AN ECOLOGICAL SURVEY OF THE KWONGAN SOUTH OF ENEABBA, WESTERN AUSTRALIA

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ABSTRACT

The results of a detailed ecological survey of a 20 km² area of kwongan (sclerophyllous sandplain or heath) vegetation south of Eneabba are reported. The study was initiated because of imminent mining for heavy mineral sands and following recognition of the considerable significance of the flora of the area. A total of 429 species of vascular plants were recorded, including 4 very localised endemic species, and a further 39 species that are in need of special attention. A relationship between soil type and vegetation is described, and species characteristic of particular soils are listed. Detailed background information is presented on soils (texture, nutrients, water holding capacity, organic matter content and geographic distribution), climate, geomorphology, fire history, floristic richness and land-use for the study area and the adjacent nature reserves and vacant Crown land. Recommendations for improved land-use planning and management are made.

I—INTRODUCTION

The kwongan of south western Australia, commonly termed sandplain or heathland (Beard 1976a, Nelson 1974), has long been acknowledged as a most important component of the vegetation of that area (Diels 1906). Two features of this vegetation have attracted particular comment: the species richness and the high degree of endemism. In a recent review, George, Hopkins and Marchant (1979) attempted to define areas of kwongan of particular importance on the basis of species richness. An area including Mt Lesueur—Eneabba was identified as one of phytogeographic importance.

Paradoxically the areas of kwongan have been little studied to date; early work by Speck (1958) has generally not been followed up. A number of biological surveys have included kwongan (e.g. George and Hnatiuk 1978; Lamont 1976; McKenzie, Burbidge and Marchant 1973 Muir 1976, 1978) but detailed ecological knowledge is scant.

The Mt Lesueur-Eneabba area is presently the focus of a land-use conflict. While the phytogeographic significance of the kwongan has been recognised, and attempts have been made to set aside areas as ecological reserves, the region is also rich in heavy mineral sands, coal and other hydrocarbons, as well as being considered suitable for agricultural land clearing. Competition between these often incompatible land-uses has yet to be resolved.

It is in the context of one such land-use conflict that the study reported here was undertaken. The 20 km² study area, just south of Eneabba, included leases held by three heavy-mineral sand-mining companies and portions of two nature reserves. A detailed ecological survey of one of the areas to be mined, together with some adjacent land was carried out in September-October 1977. The objectives were to determine the distributions of plant species, particularly rare species, and factors influencing their distributions, with a view to providing floristic data needed in the development of balanced management of the mining operations and subsequent rehabilitation. The present paper presents background information and a summary of findings, while the detailed analysis and synthesis is being published separately.

II—THE STUDY AREA

LOCATION AND LAND STATUS

The area is about 5 km x 4 km and lies some 10 km south of Eneabba township. It falls within the rectangle prescribed by latitudes 29°50′–29°55′ South and longitudes 115°15′–115°18′ East. Details of major features of the present survey area are shown on the Location Map (Figure 1). The study area overlaps that surveyed by Lamont (1976).

The study area covers portions of (a) two reserves for the conservation of flora and fauna: Reserve C31030, 4 946 ha, created 15/10/71, vested in W.A. Wildlife Authority 25/8/72, and Reserve C27886, 1 246 ha, created 18/2/66, vested in W.A. Wildlife Authority 25/8/72; (b) vacant Crown land: Victoria Location 10235 and an un-numbered location to the North East of Reserve C31030; and (c) a freehold block: Victoria Location 10240.

Competing land-uses for the area include (a) nature conservation; (b) mining for heavy mineral sands: the area includes mineral tenements of three companies: Allied Eneabba Pty. Ltd., Western Titanium Ltd. (now Associated Minerals Consolidated Ltd.) and Ilminite Pty. Ltd. (now Westralian Sands Ltd.) which are concerned with the extraction of heavy minerals; (c) coal mining: a number of coal mining leases exist over the area; (d) petroleum production: a petroleum exploration permit covers the area; and (e) agriculture. Allied Eneabba Pty. Ltd. and Western Titanium Ltd. are currently extracting the heavy minerals from their leases using open cut methods described generally by Scott (1975); it is anticipated that an area in excess of 2 000 ha will be mined or otherwise significantly disturbed during the first 20 years of their operation.

PHYSICAL ENVIRONMENT

The study area is contained in the northern portion of the Swan Coastal Plain, variously referred to as the Eneabba Plain (Commander 1978), Alluvial Fans (Lowry 1974) or Slopeland (Scott 1975). It lies immediately to the west of the Gingin Scarp, an imprecise landscape feature in this area representing an ancient (Tertiary or Pleistocene) coastline between 91–105 m higher than the present one (Baxter 1972). However fossil strand lines are reported in this area at elevations of up to 115 m (Scott 1975). Rising to 300 m elevation to the east of the escarpment are the remnant, lateritised, Mesozoic strata of the Dandaragan Plateau which has been dissected by mature drainage channels (Lowry 1974; Commander 1978).

The Eneabba Plain consists mainly of alluvial deposits of gravel, sand and clay from streams flowing westward off the lateritic plateau areas. In close proximity to the Gingin Scarp, colluvial deposits of materials similar to those of the plateau are to be found (Figure 2). The ancient coastline, with beach deposits which include concentrations of heavy minerals, separates the colluvial deposits above from the largely alluvial deposits below, whereas elsewhere, most rock types are mantled by a veneer of Quaternary eolian sand which effectively

obscures the underlying geology (Baxter 1972; Lowry 1974). This overlying sand unit is not shown on the Geological Map of the study area (Figure 2) taken from Baxter (1972). Features of the solid geology of the region have been discussed by Lowry (1974) and Playford, Cockbain and Low (1976).

The topography of the study area reflects its geology as is shown on Figure 3. The area has a predominantly westerly aspect sloping from the lateritic plateau and Gingin Scarp in the east, to the dune and swale sequence in the west. This westerly aspect is emphasised in the topographic cross section given in Figure 4. Some small ephemeral (i.e. winter-wet) wetlands are located in the low-lying swales; these are indicated on Figure 3.

The foregoing discussion of the geology of the study area provides a good indication as to the nature of the soils since, with the exception of the massive laterite, the sediments remain poorly consolidated. This is reflected in the 1:2 000 000 map of Northcote, Bettenay, Churchward and MacArthur (1967) where the soils of the Eneabba Plain are shown as undifferentiated, leached sands.

A substantial proportion of the study area and of the reserves has been assessed by the Department of Lands and Surveys for agricultural suitability. The relevant section of the soils map produced for this assessment is reproduced in Appendix I; the soils of the study are shown in Figure 5. The study area is shown as consisting of a mosaic of grey and yellow sand units with lateritic gravels common in the upper metre of the profile, particularly in the south eastern portion of the area.

