

Soils sampled during a biological survey of the Western Australian wheatbelt

E.A. Griffin¹ and T.C. Stoneman²

¹Department of Agriculture, Baron-Hay Court, South Perth, Western Australia 6167, Australia

²18b Whitfield Street, Floreat, Western Australia 6014, Australia

Abstract – As part of a biodiversity survey, soil profiles are described and classified at 304 quadrats set in uncleared vegetation remnants throughout the Western Australian wheatbelt.

The Department of Agriculture, Western Australia, has developed a hierarchical soil-landscape GIS for the region. The Western Australian Soil Group layer in this classification was used to assess how well the 304 quadrats sampled the region's soils. The predominance of quadrats with sandy surface soils reflects the general nature of the region as well as the preferential clearing of its loamy and clayey soils for agriculture.

While soils of saline drainage lines were sampled more frequently than expected, given their regional extent, it was a deliberate strategy of the survey to sample areas where biodiversity is threatened by the effects of rising saline groundwater. On the other hand, some regionally common sandy soils such as Yellow deep sand and sandy earths were under-sampled, as were the regionally less common loamy and clayey soils.

In terms of wheatbelt soil-landscapes, the Lockier and Southern Cross areas were under-sampled while peripheral areas more typical of the forest than the wheatbelt were over-sampled.

Some of this sampling bias would have been difficult to redress because the loamy and clayey soil groups and the Lockier area have been largely cleared for agriculture.

INTRODUCTION

Overview of soils of south-western Australia

South-western Australia has long been recognized for having a predominance of sandy and infertile soils (McArthur, 1991). Traditional paradigms to explain these characters invoke deep weathering and planation over a long period, perhaps eons (Jutson, 1950; Mulcahy, 1973).

The major influences on soils are the soil parent material and the degree of weathering and landscape rejuvenation caused primarily by tectonic activity and climate change (Mulcahy, 1973; McArthur *et al.*, 1977; Tille *et al.*, 2001). This recognition is the basis of small-scale soil mapping products (Prescott, 1931; Northcote *et al.*, 1967; McArthur *et al.*, 1977). These authors broadly recognize the dominance of the weathered acidic granitic shield with sandy sediments fringing its coastal margins. Areas of significant stripping, principally by water (Finkl and Churchward, 1973), are identified as such in the Zone of Rejuvenated Drainage (Mulcahy and Hingston, 1961). These contrast with the drier Zone of Ancient Drainage with its limited stripping and sluggish drainage lines.

Vegetation type distribution has been explained as being determined by soil and climate (Gardner, 1944; Lange, 1960). These views are being challenged by Pate *et al.* (2000) who, through investigation of relationships between soil and native plants, invert this relationship. They provide evidence that many of the soil types in south-western Australia are the product of plant exudates and the actions of micro-organisms. While the influence of root exudates in mineral weathering has long been recognized, the novelty lies in the active influence of particular plant groups, e.g. Proteaceae, in modifying their soil environment to their own advantage. They assert that these formation processes, being both long standing and contemporary, have contributed much to the planation.

No matter what the predominant soil formation process is, it is clear that plants and soil have a strong relationship. Early settlers recognized this (Moore, 1884 cited in McArthur, 1991) in their selection of land. The extension of agriculture into the wheatbelt continued largely based on vegetation types as a guide to the suitability of the land.

No accurate soil type map of south-western Australia has been prepared; only various

representations of land tracts with different suites of soils. The Atlas of Australian Soils (Northcote *et al.*, 1967) has been until recently the most detailed complete map (scale 1:2,000,000) of the soils of south-western Australia.

Landscape characteristics are a major component of recent soil-landscape mapping by the Department of Agriculture, Western Australia (Purdie, 1993). These 1:50,000 to 1:250,000 scale maps use an hierarchy of map units. A map of the dominant soils in south-western Australia (Schoknecht, 2002) represented on a consistent soil-landscape systems unit (Purdie, 1993) has been a product of this programme.

An important small-scaled product is a soil-

landscape zone map of south-western Australia in which the broad patterns of landscapes are indicated (Figure 1). These zones are convenient vehicles by which the broad soil and landscape characteristics can be communicated. They have modest correlation with the IBRA regions (see Figure 1 of McKenzie *et al.*, 2004) but are units of a more detailed scale. Summary descriptions of these zones, including parent material, degree of stripping, and dominant soils, are provided in Table 1.

Figure 1, which shows these zones and average annual rainfall, suggests that climate has had a strong influence on geomorphology and soil development.

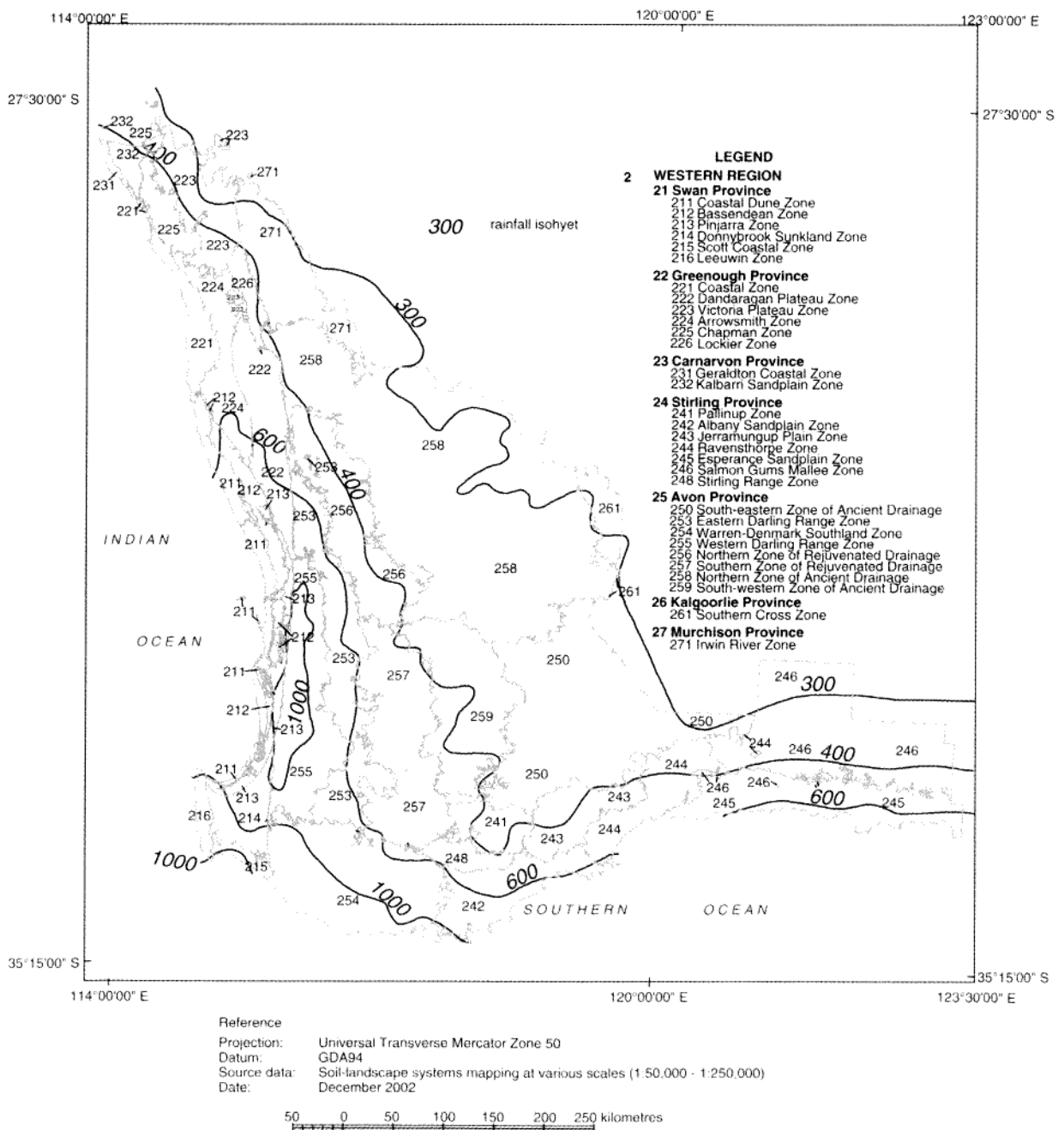


Figure 1 Soil-landscape zone map with rainfall isohyets.

