

The temperate to arid transition of the Irwin - Carnarvon phytogeographic boundary, Western Australia

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Abstract – The southern boundary of the Carnarvon phytogeographic district separates the arid *Acacia* shrublands from the species rich heaths and woodlands of the Irwin region. This boundary has previously been mapped at a scale of 1 : 250 000 using the structure, density and composition of the dominant perennial plant species. One hundred quadrats were established across this boundary to determine if floristic composition correlated with the mapped position of this boundary. Our results suggest that the boundary of the Southwestern Botanical Province should move west and south to exclude the *Acacia* – *Casuarina* thicket on red sandplain and the tree heaths south of Shark Bay. In terms of species and family composition the vegetation of these areas is more similar to typical Carnarvon vegetation than to the scrub heaths of the yellow sandplains of the Irwin. Major edaphic patterns are strongly correlated with the position of the revised boundary.

INTRODUCTION

The boundary between the Southwestern and Eremaean Botanical Provinces runs roughly south-east from Shark Bay (Beard, 1976a) and bisects the lower third of the Carnarvon Basin study area of Keighery *et al.* (2000; Figure 1). This boundary represents the transition from the complex and species rich heathlands and woodlands of south-western Australia to the less diverse *Acacia* shrublands of the Carnarvon Basin and is clearly related to the increasing quantity and reliability of rainfall to the south-west (Beard, 1976a). This major floristic boundary was first mapped by Diels (1906) and later work by Gardner (1944) and Gardner and Bennetts (1956) further refined its position but on maps at very large scale. Detailed mapping of this boundary did not take place until Beard's pioneering Vegetation of Western Australia project was undertaken, culminating in the publication of vegetation maps of the south-west at 1 : 250 000 scale and the rest of the State at 1 : 1 000 000 scale (e.g. Beard, 1975, 1976a, 1976b, 1976c) and allowing detailed boundaries for 21 districts and 4 subdistricts to be defined across the State (Beard, 1980). The terminology of these districts has subsequently undergone some minor modification (Beard, 1990).

Beard's vegetation mapping used vegetation structure, density and composition and generally showed remarkable concordance with the earlier published phytogeographic boundaries (Beard, 1976b). The position of this boundary in the Shark Bay area is, however, equivocal due to the intermediate nature of the structure and floristic

variation in the vegetation. Diels (1906) originally included Edel Land and Peron Peninsula in the Southwestern Province, Gardner (1944) and Gardner and Bennetts (1956) showed the boundary bisecting the Peron Peninsula, while Burbidge (1960) followed Diels' line. Beard (1976b) considered that Peron Peninsula with its *Acacia ramulosa* scrub and *Triodia plurinervata* hummock grasslands clearly represented southern Eremaean vegetation, as did the vegetation of Bernier and Dorre Islands. The tree heaths of the Tamala area (immediately south of Shark Bay) are a unique vegetation type. Beard (1976a, 1976b) considered these tree heaths had clear floristic affinities to the *Acacia* – *Casuarina* thicket of the Eurardy system (within the Irwin botanical district).

Edel Land and Dirk Hartog Island, however, have a complex of intermediate vegetation types with affinities both to the Eremaean and the Southwestern Provinces (Beard, 1976b). Beard placed Edel Land and Dirk Hartog Island in the Eremaean Province based on general impression of desolation and aridity while recognising their intermediate character. In subsequent work on Dirk Hartog Island Burbidge and George (1978) disagreed with the placement of this island in the Eremaean Province and considered it better treated as a 'transitional zone' or placed in the Southwestern Province based on its flora and vegetation formations with the exception of the hummock grassland. In the most recent review of the biogeographic regions in Western Australia, Thackway and Cresswell (1995) placed Edel Land in the Southwestern Province (in their Geraldton

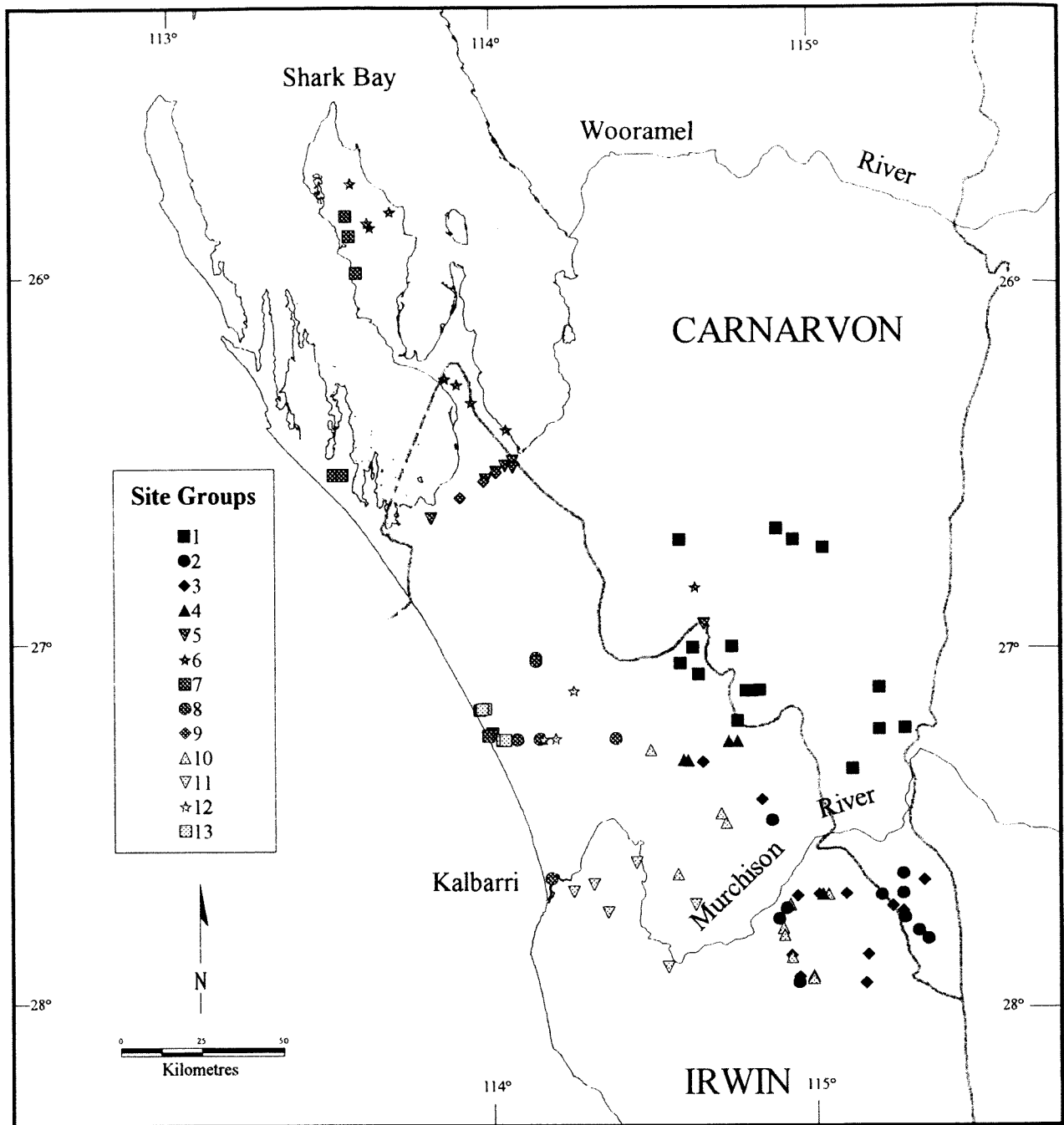


Figure 1 Location of sites in the study area showing site groupings based on floristic similarity. Boundaries between phytogeographic districts (Beard, 1980) shown as solid lines.

Sandplains Region) and Dirk Hartog Island with Peron Peninsula in the Eremaean Province.

Beard (1976a, 1976b, 1976c) has also mapped vegetation systems within the districts of the Southwestern Province and for part of the Carnarvon botanical district. Vegetation systems consist of particular series of plant communities recurring in catenary sequences or mosaics linked to topographical, pedological and/or geological features (Beard, 1976a, 1976b, 1976c). The aim of the present paper is to test the placement of the Carnarvon – Irwin boundary and the vegetation system boundaries within these two districts using

plot-based floristic data derived from 100 quadrats straddling the Irwin – Carnarvon boundary.

METHODS

One hundred sites occurring on sandplains were sampled across the Irwin – Carnarvon boundary from Peron Peninsula to south of the Murchison River (Figure 1) where access permitted. Quadrats 30 m x 30 m were established at each site and all vascular plant species occurring in the quadrats were recorded. Recently burnt sites were avoided. Seventy-five quadrats were established on four

spring sampling trips during 1988–92, following good winter rains. Most of these quadrats were sampled once. A further 25 quadrats were established in August 1994, with most being revisited in August 1995. As all sites were visited at least once following good winter rains, differences in species composition in the dataset due to seasonality were considered to be minimal. Each site was allocated to the appropriate phytogeographic district and vegetation system following Beard (1980, 1976b, 1976c).

