river systems, or palaeorivers, formed under climatic conditions much wetter than those today in arid Australia (65 – 25 mya), with the palaeovalleys infilled predominantly with Cenozoic sediments. Although the palaeorivers do not act as modern rivers, they are still active and important groundwater systems that support unique communities of plants and animals. Beard (1973) noted in the course of mapping the vegetation of Western Australia that the drainage lines and valleys were frequently distinguishable by the particular vegetation that grew along them. This paper aims to describe the communities found within these palaeodrainage channels, with specific focus upon the communities occurring on the calcrete units.

Calcrete formation

The palaeodrainage channels are composed of early to mid Cenozoic sedimentary deposits grading from fluvial and lacustrine deposits to interfingering sequence of alluvium and colluvium. These upper sediments, under favourable climatic conditions, have been locally replaced or displaced by calcium carbonate, or calcrete deposits (Johnson *et al*. 1999). Within these drainage systems, calcretes are formed at the down stream end of an individual drainage channel and immediately upstream from an evaporation outflow area such as a salt lake (Morgan 1993). Within the study area, groundwater calcrete occur preferentially in the midlines and downstream areas of large low-gradient drainage basins (Mann & Horwitz 1979).

The calcrete present in the northern goldfields is derived from groundwater sources which, in many of the calcrete systems, lie at depths of 2-5m below the surface (Mann & Horwitz 1979). The formation or modification of calcrete is continual and because of this continual process groundwater calcretes can grow and expand to more than 10m thick (Mann & Horwitz 1979). Groundwater calcretes are usually mounded, attributed to the increase on the volume of solid material as calcium carbonate precipitates from solution (Mann & Horwitz 1979).

Within the northern goldfield of Western Australia, groundwater calcrete only occurs north of a boundary called the Menzies Line, at 30ºS latitude (Mann & Horwitz 1979). South of this latitude, prevailing environmental conditions combine to make it non-conducive for calcrete formation. Calcrete is a product of current arid climate that began in the Neogene (~23 mya). Climatic conditions are important for calcrete development as under conditions of continual excess moisture any accumulated carbonate tends to be dissolved and removed from the profile and eventually the landscape, rather than to be concentrated at a particular site (Mann & Horwitz 1979). Key to calcrete formation is the presence of suitable aquifer for the transportation of calcium and carbonate ions, and high evaporation and evapo-transpirations rates that are essential for concentration of calcium ion concentrations in the groundwater required for direct chemical precipitation of carbonate (Mann & Horwitz 1979).

In the early 1970s, a significant deposit of uranium within the calcrete deposits was discovered at Yeelirrie. This spurred additional exploration for uranium within other palaeodrainage channels and consequently other deposits were found at Lakeway and Lake Maitland (Ferguson 1998). Uranium hosted in calcrete is the dominant type of uranium mineralization within Western Australia accounting for 3.5% of Australia's uranium resources (Lambert *et al*. 2005) and the occurrences are concentrated in the northeast of the Yilgarn Craton (Roberts & Flint 2009).

Two forms of uranium are found within the calcrete, evaporative uranium deposits in carbonate/gypsum deposits such as Lake Maitland and Lakeway at the head of the Carey palaeovalley; and uranium enrichment in the form of carnotite within calcrete such as is found at Yeelirrie (Butt *et al* 1977). The source of uranium is considered to have been from the weathering granite bedrock which was transported laterally in groundwater and depositied in an oxidising environment (Anand & Butt 2010).

Study Area

The northern goldfield region in this study extends from Lenister in the south to Wiluna and Meekatharra in the north (Figure 1). Eight sites of calcrete were surveyed within the northern goldfield and all were located within larger palaeodrainage systems. In the northern goldfields, the palaeodrainage systems can be separated into east or west draining systems. The east drainage system drains into the Eucla basin on the Nullabor plain while the western drainage into the Murchison River system, and eventually into the Indian Ocean. In addition, the palaeodrainage networks can be divided further into three different palaeodrainage systems. All of the calcretes within this study, except for Nowthanna and Lake Mason, occur as part of the Carey palaeovalley (Magee 2009). Lake Mason is part of the Raeside paeleovalley while Nowthanna is part of a paleaodrainage system that drains eastward via Lake Annean and is part of the Murchison River catchment (Magee 2009). The Carey & Raeside paleovalleys drain eastward to the Nullarbor.

Climate

The northern goldfields, or the study area, covers an area of approximately 61, 000 km^2 and lies between the latitudes 26º20" S and 27º50" S (Figure 1). The rainfall pattern grades from a bimodal summer winter rainfall in the east towards a summer dominated rainfall pattern with mean ranging from 233.0 mm at Meekatharra (1944-2011) to 255.6 mm at Wiluna (1898-2011). Mean evaporation per day 16.2 mm per day (Meekatharra) and 11mm (Wiluna).

Vegetation

The calcrete formations described in this paper are located within the Murchison Bioregion. The bioregionis characterised by low hills and mesas separated by flat colluvium and alluvial plains, predominantly vegetated by low mulga (*Acacia aneura*) woodlands. Within the Murchison, Beard (1976) broadly characterised the palaeodrainage channels as succulent steppe of Mulga (*Acacia aneura*) and wattles (*Acacia* spp.) with saltbush (*Atriplex* spp.) or bluebush (*Maireana* spp.).

The Department of Agriculture has conducted several rangeland condition surveys within the study area and have mapped the regions in terms of land systems (Curry *et al*. 1994, Payne *et al*. 1998, Pringle *et al*. 1998). A land system describes a combination of landform, soil and vegetation that occur in a recurring pattern across the landscape (Pringle *et al*. 1994). Cunyu and Mileura are the main land systems that describe the numerous palaeodrainage channels in the study area, the Melaleuca and Cosmo comprise other minor systems.