Sampling for Salinity Action Plan

This paper presents descriptions of the soils at each of the terrestrial biodiversity quadrats sampled during the Salinity Action Plan survey (McKenzie *et al.*, 2004). A summary of the main soils sampled is provided. It includes an assessment of the representativeness of these quadrats, individually and collectively, in terms of the soils documented to occur in the wheatbelt during the Department of Agriculture's soil-landscape mapping programme. An attempt is also made to predict if any under-sampled soils could have been found in extant native vegetation in the wheatbelt.

METHODS

Soil sampling at survey quadrats

The wheatbelt study area was divided into 24 survey areas (see Figure 1 in McKenzie *et al.*, 2004). Twelve or 13 quadrats were established in each survey area, with each quadrat attempting to represent a different landscape or vegetation type. All were in apparently natural vegetation relatively unaffected by European activities. There was a deliberate pairing of some quadrats so that effects of rising saline ground waters might be examined.

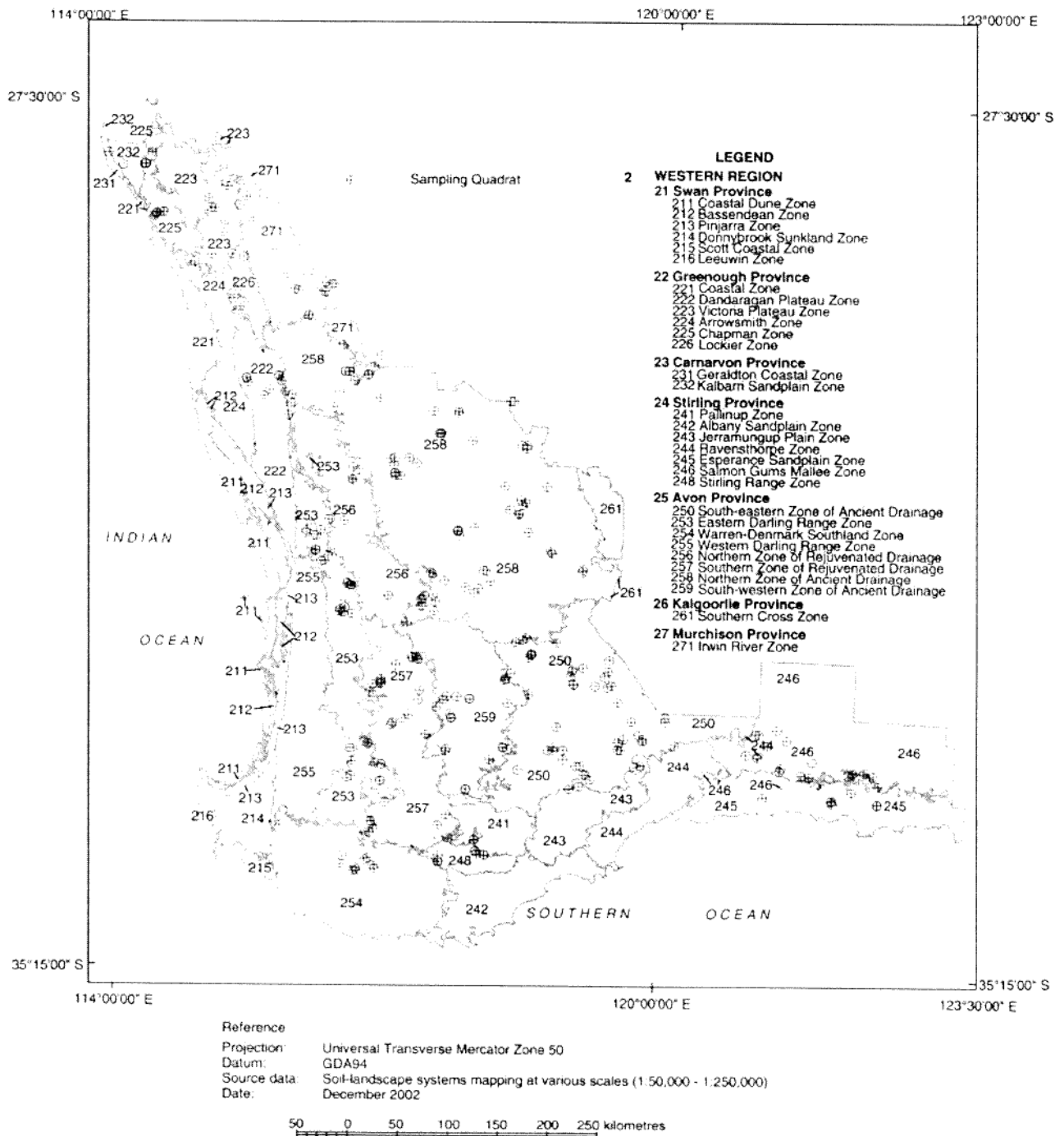


Figure 2 Sampling quadrat locations on soil-landscape zone map

Table 1 Summary description of soil-landscape zones in south-western Australia (unpublished from Map Unit database, Department of Agriculture). Symbols that are underlined form the wheatbelt or have been sampled in this study.