Sites were classified according to similarities in species composition (presence/absence data) using the Czekanowski coefficient and 'unweighted pair-group mean average' fusion method (UPGMA, Sneath and Sokal, 1973), while species were classified using the 'two step' method of Austin and Belbin (1982) and the UPGMA fusion method. Annuals and geophytes were included in the analysis as all sites were considered to have had good rains prior to the sampling period.

A bulked soil sample of the top 10 cm was collected from 96 of the 100 sites and soil mechanical analysis and macro nutrient analyses were undertaken on these samples using standard techniques (McArthur, 1991). Climate parameters for each site were estimated from the climate modelling program AUSCLIM [see Wyrwoll *et al.* (2000) for details]. Statistical relationships between site groups (at the 13 group level) and within the three major groups identified were tested using Kruskal-Wallis non-parametric analysis of variance (Siegel, 1956).

Nomenclature generally follows Green (1985) and current usage at the Western Australian Herbarium. Selected voucher specimens have been lodged in the Western Australian Herbarium.

RESULTS

Vegetation classification

Six hundred and ninety taxa (species, subspecies and varieties) were recorded from the 100 quadrats. Of these, 224 (32%) were recorded at only one site. Preliminary analyses showed these singletons contained little information and were subsequently excluded from the analysis. The 466 remaining taxa were recorded from between two and 48 sites. Species richness ranged between 10 and 73 taxa/plot. The classification is discussed at two levels, the 3 group level (referred to as groups I, II and III) and the 13 group level (referred to as site group 1 to site group 13) (Figure 2).

At the three group level the 100 sites fall in more or less discrete geographical entities, with group I occupying the southern inland sector, group II the northern coastal sector and group III the southern coastal sector (Figure 1). There is some degree of

overlap in species composition between groups. Species assemblages S, T, U and V are characteristic of the southern coastal group with species assemblages P, Q and R being typical of the northern coastal group (Table 1). Species assemblage O is well represented in both the northern coastal group and the southern inland group but largely lacking from the southern coastal group (Table 1). The northern coastal group occurs mostly on red sands, the southern inland groups occurs on either red or yellow sands and the southern coastal group was restricted to yellow sands.

These three major groups can be further divided into 13 site groups and the inverse analysis of the species gave 22 species assemblages (Table 1). The southern inland group (group I) can be subdivided into four site groups. All four site-groups are generally open mallee over *Acacia* shrublands often with emergent *Callitris glaucophylla* in site groups 1, 2 and 3. Site group 1 is largely restricted to the Toolonga plateau while site group 2 is found on the sandplain south of the Murchison River. Both groups have high representation of species assemblage O but differ in terms of species assemblages A, B, L, M and N. Site group 1 had an average species richness of 38.6 taxa/site while site group 2 was richer with an average richness of 49.7 taxa/plot. Site group 3 differs from the previous two in having a diverse heath understorey (species assemblage C), a much lower representation of species assemblage O, and lower overall species richness (average of 29.7 taxa/plot). Site group 4 was closely related to site group 3 but was less rich (average 20.4 taxa/plot) and had low to moderate representation of species assemblages G, H and I which are more typical of the northern coastal group (group II).

The northern coastal group can be divided into 5 site groups. Site groups 5 and 9 largely correspond to the tree heath found on the red sands south of Shark Bay. This group also included an *Acacia* shrubland immediately adjacent to the boundary with the tree heath and an outlying site well to the south. This outlying site (48) would probably be better considered a species poor example of site group 1 (see Table 1). Site group 9 has lower average species richness (30.7 taxa/plot) than site group 5 (39.7 taxa/plot) and lower representation of species in species assemblages O and P, with the missing taxa mostly being annuals or geophytes. Most sites in site group 5 were scored in 1991 while sites in site group 9 were scored in 1994 and 1995. These two site groups may represent a seasonal component in the dataset but no other floristic groupings were correlated with year of sampling.

Site group 6 includes *Acacia* shrublands on red sands on the Peron Peninsula with one outlying site to the south. Species richness averages 40.7 taxa/

Table 1 Two-way table showing three group classification, the 13 site groups and 22 species assemblages for 100 sites across the Carnarvon-Irwin boundary. Quadrats are shown as columns and taxa as rows. (Ms indicates manuscript name).

Major groups Site groups	I				II					III				Species Assemblage	
	1	2	3	4	5	6	7	8	9	10	11	12	13		
	007566000266nnnn	0030711322	011282336333	16568	455n455	77777p77	eezpppzz	566zz	nnn	12322454422	344345	5zz6	zzzz		
	128459354746eeee	6839901634	767001243075	97681	823a901	067123e45	1lueeeuu	910uu	aaa	82156176789	823905	8uu2	uuuu		
	3451				2	4	12725318	63	345			45	1219	1	
							0								
<i>Acacia acuarria</i>		***	**	**											A
<i>Stipa tenuifolia</i>		***	**												
<i>Eriostemon tomentellus</i>		**	*	*											
<i>Scaevola oxyclona</i>		**	*	*	*										
<i>Eucalyptus kochii</i>	*	*													
<i>Ptilotus grandiflorus</i>	*	*													
<i>Chamaelucium sp. i (AHB 4233)</i>		**													
<i>Eremophila platycalyx</i>	*	*													
<i>Menkea australis</i>		*		*											
<i>Angianthus pusillus</i>	*	*				*	*								
<i>Podolepis capillaris</i>		**		*		**									
<i>Cryptandra nutans</i>		*									*				B
<i>Eremophila physocalyx MS</i>	*										*	*			
<i>Hakea circumalata</i>	**										*	*			
<i>Acacia longispinea</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Amphipogon strictus</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Labichea teretifolia subsp. teretifolia</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Blennospora drummondii</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Eucalyptus oldfieldii</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Malleostemon minilyaensis</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Malleostemon peltiger</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Malleostemon roseus</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Calytrix strigosa</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Eucalyptus jucunda</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Pileanthus peduncularis</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Mirbelia aff. viminalis</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Plectrachne drummondii</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Eucalyptus obtusiflora</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Santalum spicatum</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Glischrocaryon aureum</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Keraudrenia hermanniifolia</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Acacia rhodophloia</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Schoenus hexandrus</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Scholtzia sp. Galena (Blackall 4728) PN</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Brachyloma sp. Kalbarri (AHB 4504)</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Hakea bucculenta</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Leptomeria preissiana</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Acacia stereophylla</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Thryptomene ninghanensis</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Melaleuca cordata</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Mirbelia depressa</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Eriostemon brucei</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Leucopogon propinquus</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Westringia rigida</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Eucalyptus lenziana</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Persoonia striata</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Eucalyptus leptopoda</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Pterostylis nana</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Calothamnus formosus subsp. formosus</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Dampiera haematotricha</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Halgania viscosa</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<i>Grevillea integrifolia</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	

Table 1 (cont.)