Soil profiles have been examined in detail at five sites on the leases held by Allied Eneabba Pty. Ltd. by environmental consultants to that Company. The raw data are reproduced in Appendix II. These data show the soils to be generally poorly developed, sandy, and low in plant nutrients. The clay fraction in these soils (0·3%) appears lower than the 10–40% reported by Baxter (1972) for the beach deposit and associated eolian sand units. The relatively high total P levels probably reflect the presence of monazite (a phosphorus-bearing mineral, 0·04–0·12%) in these units.

Some results of soil moisture determinations for a nearby similar area, given in Appendix III show the very low levels to which soil moisture may fall, particularly during the normal summer drought.

CLIMATE

Although three stations near our study area have contributed data to the Bureau of Meteorology (viz. Eneabba-Windie, Eneabba-Udale, and Eneabba Post Office), none of these has been recording for a sufficient period to indicate long term trends. Furthermore, the period of overlap between these three stations does not permit extrapolation of long term trends.

Published climatic data are given in Bureau of Meteorology (1968, 1975) and up to date unpublished records have been examined.

Eneabba (Windie) has an average annual rainfall of about 550 mm p.a. (Bureau of Meteorology 1968). Rainfall only exceeds evaporation for the months June, July, August. Mean summer temperature is given as 21°C, and that for winter 13·5°C but individual summer days may exceed 40°C in standard meteorological screens, and frequently fall in the range 60–70°C at ground surface (R. J. H. unpublished records).

Average data for Eneabba Post Office are presented as an ombrothermic diagram prepared according to the guidelines of UNESCO-FAO (1963) (Figure 6). The Eneabba ombrothermic diagram is comparable with the type for a "Thermomediterranean (accentuated) climate" given in that publication.

The area is mapped by Gentilli (1972) as Köppen Csa (wet warm climate with long hot dry summer) or Thornthwaite's CB's (subhumid warm with great moisture deficiency in summer).

At the time of the survey reported here, Eneabba was experiencing the second consecutive year of below-average rainfall. Monthly rainfall data for the past six years (Table 1) illustrate this point. As a consequence, the flowering of many species was poor, which exacerbated problems of field identification. Other effects of the drought (mortality, recruitment, resprouting, etc.) have been reported separately (Hnatiuk and Hopkins 1980).

VEGETATION

The survey area lies in the Irwin District of the South-West Botanical Province of Beard (1980). More particularly, the area is close to the western edge of the Tathra Vegetation System of Beard (1976b), which unit includes the slope between the lateritic plateau region and the flatter areas of the Eneabba Plain.

The vegetation of the Tathra System consists of kwongan (sandplain) with a fairly uniform scrub heath assemblage containing patches of *Meleleuca* thicket, thicket with scattered trees, and woodlands. The survey area is shown by Beard (1976b) as scrub heath on lateritic sandplains. Further general description of the vegetation in the area has been given by Lamont (1976).

TABLE 1

RAINFALL RECORDS (mm) ENEABBA POST OFFICE

Time Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Total
Mean (12 years*) (1964–1978)	4	10	9	34	67	135	104	77	42	28	12	7	529
1974	0	6	9	31	175	132	145	79	15	59	20	0	671
1975	0	9	49	56	42	106	126	44	47	38	9	1	527
1976	17	73	6	23	92	27	35	119	36	14	25	0	467
1977	2	1	1	25	52	65	41	97	23	40	3	22	372
1978	6	4	1	26	64	154	158	33	71	22	7	27	572

* Observations for years 1970, 1971 missing.

FIRE HISTORY

Extensive and repeated aerial photographic coverage of the study area since 1969 by the Department of Lands and Surveys and private contractors to mining companies has permitted accurate mapping and estimation of timing of fires in the area over the past 10–12 years. This fire history is summarised on Figure 7.

The whole of the study area, with the exception of a small portion in the south east corner (including site 77), was burned by an extensive fire in spring to early summer 1967/68. Fire scars suggest south west to south-easterly winds at the time of this fire. A subsequent fire in the summer of 1969/70 burned a portion of Reserve 31030 to the south of the Allied Eneabba Pty. Ltd. leases. Winds were probably easterly during this fire. Both fires are thought to have been escapes from clearing-burns on properties adjacent to the reserves.

A more recent fire was started by the Eneabba Bush Fire Brigade on 7 October 1977 under conditions of 5–8 m/sec westerly to north-westerly winds. An extensive area to the east of the study area and a smaller section beside the eastern boundary of Reserve 31030 were burnt.

A small area between the wet plant of Allied Eneabba Pty. Ltd. and the gravel pit on Reserve 31030 was burnt in January 1978.

Little is presently known of the fire ecology of the plant species comprising the northern kwongan. Most of the species appear to regenerate readily after fire but progression to complete recovery of the vegetation appears to be slow. Preliminary estimates from work on south coastal kwongan (1 500 mm annual rainfall) (A.J.M.H. unpublished data) suggest that at least 15 years must elapse from the time of the fire to vegetation maturity. The recovery period for the Eneabba vegetation (550 mm annual rainfall) could exceed that estimated for the similar south coastal vegetation judging by the persistence of fire scars as seen on recent aerial photographs.

III—METHODS

FIELD SAMPLING

To achieve the objective of mapping distributions of individual species throughout the study area, a systematic sampling strategy was adopted. Sampling sites were laid out on a 400 m x 400 m grid pattern. The sites were located in the field with a high degree of precision by direct measurement (tape and compass) from existing geological survey points.

Of 104 sites incorporated into the original study design, 17 were abandoned during the field work because of the encroachment of mining activity onto sample points and a number of others were relocated a short distance to avoid small areas of disturbance. A total of 87 sites were sampled in September and October 1977. The layout of the study sites is shown on Figure 3.

Each of the sites was sampled at either two or three levels of intensity. All of the sites were sampled for species present within a single 4 x 4 m quadrat. Additional presence-absence data were gathered for species outside the quadrat, within a subjectively defined relevé of about 0·1 ha surrounding each quadrat.

The 4 x 4 m quadrat size was selected as a readily assessable unit which could be expected, on the basis of earlier species-area studies (George *et al.* 1979) to include 60–70% of the species at a site.

A random subset of 31 of the 87 systematic grid points was selected for more intensive study of the ecological factors affecting the plant distribution patterns. At each of these intensive study sites, four 4 x 4 m quadrats were laid out. Quantative data were gathered on species present in each quadrat using the Domin-Krajina scale of cover-abundance (Mueller-Dombois and Ellenberg 1974 p. 62). The soil profile to a depth of about 1·0 m was examined at each site and soil samples taken. These samples were later subjected to moisture-retention and particle-size analysis in the Soils Laboratory of the Department of Agriculture, and to total organic carbon analysis by combustion at the Government Chemical Laboratories. (See Appendix IV).

Because of the drought conditions prevailing at the time of the survey (see Climate section above), a number of species had suffered widespread mortality. Data on species with dead individuals present at each site were recorded. Other information recorded at each site included general topography and vegetation descriptions. Voucher specimens were collected for all species recognized in the field and determined by the authors at the Western Australian Herbarium (PERTH). Voucher specimens for most species have been retained at that institution and have been stamped "Voucher specimen for Eneabba Survey 1977" to identify them.