Symbol	Zone name	Summary description
211	Perth Coastal Zone	Coastal sand dunes and calcarenite. Late Pleistocene to Recent. (Quindalup and Spearwood systems). Calcareous and siliceous sands and calcarenite.
212	Bassendean Zone	Mid Pleistocene Bassendean sand. Fixed dunes inland from coastal dune zone. Non-calcareous sands, podsolized soils with low-lying wet areas.
213	Pinjarra Zone	Alluvial deposits (early Pleistocene to Recent) between the Bassendean Dunes Zone and the Darling Scarp, colluvial and shelf deposits adjacent to the Darling Scarp. Clayey to sandy alluvial soils with wet areas.
214	Donnybrook Sunkland Zone	Moderately dissected lateritic plateau on Perth Basin sedimentary rocks. Soils are formed in lateritic colluvium, weathered in-situ sedimentary rocks and alluvium (poorly drained sandy alluvial plain in the south).
215	Scott Coastal Zone	Pleistocene to Recent coastal barrier dunes and backplain. Non-calcareous sands dominate with podsolized soils with low-lying wet areas.
216	Leeuwin Zone	Leeuwin Block (tectonic geology), moderately dissected lateritic plateau on granite. Colluvial soils in the valleys. On the western margin the granite is overlain by Tamala Limestone and there are some coastal dunes.
221	Geraldton Coastal Zone	Dunes with alluvial plains and sand sheets. Low hills of Pleistocene Tamala Limestone, Recent calcareous and siliceous dunes.
222	Dandaragan Plateau Zone	Gently undulating plateau with areas of sandplain and some laterite. On Cretaceous sediments. Broad u-shaped valleys 80–150 m deep, smaller v-shaped east of the Gingin Scarp in the south. Soils are formed in colluvium and weathered rock.
223	Victoria Plateau Zone	Gently undulating sandplain on Silurian sandstone and Proterozoic granulite with laterite exposed at dissected margins.
224	Arrowsmith Zone	Dissected lateritic sandplain on Cretaceous and Jurassic sediments. Bounded in the east by the Dandaragan Scarp and in the south and west by the Gingin Scarp. Sandy and gravelly soils formed in colluvium and weathered in-situ rock.
225	Chapman Zone	Mesas of Triassic and Jurassic sediments on undulating Proterozoic granulite and migmatite with numerous dolerite dykes. Soils formed in in-situ weathered rock, and lateritic colluvium on the sedimentary rocks (mesas).
226	Lockier Zone	River valleys of the Irwin, Lockier and Arrowsmith rivers. Alluvial valley plains underlain by Proterozoic granulites, Permian and Jurassic sediments. Outliers of Victoria Plateau Zone occur within the zone. Clayey to silty soils.
231	Port Gregory Coastal Zone	Coastal dunes, calcareous in places. Undulating sandplain on limestone (Pleistocene calcarenite).
232	Kalbarri Sandplain Zone	Undulating sandplain on Silurian and Devonian sediments of the Gascoyne Sub Basin (Carnarvon Basin), some Cretaceous sediments. Moderately dissected in places with laterite remnants.
241	Pallinup Zone	Undulating rises on Archaean granitic rocks in the Upper Pallinup catchment. Shallow duplex soils, commonly with sodic and alkaline subsoils. Woodlands of York and Salmon gums, wandoo and yate dominate.
242	Albany Sandplain Zone	Gently undulating plain dissected by a number of short rivers flowing south. Eocene marine sediments overlying Proterozoic granitic and metamorphic rocks. Soils are sandy duplex soils, often alkaline and sodic, with some sands and gravels.
243	Jerramungup Zone	Level to gently undulating plain dissected by a number of short rivers flowing south. On Eocene marine sediments overlying Proterozoic granitic and metamorphic rocks. Soils are alkaline sandy duplex soils with some clays, sands and gravels.
244	Ravensthorpe Zone	Rolling low hills on greenstone (mafic and ultramafic). Moderately dissected with south-flowing rivers. Red fine-textured soils.
245	Esperance Sandplain Zone	Level to gently undulating plain dissected by a number of short rivers flowing south. Formed on Eocene marine sediments overlying Proterozoic granitic and metamorphic rocks. Soils are grey fine sandy duplex soils and fine sands.

Symbol	Zone name	Summary description
246	Salmon Gums-Mallee Zone	Level to gently undulating plain, with Tertiary sediments over Proterozoic granites. Salt lakes, scattered or in swarms are a common feature. Drainage lines become indistinct towards the north.
248	Stirling Range Zone	Mountains on metasediments with associated rises and poorly drained plains to the north. Rocky and gravelly soils occur the mountains and sandy duplexes on the rises and plain. Shrublands dominate the mountains and woodlands the rises
250	South-eastern Zone of Ancient Drainage	A smooth to irregularly undulating plain dominated by salt lake chains in the main valleys with duplex and lateritic soils on the uplands. Mallee vegetation on duplex soils, proteaceous vegetation on gravels and sands.
253	Eastern Darling Range Zone	Moderately to strongly dissected lateritic plateau on granite with some surficial Eocene sediments. Soils are formed in laterite colluvium or weathered in-situ granite. Minor streams tend to be eastward-flowing.
254	Warren-Denmark Southland Zone	Rises in a series of broad benches from the Southern Ocean north to the Blackwood Valley. Deeply weathered granite and gneiss overlain by Tertiary and Quaternary sediments in the south. Swampy in places.
255	Western Darling Range Zone	Moderately dissected lateritic plateau on granite with deeply incised valleys, includes the Darling Scarp on the western margin. Soils are formed in laterite, lateritic colluvium and weathered in-situ granite and gneiss.
256	Northern Zone of Rejuvenated Drainage	Erosional surface of gently undulating rises to low hills. Continuous stream channels that flow in most years. Colluvial processes are active. Soils formed in colluvium or in-situ weathered rock. Mainly from Jimperding Metamorphic Rocks.
257	Southern Zone of Rejuvenated Drainage	Erosional surface of gently undulating rises to low hills. Continuous stream channels that flow in most years. Colluvial processes are active. Soils formed in colluvium or in-situ weathered rock.
258	Northern Zone of Ancient Drainage	An ancient plain with low relief on weathered granite. There is no connected drainage, salt lake chains occur as remnants of ancient drainage systems which now only function in very wet years. Lateritic uplands dominated by yellow sandplain
259	South-western Zone of Ancient Drainage	An ancient plain of low relief on weathered granites with sluggish drainage systems and uplands dominated by sands and gravels. Lateritic uplands dominated by grey sandy gravel plain predominately with proteaceous species.
261	Southern Cross Zone	Rises and low hills on Archaean greenstones, with broad valleys often containing salt lake chains. Soils are usually red, loamy to clayey and calcareous.
271	Irwin River Zone	The Irwin and Lockier River catchments within the Yilgarn Craton. Archaean granites, gneisses, metasediments and basic igneous rocks.

At each of the 304 quadrats (Figure 2) landscape and soil descriptions were made using Department of Agriculture, Western Australia, standards which are based on McDonald *et al.* (1990). These edaphic descriptions provide opportunities for correlations with the observed biota to be examined. The standardized observations made allow potential extension of biological findings to areas not sampled through the point and polygon datasets of the Department of Agriculture.

Soil profiles were described from hand auger borings, made to a depth of about 1 m where possible. The morphological characters/properties recorded included colours, field textures, coarse fragments, structure, mottles, and the presence of root limiting layers such as pans. Field pH of most layers was determined using an Inoculo Soil pH kit. Soil profiles were classified into Western Australian

Soil Groups (Schoknecht, 2002) and the Australian Soil Classification (ASC) (Isbell, 2002). The latter was often tentative due to the absence of all of the required laboratory data. Tenosols, which require little or no laboratory data, are probably quite reliable. However, the distinction between Chromosols and Sodosols and many lower levels of the classification require laboratory data for reasonable certainty. Some morphological property correlations and geographic and landscape distributions often assisted in guessing the likely ASC Soil Order.