Major groups Site groups	I				II					III				Species Assemblage
	1	2	3	4	5	6	7	8	9	10	11	12	13	
	007566000266nnnn	0030711322	011282336333	16568	455n455	777777p77	eezpppzz	566zz	nnn	12322454422	344345	5zz6	zzzz	
	128459354746eeee	6839901634	767001243075	97681	823a901	067123e45	11ueeeuu	910uu	aaa	82156176789	823905	8uu2	uuuu	
	3451				2	4	12725318	63	345			45	1219	1
							0							
<i>Lepidium phlebopetalum</i>							*	*						
<i>Clematicissus angustissima</i>							*	*	*					
<i>Phyllanthus maderaspatensis</i>						*	*	*	*					K
<i>Ehrharta brevifolia</i>							*	*	*					
<i>Isolepis congrua</i>							*	*	*					
<i>Polycarpon tetraphyllum</i>							*	*	*					
<i>Zygophyllum apiculatum</i>						*	*	*	*					
<i>Thryptomene strongylophylla</i>							*	*	*			*		
<i>Stipa nitida</i>							*	*	*					
<i>Acacia acuminata</i>			**	*										
<i>Senecio glossanthus</i>	*	***			**									
<i>Wahlenbergia preissii</i>		**			*				*					
<i>Calotis hispidula</i>	*	**	*						*					
<i>Ptilotus helipteroides</i>	*	*			*	*								
<i>Rhodanthe laevis</i>	*	*												
<i>Ceratogyne obionoides</i>	*	*	*											
<i>Lawrencea rosea</i>	**	**	**											
<i>Plantago aff. hispidula (NG and ML 1732)</i>	*	**	**		*									
<i>Velleia cynopotamica</i>	*	*	**							*				
<i>Angianthus tomentosus</i>	***	*	**											
<i>Cuscuta epithymum</i>	***	**	**				**							
<i>Chthonocephalus spathulatus</i>	*	*	**				*		*					
<i>Calotis multicaulis</i>	*	*	**				*		*					
<i>Rhodanthe maryonii</i>	**	*	**		*		*		*					
<i>Cephalopterum drummondii</i>	*	*	*				*		*					
<i>Pentaschistis airoides</i>	*	**	***				*		*					
<i>Bromus arenarius</i>		*	**				*		*					
<i>Daucus glochidiatus</i>		*	*				*		*					L
<i>Hypochaeris glabra</i>		*	**				*		*					
<i>Stipa trichophylla</i>		*	**				*		*					
<i>Omphalolappula concava</i>		*	*				*		*					
<i>Zygophyllum iodocarpum</i>		*	*				*		*					
<i>Calandrinia calyptrata</i>	*	*	*				*		*					
<i>Calocephalus multiflorus</i>	*	*	*				*		*					
<i>Wahlenbergia tumidiflora</i>		*	*				*		*					
<i>Zygophyllum ovatum</i>		*	*				*		*					
<i>Caladenia roei</i>		*	*				*		*					
<i>Hydrocotyle pilifera var. glabrata</i>		*	**				*		*					
<i>Mitrasacme paradoxa</i>		*	**				*		*					
<i>Schoenus nanus</i>		*	**				*		*					
<i>Drosera macrantha</i>		*	**				*		*					
<i>Cheilanthes austrotenuifolia</i>		*	**				*		*					
<i>Pogonolepis muelleriana</i>		*	**				*		*					
<i>Melaleuca eleuterostachya</i>		*	**				*		*					
<i>Chorizema ericifolium</i>		*	*				*		*					
<i>Acacia coolgardiensis subsp. effusa</i>	***	*			*		*		*					
<i>Waitzia nitida</i>	****				*		*		*					
<i>Marsdenia australis</i>	***				*		*		*					
<i>Gnephosis eriocephala</i>	***				*		*		*					
<i>Wurmbea densiflora</i>	****				*		*		*					
<i>Lysiana casuarinae</i>	**				*		*		*					
<i>Synaptantha tillaeacea</i>	**				*		*		*					
<i>Chthonocephalus pseudevax</i>	*	*	*		*		*		*					K
<i>Goodenia havilandii</i>	*	*	*		*		*		*					

Aira caryophylla
Amyema preissii
Persoonia angustiflora

Erachycton gregorii
Rhodanthe charsleyae
Myriocephalus gueriniae
Thryptomene decussata
Rhodanthe stricta
Stenopetalum robustum
Rhodanthe humboldtiana
Stipa tuckeri
Grevillea brachystachya
Pseudanthus intricatus MS
Hyalosperma glutinosum subsp. *glutinosum*
Rhodanthe manglesii
Stenopetalum lineare
Pityrodia paniculata
Wurmbea tenella

Acacia linophylla
Podolepis canescens
Rhodanthe citrina
Schoenia cassiniana
Brachyscome cheilocarpa
Calandrinia lehmannii
Lawrencella davenportii
Rhyncharrhena linearis
Ptilotus polystachyus
Tetragonia diptera
Brachyscome iberidifolia
Goodenia berardiana
Sida calyxhymenia
Nicotiana occidentalis
Calandrinia polyandra
Pimelea microcephala
Chenopodium gaudichaudianum
Ptilotus obovatus
Solanum orbiculatum
Crassula colorata
Rhagodia latifolia
Erodium cygnorum
Ptilotus gaudichaudii
Millotia myosotidifolia
Acacia ramulosa
Gilberta tenuifolia
Trachymene ornata
Goodenia occidentalis
Actinobole uliginosum
Brachyscome ciliaris
Grevillea stenostachya
Velleia glabrata
Brunonia australis
Eremophila clarkei
Acacia roycei
Monachather paradoxus
Callitris glaucophylla
Bursaria occidentalis
Eucalyptus mannensis
Leucochrysum fitzgifbonii
Eremophila granitica
Eremophila latrobei
Lobelia gibbosa
Stenopetalum filifolium
Ptilotus drummondii
Persoonia bowgada
Allocasuarina acutivalvis
Bellida graminea
Waitzia acuminata
Comesperma integerrimum
Trachymene cyanopetala

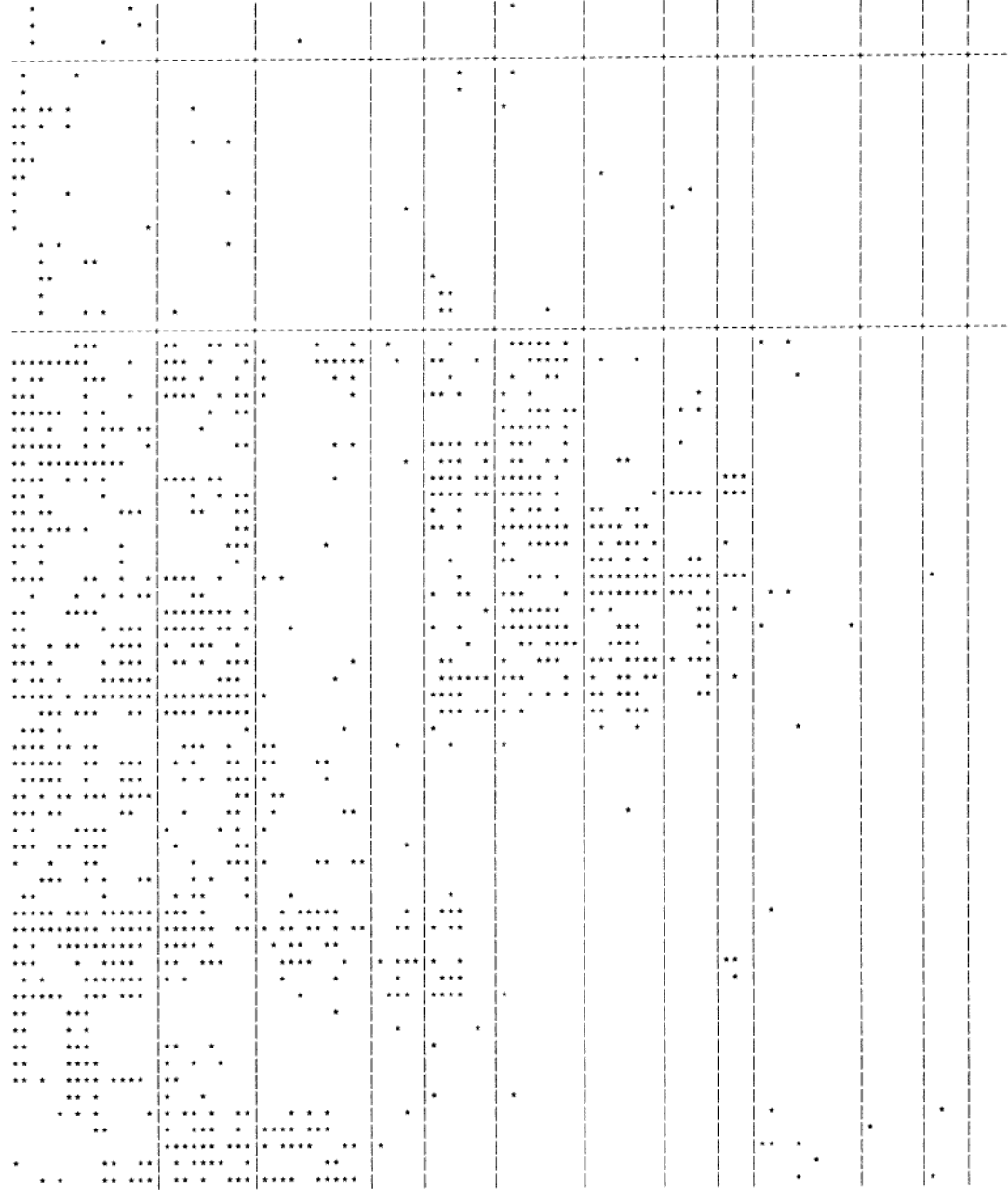


Table 1 (cont.)