DATA ANALYSIS

Field survey data were analysed using a variety of techniques available through "Ordiflex" (Gauch 1977) and the "Taxon Library" (CSIRO Division of Computing Research, Canberra). Best results were achieved with the Taxon MULCLAS (an agglomerative polythetic classification), MINSPAN (Minimum spanning tree, Gower and Ross 1969), GOWER (a principal coordinate analysis, Gower 1967) and GOWECOR (a correlative algorhithm for determining the relative importance of attributes to the production of vector scores of individuals). The similarity measure selected for use in the MULCLAS and GOWER analyses was the Canberra Metric with double-zero matches suppressed and the flexible sorting strategy with β set at –0·25.

The sites x species data matrix was also sorted by means of computer programmes provided by Dr. P. W. Bridgewater of Murdoch University, Western Australia, using some of the basic techniques that apply to the construction of association tables in the Zurich-Montpellier (ZM) school of phytosociology. The procedure was used to assist in understanding the relationships between the 338 species and the 87 sample sites. A vegetation map was drawn, based on interpretation of aerial photographs of the study area taken by the Department of Lands and Surveys in 1969 and 1977. The vegetation units recognised corresponded largely with Plant Formations based on physiognomy.

IV—RESULTS AND DISCUSSION

FLORA

Of the 429 species of vascular plants, belonging to 50 families and 162 genera, which were found in the study area, 338 were recorded as occurring at one or more of the 87 sample sites. The relevés therefore sampled about 80% of the known flora. Sixty-four of the 429 species (15%) could not be identified to species level. Lamont (1976) recorded only 239 species in an adjacent area to the south of ours. He later (Lamont *et al.* 1977) argued that the floristic richness of his area was comparable to any yet reported in the literature. Comparing the species lists of his area and ours, we find them to have about 55% (184) of their species in common. The species encountered within the study are listed in Appendix V.

The forty-three species (14%) in our area that can be classified as either rare or poorly known (Table 2) are all endemic to Western Australia. We recognize three as being rare and occurring in a restricted geographic area category B, "the most significant"—(Marchant and Keighery 1979). These are *Calytrix superba*, *Lepidobolus* sp. (AJMH s.n.) and *Leucopogon obtectus*. The first is reasonably abundant in the small area about 10–15 km south of Eneabba, whereas the last is known from less than 5 plants. The *Leipdobolus* is found between Eneabba and Coomallo Creek (near Jurien Bay) but is not common and appears restricted to lateritic soils.

Calytrix spp. can generally be propagated from cuttings, but propagation of *Leucopogon* spp. has not yet been successful. The undescribed *Lepidobolus* can be grown from rhizomes but care must be taken to prevent decimation of natural populations if management programmes include this method of artificial propagation.

Only one species, *Thysanotus rectantherus*, is classed as poorly known (category C, Marchant and Keighery 1979) but eight species rank as poorly known (category D) (see Table 2 for explanation of categories). Fifteen species are classified as restricted to areas of less than 100 km diameter, and a further 13 are restricted to areas of less than 160 km diameter. The 28 species in these last two categories appear relatively safe at the present time, but the continued extensive clearing for agriculture, together with selective clearing for mining on reserved land, means that the status of these species needs to be kept under frequent review.

Maps showing the distribution of rare and poorly known species are given in Figure 8.

The genus *Banksia* is somewhat indicative of the status of our taxonomic knowledge of the flora of our area, and the south west of Australia as a whole. Seven out of our 10 species of *Banksia* are classified as rare or restricted. Five of these are undescribed taxa (A. S. George. pers. comm. 1977) and in earlier surveys all would have been called *B. sphaerocarpa.*

When modern taxonomic studies of large taxa are done, it may be expected that many more species will become known as a result of more extensive knowledge of distribution and variation. The implication for the flora of our area is that many more species may actually occur in our area than we currently recognize; thus the botanical importance of the area is likely to be underestimated.

TABLE 2

SUMMARY OF POORLY KNOWN AND RARE SPECIES

Categories B–F follow those of Marchant and Keighery (1979). B = most significant category—species that are apparently rare and have a restricted geographic distribution; C = poorly known (1 specimen at Western Australian Herbarium); D = poorly known (2–5 specimens at Western Australian Herbarium); E = distribution restricted to an area 100 km diameter; and F = distribution restricted to an area with diameter 160 km. * = species additional to those listed in Marchant and Keighery; (x) = original classification by Marchant and Keighery; † = our estimate of status.

Species	Category B	C	D	E	F
Adenanthos drummondii					x
Banksia candolleana					x
Banksia hookerana				x	
Banksia sp. 1 (EAG 975)			x		
Banksia sp. 2 (RJH 771510)				x	
Banksia sp. 3				x	
Banksia sp. 4 (RJH 771519)	(x)			†	
Banksia sp. 5 (EAG 857)					x
Byblis gigantea					x
Caesia rigidifolia			x		
Calothamnus longissimus				x	
Calytrix superba	x				
Cassytha pubescens			x		
Commesperma acerosum			x		
Conospermum nervosum				x	
Conostylis crassinervia				x	
Cryptandra humilis				x	
Dampiera carinata			x		
**Daviesia dielsii*					?
**Daviesia epiphylla*				?	
**Daviesia* sp. aff. *nudiflora* (RJH 771559)				?	
Diplolaena ferruginea			x		
Dryandra tridentata				x	
Dryandra vestita					x
**Dryandra tortifolia*					x
Eremaea acutifolia	(x)				†
Gastrolobium pauciflorum					x
*gen. nov. aff. *Ecdeiocolea* (RJH 771147)					†
Hakea flabellifolia				x	
Isopogon adenanthoides				x	
Isopogon linearis					x
Lasiopetalum drummondii					x
**Lepidobolus* sp. (AJMH s.n.)	†				
Leucopogon obtectus	†		(x)		
Macropidia fuliginosa					x
Persoonia acicularis				x	
**Sphaerolobium* sp. (EAG 1003)				†	
Strangea cynanchicarpa				x	
Stylidium maitlandianum			x		
Thysanotus rectantherus		x			
Thysanotus spiniger			x		
Thysanotus teretifolius			x		
**Verticordia* sp. aff. *nitens* (RJH 771142)					x

VEGETATION

As detailed analyses of the vegetation data will be published elsewhere (Hnatiuk and Hopkins, in press), only a summary of our findings is presented here.

Analyses based upon the floristic information obtained at each site showed that the 87 sites could be classified into 3 major groups and 2 sub-groups, using the Taxon library of programmes (mapped on Figure 9).

The groups appeared to correspond most strongly with 3 major and 2 minor soil units: (1) winter wet depressions and associated sites, (Plate 1); (2) deep sands (2a—sand dunes), (Plate 2); and (3) lateritic gravels and sands (3a—the most lateritic sites) (Plate 3).