Samples of layers were taken for laboratory analysis at all quadrats. Financial constraints restricted analysis to one representative subsoil layer from each quadrat. The analyses included pH, electrical conductivity, chloride, calcium carbonate and gypsum content and were conducted by the

1. Regions
 Broad subdivisions of the Australian continent
 (Bettenay 1983).
 e.g. **The Western Region (2)**

2. Provinces
 Provide a broad overview of the whole state
 suitable for maps at scales of about 1:5,000,000
 (Bettenay 1983).
 e.g. **The Avon Province (25)**

3. Zones
 Areas defined on geomorphologic or geological
 criteria, suitable for regional perspectives.
 e.g. **South-western Zone of Ancient Drainage (259)**

4. Systems
 Areas with recurring patterns of landforms, soils
 and vegetation, suitable for regional mapping at
 scales of 1:250,000.
 e.g. **Kukerin System (259Kk)**

5. Subsystems
 Areas of characteristic landforms features
 containing definite suites of soils, suitable for
 mapping at regional scales of 1:100,000.
 e.g. **Kukerin 1 Subsystem (259Kk_1)**

6. Subsystem phases
 Division of subsystems based on land use
 interpretation requirements.
 e.g. **Kukerin 1 sandy phase (259Kk_1s)**

7. Land units (unmapped at regional scale)
 Describe areas of land with similar soils, slopes
 and landforms.

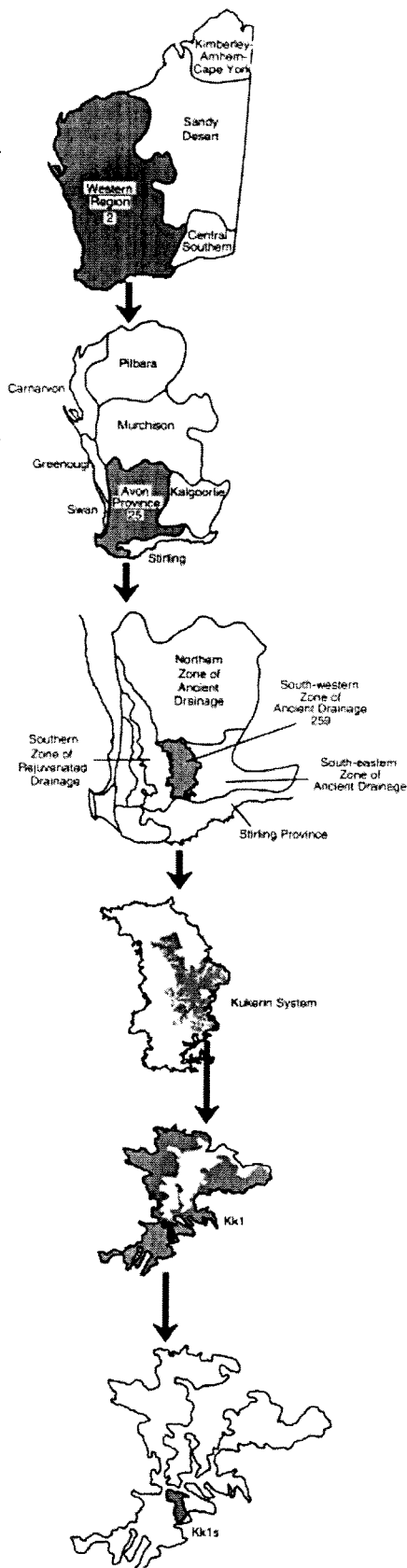


Figure 3 Soil-landscape map unit hierarchy used by the Department of Agriculture.

Department of Conservation and Land Management laboratories. Some of the samples were analyzed by the Chemistry Centre of WA for clay and organic carbon content as part of a study of soil organic carbon (Griffin and Schoknecht, 2002). Methods used are briefly outlined in Appendix 1.)

Bulked soil samples were also taken at depths of between 50 – 100 mm from a 30m x 30 m vegetation plot within each of the terrestrial biodiversity quadrats (see Methods in McKenzie *et al.*, 2004). These 0.5 to 1 kg samples were analyzed by the Chemistry Centre of WA for pH, EC, organic carbon, total N and P, bicarbonate extractable P and K, as well as exchangeable cations, gypsum and calcium carbonate (see Appendix 3 in McKenzie *et al.*, 2004).

The descriptions of individual quadrats and their profiles have been incorporated into the Soil Profiles database of the Department of Agriculture, Western Australia. This contains over 50,000 similar observations, mostly from south-western Australia.

Analysis of representativeness

The soil units used for the analyses in this paper are Western Australian Soil Groups (Schoknecht, 2002) rather than the Australian standard (Australian Soil Classification, Isbell 2002) (ASC). Soil Groups were developed by the Department of Agriculture as a standard way for describing the soils of Western Australia, particularly those in the State's south-west. Sixty Soil Groups in 13 Super Groups are recognized. All 60 are quite general units, each of which represents many different soil types, used for land-use communication. The Soil Groups' virtues include ease of recognition and simplicity in concepts such as uniform, gradational and texture contrast profile types used in the system of Northcote (1979) plus soil colours and gravel content.

The ASC is a system widely used in land resource assessment in Australia but its adoption is limited in Western Australia. It has been used in the definition of major soil types (soil series), e.g. Percy (2000). Schoknecht (2002) shows that there are some broad relationships between the ASC and Soil Groups, but the significant differences between these systems restrict its use for mapping soil units in Western Australia.

The Department of Agriculture's regional soil-landscape mapping was used for comparison of the soil sampled at the quadrats. While there is complete coverage by this mapping for south-western Australia, only about half has been published (e.g. Percy, 2000), and much was in draft form at the time of analysis (e.g. Verboom and Galloway, 2004). All mapping has descriptions and soil attribution and is being progressively reviewed. The soil-landscape maps are hierarchical, with a

number of ranks that recognize different levels of complexity in soil, parent material and landscape (Purdie, 1993). Figure 3 provides an example of the hierarchy. The most detailed mapped units are typically subsystems and phases but are systems in some areas. All these units are heterogeneous and are partially characterized by the proportional allocation of Soil Groups by landscape position, e.g. Grey shallow sandy duplex on a footslope.

The soil-landscape hierarchy provides a number of levels at which soil and landscape data can be presented and interpreted. Soil-landscape zones provide useful units to represent the major geomorphic character and soils of south-western Australia (e.g. Figure 1). As a map unit they are similar to IBRA subregions (Cummings and Hardy, 2000) in their intended scale of use.

The soil-landscape map unit in which each of the quadrats occurred was determined by a geographic information system (GIS) spatial query. Combining these data it was possible to determine what soils were considered characteristic of the wheatbelt and identify areas and soils that might have been under- or over-sampled by the quadrats.

There are several reasons why the soil type observed at a quadrat can be different from that expected on the basis of the soil-landscape mapping. All mapping is affected by landscape heterogeneity, soil sampling intensity and soil mapping scale. The observed soil type may belong to a different land tract that was overlooked during the mapping programme, or be rare at local, general or at all scales of mapping in an area.

Determining just how well a quadrat's soil represented the map unit in which it fell was, therefore, somewhat problematical. Uncertainties included the classification of the soil at the quadrats and the allocation of soils to a map unit. The latter was influenced by the accuracy of the mapping and the knowledge of the soil types in the map unit. Thus comparisons were made at several mapping scales to gain an overall assessment.

Firstly, the comparison was made at the map unit, soil-landscape system and soil-landscape zone levels. These were all valid map units of different rank directly related to the individual quadrats. Secondly, to try to accommodate the likelihood of some differences in the soil classification, comparisons were made at both the soil group level and the super-group level. More weighting was given to the soil group than to the super group.

For each level of mapping, each quadrat was assigned to one of several levels of representativeness based on score classes of common, frequent, similar, uncommon, rare and not recorded. These were a somewhat arbitrary ranking with qualitative meaning only.