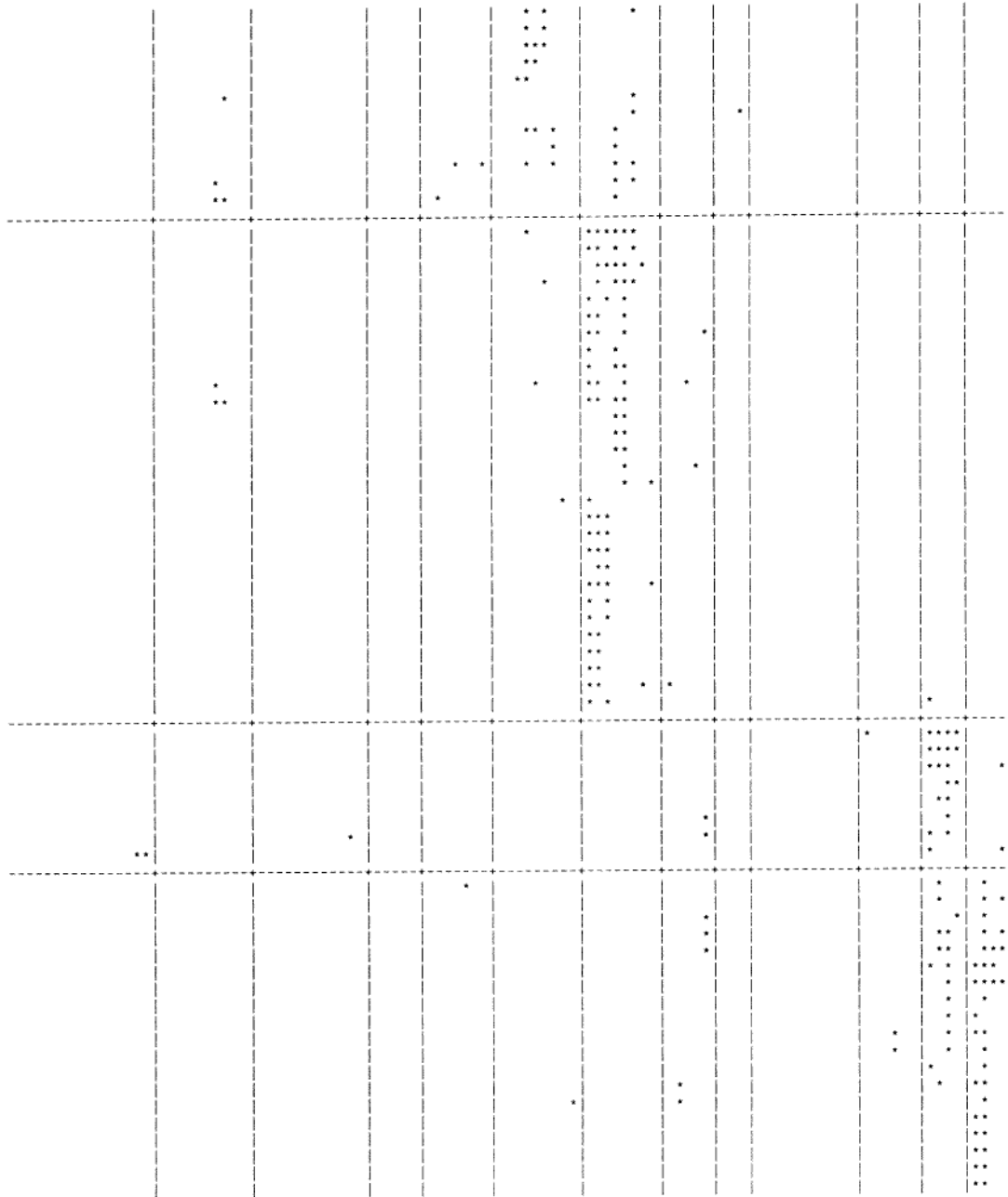
Major groups Site groups	I			II						III			Species Assemblage
	1	2	3	4	5	6	7	8	9	10	11	12	
	007566000266nnnn	0030711322	011282336333	16568	455n455	777777p77	eezpppzz	566zz	nnn	12322454422	344345	5zz6	zzzz
	128459354746eeeee	6839901634	767001243075	97681	823a901	067123e45	llueeeuu	910uu	aaa	82156176789	823905	8uu2	uuuu
	3451				2	4		0	63	345		45	1219
													1
<i>Uldinia ceratocarpa</i>
<i>Alyxia buxifolia</i>
<i>Cassia nemophila</i>
<i>Chthonocephalus muellerianus</i>
<i>Dicrastylis linearifolia</i>
<i>Calandrinia corrigioloides</i>
<i>Gnephosis tenuissima</i>
<i>Dianella revoluta</i>
<i>Stipa elegantissima</i>
<i>Thysanotus manglesianus</i>
<i>Eucalyptus eudesmioides</i>
<i>Lamarchea hakeifolia</i> var. <i>brevifolia</i>
<i>Podotheca gnaphalioides</i>
<i>Poranthera microphylla</i>
<i>Olearia axillaris</i>
<i>Trachymene pilosa</i>
<i>Acacia ligulata</i>
<i>Melaleuca cardiophylla</i>
<i>Euphorbia drummondii</i>
<i>Paractaenum novae-hollandiae</i>
<i>Scaevola spinescens</i>
<i>Exocarpos aphyllus</i>
<i>Scaevola tomentosa</i>
<i>Threlkeldia diffusa</i>
<i>Sonchus oleraceus</i>
<i>Parietaria debilis</i>
<i>Zygophyllum fruticosum</i>
<i>Rhagodia preissii</i>
<i>Solanum lasiophyllum</i>
<i>Acacia tetragonophylla</i>
<i>Chthonocephalus tomentellus</i>
<i>Brassica tournefortii</i>
<i>Ptilotus divaricatus</i>
<i>Enchylaena tomentosa</i>
<i>Rostraria pumila</i>
<i>Calocephalus francisii</i>
<i>Triglochin calcitrapum</i>
<i>Aristida holathera</i>
<i>Lobelia heterophylla</i>
<i>Heterodendrum oleifolium</i>
<i>Stenopetalum pedicellare</i>
<i>Cassia chatelainiana</i>
<i>Cassia glutinosa</i>
<i>Atriplex vesicaria</i>
<i>Rhagodia drummondii</i>
<i>Eremophila glabra</i>
<i>Waitzia suaveolens</i>
<i>Podotheca angustifolia</i>
<i>Acacia sclerosperma</i>
<i>Convolvulus erubescens</i>
<i>Bulbostylis barbata</i>
<i>Euphorbia tannensis</i>
<i>Olearia rudis</i>

Dodonaea inaequifolia
Gymnema granitica MS
Heliotropium undulatum
Tribulus forrestii
Eremophila youngii
Bromus diandrus
Cryptandra leucophracta
Commicarpus australis
Eremophila maitlandii
Porana sericea
Danthonia caespitosa
Maireana trichoptera

Brachyscome latisquamea
Trichanthodium skirrophorum
Erodium cicutarium
Euphorbia boophthona
Eragrostis barrelieri
Lepidium rotundum
Wurmbea inframediana
Gnephosis arachnoidea
Triodia plurinervata
Salsola kali
Scleroiaena diacantha
Cenchrus ciliaris
Eragrostis dielsii
Urospermum picroides
Centaurea melitensis
Euphorbia australis
Cassyytha glabella
Dysphania rhadinostachya
Frankenia pauciflora
Lepidium puberulum
Tetragonia implexicoma
Stipa crinita
Lepidium linifolium
Thryptomene sp. Carrarang (Trudgen 7420)
Olearia aff. *axillaris* (GJK and NG 1025)
Poa drummondiana
Triglochin trichophorum
Zygophyllum ammophilum
Diplolaena grandiflora

Acacia blakelyi
Thryptomene denticulata
Burnettia nigricans MS
Conostephium preissii
Leucopogon cucullatus
Hibbertia pungens
Conostylis stylidioides
Centrolepis drummondiana

Acacia cavealis MS
Drosera stolonifera subsp. *stolonifera*
Hibbertia subvaginata
Conospermum microflorum
Lepidobolus preissianus
Petrophile brevifolia
Schoenus clandestinus
Brachysema aphyllum
Melaleuca conothamnoides
Lysinema ciliatum
Scaevola canescens
Laxmannia sessiliflora
Cassyytha aurea
Conostylis candicans
Amphipogon turbinatus
Cassyytha racemosa
Dryandra borealis subsp. *borealis*
Hibbertia spicata subsp. *spicata*
Pimelea leucantha