Within the land systems, the calcrete formations are described as a combination of different landform types; calcrete platforms, characterised as gently undulating rises of calcrete, with calcrete rubble and outcrops; the platforms grade into calcrete plains, which are level to gently undulating plains with calcrete rubble and calcrete outcrops; and drainage lines and drainage foci, occurring as a mosaic within the calcrete platforms and plains that collect run-off from surrounding plains (Pringle *et al*. 1994).

On the calcrete platforms and plains, there were four vegetation units based upon a structural classification, which were present on most calcrete palaeodrainage channels. The units are *Acacia burkittii* shrublands predominantly found on the calcrete platform; *Casuarina pauper* woodlands and *Eucalyptus* woodlands on the calcrete platforms and plains; and *Melaleuca* shrublands, fringing the drainage foci or drainage lines.

The calcrete formations are not continuous plains or platforms but are mosaics with hardpan plains (red sand on hardpan) occur in pockets within the calcrete plains. These are generally characterised by *Acacia aneura* shrublands and wanderrie grass (*Eragrostis eriopoda* and *E. helmsii*) (Pringle 1994).

Aims

Previous studies on the Banded Ironstone Ranges within the Yilgarn Craton, encompassing the northern goldfields, have shown high levels of beta diversity between ranges as a result of both varying species richness and uniformly high species turnover (Gibson *et al*. in review). In addition, recent discoveries of new and range-limited taxa identified on a calcrete system, provided the impetus to test if similar levels of endemisim and species turnover also occur on the calcrete systems.

With the widespread distribution of calcrete formations within the study area (Figure 1) and the potential for mining the uranium resource within the formation, it is important to have an understanding of the vegetation occurring on these formations. The main aims were to compare vegetation between calcrete paleochannels and determine if each calcrete unit had unique flora or plant communities, and to determine if patterns in biodiversity were similar to those found on ironstone ranges within the Yilgarn.

METHODS

One hundred and thirty-five 20 x 20 m quadrats were established on the exposed calcrete paleochannels in the Yilgarn Craton (Figure 1). Eight paleochannels were surveyed from August to November 2010. Within the paleochannels there were four consistent structural vegetation units, *Eucalyptus* woodland, *Casuarina pauper* woodland, *Melaleuca* shrubland and *Acacia burkittii* shrublands. At least five quadrats were established in each vegetation unit, when present, at each paleochannels.

Quadrats were permanently marked with a steel star picket with a plaque in one corner and three steel fence droppers in the remaining corners. The positions at the star picket were determined using a Global Positioning System (GPS) unit. All vascular plants within the quadrat were recorded and collected for later identification. A total of six hundred and seventy specimens have been lodged at the Western Australian Herbarium representing two specimens of each taxa and all collections of priority taxa and range extensions.

Data on topographical position, disturbance, abundance, size and shape of coarse fragments on the surface, the abundance of rock outcrops (defined as the cover 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 stratum (tall, mid and lower). The quantitative data were used to describe the plant communities following McDonald *et al.* (1990).

Twenty soil samples were collected from the upper 10 cm of the soil profile within each quadrat. The samples were bulked and the 2 mm fraction extracted using the Mehlich No. 3 procedure (Mehlich 1984). The extracted samples were analysed for Organic carbon, nitrogen, magnesium, sodium, phosphorus, calcium, electrical conductivity (EC) and pH. Methods for soil analysis are fully described in Meissner & Wright (2010).

To test if vegetation communities differ was between calcrete paleochannels and if the vegetation communities were different from each other, the presence–absence community data was analysed using permutational multivariate analysis of variance (PERMANOVA; Anderson 2001, McArdle & Anderson 2001). The overall experimental design consisted of two factors, location (fixed with 8 palaeodrainage channels) and vegetation (fixed with four vegetation types). Significant terms and interactions were investigated using *a posteriori* pair-wise comparisons with the PERMANOVA t-statistic and 999 permutations. To visualise the patterns in the community data non-metric multidimensional scaling (MDS) was produced based on a Bray-Curtis similarity matrix (Clarke & Warwick 2001).

To determine the environmental variable that best explain the community pattern, the BEST analysis using BIOENV algorithm in PRIMER v6 (Clarke & Gorley 2006) was undertaken on a Euclidean Distance resemblance matrix based on normalised environmental data. Prior to normalisation, EC, organic carbon, nitrogen, magnesium, sodium, phosphorus and calcium was transformed using log(x +1). The BEST routine selects environmental variables, or that best explain the community pattern, by maximising a rank correlation between their respective resemblance matrices (Clarke & Warwick 2001). In the BIOENV algorithm, all permutations of the following environmental variables were tried and the five best variables selected. The environmental variable were then fitted to the MDS ordination using Spearman rank correlation values ($r > 0.6$) to determine linear relationships between the variables and the vegetation communities

RESULTS

Flora

A total of 186 flora were recorded from the quadrats established on the eight palaeodrainage channels with 32 species collected opportunistically (Appendix). Approximately 37 % of the taxa collected were annuals and approximately 30% of the taxa were recorded in only one plot. The number of perennial taxa recorded at each calcrete location ranged from 60 taxa at Lake Darlot and Lake Miranda to 38 taxa at Paroo (Appendix).

Mean species richness ranged from a mean of 4.8 taxa per plot in *Acacia burkittii* shrublands from Nowthanna to 12 taxa per plot from *Eucalyptus* woodlands from Lake Darlot. The best represented families were Asteraceae (27 taxa, mainly annuals), Chenopodiaceae (43 taxa), Fabaceae (34 taxa), Poaceae (17) and Scrophulariaceae (18 taxa). The dominant taxa are typical of arid zone flora, with *Acacia* (21 taxa) the most common genus recorded. *Eremophila* (18 taxa), *Sclerolaena* (10 taxa), *Senna* (9 taxa) and *Maireana* (8 taxa) were the next best represented genera within the collections.

Priority Flora

Four priority taxa were recorded during the survey.

Ptilotus lazaridis (P3) is a climbing shrub found growing intertwined among larger shrubs. It is restricted to the upper Murchison River catchment around Meekatharra in the floodouts between calcrete platforms. In this survey, it was collected from Nowthanna calcrete in the *Eucalyptus* woodland vegetation unit.