Plate 1—A view of a Group 1 site (foreground) dominated by *Verticordia* spp. and *Calytrix* spp. In the background from centre to right side of photograph is a large winter-wet depression dominated by *Eucalyptus rudis*, *Melaleuca rhaphiophylla*, and *Acacia saligna*.

The strong continuity between these groupings was clearly illustrated by the ordination studies. These studies also indicated the possibly non-linear relationship of sites, defined by floristic composition and soil type. The second ordination axis, that most strongly related to soil variation, only accounted for 6% of the variability in the data (the first four axes accounted for only 23%). Similar groupings were also provided through a ZM type sorting of the site x species data matrix.

Some indication of the plant species that characterise the vegetation can be obtained from the results of the ZM type sorting of the data. Only 37 species (*ca.* 11% of the 338 species recorded at sample sites) could be designated as characteristic of the most clearly defined unit—Group 3, the lateritic gravel and sands and associated sites. Thirty-two species (*ca.* 9%) were largely restricted to sites of Group 1—the heterogeneous wetlands and associated sites. One hundred and twenty-three species (36%) occurred either predominantly in Group 2—the deep sandy sites—or were transitional between Groups 2 and 3. Seventy-five species (22%) were uncommon, and 71 (21%) were ubiquitous.

The 91 species that were recorded from the study area but not at sample sites could also be considered uncommon.

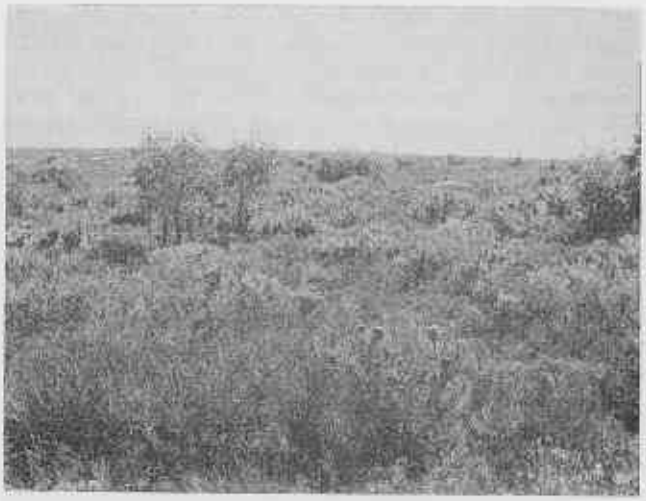

Plate 2—A dune-crest from Group 2 dominated by *Banksia hookerana* (centre foreground, ht. 1·2 m), *B. candolleana* (left foreground ht. 1·0 m), and *Eucalyptus todtiana* (right and left centre ht, 2·5 m).

The lateritic sites (Group 3) were readily characterised by a suite of species which included:

Adenanthos drummondii	*Grevillea synapheae*
Beaufortia bracteosa	*Haemodorum paniculatum*
Conostylis androstemma	*Hibbertia polystachya*
Darwinia sanguinea	*Isopopon adenanthoides*
Dryandra bipinnatifida	*Isopogon linearis*
Dryandra carlinoides	*Lepidobolus* sp. AJMH s.n.
Dryandra kippistiana	*Macropidia fuliginosa*
Dryandra vestita	*Petrophile striata*
Dryandra sp. RJH 771286	

The species characteristic of the sand ridges and dunes (Group 2a) included:

Adenanthos cygnorum	*Pityrodia hemigenioides*
Banksia hookerana	*Thysanotus rectantherus*

Plate 3—An area of species-rich low open-heath on lateritic gravel representative of Group 3.

Also important in this group but not restricted to it were *Eucalyptus todtiana*, *Synaphea polymorpha*, and *Xylomelum angustifolium*. The vegetation of and near winter-wet depressions (Group 1) was very heterogenous. There were gross differences between depressions even in their central regions. Some were dominated by

Acacia blakelyi, others by *Melaleuca hamulosa*, *M. rhaphiophylla*, still others had an open forest of *Eucalyptus rudis* and *Melaleuca rhaphiophylla* with broad clearings with numerous herbs. Fire history and possibly soils and ground water may have contributed to the heterogeneity. The depressions with heavy clay at the surface supported a rich community of ephemeral herbs not found elsewhere. A variety of fringing communities also existed around the depressions. These appeared to vary in species composition, at least in part, because of either the variation in depth of sand over clay or the degree of mixing of sand and clay as distance from the edge of the depression increased.

The classification of the vegetation through interpretation of air photos provided six units (Figure 10 Table 3); however, there is some disparity between these units and those described above. The six could be grouped into 3 large units that then corresponded most closely to the 3 Groups of the other analysis. When the 87 sites were assigned to these 3 units and the classification compared with that derived from the analysis of the floristic data from each site, several disparities were revealed. Between 16% and 40% of sites in each group were classified differently by the two methods. The differences were greatest in the heterogeneous "wetland" group and least in the deep sand group. The classification from the aerial photos appeared least satisfactory because it was dominated, in 2 of the 3 units, by the distributions of a few individual species, e.g. *Banksia attenuata*, *B. hookerana*, *Eucalyptus todtiana*, and *Xylomelum angustifolium*. Whilst the distribution of these species could be related to certain habitat factors, their precise distribution was not shared by a sufficient number of others to make it possible to use them as indicators of vegetation groups. In the low shrublands, differentiation was poor because there was very little variation in tone or texture on the photos for these areas.

It is evident from the above that there are many ways in which low sclerophyllous vegetation of our area can be described. This abundance of terms and lack of clear correspondence between systems highlights the utility of the term kwongan to encompass all the variants.

TABLE 3

RELATIONSHIPS BETWEEN THE VEGETATION UNITS INTERPRETED FROM AIR PHOTOS AND THE STRUCTURAL FORMATIONS OF SPECHT (IN APLIN 1979).

Air Photo Units	Structural Formations
Eucalyptus Unit	low woodland
Wetland Unit	low open-forest
Banksia—Xylomelum Unit	high shrubland / open-scrub / shrubland / open-heath
Heath 1	low open-heath
Heath 2	
Lateritic Plateau Unit	

SPECIES RICHNESS

There was considerable variation in the number of species recorded at each site for any one level of sampling intensity. For example, the species richness within the relevés varied from 13 at site 15 to 129 at site 39. A trend in species richness, which ran approximately at right angles to the major topographic features, became apparent when the data were plotted on a map (Figure 11). A band of greatest species richness appeared as a zone of overlap between 2 suites of species: those predominant on the lateritic country to the east and those from the deep-sand to the west. Although a few species were found only in the overlap zone (e.g. *Eucalyptus jucunda*), no species appeared to be characteristic of it. The extensive areas of lateritic gravels and deep sands each had between 62 and 129 species per site (means of 91 and 82 respectively) with fewest species in those groups being recorded on the sand ridges (range 61–83, mean 73). The winter-wet depressions had the fewest number of species (range 13–65, mean 46).