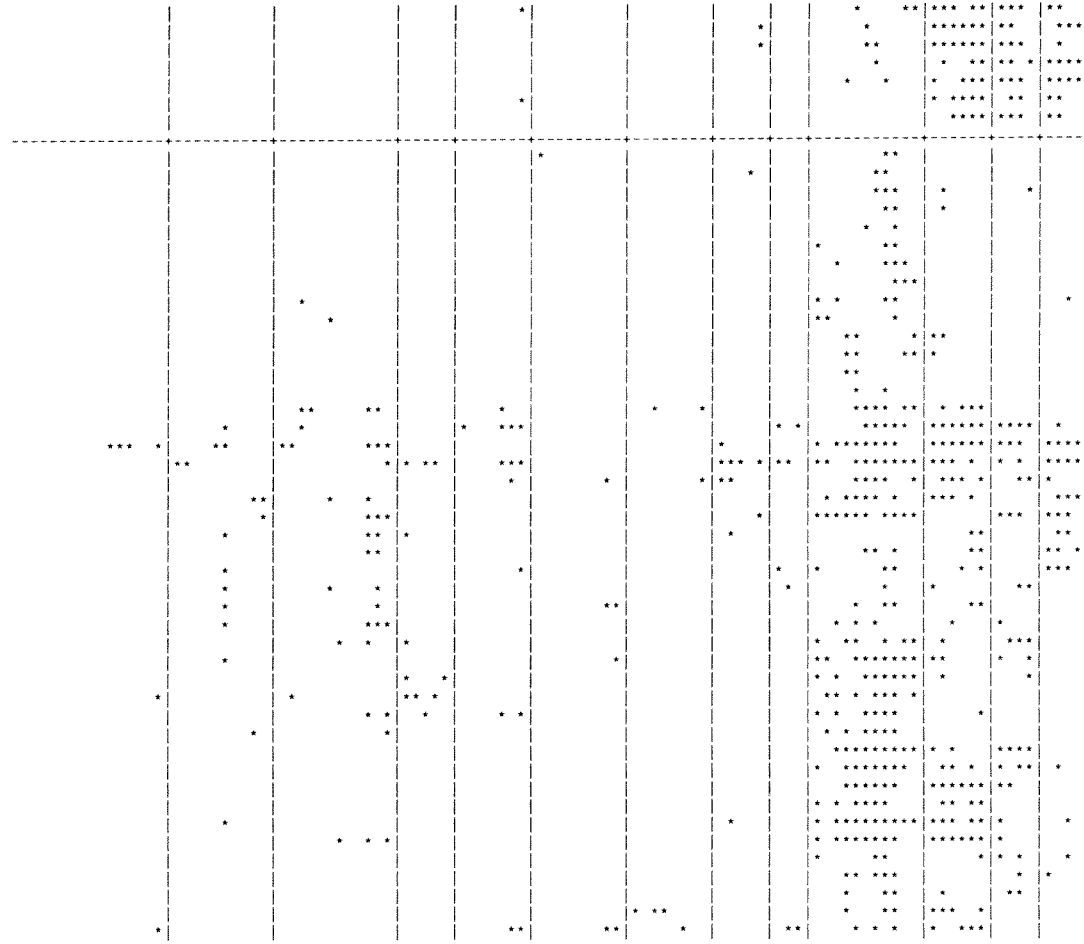
Q
R
S

Table 1 (cont.)

Major groups Site groups	I				II					III				Species Assemblage
	1	2	3	4	5	6	7	8	9	10	11	12	13	
	007566000266nnnn	0030711322	011282336333	16568	455n455	777777p77	eezpppz	566zz	nnn	12322454422	344345	5zz6	zzzz	
	128459354746eeee	6839901634	767001243075	97681	823a901	067123e45	1luueeu	910uu	aaa	82156176789	823905	8uu2	uuuu	
	3451				2	4	12725318	63	345			45	1219	1
							0							
<i>Boronia purdieana</i>														***
<i>Lepidosperma angustatum</i>														***
<i>Conostylis aculeata</i>											*			***
<i>Gompholobium tomentosum</i>											*			***
<i>Pityrodia oldfieldii</i>											*			***
<i>Brachysema macrocarpum</i>						*								**
<i>Tricoryne elatior</i>														**
<i>Labichea cassioides</i>					*									**
<i>Diplolaena mollis</i> MS								*						**
<i>Hibbertia acerosa</i>									*					**
<i>Cassytha pomiformis</i>								*						**
<i>Malleostemon</i> sp Cooloomia (Hopper 1353)								*						**
<i>Grevillea preissii</i>								*						**
<i>Melaleuca acerosa</i>								*						**
<i>Hibbertia racemosa</i>								*						**
<i>Loxocarya aspera</i> MS						*		*						**
<i>Acacia gelasina</i>										*	*			*
<i>Eucalyptus gittinsii</i>										*	*			*
<i>Verticordia capillaris</i>										*	*			*
<i>Leptosema tomentosa</i> MS										*	*			*
<i>Pityrodia glabra</i>										*	*			*
<i>Baeckea robusta</i>										*	*			*
<i>Calothamnus chrysanthus</i>										*	*			*
<i>Conostylis aurea</i>										*	*			*
<i>Jacksonia</i> aff. <i>hakeoides</i>										*	*			*
<i>Conostylis androstemma</i>										*	*			*
<i>Haemodorum simulans</i>										*	*			*
<i>Grevillea acuaria</i>										*	*			*
<i>Xylomelum angustifolium</i>										*	*			*
<i>Lachnostachys eriobotrya</i>										*	*			*
<i>Scholtzia</i> sp. Coolcalalaya										*	*			*
<i>Platysace teres</i>										*	*			*
<i>Banksia attenuata</i>										*	*			*
<i>Daviesia nudiflora</i>										*	*			*
<i>Scaevola anchusifolia</i>										*	*			*
<i>Scholtzia spatulata</i>										*	*			*
<i>Xanthorrhoea preissii</i>										*	*			*
<i>Darwinia virescens</i>										*	*			*
<i>Pimelea angustifolia</i>										*	*			*
<i>Hibbertia exasperata</i>										*	*			*
<i>Haemodorum paniculatum</i>										*	*			*
<i>Chrysitrix distigmatosa</i>										*	*			*
<i>Patersonia drummondii</i>										*	*			*
<i>Hyalosperma cotula</i>		*								*	*			*
<i>Allocauarina humilis</i>										*	*			*
<i>Neurachne alopecuroidea</i>										*	*			*
<i>Patersonia occidentalis</i>										*	*			*
<i>Hakea candolleana</i>										*	*			*
<i>Haemodorum discolor</i>										*	*			*
<i>Baeckea blackallii</i> MS										*	*			*
<i>Grevillea annulifera</i>			*							*	*			*
<i>Boronia coerulescens</i>										*	*			*
<i>Schoenus pleiostemoneus</i>										*	*			*
<i>Mirbelia spinosa</i>					*					*	*			*
<i>Monotaxis lurida</i>		*								*	*			*

Calothamnus blepharospermus
Mesomelaena pseudostygia
Phymatocarpus porphyrocephalus
Leucopogon cordifolius
Stylidium repens
Eremaea ebracteata
Stylidium macrocarpum

Acacia isoneura MS
Thysanotus speckii
Baekkea sp Murchison River (Hopper 1428)
Lepidosperma tenue
Calytrix formosa
Dampiera oligophylla
Jacksonia nematoclada
Verticordia monadelpha
Comesperma scoparium
Thelymitra sargentii
Beaufortia squarrosa
Thryptomene sp. Wandana
Daviesia hakeoides
Grevillea commutata
Acanthocarpus preissii
Calytrix brevifolia
Ecdiocola monostachya
Hibbertia conspicua
Melaleuca scabra
Drosera menziesii subsp. *thysanosepala*
Drosera stolonifera subsp. *humilis*
Calothamnus quadrifidus
Stylidium elongatum
Geleznovia verrucosa
Grevillea eriostachya
Opercularia aff. *spermacocea* (AHB 4502)
Tricoryne corynothecoides
Actinostrobos arenarius
Grevillea candelabroides
Melaleuca aff. *holosericea*
Baekkea pentagonantha
Calothamnus kalbarriensis
Platysace commutata
Allocauarina campestris
Petrophile semifurcata
Schoenus latitans
Bonamia rosea
Conospermum stoechadis
Lepidobolus chaetocephalus
Isotropis cuneifolia
Mesomelaena preissii
Tetraria microcarpa
Beyeria cinerea
Stenanthemum complicatum



v

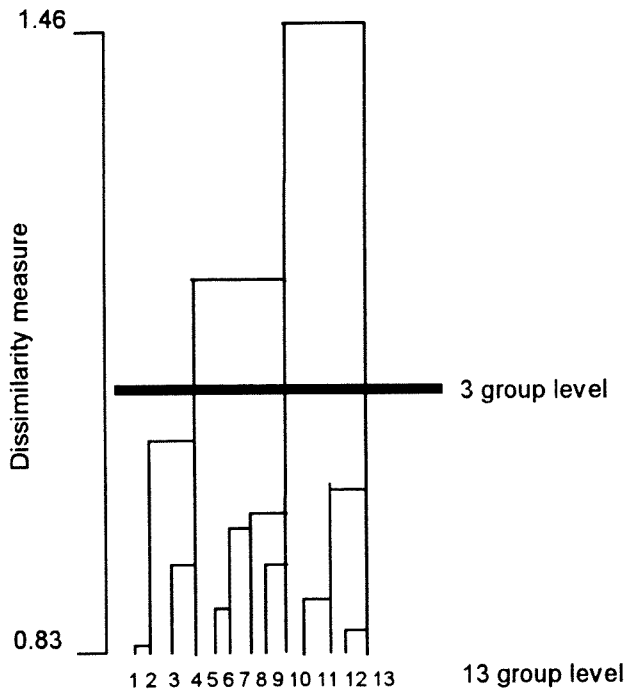


Figure 2 Dendrogram showing the 3 and 13 group classification of the 100 sandplain sites located across the Irwin - Carnarvon boundary.

plot with species assemblages P and Q being typical of this site group. Site group 7, by contrast, generally consisted of *Acacia ligulata* and/or *Melaleuca cardiophylla* shrublands with moderate to high representation of species assemblage R, an assemblage almost totally lacking in all other site groups. This assemblage has a high proportion of weeds. Species richness averages 45.5 taxa/plot. Site group 7 is the most widespread group, stretching from the Zuytdorp cliffs through Edel Land and north to Peron Peninsula (Figure 1).