Atriplex sp. Yeelirrie Station (L. Trotter &A. Douglas LCH 25025) (P1) was an opportunistic collection found growing on self-mulching clays. This taxon is known from only two populations, both occurring within the Yeelirrie mining lease. It is described as a rounded divaricately branched, predominantly dioecious perennial shrub, to 0.4 m high. It has small ovate blue-green (Western Botanical 2010).

Rhagodia sp. Yeelirrie Station (K.A. Shepherd et al. KS 1396) (P1) is a compact shrub to 2m growing in the shallow depressions in red clay found in only a few locations within the north eastern goldfields. This was an opportunistic collection from the Yeelirrie mining lease.

Eremophila arachnoides subsp. *arachnoides* (P3) is a broom like shrub usually 2 to 3.5 m tall, with purple flowers. It is superficially similar to *Eremophila pantonii* but can be distinguished by regular rows of tubercles below the petiole. These two species can co-occur but in this survey they were found on different calcrete paleochannels. *Eremophila arachnoides* subsp. *arachnoides* was found at Lake Mason, Lakeway and Yeelirrie.

Calcrete Endemic Flora

There were 5 endemic taxa recorded from the survey, with *Eremophila arachnoides* subsp. *arachnoides* (P3). *Atriplex* sp. Yeelirrie Station (L. Trotter &A. Douglas LCH 25025), *Rhagodia* sp. Yeelirrie Station (K.A. Shepherd et al. KS 1396) and *Ptilotus lazaridis* already discussed.

Eragrostis sp. Yeelirrie Calcrete (S. Regan LCH 26770) is a small grass 5 to 15 cm tall forming small mounds. This species was most commonly found associated with *Eucalyptus* woodlands, but was also found associated with *Acacia burkittii* shrublands at Lake Maitland. The species was initially found at Yeelirrie in 2010 but has been found to be more widespread across the region, but only on the calcrete palaeodrainage channels.

Range Extensions

In addition to priority and endemic flora, four taxa had significant range extensions (>200km from nearest known population).

Austrostipa eremophila is a perennial tussock grass to 80cm with a distinct orange seed. It was recorded from Yeelirrie, Lake Miranda and Lake Darlot, with the nearest population found at Lake Goongarrie, 260km south of Lake Miranda.

Dysphania sphaerosperma is an annual chenopod to 80cm, commonly found around salt lakes on gypseous or calcareous soil. In this survey, it was collected from Lake Maitland, with the nearest population recorded from Beyondie Lakes, 280 km north of Lake Maitland.

Sclerolaena symoniana is a low chenopod shrub to 30 cm, with the nearest population 620 km north east at Vander Linden Lakes in the Central Desert. In this survey it was recorded from Lake Maitland.

Sida spodochroma is a prostrate perennial shrub to 30cm commonly found growing on red clay over limestone. This species was commonly found on five of the calcrete paleochannels surveyed. The nearest population was 250 km south of Lake Mason.

Floristics

The PERMANOVA showed significant differences in composition between locations, vegetation units and a significant vegetation x location interaction (Table 1). While the vegetation units were compositionally distinct at all locations compared, there were distinct differences in the compositional patterns of the individual vegetation units across the palaeodrainage channels (Figure 2). Lack of replication did not allow three vegetation comparisons at each of two locations.

The *Acacia burkittii* shrublands were found at all locations, and it was compositionally different at most locations except for some adjacent systems (Yeelirrie was similar to Lake Miranda, Lakeway, and Nowthanna; and Paroo was similar to Lakeway and Nowthanna). In addition no significant difference in composition was found between Nowthanna and Lake Maitland on opposite sides of the study area (Figures 1 & 2). The *Acacia* structural unit generally occurred in the upper part of the palaeodrainage channels on the calcrete platforms or mounds, and further away from the discharge into the salt lakes.

Eucalyptus woodlands were found at all locations except Lake Maitland. It was compositionally different between all locations except Lake Miranda which was similar to the adjacent Lake Mason and Lake Darlot. The dominant species of *Eucalyptus* was one of three, *Eucalyptus gypsophila*, *E. striaticalyx* and *E. eremicola* subsp. *peeneri*. The first two taxa are closely related occurring in series that also includes *E. clelandii*. This vegetation type generally occurred on the calcrete plains where the palaeodrainage channel enters a salt lake or playa.

The *Melaleuca* shrubland was the most species poor vegetation type and was not recorded at Lake Darlot, Lake Maitland or Paroo. It was the most compositionally uniform with only Lakeway being compositionally different from the other calcrete locations except Nowthanna. This unit is typically found fringing the playa, small closed depressions or ephemeral lakes within the calcrete.

The *Casuarina* woodland was found at all locations, except Nowthanna and Paroo. While this vegetation type was found at Lake Miranda, the area occupied was too small to obtain replication. The *Casuarina* woodland of the central group of calcretes (Yeelirrie – Lake Mason – Lake way) were compositionally similar compared to the outlying calcrete areas (Lake Maitland and Lake Darlot) which were also distinct from each other (Figures 1 & 2). This vegetation occurs in similar locations to the *Eucalyptus* woodland community and occurs on the calcrete plains.

The two dimensional MDS (stress=0.21; Figure 3) shows the patterns consistent to those found in the PERMANOVA analysis. The four vegetation units were clearly separated in the MDS with the *Eucalyptus* woodland graded into the *Casuarina* woodland, into the *Acacia burkittii* shrubland, with the *Melaleuca* shrubland distinctly separated.

Environmental correlates

The BIOENV analysis indicated that the best correlation with was obtained with five environmental variables: sodium, phosphorus, calcium, closed depression landform and percentage cover of leaf litter ($r = 0.483$). Six environmental variables correlated with the MDS ($r > 0.6$; Figure 3). Nitrogen, organic carbon, magnesium, phosphorus and sodium were positively correlated with the *Casuarina* woodland and more strongly with the *Eucalyptus* woodland, while the *Melaleuca* shrubland was positively correlated with the closed depression landform (ie. playas, ephemeral pools or depressions).