Only a small fraction (<1%) of vegetation remnants in the wheatbelt could be sampled using 304

Table 2 Expected percentage occurrence of different Soil Groups in soil-landscape zones, with the number of quadrats sampled in brackets. Table cells shaded grey indicate Soil Groups in zones that appear to be over-sampled (% of sampled quadrats in zone for Soil Group > twice the proportion of soil predicted for zone). Table cells that are outlined in black indicate Soil Groups in zones that appear to be under-sampled (% of sampled quadrats in zone of Soil Group < half the proportion of soil predicted for zone and soil predicted in >5% of zone). Soil Groups shaded grey appear to be oversampled, whereas those outlined in black appear to be under-sampled..

Code	Soil Group or Super Group	Total quads	Soil-landscape zone code % of zone							
			222	223	225	226	231	232	241	243
100	Wet or waterlogged soils	1								
101	Saline wet soil	20	1	1	0	1		0	3	5
102	Salt lake soil	12	0	(1)			7		0	
103	Semi-wet soil	5	1	0		0			(1)	3
104	Tidal soil									
105	Wet soil	5	0		(2)		0	0(1)	0	
201	Bare rock		0	0	2	0		0	4	4
202	Calcareous stony soil		0							
203	Stony soil	1	0	0	0(1)	1		2	0	1
300	Ironstone gravelly soils supergroup	1								
301	Deep sandy gravel	7	7			0			0(1)	1
302	Duplex sandy gravel	5	5	0	1	0			5	0
303	Loamy gravel	2	0			1			0	
304	Shallow gravel	23	3	2	2(1)	1		8	2	0
400	Sandy duplexes supergroup							7		
401	Alkaline grey deep sandy duplex	2	0						3	2
402	Alkaline grey shallow sandy duplex	16	0(1)				1		12	9
403	Grey deep sandy duplex	18	1(2)	1	2	0		0	12	7
404	Grey shallow sandy duplex	15	0	(1)					13(1)	15
405	Red deep sandy duplex	8	0	2	0	3(1)			0	
406	Red shallow sandy duplex	11	0	0(1)	10	1			3	
407	Yellow/brown deep sandy duplex	5	0		1	1			1	0
408	Yellow/brown shallow sandy duplex	6	0	0	7	0	1		1	0
409	Reticulite deep sandy duplex									
421	Calcareous shallow sand						10			
422	Pale shallow sand	12	1(1)	0(1)	0	0		3	0	1
423	Red shallow sand	2	0			0	3			
424	Yellow/brown shallow sand	10	0	0(1)			17			
440	Deep sands supergroup	1								
441	Brown deep sand		3		0	0			0	
442	Calcareous deep sand	2					33(1)			
443	Gravelly pale deep sand	2	10	4	1	0		5	0	0
444	Pale deep sand	22	22(4)	1(1)	2(1)	0		31	2	3
445	Red deep sand		3	2		2				
446	Yellow deep sand	22	30	57(2)	12(2)	9	22	33		0
460	Sandy earths supergroup									
461	Acid yellow sandy earth									
462	Brown sandy earth	2	0						0	

occupied by Soil Group (number of quadrats)

	244	245	246	248	250	253	254	255	256	257	258	259	261	271	RGE
					(1)										
	2	2(1)	0(1)	2	4(2)	2(2)	2(1)	2	3(1)	3(1)	3(6)	7(5)	0	2	
		0(1)	8(1)	5(1)	7(3)	0	(1)		(1)	0	2(3)	0	1	1	
	2	0(2)	(1)	4	0	1	7(1)	3	0	0	0			0	
	0	(1)		0	0	1(1)	11	4	1	0	0	0			
	6	1	0	2	1	3	0	2	2	3	2	0	0	0	
							0								
	4		0	12	0	1	1	2	0	0	2	0		3	
					0	1		(1)		0					
	1	0		0	1(2)	14(1)	4	3(1)	1(1)	3	0(1)	4	3		
	2			13(3)	2	9	13	17(1)	0	8	3(1)	6			
	0			1	0(1)	16	18	18	3	2(1)	3	4	0	1	
	6	5(1)	1(1)	6	2(5)	7(5)	4(1)	4	1(3)	2(2)	2(2)	6(1)		2(1)	(1)
	0	5	3	3	3(1)	0	0		3(1)	0	3	4	1		
	23	0	48(4)	2(1)	18(7)	0	0		0	1	5(1)	13(2)	2		
	10	37(2)	0	16	6(2)	7(1)	5	1	11	26(6)	4(4)	12(1)		0	
	14	14	0(1)	8(1)	9	1(4)	1	0(2)	5	7(3)	0(1)	3(1)	1		
				0	0	0	0	0	4	0	0(5)	0(1)	0	1	(1)
				0	0	0	0	0	1	0	0(5)	0	1(3)	5(2)	(2)
				0	2	3(2)	0	1	1	6(1)	0(2)	1	0	0	
					2(2)	0		2	0	2(1)	0(3)	1		2	
	3				0	0			0	0		1			
		2												0	
	2	0	0	2	0(2)	0(2)	0	0	1	0(1)	0(1)	0(4)			
					0	0			0	0	0(2)	0		7	
	(1)			0	4(4)	0		0	3	0(1)	0(2)	0	3	(1)	
							(1)								
		0		0	0	1	0	0	0	3	0	1	2	0	
		5	(1)				1				0				
	0			0	0(1)	2	0	2	2	1	0(1)	2		0	
	6	20(1)	8(1)	5(2)	2(1)	1(6)	5(3)	2	3	2(2)	0	1	1		
							0				0			0	
					2(2)	0(2)	4(1)	3	2	0(2)	8(8)	1(2)	3	11(1)	
														0	
					0						4		0	0	
	0			0	3	0		0	5	0	1(2)		3	1	

Table 2 (cont.)

Code	Soil Group or Super Group	Total quads	Soil-landscape zone code % of zone							
			222	223	225	226	231	232	241	243
463	Red sandy earth		0	3	3	1				
464	Yellow sandy earth	5	1(1)	7	0	2		1		
465	Pale sandy earth	2	0							
500	Loamy duplexes supergroup									
501	Acid shallow duplex	5							0	1
502	Alkaline grey shallow loamy duplex	11							10	16(1)
503	Alkaline red shallow loamy duplex	7				7			3	1
504	Grey shallow loamy duplex	6	0						4	8
505	Brown deep loamy duplex	1	0			0				
506	Red deep loamy duplex	3	0		1(1)	0			0	3
507	Red shallow loamy duplex	8	0		21(1)	6		2	1	4
508	Yellow/brown shallow loamy duplex	1	0			2			1	0
520	Shallow loams supergroup	1								
521	Calcareous shallow loam		0							
522	Red shallow loam		0		10	5				
523	Red-brown hardpan shallow loam			9	0	6				
540	Loamy earths supergroup	1								
541	Brown loamy earth		0		0	1				
542	Calcareous loamy earth	7	0	0		7			1	
543	Friable red/brown loamy earth									
544	Red loamy earth	2	0	2	11	6		1		
545	Yellow loamy earth		0			0				
601	Hard cracking clay		0			18		0	1	1
602	Self-mulching cracking clay		0		2	0			0	
621	Grey non-cracking clay	3	0			3			1	4
622	Red/brown non-cracking clay	2			0	0			2	1
	Total	304	9	8	10	1	1	1	3	1
			222	223	225	226	231	232	241	243

quadrats. It was, therefore, considered useful to evaluate whether any apparently under-sampled soils were likely to be represented in the wheatbelt's remnant areas of native vegetation. While this knowledge was not available directly, a GIS intersection of remaining vegetation (Shepherd *et al.*, 2001) with the regional soil-landscape mapping provided an approximation. This involved determining the apparent area of remnant vegetation in each of the most detailed soil-landscape map units. By assuming that the remnant vegetated areas in a map unit had the same proportion of soil types as did the map unit as a whole, the area of each of these poorly sampled soils in remaining vegetation in each zone was calculated.