Site group 8 generally consisted of low woodlands of eucalypts or *Melaleuca* over heath confined to Cooloomia Nature Reserve and areas to the south on red sands generally in swales. Species richness is 34.6 taxa/plot with moderate representation of species assemblage P, while species assemblages Q and R are almost totally lacking.

The final major grouping includes the four site groups of the southern coastal area (group III). Site group 10 includes open mallee or *Allocasuarina* and/or *Actinostrobos* shrubland over heath on yellow sands. Species richness is relatively low (average of 30.4 taxa/plot). Species assemblage V is well represented, species assemblage U is less well represented and assemblages S and T are totally lacking. This site group geographically overlaps with site groups 2 and 3. Site group 11 comprises the *Actinostrobos* - *Banksia* scrubs and heaths confined to the yellow sands of Kalbarri National Park. High representation of species assemblage V separates this group from other site groups in the southern coastal area. Average species richness is 43.3 taxa/plot.

Site groups 12 and 13 are the limestone heaths and shrublands of the Zuytdorp and Cooloomia area. Site group 12 occurs on the deeper sands over limestone while site type 13 occurs on skeletal soils over limestone. Species composition is similar with species assemblage S being more typical of the deeper soils and assemblage T of the skeletal soils (Table 1). Average species richness rises from 36.5 taxa/plot on the deeper soils to 43.0 on the thinner soils.

Environmental correlates - Both the 3 and 13 group classifications showed highly significant differences between group means for both climatic and soil parameters. There was also a high degree of correlation between both the climate and soil parameters (Appendix 1). Given this high degree of correlation within the climatic parameters, only patterns in mean annual temperature, mean annual temperature range, mean annual rainfall, and rainfall seasonality are discussed here (Table 2).

Group II (the northern coastal site groups) had the highest annual mean temperatures followed by the southern inland group (group I) and then the southern coastal group (group III) which is consistent with their geographical spread (Figure 1). Within the northern coastal group, site group 6 experienced slightly higher temperatures than site group 5 and 9 due to its generally more northern distribution. Site group 7 had a lower mean temperature reflecting its wider geographic spread while site group 8 was much lower than the other

Table 2 Site group averages for mean annual temperature, mean annual temperature range, mean annual rainfall, and rainfall seasonality. (Kruskal-Wallis one way analysis of variance of the 13 site groups showed significant difference between means for all parameters at $P < 0.0001$).

Major Group Site Group	I				II				III				
	1	2	3	4	5	6	7	8	9	10	11	12	13
Mean temperature (°C)	21.4	20.9	20.8	21.0	21.6	21.8	21.3	21.0	21.6	20.8	20.6	20.8	20.8
Temperature range (°C)	28.6	28.7	28.6	28.2	27.3	26.7	26.5	27.1	27.1	28.3	27.4	27.2	27.2
Mean rainfall (mm)	239	267	272	273	247	245	296	302	253	290	355	310	329
Seasonality	77.5	75.2	76.6	83.6	93.0	93.3	99.5	97.6	96.3	81.8	94.3	97.0	99.5

site groups reflecting its concentration to the south (Figure 1).

The southern inland group (group I) also showed significant inter site group differences in mean annual temperature (Kruskal-Wallis 31.9, $p < 0.0001$). Site group 1 (the most northern in this group) showed consistent higher temperatures than site groups 2, 3, and 4. Within the southern coastal group (group III), which experienced the lowest annual mean temperatures, site group 11 (on Kalbarri sandplain) was significantly cooler than the more northerly site groups 12 and 13 found in the Zuytdorp Cliff area (Kruskal-Wallis 12.6, $p < 0.01$).

When annual temperature range is considered, the southern inland group (group I) show a consistent range of about 28–29°C. The northern coastal group (group II) has a significantly lower temperature range, especially those sites on Peron Peninsula and Edel Land, where the annual temperature range drops to 26–27°C. Site groups 5, 8 and 9 have similar ranges. Within the southern coastal group (group III) the inland site group (site group 10) has a greater annual temperature range than the other three site groups.

Mean annual rainfall and rainfall seasonality both showed highly significant between group differences both at the 3 group and 13 group classifications. Rainfall generally decreases away from the coast across the study area and is somewhat higher in the south than the north (Beard 1976a). The southern coastal group (group III) has the highest annual rainfall and within this group, site group 11 (the Kalbarri sandplain sites) is higher than the remaining site groups. Site group 10 (the

most inland of this group) has the lowest annual rainfall. Site groups 3 and 4 (belonging to the southern inland grouping (group I)) occur further inland still and show further decreases in rainfall. The lowest mean annual rainfall (240 – 245 mm) are found in site groups 1, 5 and 6, consistent with the above pattern (Figure 1).

The most strongly seasonal patterns in rainfall are seen in the high rainfall southern coastal group (group III) and the northern coastal grouping (group II) (Table 2). The more inland site groups had a less predictable climate and hence less pronounced seasonality. This trend is apparent within the southern coastal group where the most inland of site groups (10) has a significantly less seasonal rainfall pattern than site groups 11, 12 and 13 (Table 2, Kruskal-Wallis 19.1, $p < 0.001$).

Soil nutrient and mechanical parameters also showed highly significant differences between group means for both the 3 group and 13 group classifications and within the three major groups (Tables 3 and 4). The most striking differences are the high pH, high electrical conductivity, and high nutrient levels of the northern coastal group (group II) with considerable variability of parameters within its 5 site groups.

The southern inland (group I) and southern coastal (group III) groups are acidic sands with the inland group having generally lower pH than the coastal group (Table 3). The yellow sands of the southern coastal group (group III) showed less variability in pH than the southern inland group (group I). Within the southern coastal group, site group 10 (inland sites) has a significantly lower pH than site group 13 (coastal scrubs) (Kruskal-Wallis

Table 3 Means values for the 13 site groups for soil parameters. Sig. Diff. indicates significant differences between means of the 13 groups based on Kruskal - Wallis one way analysis of variance (** = $p < 0.001$, **** = $p < 0.0001$).

Major Group Site Group	I				II					III				Sig. Diff.
	1	2	3	4	5	6	7	8	9	10	11	12	13	
EC	1.64	1.60	1.08	1.00	5.29	5.56	12.75	5.00	8.00	1.09	2.17	3.00	2.00	****
pH (H ₂ O)	5.8	6.5	5.9	6.1	8.0	7.6	8.9	7.2	8.5	6.2	6.5	6.5	6.7	****
C	0.37	0.41	0.41	0.37	0.33	0.31	0.96	0.46	0.41	0.30	0.35	0.39	0.46	***
Total N	0.02	0.03	0.02	0.02	0.02	0.03	0.08	0.03	0.02	0.01	0.01	0.02	0.02	****
Total P	70.8	61.2	36.1	32.3	41.4	61.6	298.5	53.0	35.3	27.5	17.7	22.3	39.0	****
Avail P	3.21	3.80	1.54	1.50	3.43	5.44	12.13	4.80	2.00	0.91	0.50	0.75	1.25	****
Avail K	36.9	101.4	23.3	21.3	40.1	115.8	75.6	41.8	29.0	18.2	16.2	18.3	26.3	****
Exch Ca	0.52	1.35	0.52	0.58	1.67	2.25	4.03	2.56	2.14	0.46	0.94	1.01	1.15	****
Exch Mg	0.13	0.51	0.13	0.17	0.27	0.53	0.57	0.27	0.26	0.13	0.19	0.23	0.28	****
Exch K	0.06	0.17	0.04	0.04	0.06	0.18	0.20	0.05	0.04	0.03	0.02	0.02	0.05	****
Exch Na	0.02	0.05	0.00	0.00	0.03	0.06	0.15	0.03	0.04	0.00	0.01	0.04	0.03	****
Sand	91.4	89.9	92.2	92.8	95.3	93.8	91.2	96.0	95.7	92.8	95.8	96.9	95.0	****
Silt	1.4	2.3	1.5	1.7	1.1	1.5	2.6	0.8	0.5	1.6	1.6	0.8	0.9	****
Clay	7.3	7.9	6.3	5.5	3.6	4.7	6.0	3.2	3.8	5.6	2.7	2.4	4.3	****
No of quadrats	16	10	12	5	7	9	8	5	3	11	6	4	4	

8.6, $p < 0.05$). The sandy soils of the northern coastal group are significantly more alkaline than either of the other major groups (Kruskal-Wallis 63.8, $p < 0.0001$). The most alkaline site group (7, mean pH 8.9) occurs on coastal dunes from Peron Peninsula to Zuytdorp Cliffs while site groups 5 and 9 of the red sandplain south of Shark Bay recorded average pH of 8 – 8.5. The mean pH of the remaining site groups of this northern coastal grouping ranges from 7.2 – 7.6.