V—CONCLUSIONS

In this paper we have reported in detail the features of the environment that we considered to have a bearing on the distribution of the plant species. We found that the subdued, gross topography hid a relatively wide range of soil patterns and meso-topographic relief, for example the low dunes, the winter-wet depressions, and the patchy distribution of lateritic gravel. The small range of physiognomic vegetation units likewise masked a complex pattern imposed by plant floristics. The interaction of the plants and the physical environment have thus produced an unexpectedly complex mosaic. We are left wondering at the influence of the past perturbations such as fire, drought and climatic change upon present-day patterns.

Our study has highlighted the floristic richness of the Eneabba kwongan: 429 species of vascular plants were recorded during this survey. This includes a number of species classified as rare or with a restricted or poorly known distribution, as well as a number with uncertain taxonomic status. The data emphasize the botanical importance of the Eneabba area.

The numbers of species recorded at each of the study sites were closely related to the major environmental features of the area. The richest sites were distributed along the old shoreline. The zone of highest richness appeared to result from the overlap of two suites of species characteristic of two different habitats. It overlay the deposits of heavy mineral sands but this seems coincidental. However, the continued existence of this zone of richness is at risk because of the economic value placed upon the mining of the underlying sand.

The vegetation of the study area appeared to consist of three units, two of which were large and represented vegetation on lateritic soils and deep sands. There were suites of species characterizing each unit, but there was also a large degree of continuity between the two large units expressed by nearly one half the species being widespread or occurring widely in both. The third vegetation unit, that of the winter-wet depressions, was very heterogenous. Although it was less widespread than the two larger units, it represented an important

floristic and vegetation assemblage in the Eneabba area. There was some correspondence between the physiognomic vegetation units and the floristic groups, but between 16% and 40% of the study sites were not similarly grouped by the two analyses. The disparity was the result of a dominance of the physiognomic units by a few species, the distribution of which were not strongly correlated with those of the rest of the species.

VI—RECOMMENDATIONS

On the basis of this study it is possible to make a number of recommendations for improved land-use planning and management which could contribute towards maintenance of conservation values in the Eneabba area. Whilst all these relate directly to the flora, probably they would also benefit the fauna.

Any major and widespread disturbance, such as the existing and proposed heavy mineral sands mining projects, is likely to cause a loss of plant species from the area. At this stage only one species, *Leucopogon obtectus*, with two extremely small populations in the mining path, is threatened with extinction, although a number may have their ranges severely reduced.

It is therefore recommended that:

1. **the companies mining heavy mineral sands in the Eneabba area initiate a special study of the reproductive biology and horticulture of** *Calytrix superba*, *Lepidobolus* **sp.,** *Leucopogon obtectus* **and** *Thysanotus rectantherus* **with a view to the inclusion of these species in the post-mining flora, and that**
2. **this study be extended to include, within five years, other poorly-known species listed in Table 2 to ensure that these too are not lost from the area.**

A number of vegetation units have been delineated. Most of these will be substantially affected by the mining although the indivudual species comprising each unit may not. The unit that we consider most in need of special conservation attention includes the ephemeral wetlands and their immediate surrounds.

The extent of these wetlands within the study area is small, and the variability between them is high. Thus many of the wetland plant species are very restricted in their distributions within the study area; some are at the limits of their ranges. Further, a substantial proportion of these wetlands have already been destroyed or seriously disturbed by activities associated with the mining.

It is recommended that:

3. **the Department of Fisheries and Wildlife negotiate with the mining companies to ensure adequate protection of the ephemeral wetlands of the area, such protection including exclusion of mining from, and protection from damage resulting from mining related activities of, selected areas of the wetlands, and that**
4. **the mining companies investigate transport and other appropriate techniques for the inclusion of representative samples of the wetland flora in rehabilitated areas.**

A number of additional mining projects have been foreshadowed for this area and adjacent similar areas. Should these proposals proceed, they, together with land clearance for agriculture, could ultimately lead to the loss of a substantial proportion of the flora of this botanically important area. There is an urgent need, therefore, to secure adequate samples of the Eneabba kwongan in perpetuity for conservation purposes.

It is recommended that:

5. **the Western Australian Wildlife Authority and the Department of Fisheries and Wildlife seek an increase in status of a selection of other reserves in the Eneabba kwongan to Class A, and to exclude mining from the southern portion of C 31030 and the whole of C 27886.**

Rehabilitation techniques presently being practised by the heavy mineral sand mining companies in this area are only promoting the return of a small proportion (e.g. about 10%) of the flora that existed prior to mining. Whilst it is acknowledged that suitable techniques are still being developed, there is an urgent need to develop techniques for re-establishing the other *ca.* 90% of the flora.

It is recommended that:

6. **the mining companies strenuously examine new rehabilitation techniques for the rehabilitation of the native flora with a view to future simultaneous use of several techniques to promote the return of a greater array of indigenous plant species.**

VII—ACKNOWLEDGEMENTS

The field work for the study reported here was supported by Western Titanium Ltd. through an arrangement with Blackwell and Cala. Mr N. G. Caputi provided invaluable assistance with data processing. Technical support was provided by Messrs. S. French, E. Griffin, J. Koch, M. Onus and C. Robinson. Drs A. Burbidge and J. Green made helpful comments on the manuscript.