The results of such analysis need to be interpreted with caution for a number of reasons. Firstly, the remnant vegetation layer in the GIS is an interpretation from satellite imagery, and includes areas of disturbed vegetation, sometimes in very poor condition. Secondly, the vegetated portion of a soil-landscape unit is assumed to have the same soils as the map unit as a whole. In many cases this will not be true because clearing has been biased towards soils of higher agricultural productivity. Thus a conservative evaluation was made of just the soils that were expected to occur in at least 5% of a zone and were poorly sampled by this study (i.e. sampled at either 0 or 1 quadrat).

occupied by Soil Group (number of quadrats)

244	245	246	248	250	253	254	255	256	257	258	259	261	271	RGE
					0		0	1	0	2		0	1	
				1(1)	0	0	2	6	0	11(3)	1	1	8	
					0	0	0	0	0	0(1)	0(1)			
					0									
				0	0(1)	0	0	0	1(1)	2(3)	2			
		2(1)	1	4(6)				0(1)	0	0	3(2)	0		
				0	0			0	0	4(5)	1	4	0(1)	(1)
0	0		2	0(1)	0	0	0	1	2(3)	0(1)	1			
			0		4	3	3	0	2(1)	0	0		0	
			0	1			0	4	0	0	0	1	0(2)	
		(1)		0	1(1)	0	0	2(1)	2(2)	0(2)	0	1	2	
			1	0(1)	1	1	3	3	1	3	1		0	
		(1)			0			0		0				
0					0	0	0	1	0	4	0		4	
				0						0		1	20	
				0	(1)				0		0			
			1	1	2	1	4	5	1	1	0	1	2	
3	0	22(1)		7(2)				0	0	8(4)	2	23	2	
				0	1	6	5	0	0	0	0			
		0	0	0	0	0	3	1	0	1	0	7	11(2)	
				0	0		0	0	0	0			0	
		1		0	0			0	0	1	1	6	0	
				0	0		0	1	0	0	0		0	
1	1	0(1)	0	2(2)	0		0	0	0	0	1			
4			0	1	0	0		2	0	1(1)	2	22	0	(1)
1	9	16	8	49	29	9	5	9	28	70	20	0	10	6
244	245	246	248	250	253	254	255	256	257	258	259	261	271	RGE

RESULTS

Soils sampled

A standard report generated from the Department of Agriculture's Soil Profiles database is provided for each of these quadrats (Appendix 1). Appendix 2 is a listing of the 304 quadrats showing the Soil Group and the soil-landscape map unit in which each falls. A coding is also provided which tries to indicate how well each quadrat's Soil Group matched that expected to occur in the map unit, in its parent soil-landscape system, and in its parent soil-landscape zone. Sandy surfaced soils were predominant amongst the quadrats. Clayey and loamy surfaced soils were represented by small numbers of quadrats.

Western Australian Soil Groups

The soils at the quadrats were from 39 Soil Groups and five Super Groups (used when it was not possible to identify a Soil Group) (Table 2). Twelve of the thirteen Super Groups in the classification system were represented by these quadrats. The predominant Super Groups sampled were Deep sands, Sandy duplexes and Wet or waterlogged soils. The most common Soil Groups sampled were Shallow gravel, Pale deep sand, Yellow deep sand, Saline wet soil, Grey deep sandy duplex, Alkaline grey shallow sandy duplex, Grey shallow sandy duplex, Alkaline grey shallow sandy duplex, Grey shallow sandy duplex, Salt lake soil, Pale shallow sand, Red shallow sandy duplex,

Table 3 Number of quadrats sampled in each Australian Soil Classification Soil Order.

Order	# quadrats	Main Suborders
Anthrosol	–	
Calcarosol	7	Supracalcic
Chromosol	79	Yellow, Grey, Red and Brown
Dermosol	2	
Ferrosol	2	
Hydrosol	32	Hypersalic, Salic, Oxyaquic
Kandosol	9	Red, Yellow
Kurosol	6	Red, Grey
Organosol	–	
Podosol	–	
Rudosol	10	Leptic
Sodosol	49	Grey, Red
Tenosol	108	Yellow-Orthic, Sesqui-nodular, Bleached-Orthic
Vertosol	1	

Alkaline grey shallow loamy duplex and Yellow/brown shallow sand.

Table 2 also presents the expected proportion of each zone occupied by each soil (from Map Unit database, Department of Agriculture). A comparison of the number of quadrats sampled in each zone with these data identifies the zones where particular soils may have been under- or over-sampled.

Ten per cent of Soil Groups appear to have been over-sampled compared to the understanding from the mapping. These include Salt lake soil, Semi-wet soil, Wet soil, Red deep sandy duplex, Pale shallow sand and Yellow/brown shallow sand). On the other hand, 30% of Soil Groups appear to have been under-sampled, including Grey deep sandy duplex, Duplex sandy gravel, Alkaline grey shallow sandy duplex, Grey shallow sandy duplex, Yellow deep sand, Yellow sandy earth, Red-brown hardpan

shallow loam, Calcareous loamy earth and Red loamy earth.

Australian Soil Classification

Each soil sampled in the present survey was classified using Isbell (2002) (Appendices 1,2). Most of the ASC Soil Orders were represented by the quadrats sampled (Table 3). Tenosols, Chromosols and Sodosols predominated as is typical for south-western Australia (Isbell *et al.*, 1997). The apparent abundance of Hydrosols, however, appears to be an over-representation for the wheatbelt.

The distribution of Soil Orders by soil-landscape zones was briefly investigated. However, the disproportionate number of quadrats in each zone prevented more than brief observations to be made. Tenosols are widespread in most zones of south-western Australia including the wheatbelt. Chromosols are also widespread, particularly in the wheatbelt. Sodosols are also important but more localized. Their main occurrences are in the south-eastern and eastern portions of the wheatbelt (Zones 250 and 258).

Geographic and landform representativeness of quadrats

Most of the 24 survey areas were predominantly in a single soil-landscape zone but few were exclusively so. Each survey area had quadrats from at least three soil-landscape systems and together these systems represented at least two major landforms. This supports the intention for each survey area to represent a range of landscapes. Some soil-landscape systems were sampled by more than one survey area. Thus, survey areas sampled overlapping portions of the edaphic environment and to some degree are likely to be arbitrary geographic groupings of quadrats. This

Table 4 Soil-landscape system area and number of quadrats

System Area class	# quadrats	# systems	Av # quadrats/system	Av # quadrats/Mha
>500K ha	62	8	7.8	11
<500 & >300K ha	36	5	5.2	21
<300 & >100K ha	113	36	3.1	18
<100K ha	93	47	2.0	66

Table 5 Number of quadrats present in each of the landforms that comprise soil-landscape systems. Landform categories are broadly based on Landform Pattern *sensu* Speight (1990).