Electrical conductivity showed an even more pronounced differentiation of the northern coastal group (group II) from the remaining groups (Table 3). Again site groups 7 and 9 recorded the highest electrical conductivity values within this group. Similar patterns are seen for available P, K, exchangeable Ca, K, Mg and Na (Table 3). Four quadrats in site group 2 show consistent elevated values for K and exchangeable Mg, Ca and K that are not clearly apparent in the electrical conductivity data. Site groups 12 and 13 show higher exchangeable Ca and Na and electrical conductivity values than are apparent for other site groups in the southern coastal grouping (group III) (Table 3).

The pattern for C, N and total P differ from the patterns described above with a strong peak only in community type 7 (Table 3). Both total and available P show elevated levels in the southern inland group (group I) compared with the southern coastal group (group III) (Table 3). Within the southern inland group there are significantly different mean values of total and available P (Kruskal-Wallis 24.3 and 16.5 respectively, $P < 0.001$) with site groups 1 and 2 showing about twice

the values of site groups 3 and 4 (Table 3). Significant differences were also found between the means of total and available P of site groups in group II and in group III (Table 4).

Mechanical analysis showed similar patterning to that seen in the soil chemistry data (Table 3). All sites were on either sands or sandy loams with the southern inland group (group I) having the highest clay contents. Within this group, site group 4 had low average clay content (5.5%) while site groups 1 and 2 had clay contents of 7.3% and 7.9% respectively. The northern coastal group also exhibited significant differences in clay content between site groups with the highest levels found in site group 7 (average of 6% clay) and the other site group means ranging from 3.2 to 4.7% (Kruskal-Wallis 11.3, $p < 0.05$). Site 70, which is an outlying site in site group 6, had much higher average clay content than other sites in this group. The level of clay at this site is similar to those of site group 1 that occur in the immediate vicinity (Table 3, Figure 1).

The southern coastal group (group III) generally showed the lowest average soil clay content. Within this group highly significant variation was seen between site groups (Table 3 and 4), with site groups 11 and 12 showing the lowest average clay content (2.4 – 2.7%) while site groups 10 and 13 had average clay contents of 4.3 to 5.6%. Percentage clay content was highly correlated with soil nutrient levels, and percentage silt showed a degree of weak correlation with some soil nutrient parameters (Appendix 1).

DISCUSSION

Beard's (1980) classification of phytogeographic regions attempts to identify natural ecological regions "each of which possesses its own characteristic landscape due to its particular features of climate, geology, landforms, soils and vegetation". He used vegetation (mapped in terms of structure, density and composition of the dominant taxa) as the indicator of these regions. The phytogeographic boundary between the Irwin and Carnarvon botanical districts also represents the boundary between two of the major floristic provinces (temperate Southwestern and arid Eremaean) in Western Australia.

Our analysis of floristic patterning of comprehensive lists from 100 sites across this boundary sought to test the current placement of this major phytogeographic boundary independently of Beard's vegetation units. One possible drawback of this approach is that seasonality in annual and geophyte occurrence could influence the floristic classification. However, while no detailed studies on seasonality have been undertaken in this region (low rainfall temperate),

Table 4 Significance differences between site group means within the southern inland group (group I), the northern coastal group (group II) and the southern coastal group (group III) based on Kruskal - Wallis one way analysis of variance. (*= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ****= $p < 0.0001$).

	Group I	Group II	Group III
EC	ns	**	*
pH (H2O)	*	***	*
C	ns	**	**
Total N	ns	**	*
Total P	****	***	**
Avail P	***	**	*
Avail K	***	***	ns
Exch Ca	*	**	***
Exch Mg	**	**	**
Exch K	***	***	ns
Exch Na	*	**	***
Sand	*	**	***
Silt	ns	**	**
Clay	*	*	***

Table 5 Comparison of the 3 group and 13 group floristic classifications with Beard's phytogeographic districts and vegetation systems. Figures in the table are the number of quadrats.

District	Vegetation system	I				II				III				
		1	2	3	4	5	6	7	8	9	10	11	12	13
Carnarvon														
	Lharidon					6								
	Denham							2						
	Peron							1						
	Carrarang							2						
	Talisker	7	6	3										
	not mapped	6				3	1							
Irwin														
	Tamala					4	2		3	3				
	Zuytdorp							3	2					4
	Eurardy	3		2	4						4	1	4	
	Yuna		4	7	1						7			
	Kalbarri											5		

all sites were visited at least once following good winter rains and, with the exception of site groups 5 and 9, the classification shows no segregation by year of sampling, implying that the influence of any seasonal component in the data analysis is low.

Our data show very strong correlation of edaphic and climatic factors with floristic composition at both the 3 and 13 group levels, but generally poor correlation with Beard's phytogeographic districts and vegetation systems (Table 5). Our southern coastal group (group III) was however entirely confined to Beard's Irwin district and within this group there was good correlation between three of

the four site groups and Beard's vegetation systems (Table 5).

This southern coastal group (group III) can clearly be considered a southwestern group in terms of family and species composition (Tables 1 and 6). It is the outlying group in our classification (Figure 2) with groups I and II being floristically more similar and having more overall similarities with the Eremaean region (Tables 1 and 6). These results are at variance with the present location of the Irwin - Carnarvon boundary and suggest that the southern section of this boundary should be placed 25 km further to the west then swing to the coast in the

Table 6 Comparison of patterns in composition of the most common families between plots in the tree heath (site groups 5 and 9) with those typical of the Irwin (site groups 10 to 13) and the Carnarvon (site group 1). Percentage composition calculated for taxa recorded within each group and mean species richness/100 m².

	Irwin plots (site groups 10-13)	Tree heath plots (site group 5 and 9)	Carnarvon plots (site group 1)
No of plots	25	10	16
Total number of species	309	166	173
Total number of families	50	46	48
Mean species richness	40.0	38.3	40.0
Myrtaceae	23.3	15.1	6.4
Proteaceae	11.3	6.0	5.2
Mimosaceae	6.1	8.4	5.7
Papilionaceae	6.1	1.8	0.6
Cyperaceae	4.5	-	-
Haemodoraceae	3.2	-	-
Asteraceae	2.9	10.8	23.7
Dilleniaceae	2.6	1.2	-
Goodeniaceae	2.6	1.2	4.6
Poaceae	2.6	5.4	4.6
Chloanthaceae	1.9	4.2	1.7
Apiaceae	1.3	0.6	2.9
Amaranthaceae	0.6	2.4	4.0
Chenopodiaceae	0.3	3.7	1.2
Myoporaceae	0.3	3.0	4.0
Solanaceae	0.3	3.0	4.0