DISCUSSION

The plant communities found on the calcrete palaeodrainage channels in the Yilgarn were species poor when compared to other communities surveyed in the Murchison. Surveys of the banded ironstone formations surrounding the calcretes found much higher numbers of perennial taxa, in addition to a greater number of endemics (Thompson & Sheehy, in review a,b; Meissner & Wright 2010).

The flora on the calcrete palaeodrainage channels did not show the same level of endemism and species richness found in other geographically isolated habitats in these landscape. There were few taxa that were found to be endemic to the calcrete palaeodrainage channels and the majority of the other taxa occur are not restricted to calcrete but are found growing on alkaline soils. For example, *Eucalyptus gypsophila* and *E. striaticalyx* also occur on the gypseous dunes that surround the salt lakes (Nicolle 1997). It is more likely that most taxa found on calcretes are alkaline generalists.

The vegetation units broadly correspond to three vegetation types described by Pringle *et al.* (1994) and Payne *et al.* (1998); .calcyphytic *Casuarina Acacia* woodlands/shrubland dominated by *Casuarina pauper* or *Acacia* spp. (*Acacia aneura* and *Acacia burkittii*); calcrete platform woodlands, either dominated by *Casuarina pauper* or *Eucalyptus clelandii* woodlands; and closed *Melaleuca* shrublands dominated by *Melaleuca xerophila*.

Each structural vegetation unit were distinct from each other, despite sharing common taxa such as *Senna charlesiana* and *Ptilotus obovatus*. However, the patterns between the vegetation units by location were more complex. Although there was similar vegetation units present on the calcrete palaeodrainage channels, the rate of compositional change of the vegetation units varied across the study area, i.e. differences in *Acacia* shublands by location were not the same as the differences found in *Eucalyptus* woodlands. The *Eucalyptus* woodlands differed in the majority of localities but showed an east-west compositional shift from Lake Mason to Lake Darlot. These patterns were not consistent with palaeodrainage systems but associated more with neighbouring calcrete paleochannels, suggesting that the calcrete were colonised by species from the surrounding landscape pre-adapted to high pH conditions.

There are several hypotheses as to why there are differences in species richness when comparing Banded Ironstone Ranges and the calcrete palaeodrainage channels. The Western Australian arid zone is dominated by acidic soils, implying a greater number of taxa adapted to lower pH. With the onset of aridity in the mid Cenozoic (25 mya) and the start of calcrete deposition, the pool of species able to grow in alkaline condition may have been much lower than those able to grow more acidic soils. Pärtel (2002) reviewed species richness and soil pH around the world found that positive relationships were more likely in floristic regions where the evolutionary centres occurred on high pH soils and negative relationships between species richness and pH were more probable in floristic regions where evolutionary centres were on low pH soils. Therefore the local relationships between richness and pH may be explained by the evolutionary history at a regional scale.

In conjunction with this relationship between richness and pH, it is possible that the age and origin of these habitats may also influence species richness. Calcrete is a relatively recent habitat and formed in a dynamic depositional environment, while Banded Ironstone ranges are static, relictual habitats. It has been hypothesised that Banded Ironstone ranges act a refugia for more relictual species as the Australian climate dried and also centres of recent speciation (Butcher *et al*. 2007). Subsequently, the richer species pool present on the ironstone may have enabled greater speciation than the much younger calcrete, with a smaller species pool.

In terms of conservation, several of the palaeodrainage channels are prospective for uranium mining but patterns in beta diversity and the low number of endemic taxa indicate that conflicts between resource development and conservation values is unlikely to be significant. The highest turnover in species composition was found in the *Acacia* shrublands found in the more upland areas and *Eucalyptus* woodlands closer to the playas while the *Melaleuca* unit, fringing the playas or small depressions, was much more compositionally uniform. Even in the units showing high turnover, a number of adjacent palaeodrainage channels were found to be compositionally uniform. This contrast to the patterns found on the BIF ranges where each range was compositionally different (Gibson *et al*. in review). The concentration of calcrete endemics is confined to the Yeelirrie palaeodrainage channel and while four out of the five endemics are recorded from Yeelirrie, only *Atriplex* sp. Yeelirrie Station (L. Trotter &A. Douglas LCH 25025) is restricted to that channel. Currently, only one of the calcrete palaeodrainage channels, at Lake Mason, is currently within conservation estate.

ACKNOWLEDGMENTS

We would like to thank the following people: the leaseholders of Lakeway, Paroo, Melrose, Coglas Downs, Yarrabubba, Pollele and Yeelirrie Stations; Caroline McCormack, Anna Johns, Wes Caton and the staff at BHP Yeelirrie, Toro Energy at Lakeway and MegaUranium at Lake Maitland or their help and support in the field; Jesse Kalic for plant identifications; and the staff at the Western Australian Herbarium. This project was funded by the Department of Environment and Conservation, Western Australia.