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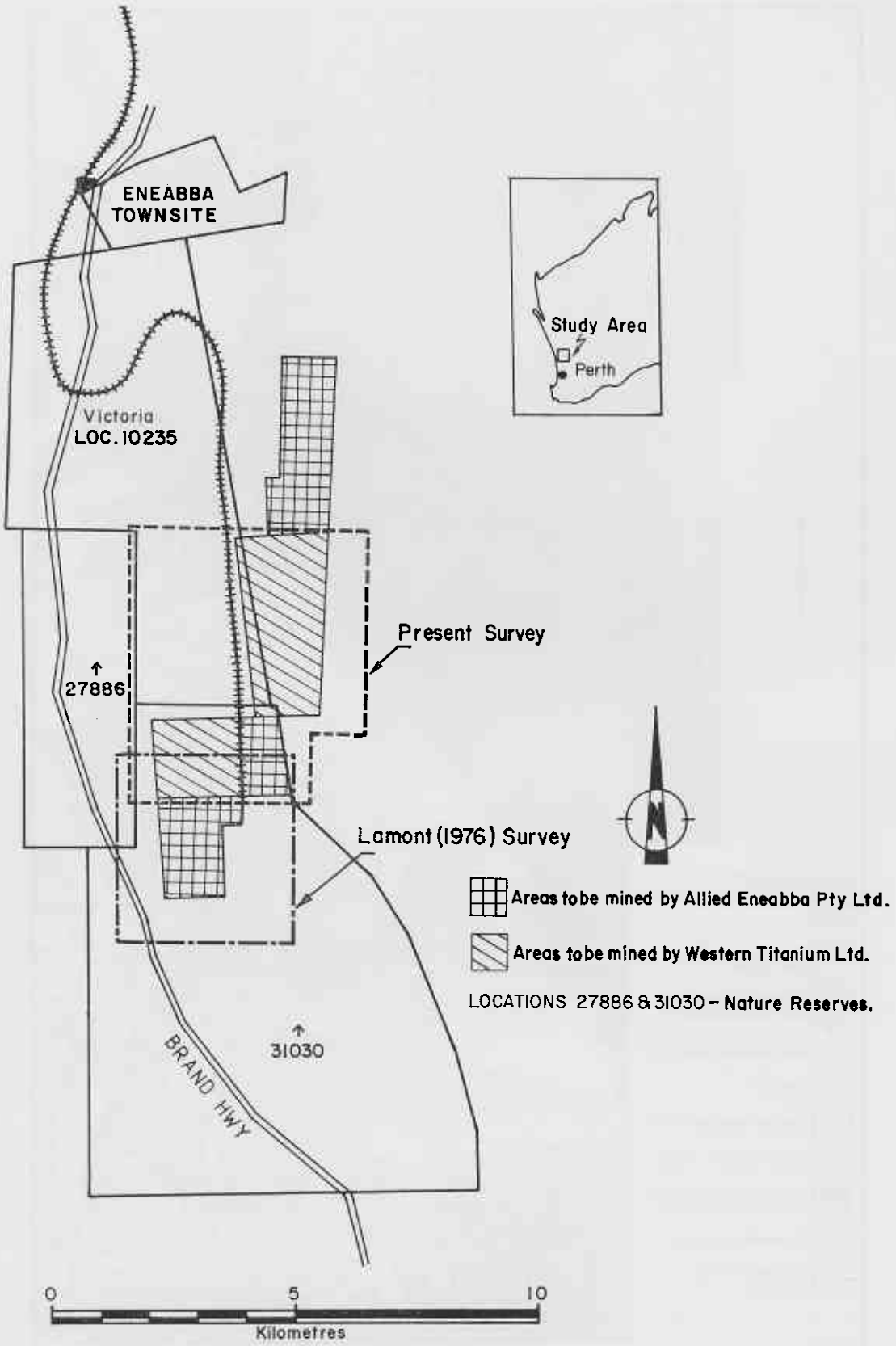


LOCATION MAP

Figure 1—Map showing the location of the study area and boundaries of reserve nos. 27886 and 31030 and mining areas.

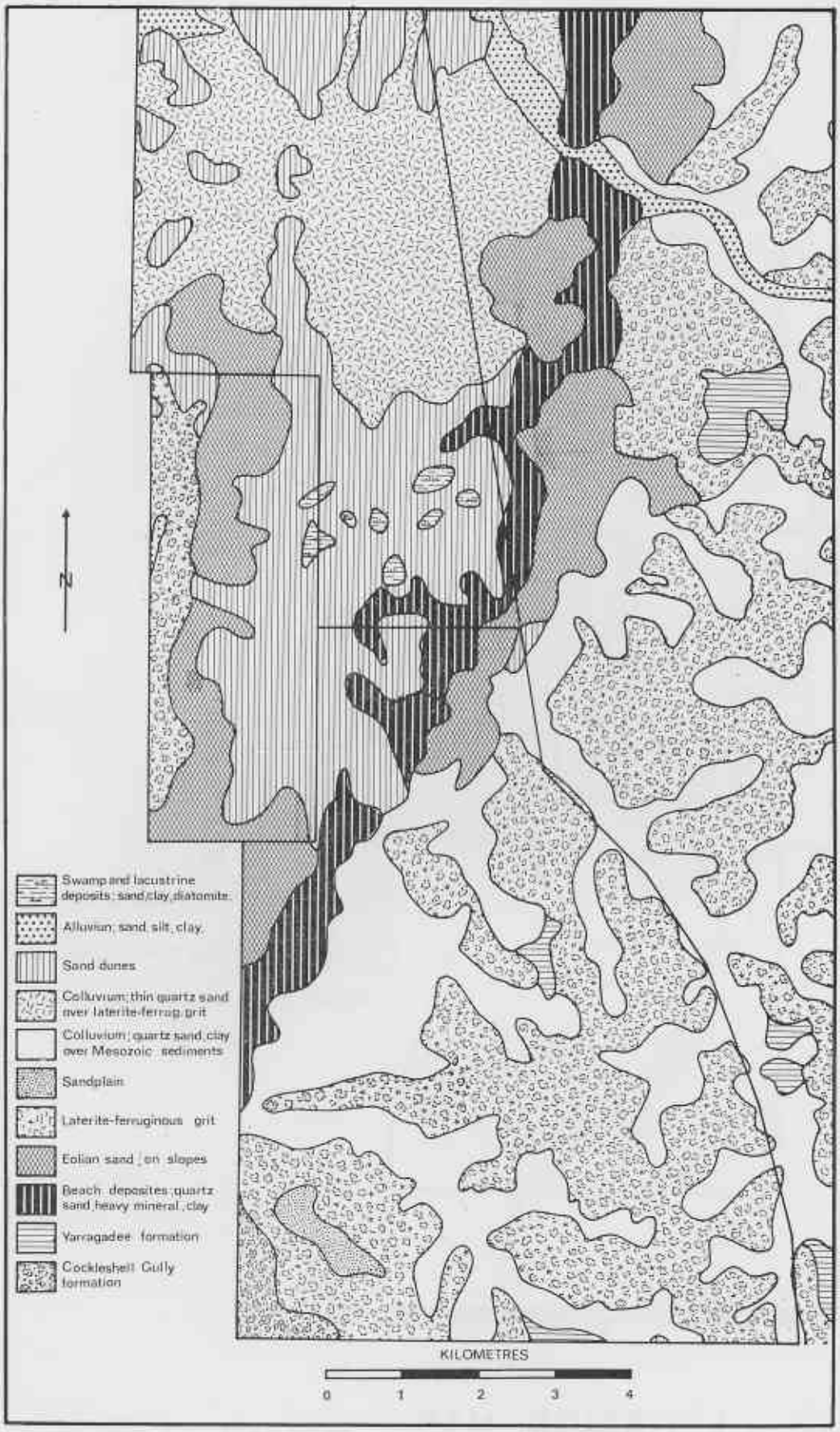


Figure 2—Map of major geological features of the study area and vicinity (from Baxter 1972).