Landform	# quadrats	# systems	Av # quadrats/system	Av # quadrats/Mha
Mountains	2	1	2	16
Low hills	60	19	3.2	46
Rises	84	30	2.8	84
Sandplains	48	14	3.4	44
Plains	28	11	2.5	27
Alluvial plain	43	14	3.0	34
Alluvial plain, saline >30%	39	7	5.6	37

Table 6 Quadrats per unit area of system, by landform and system area class (Av # quadrats/Mha). Landform categories are broadly based on Landform Pattern *sensu* Speight (1990).

Landform	>500K ha	<500 - >300K ha	<300 - >100K ha	<100K ha
Mountains			16	
Low hills	21		20	65
Rises	4	16	19	51
Sandplains	7	15	17	70
Plains	16		6	193
Alluvial plain	8	9	22	57
Alluvial plain, saline >30%		33	42	38

implies that biological differences based on aggregating quadrats into survey area units should be interpreted cautiously.

The 304 quadrats were located in 188 different map units (mostly of subsystem rank, but also some phases) from 96 systems (Appendix 2). Of these systems, Kwolyin, Lagan, Wallambin, Scaddan, Coblinine, Boyagin, Bonnie Rock and Newdegate had more than seven quadrats each. The systems with most quadrats tended to have been sampled by two or more survey areas. There was a tendency for the larger systems to have more of the quadrats (Table 4). However, of the systems with quadrats, several of the larger ones were relatively poorly sampled (e.g. Tandagin and Halbert).

The systems with quadrats can be grouped into a number of broad landforms (Table 5). These data show that saline alluvial plain systems (e.g. Lagan, Wallambin and Coblinine) had about twice the number of quadrats per system as did systems of other landforms. This was not just related to the

area of these systems. Table 6 shows that there were many more quadrats on saline alluvial plains of systems in the area classes '100 to 300K ha' and '300 to 500K ha'.

Of the soil-landscape zones sampled, Northern Zone of Ancient Drainage (258) had the greatest number of quadrats (70, Table 7). However based on their area, Zones 248, 225, 253, 257 and 250 had relatively more quadrats than did other zones. On a similar area basis, Zones 261, 244, 243, 255, 254, 226, 256, 232 and 246 had very low numbers of quadrats. Many of these zones are on the margin of the wheatbelt and could be expected to have been poorly sampled in this study. It could also be argued that two of them are not typical wheatbelt areas and should not have been sampled: Warren-Denmark Southland (254) and Western Darling Range (255). However, some typical wheatbelt zones had low sampling densities: Southern Cross (261), Lockier (226) and Salmon Gums-Mallee (246).

Table 7 Number of quadrats in soil-landscape zones.

Symbol	Soil-landscape zone	area (K ha)	quadrats	Av # quadrats/Mha
RGE	(rangeland area, not assigned yet)	-	6	-
261	Southern Cross Zone	249	0	0
243	Jerramungup Zone	542	1	2
244	Ravensthorpe Zone	606	1	2
255	Western Darling Range Zone	1177	5	4
226	Lockier Zone	164	1	6
254	Warren-Denmark Southland Zone	1576	9	6
232	Kalbarri Sandplain Zone	125	1	8
246	Salmon Gums-Mallee Zone	1887	16	8
256	Northern Zone of Rejuvenated Drainage	1137	9	8
241	Pallinup Zone	330	3	9
245	Esperance Sandplain Zone	1021	9	9
271	Irwin River Zone	871	10	11
222	Dandaragan Plateau Zone	735	9	12
223	Victoria Plateau Zone	688	8	12
258	Northern Zone of Ancient Drainage	5404	70	13
259	South-western Zone of Ancient Drainage	1262	20	16
250	South-eastern Zone of Ancient Drainage	2503	49	20
257	Southern Zone of Rejuvenated Drainage	1409	28	20
253	Eastern Darling Range Zone	1266	29	21
231	Port Gregory Coastal Zone	38	1	26
225	Chapman Zone	290	10	34
248	Stirling Range Zone	210	8	38

Table 8 Summary of representation classification by map unit, by system and by zone.

From	Quadrats	Ranking Class					
		common	frequent	similar	uncommon	rare	not recorded
Mapped Unit	Number	44	44	30	55	49	81
	% of 303	15	15	10	18	16	27
System	Number	23	61	37	63	78	41
	% of 303	8	20	12	21	26	14
Zone	Number	19	50	37	87	101	9
	% of 303	6	17	12	29	33	3

Representativeness at map unit level

Soils of quadrats that were common or frequent at the map unit level were often at least frequent at the system or zone level. At all levels of analysis (either mapping scales or soil classification rank), less than a third of the quadrats had soils that were considered common or frequent in the mapped unit, the system or the zone in which they occurred. On the other hand, more than 50% were uncommon, rare or not previously recorded (Table 8). While this suggests that the quadrats are skewed towards the less common soils, no test of significance was performed.

There appeared to be systematic differences in the analysis from the different levels of mapping. At the mapped unit level, more of the soils tended to be either common, or not previously recorded compared to the assessment for systems and particularly for zones. This is explainable in terms of the characteristics of these map units. The most detailed levels of the mapping hierarchy tend to contain few soils, all of which are relatively common. They may contain small inclusions of different soils which are often not recognised because of their rare occurrence. Thus the likely result is a high proportion of soils not previously recorded at the mapped unit level. Systems and Zones, however, are the amalgamation of different mapped units and tend to be more heterogeneous with fewer soils being common. They contain many more soils from often quite different map units. Thus, as in this analysis, the number of soils not previously recorded for these units will be less compared to the detailed mapping.

Potential to find poorly sampled soils in remnant vegetation

The areal extent of indigenous vegetation remaining in each zone varied from over 50% (Zones 246 and 248) to less than 10% (Zones 226, 256 and 259) (Table 9). These data reflect the differential clearing of the south-western Australia. Of the typical wheatbelt areas (Zones 223, 225, 226, 250, 256, 257, 258, 259, 261 and 271), only Zones 250 and 261 have retained significant areas of native vegetation. Both are on the eastern margin of the wheatbelt.

A number of Soil Groups that were at least

moderately abundant in a zone according to the mapping (>5% coverage) were poorly sampled by quadrats in the same zone. These amounted to 11.4% (72) of the combinations of Soil Group by zone from 35 Soil Groups and 18 zones (Table 9). For each of these, a code has been inserted in the Table to indicate the proportion of the zone that is expected to be the particular Soil Group. The inferred area of each combination is also shown. All of these apparently poorly sampled and relatively important soils appear to occur in remnant vegetation in their respective zones, varying from small areas to hundreds of thousand hectares. Those with large areas are probably real, but those with small areas could be artefacts of the analysis or mapping.

Table 10 is an attempt to summarise these data. It shows that more than half of these combinations are of Soil Groups that are <10% of the zone and may have been difficult to find, even in areas which had significant remnant vegetation. Nearly a third of occurrences in Table 9 appear to have much (>10,000 ha) vegetation in the indicated Soil Group in the relevant zone. This includes Soil Groups from a range of zones; the Dandaragan Plateau Zone (222 – Yellow deep sand and Gravelly pale deep sand), the Kalbarri Sandplain Zone (232 – Pale deep sand), the Jerramungup Zone (243 – Grey shallow sandy duplex), the Esperance Sandplain Zone (245 – Pale deep sand and Grey shallow sandy duplex), the Salmon Gums-Mallee Zone (246 – Calcareous loamy earth), the Stirling Range Zone (248 – Stony soil and Grey deep sandy duplex), the Eastern Darling Range Zone (253 – Deep sandy gravel and Loamy gravel), the Southern Cross Zone (261 – Calcareous loamy earth and Red/brown non-cracking clay) and the Irwin River Zone (271 – Red-brown hardpan shallow loam). Except for the Irwin River Zone, all have more than a 25% coverage of native vegetation. Of these, only the Southern Cross and Irwin River Zones are core wheatbelt areas.