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FIGURES AND TABLES

Table 1. Tests for the fixed effects of Location (8 sites) and Vegetation (Acacia, Eucalyptus, Casuarina and Melaleuca) and their interaction on vegetation community.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Location	7	53812	7687.4	4.1686	**0.001**	998
Vegetation	3	92053	30684	16.639	**0.001**	996
Location x Vegetation	16	69903	4368.9	2.3691	**0.001**	997
Residual	108	199165	1844.1			

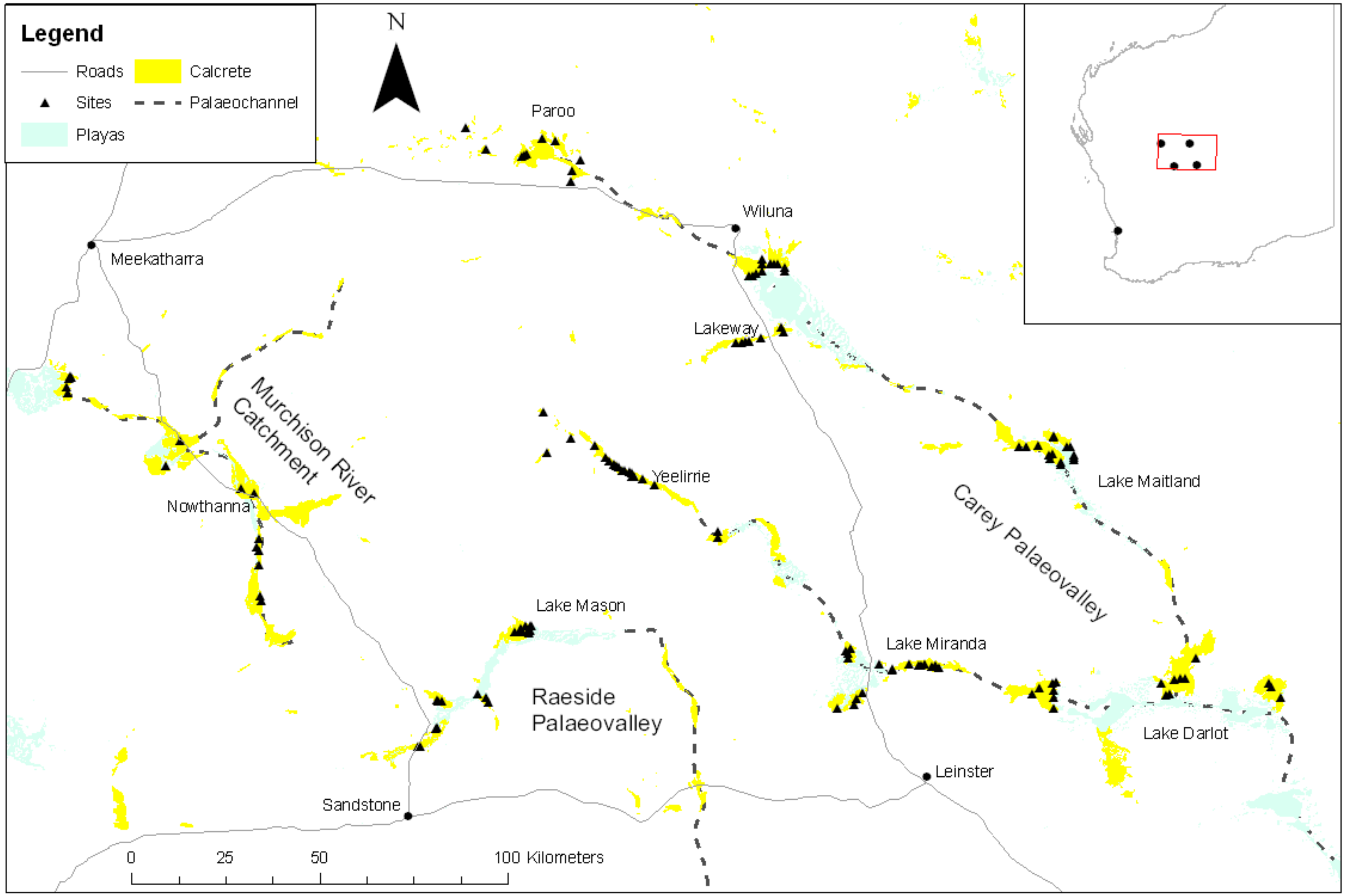

Figure 1. Location of the eight study sites, Paroo, Lakeway, Nowthanna, Yeelirrie, Lake Mason, Lake Miranda, Lake Maitland and Lake Darlot. Palaeodrainge channels are highlighted by dashed lines, with the 3 drainage networks also shown. Note the location of the calcrete upstream from the discharge into the salt lakes.