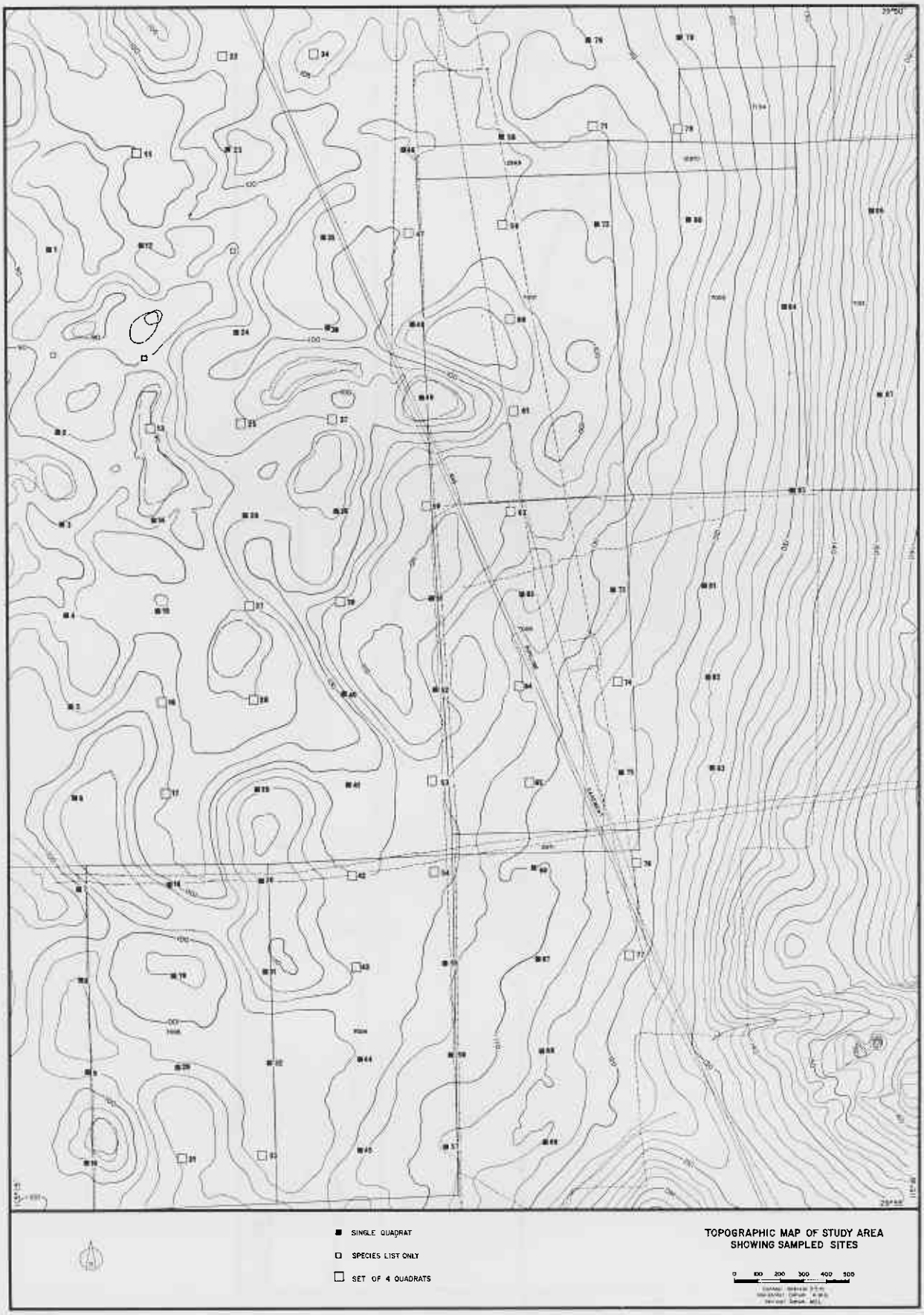


Figure 3—Map of topography of study area. Sample sites and numbers are marked.

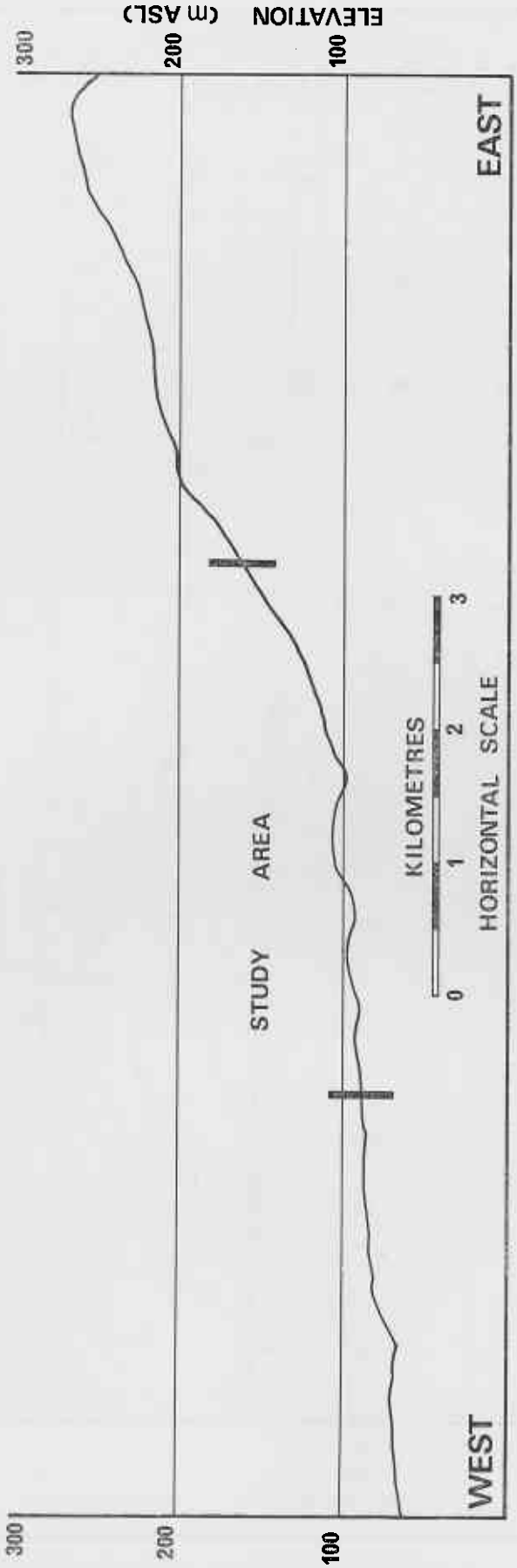


Figure 4—Topographic cross-section (east-west) across study area. Vertical scale exaggeration is about 12·6 times the horizontal scale.

Figure 5—Distribution of soil types as determined by the Department of Lands and Surveys. Vegetation sampling sites are marked with black squares.