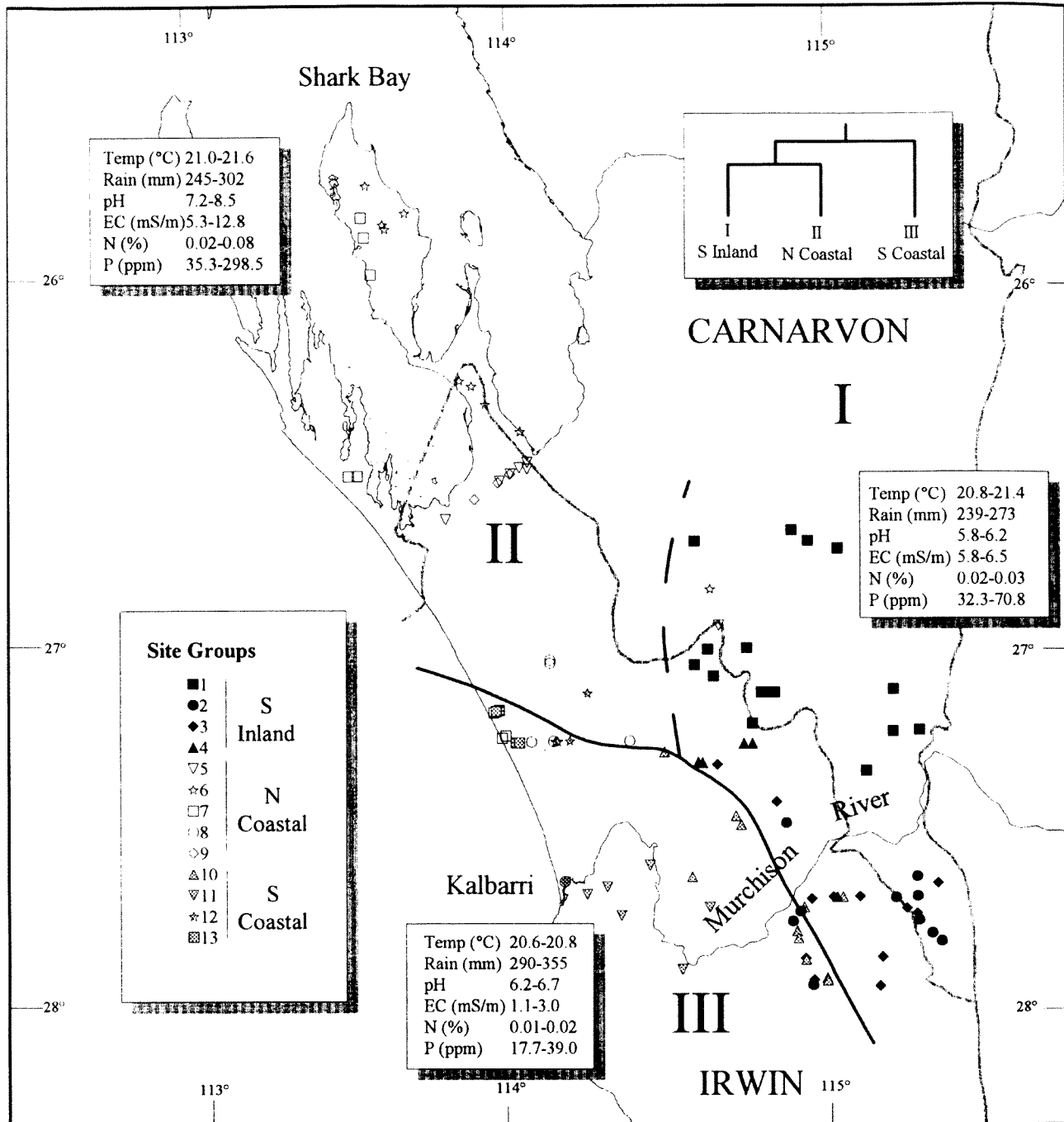


Figure 3 Present location of the phytogeographic boundaries (solid grey lines), proposed position of the Irwin - Carnarvon boundary (solid black line), and separation between southern inland (group I) and northern coastal (group II) floristic groups (dashed black line). For each of the three major groups the range in site group means for temperature, rainfall, pH, electrical conductivity and total P and total N shown in boxes.

vicinity of the Zuytdorp cliffs south of the tree heath to more fully conform with patterns in species composition (Figure 3).

The present position of the southern section of the Irwin - Carnarvon boundary separates the *Acacia - Casuarina* thicket on red sandplain (Irwin) from the *Acacia ramulosa/linophylla* scrub with scattered pines and eucalypts (Carnarvon) (Beard, 1976a, 1976b, 1976c). Moving this boundary 25 km to the west would include the *Acacia - Casuarina*

thicket in the Carnarvon district and result in the Irwin boundary being defined by Beard's scrub heaths on yellow sandplain. Our analysis then suggests that the Irwin boundary should then follow the southern boundary of the tree heaths to the coast.

All previous workers, except Clarke (1926), have placed these tree heaths in the Irwin district, however when patterns in species and family composition of sites in this unit (site

groups 5 and 9) are compared with site groups 10 to 13 (all within the Beard's Irwin district) and site group 1 (predominantly in Beard's Carnarvon district) it is clear that tree heaths are more similar in terms of total species composition (cf. dominants) to typical Eremaean pattern than that of the Southwest. There is no difference in mean species richness between these groups (Table 6).

Our soil chemical data lend no support to the current placement of the Irwin - Carnarvon boundary (Table 3, Figure 3) The predominantly red sand sheets occupied by sites in our southern inland group (group I) show almost total segregation in terms of pH, electrical conductivity, and total N and total P and clay content for site group means from the other groups (Figure 3, Table 3). Similarly our northern coastal group (group II) has more calcareous sands of higher P content than either groups I or III, suggesting these three sand sheets have different origins. More detailed analysis of the soil profiles would be needed to confirm this.

The shallow nature of climatic gradients is a feature of this part of Western Australia, where the whole of the study area is in a predominantly winter rainfall zone, with total mean annual precipitation decreasing to the north and east. Climate estimates for our sites are consistent with this pattern with the highest rainfall and a high seasonality seen in the southern coastal group (group III) (Table 2, Figure 3). Rainfall maps in Beard (1976a) suggest the 300 mm isohyet extends up the Edel Land Peninsular and bisects Dirk Hartog Island, although more recent data (Anonymous, 1986) indicate that this isohyet cuts the coast just north of Kalbarri. This isohyet has long been regarded as significant in delimiting the Southwestern and Eremaean Provinces, disregarding its incorrect map position (Diels, 1906; Gardner and Bennetts, 1956; Beard, 1976a).

The placement of the Carnarvon - Irwin boundary 25 km to the west and swinging south of the tree heath on red sandplain (Figure 3) would make it consistent with strongly correlated patterns demonstrated between the species composition analysis and the edaphic and climatic parameters of our sites, and more closely fit Beard's (1980) concept of natural ecological regions. Our data strongly suggest Beard's interpretation of the vegetation of the peninsulas and islands of the Shark Bay area in the Carnarvon botanical district is correct (cf. Burbidge and George, 1978; Thackway and Cresswell, 1995) however our analysis suggests that the tree heaths and *Acacia* shrublands on the red sandplains east of Kalbarri should also be regarded as part of the Carnarvon botanical district.

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APPENDIX 1

Matrix of Spearman Rank Correlation coefficients for climatic and soil parameters. Correlations in bold are significant at $p < 0.01$.

	Ca Exch	Clay	C	EC	K Exch
Ca Exch	1.000				
Clay	-0.146	1.000			
C	0.488	0.194	1.000		
EC	0.818	-0.174	0.376	1.000	
K Exch	0.553	0.424	0.285	0.535	1.000
K	0.661	0.298	0.311	0.614	0.867
Mg Exch	0.921	-0.110	0.429	0.754	0.614
Na Exch	0.756	-0.023	0.419	0.758	0.566
Total N	0.714	0.295	0.770	0.624	0.670
Rainfall	0.125	-0.258	0.260	-0.029	-0.250
P Available	0.614	0.336	0.288	0.621	0.731
pH	0.904	-0.285	0.265	0.785	0.441
Seasonality	0.634	-0.559	0.271	0.642	0.154
Total P	0.415	0.588	0.417	0.432	0.756
Sand	0.322	-0.745	0.004	0.374	-0.204
Silt	0.161	0.584	0.281	0.047	0.334
Annual Temp	0.219	-0.024	-0.127	0.407	0.407
Temp Range	-0.654	0.533	-0.233	-0.638	-0.205
	K	Mg Exch	Na Exch	Total N	Rainfall
K	1.000				
Mg Exch	0.691	1.000			
Na Exch	0.602	0.752	1.000		
Total N	0.756	0.660	0.626	1.000	
Rainfall	-0.351	0.133	-0.010	-0.067	1.000
P Available	0.839	0.556	0.576	0.725	-0.412
pH	0.517	0.822	0.673	0.481	0.151
Seasonality	0.155	0.588	0.533	0.281	0.442
Total P	0.770	0.384	0.506	0.749	-0.383
Sand	-0.070	0.287	0.248	-0.092	0.251
Silt	0.278	0.178	0.051	0.339	0.132
Annual Temp	0.486	0.191	0.332	0.260	-0.805
Temp Range	-0.192	-0.616	-0.529	-0.269	-0.453
	P Available	pH	Seasonality	Total P	Sand
P Available	1.000				
pH	0.500	1.000			
Seasonality	0.102	0.696	1.000		
Total P	0.843	0.247	-0.022	1.000	
Sand	-0.119	0.457	0.584	-0.350	1.000
Silt	0.281	0.074	-0.173	0.325	-0.482
Annual Temp	0.551	0.227	0.099	0.441	0.011
Temp Range	-0.126	-0.747	-0.943	0.047	-0.596
	Silt	Annual Temp.	Temp. Range		
Silt	1.000				
Annual Temp	-0.231	1.000			
Temp Range	0.113	-0.075	1.000		