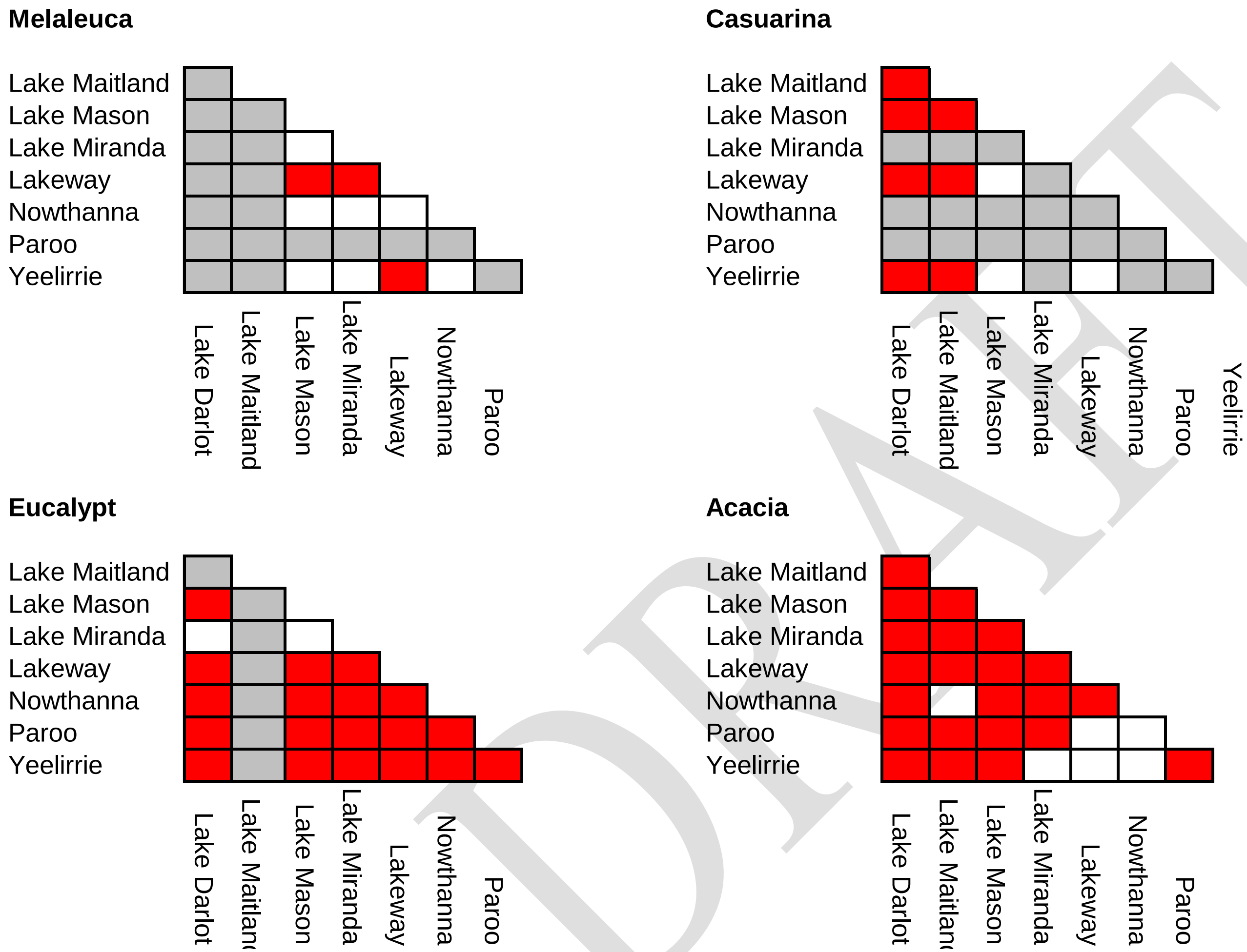

Figure 2. Shows *a posteriori* pair-wise comparisons of the four vegetation units (*Melaleuca* shrublands, *Casuarina* woodlands, *Eucalypt* woodlands, and *Acacia burkittii* shrublands) by location (8 sites). Red indicates significant at P(perm) < 0.05, grey represents no replication or absent at the location.

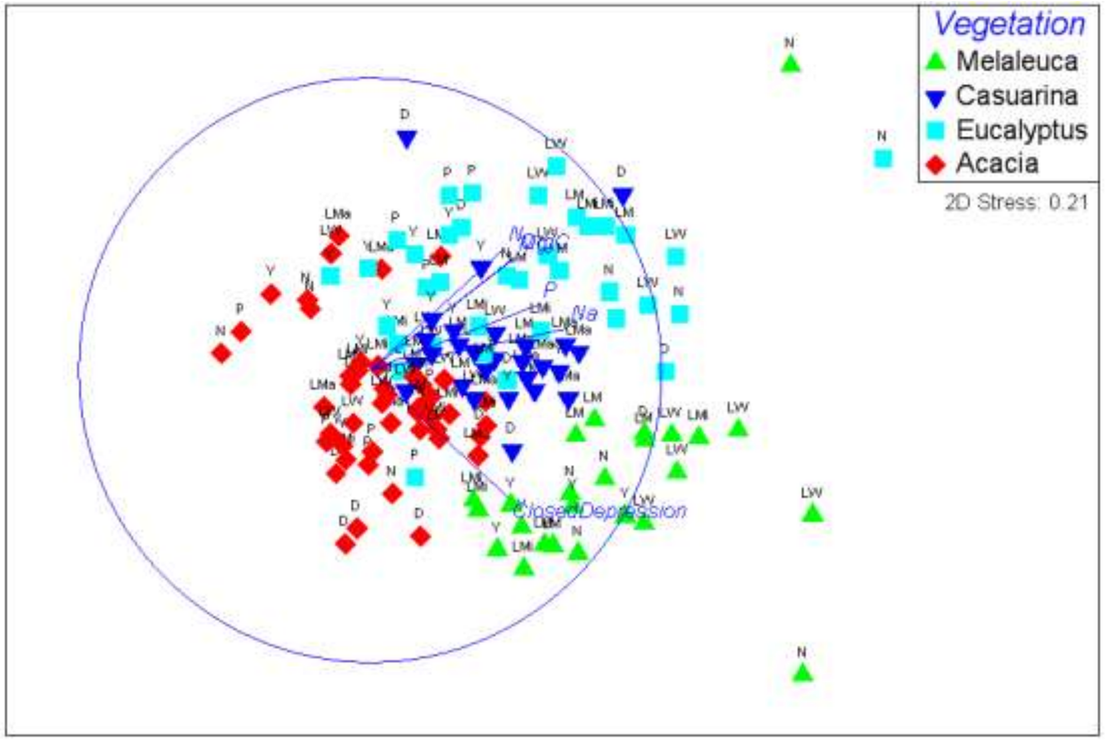

Figure 3. The two-dimensional MDS ordination of the 135 survey plots on the eight calcrete palaeodrainage channels (P - Paroo, LW - Lakeway, N - Nowthanna, Y - Yeelirrie, LM - Lake Mason, LMi - Lake Miranda, LMa - Lake Maitland and D - Lake Darlot). The five environmental variables correlated with the MDS using Spearman rank correlation r>0.6).

APPENDIX

Floristic list for the calcrete paleaodrainage channels, including all taxa from the sampling quadrats and adjacent areas. Nomenclature follows Paczkowska and Chapman (2000).