On the other hand, about a third of these 72 occurrences have little or very little vegetation. These are some of the poorly sampled Soil Groups from Lockier Zone (226), Port Gregory Coastal Zone (231), Chapman Zone (225), Northern Zone of Rejuvenated Drainage (256), Kalbarri Sandplain Zone (232), Stirling Range Zone (248), South-

Table 9 Expected area of remnant native vegetation for under-sampled soils, by Soil Group and soil-landscape zone.

Code	% uncleared	Soil-landscape zone code																	
		222 37	223 10	225 13	226 8	231 35	232 29	243 36	245 31	246 56	248 56	250 26	253 41	256 7	257 14	258 11	259 8	261 27	271 15
101	Saline wet soil							C(6)											
102	Salt lake soil					C(0)				C(121)	C(2)								
203	Stony soil										B(27)								
301	Deep sandy gravel	C(14)											B(108)						
302	Duplex sandy gravel	C(11)											C(37)	C(19)		C(5)			
303	Loamy gravel												B(97)						
304	Shallow gravel						C(2)		C(7)		C(9)						C(7)		
400	Sandy duplexes supergroup						C(2)												
401	Alkaline grey deep sandy duplex									C(23)									
402	Alkaline grey shallow sandy duplex							C(13)							C(16)				
403	Grey deep sandy duplex							C(19)			B(15)		C(30)	B(8)			B(9)		
404	Grey shallow sandy duplex							B(20)	B(56)		C(10)	C(30)		C(3)					
406	Red shallow sandy duplex			B(4)															
407	Yellow/brown deep sandy duplex														C(15)				
408	Yellow/brown shallow sandy duplex			C(3)															
421	Calcareous shallow sand					B(3)													
423	Red shallow sand																		C(11)
424	Yellow/brown shallow sand					B(2)													
442	Calcareous deep sand					A(4)				C(40)									
443	Gravelly pale deep sand	B(23)						C(3)											
444	Pale deep sand							A(20)		A(61)	C(90)								
446	Yellow deep sand	A(77)			C(2)	A(2)	A(7)												B(8)
462	Brown sandy earth														C(3)				
464	Yellow sandy earth		C(4)												C(4)				C(6)
502	Alkaline grey shallow loamy duplex								B(8)										
503	Alkaline red shallow loamy duplex				C(1)														
504	Grey shallow loamy duplex								C(9)										
507	Red shallow loamy duplex			A(9)	C(1)														
522	Red shallow loam			B(3)	C(1)														
523	Red-brown hardpan shallow loam		C(6)		C(1)														A(25)
541	Brown loamy earth														C(4)				
542	Calcareous loamy earth				C(1)					A(273)									A(15)
544	Red loamy earth			B(4)	C(1)														C(6)
601	Hard cracking clay				B(0)														C(4)
622	Red/brown non-cracking clay																		A(14)

Cell values; A, B, C coding of expected area of Soil Group in zone, A – 20–80% of zone, B – 10–20%, C – 5–10%. In brackets is apparent area of Soil Group in vegetation (K ha)
Under-sampled Soil Groups had one or no quadrats in the particular zone and from the soil mapping were expected to occupy at least 5% of the zone.
Empty cells are either soils which had a number of quadrats in the zone or were expected to occupy < 5% of the zone.

Table 10 Summary of importance of under-sampled soil by area of Soil Group with vegetation. Summarized from Table 9

Vegetation on Soil Group in zone	Relative importance of soil in zone			Total
	A (20–100%)	B (10–20%)	C (5–10%)	
Much (>10,000 ha)	7	7	15	29
Some (5,000 – 10,000 ha)	2	4	9	15
Little (1,000 – 5,000 ha)	2	5	13	20
Very little (<1,000 ha)		1	7	8
All	11	17	44	72

western Zone of Ancient Drainage (259) and Victoria Plateau Zone (223). Many of these are typical wheatbelt zones. The Lockier Zone, for example, was both poorly sampled (only one quadrat) and virtually all of its common soils have very little remnant vegetation because most of its soils had agricultural potential and are cleared. Twenty of the 35 soils in this table had low or very low apparent areas of vegetation. Most of these soils are loamy or clayey surfaced soils (e.g. Alkaline grey shallow loamy duplex, Calcareous loamy earth and Hard cracking clay).

DISCUSSION

The virtue of sampling the biota of most of the major soils in different parts of the wheatbelt is undeniable. However, the task of obtaining comprehensive and representative sampling is substantial. To sample just once in each of the Soil Groups that apparently occupy 5% or more of each of the 18 soil-landscape zones covering the present study area would require about 100 quadrats. This overlooks the fact that, each Soil Group is a broad concept that often, for example, makes no distinction between many soils with alkaline, calcareous, acid or sodic subsoils, so several hundred additional quadrats would have been needed to represent the major soil variations just once. Therefore, with funding for only 304 quadrats available under the current study, it would have been nearly impossible to achieve a comprehensive coverage of soils.

Locating a representative range of soils, particularly the less common ones, is a difficult task anywhere, let-alone in natural vegetated remnants. Nevertheless, it was still instructive to evaluate just how well the wheatbelt's soils were sampled. The 304 quadrats included 39 of the 60 Soil Groups, most of which are present in the wheatbelt. Those either not sampled or poorly sampled tended to be from the loamy or clayey surfaced soils. Their low frequency of sampling is not surprising as these soils are those most likely to have been cleared for agriculture. The analysis showed that these appeared to have only a small potential to exist in native vegetation; they were unlikely to be readily

available in extant remnant vegetation. On the other hand, some of the more common soils were under-sampled (in terms of low numbers of quadrats in relation to the area occupied by the soil). In some zones these included soils such as Yellow deep sand. Most of these appeared to have remnant vegetation available for sampling.

A parallel aim of the sampling program was to document some of the biodiversity in areas under threat from the effects of advancing salinity, which is more pronounced on valley floors. Sampling was, therefore, skewed towards soils of wet and saline valley floors. These areas were deliberately sampled more than the interfluves, with additional quadrats on the valley floors representing salt-affected examples of these environments. In addition, quadrats were sampled on the margin of the wheatbelt to provide comparison. The quadrats around Lake Muir (in Zones 254 and 255) are examples.

The data were too few to conclusively define poorly sampled parts of the wheatbelt. However, two small soil-landscape zones stand out in this regard. The Lockier Zone (near Mingenew) had just one quadrat, but it appears that there was very little remnant vegetation in good condition to sample. On the other hand, the Southern Cross Zone, an area dominated by greenstone parent material on the eastern edge of the study area, was not sampled even though there are significant areas of native vegetation in that zone. The apparent over-sampling of Zones 254 and 255 was a product of deliberate sampling of valley floors mentioned above.

Although a number of common sandy soils were under-represented, the relatively few loamy or clayey soils sampled during the study is more concerning. These are now rare in wheatbelt remnants, and even in pre-European times would not have been common. It is probable that significant vegetation types on these soils may have been over-looked. Finding and managing suitable examples should be a conservation priority.

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