Species	Lake Darlot	Lake Maitland	Lake Mason	Lake Miranda	Lakeway	Nowthanna	Paroo	Yeelirrie
Total Number of taxa	87	75	57	114	81	59	46	86
Number of Annual Taxa	27	19	9	54	23	13	8	34
Number of Perennial Taxa	60	56	48	60	58	46	38	52
Aizoaceae								
Tetragonia eremaea	+			+		+		+
Amaranthaceae								
Ptilotus aervoides	+		+	+				+
Ptilotus chamaecladus	+	+		+	+			
Ptilotus exaltatus	+		+	+	+			+
Ptilotus helipteroides	+			+	+			+
Ptilotus lazaridis (P3)						+	+	
Ptilotus obovatus	+	+	+	+	+	+	+	+
Apocynaceae								
Marsdenia australis	+		+	+	+	+	+	+
Asteraceae								
Angianthus tomentosus						+		
Asteridea athrixioides	+			+				+
Asteridea chaetopoda		+						
Brachyscome ciliaris				+				
Calocephalus francisii				+				
Calocephalus knappii				+				
Calocephalus multiflorus	+			+				+
Calotis hispidula								+
Calotis multicaulis				+		+		+
Cephalipterum drummondii	+							+
Cratystylis subspinescens	+			+		+		
Gnephosis arachnoidea				+				
Helipterum craspedioides		+						
Isoetopsis graminifolia			+	+				
Lemooria burkittii				+				

Species	Lake Darlot	Lake Maitland	Lake Mason	Lake Miranda	Lakeway	Nowthanna	Paroo	Yeelirrie
Minuria cunninghamii			+					
Minuria gardneri		+						
Olearia adenolasia			+					
Olearia muelleri	+	+						
Pogonolepis muelleriana								+
Rhodanthe charsleyae				+				
Rhodanthe floribunda				+		+		
Rhodanthe humboldtiana				+				
Rhodanthe sterilescens				+		+		+
Schoenia ayersii	+	+		+				
Senecio glossanthus				+				
Vittadinia eremaea								+
Brassicaceae								
Lepidium phlebopetalum	+			+				
Menkea australis				+				
Menkea sphaerocarpa				+				
Casuarinaceae								
Casuarina pauper	+	+	+	+	+			+
Chenopodiaceae								
Atriplex amnicola	+							
Atriplex bunburyana	+	+	+	+	+	+		
Atriplex codonocarpa	+				+			
Atriplex semilunaris						+		
Atriplex sp. Yeelirrie Station (L. Trotter & A. Douglas LCH 25025) (P1)								+
Atriplex spongiosa					+			
Chenopodium cf. *gaudichaudianum*					+			
Chenopodium gaudichaudianum			+			+		
Chenopodium murale								+
Dissocarpus paradoxus	+			+	+	+		+
Dysphania cristata						+		
Dysphania kalpari				+				+
Dysphania melanocarpa forma *melanocarpa*				+				
Dysphania sphaerosperma		+						
Enchylaena tomentosa var. *tomentosa*	+	+	+	+	+	+	+	+

Species	Lake Darlot	Lake Maitland	Lake Mason	Lake Miranda	Lakeway	Nowthanna	Paroo	Yeelirrie
Eremophea spinosa	+	+	+	+	+	+		+
Eriochiton cf. *sclerolanoides*						+		
Eriochiton sclerolaenoides	+	+	+	+	+			+
Maireana eriosphaera		+						
Maireana georgei			+	+				
Maireana pentatropis	+	+		+		+		
Maireana pyramidata		+	+	+	+	+		+
Maireana thesioides			+					
Maireana trichoptera		+	+	+	+			
Maireana triptera	+		+	+				
Rhagodia drummondii	+	+	+	+	+	+	+	+
Rhagodia eremaea						+		+
Rhagodia sp. Yeelirrie Station (K.A. Shepherd et al. KS 1396) (P1)								+
Salsola australis	+	+	+	+	+	+	+	+
Sclerolaena burbidgeae								+
Sclerolaena cuneata						+		
Sclerolaena densiflora			+	+		+		+
Sclerolaena deserticola				+	+			
Sclerolaena diacantha	+	+		+	+			
Sclerolaena fimbriolata					+			
Sclerolaena gardneri		+	+	+				+
Sclerolaena obliquicuspis	+	+	+	+	+	+		+
Sclerolaena symoniana		+						
Tecticornia doleiformis						+		
Tecticornia indica					+			
Tecticornia laevigata					+			
Convolvulaceae								
Cuscuta epithymum								+
Duperreya commixta			+	+				
Crassulaceae								
Crassula colorata var. *acuminata*				+				
Euphorbiaceae								
Euphorbia drummondii	+	+		+	+		+	+
Fabaceae								
Acacia ?aptaneura							+	

Species	Lake Darlot	Lake Maitland	Lake Mason	Lake Miranda	Lakeway	Nowthanna	Paroo	Yeelirrie
Acacia aff. *oswaldii*	+	+			+			+
Acacia aneura group	+			+	+	+		
Acacia aneura hybrid				+				
Acacia aptaneura						+		
Acacia burkittii	+	+	+	+	+	+	+	+
Acacia colletioides			+					
Acacia craspedocarpa hybrid							+	+
Acacia grasbyi	+			+				
Acacia jennerae			+				+	
Acacia ligulata					+		+	
Acacia macraneura		+			+		+	+
Acacia mulganeura				+				
Acacia nyssophylla		+	+	+	+		+	
Acacia oswaldii	+							+
Acacia pruinocarpa						+		
Acacia pteraneura		+						
Acacia sclerosperma subsp. *sclerosperma*						+		
Acacia synchronicia	+	+	+		+	+	+	+
Acacia tetragonophylla	+	+	+	+	+	+	+	+
Acacia tysonii						+		
Senna artemisioides subsp. filifolia	+							
Senna artemisioides subsp. filifolia x *artemisioides* subsp. x *artemisioides*						+	+	
Senna artemisioides subsp. filifolia x *charlesiana*	+					+	+	+
Senna artemisioides subsp. x *artemisioides*	+	+			+		+	
Senna charlesiana	+	+	+	+	+	+	+	+
Senna charlesiana integrade					+			
Senna charlesiana x *artemisioides* subsp. *filifolia*	+	+		+	+		+	+
Senna charlesiana x *artemisioides* subsp. x *artemisioides*					+			
Senna sp. Meekatharra (E. Bailey 1-26)			+					
Swainsona kingii	+	+		+				+
Swainsona leeana					+			
Templetonia egena								+

Species	Lake Darlot	Lake Maitland	Lake Mason	Lake Miranda	Lakeway	Nowthanna	Paroo	Yeelirrie
Frankeniaceae								
Frankenia pauciflora	+							
Geraniaceae								
Erodium cygnorum				+				
Goodeniaceae								
Goodenia maideniana					+			
Goodenia mimuloides	+	+		+				+
Goodenia wilunensis							+	
Scaevola spinescens	+	+	+	+	+	+		+
Haloragaceae								
Haloragis trigonocarpa	+	+		+	+			+
Lamiaceae								
Dicrastylis brunnea		+						
Dicrastylis flexuosa		+						
Loranthaceae								
Amyema gibberula var. *gibberula*					+			
Amyema microphylla			+	+	+			+
Lysiana murrayi		+	+	+				+
Malvaceae								
Abutilon fraseri	+						+	
Abutilon oxycarpum subsp. *prostratum*				+				+
Lawrencia densiflora				+	+			+
Lawrencia sp. small fruits (Symon 2338)	+							
Lawrencia squamata		+						
Sida cf. *intricata*				+				
Sida sp. dark green fruits (S. van Leeuwen 2260)		+		+	+			
Sida spodochroma	+		+		+		+	+
Myrtaceae								
Eucalyptus camaldulensis							+	
Eucalyptus camaldulensis subsp. *obtusa*							+	

Species	Lake Darlot	Lake Maitland	Lake Mason	Lake Miranda	Lakeway	Nowthanna	Paroo	Yeelirrie
Eucalyptus eremicola subsp. *peeneri*	+		+	+			+	
Eucalyptus gypsophila	+		+	+			+	+
Eucalyptus striaticalyx		+			+	+		
Melaleuca interioris	+			+	+	+		+
Melaleuca xerophila	+	+	+	+	+	+		+
Nyctaginaceae								
Boerhavia repleta				+				
Pittosporaceae								
Pittosporum angustifolium	+	+	+	+		+	+	
Plumbaginaceae								
Muellerolimon salicorniaceum					+			
Poaceae								
Aristida contorta	+	+	+	+	+			+
Austrostipa elegantissima	+		+			+	+	+
Austrostipa eremophila	+			+				+
Austrostipa nitida	+	+	+	+		+	+	+
Austrostipa platychaeta	+		+		+			+
Enneapogon caerulescens	+	+		+	+		+	+
Eragrostis dielsii				+				+
Eragrostis eriopoda		+		+				
Eragrostis laniflora		+						
Eragrostis sp. (RAM 3456)	+							
Eragrostis sp. Yeelirrie Calcrete (S. Regan LCH 26770)	+	+	+	+	+	+		+
Eriachne pulchella			+	+		+		
Paspalidium basicladum				+				
Paspalidium constrictum	+	+		+	+		+	
Themeda triandra				+				
Triraphis mollis	+							
Polygalaceae								
Polygala isingii	+			+	+		+	+
Muehlenbeckia florulenta				+	+			+
Portulacaceae								
Calandrinia aff. *eremaea*				+	+			

Species	Lake Darlot	Lake Maitland	Lake Mason	Lake Miranda	Lakeway	Nowthanna	Paroo	Yeelirrie
Calandrinia aff. *polyandra*				+				
Calandrinia eremaea				+				
Calandrinia polyandra		+		+				
Calandrinia ptychosperma				+				
Portulaca oleracea				+				+
Proteaceae								
Grevillea nematophylla subsp. *supraplana*		+	+		+			+
Grevillea sarissa subsp. *bicolor*		+			+			
Grevillea sarissa subsp. *sarissa*				+				
Grevillea striata							+	
Rubiaceae								
Psydrax rigidula				+		+		
Santalaceae								
Exocarpos aphyllus	+	+		+	+	+		
Santalum lanceolatum	+				+		+	
Santalum spicatum	+				+	+		+
Sapindaceae								
Dodonaea viscosa subsp. *angustissima*				+				
Scrophulariaceae								
Eremophila alternifolia	+	+		+				+
Eremophila arachnoides subsp. *arachnoides (P3)*			+		+			+
Eremophila cf. *forrestii*		+						
Eremophila eriocalyx	+	+		+	+			+
Eremophila falcata		+		+	+		+	+
Eremophila forrestii subsp. *forrestii*	+							
Eremophila gilesii subsp. *variabilis*	+			+				
Eremophila glabra subsp. *glabra*			+		+	+	+	
Eremophila glabra subsp. *tomentosa*		+				+		+
Eremophila latrobei subsp.		+					+	

Species	Lake Darlot	Lake Maitland	Lake Mason	Lake Miranda	Lakeway	Nowthanna	Paroo	Yeelirrie
filiformis								
Eremophila latrobei subsp. *latrobei*							+	
Eremophila longifolia				+		+	+	+
Eremophila maculata subsp. *brevifolia*	+							
Eremophila malacoides		+	+	+				
Eremophila margarethae	+							
Eremophila miniata		+						
Eremophila pantonii	+	+		+				
Eremophila youngii subsp. *youngii*	+	+	+		+			+
Solanaceae								
Lycium australe	+	+	+	+	+	+	+	+
Nicotiana rosulata subsp. *rosulata*								+
Solanum lasiophyllum	+	+	+	+	+	+	+	+
Solanum nummularium	+	+	+	+				
Thymelaeaceae								
Pimelea microcephala	+				+		+	+
Zygophyllaceae								
Tribulus astrocarpus				+				+
Tribulus cf. *macrocarpus*				+				
Tribulus terrestris				+	+			+
Zygophyllum aurantiacum	+				+			
Zygophyllum compressum	+	+	+	+	+			+
Zygophyllum eichleri	+	+	+	+	+	+	+	+
Zygophyllum eremaeum	+					+		
Zygophyllum ovatum	+	+	+	+	+	+	+	+
Zygophyllum reticulatum					+			
Zygophyllum simile					+	+		+