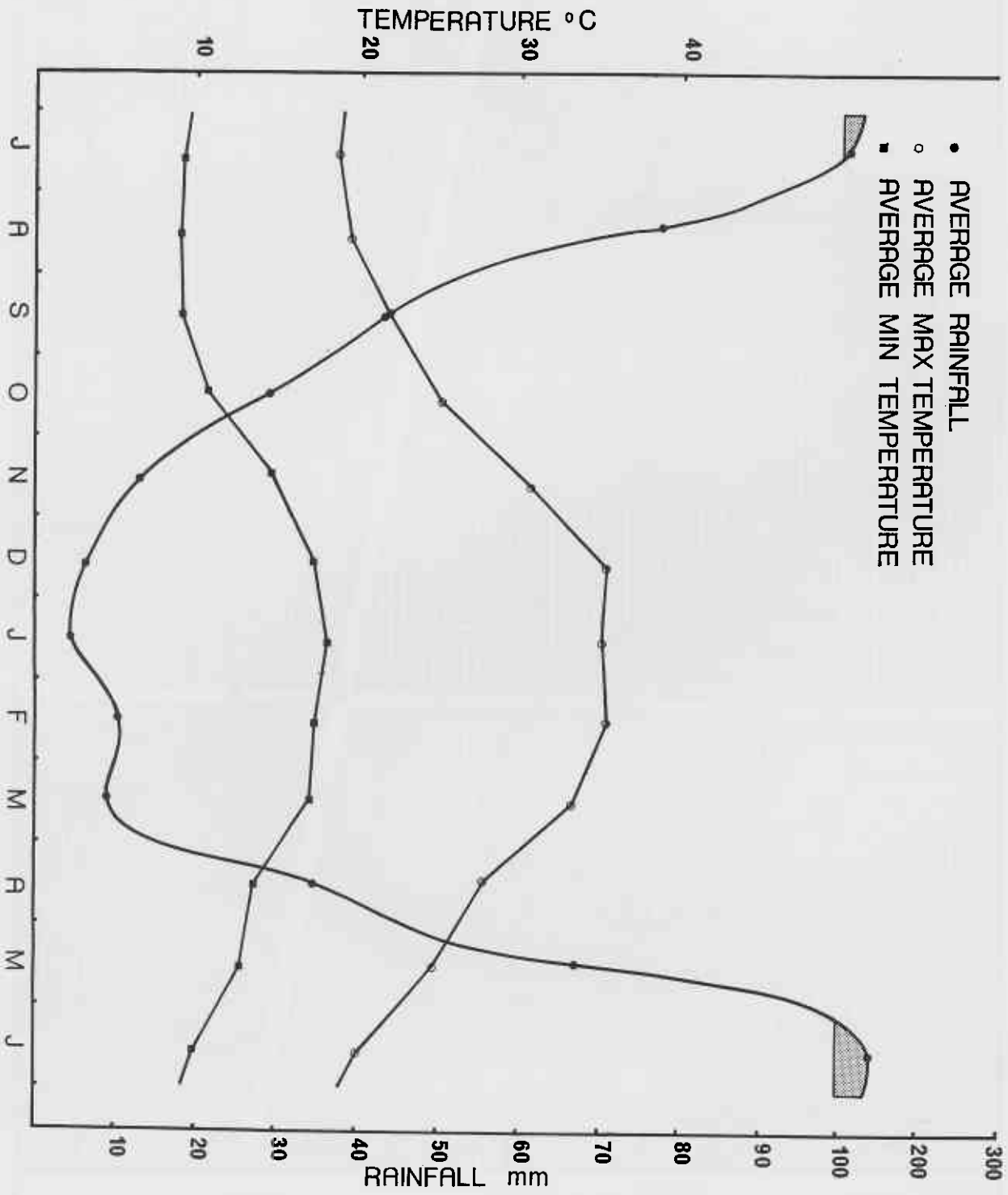


Figure 6—Ombrothermic diagram for Eneabba.

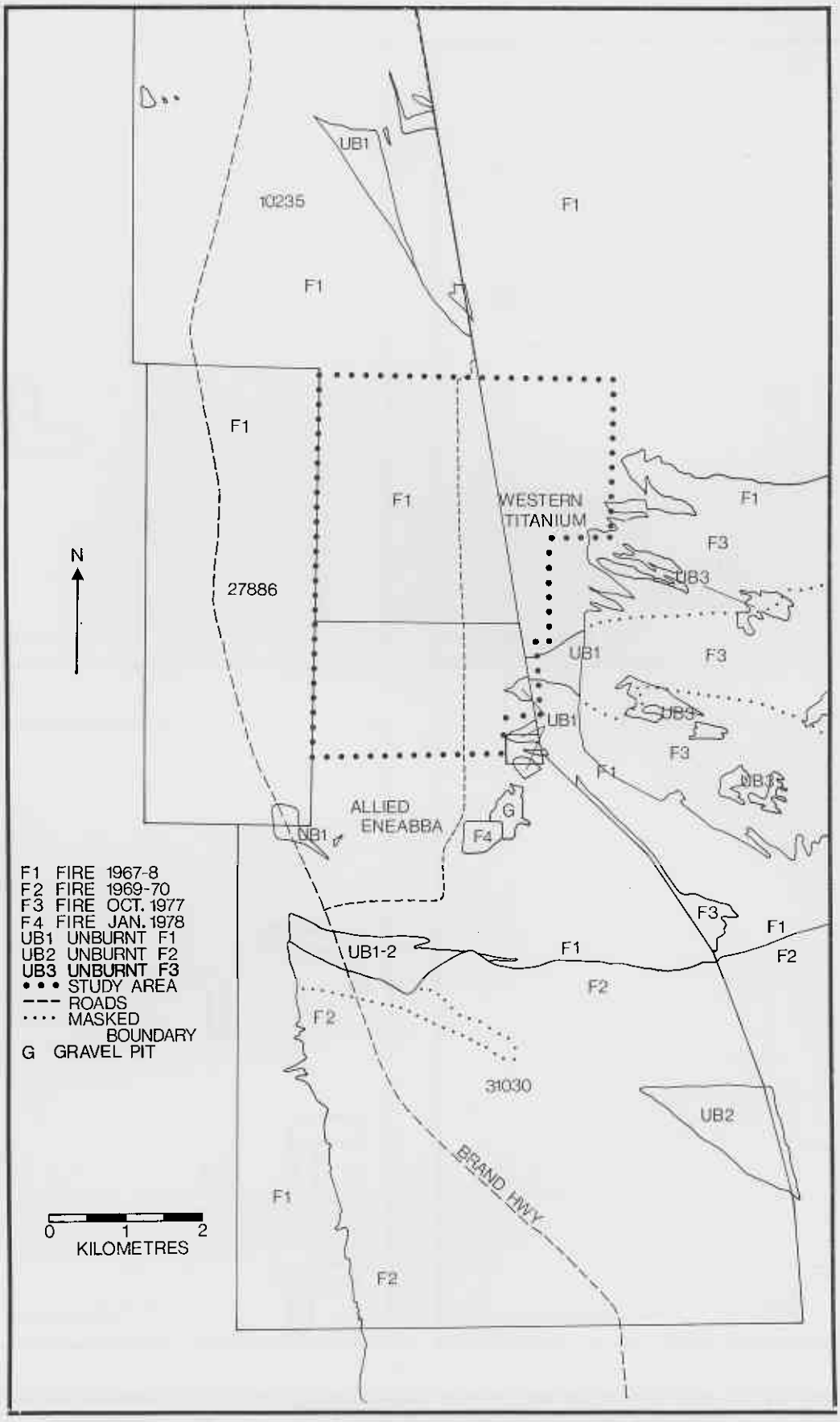


Figure 7—Map showing the areas in the vicinity of the study area which were burnt since 1967.

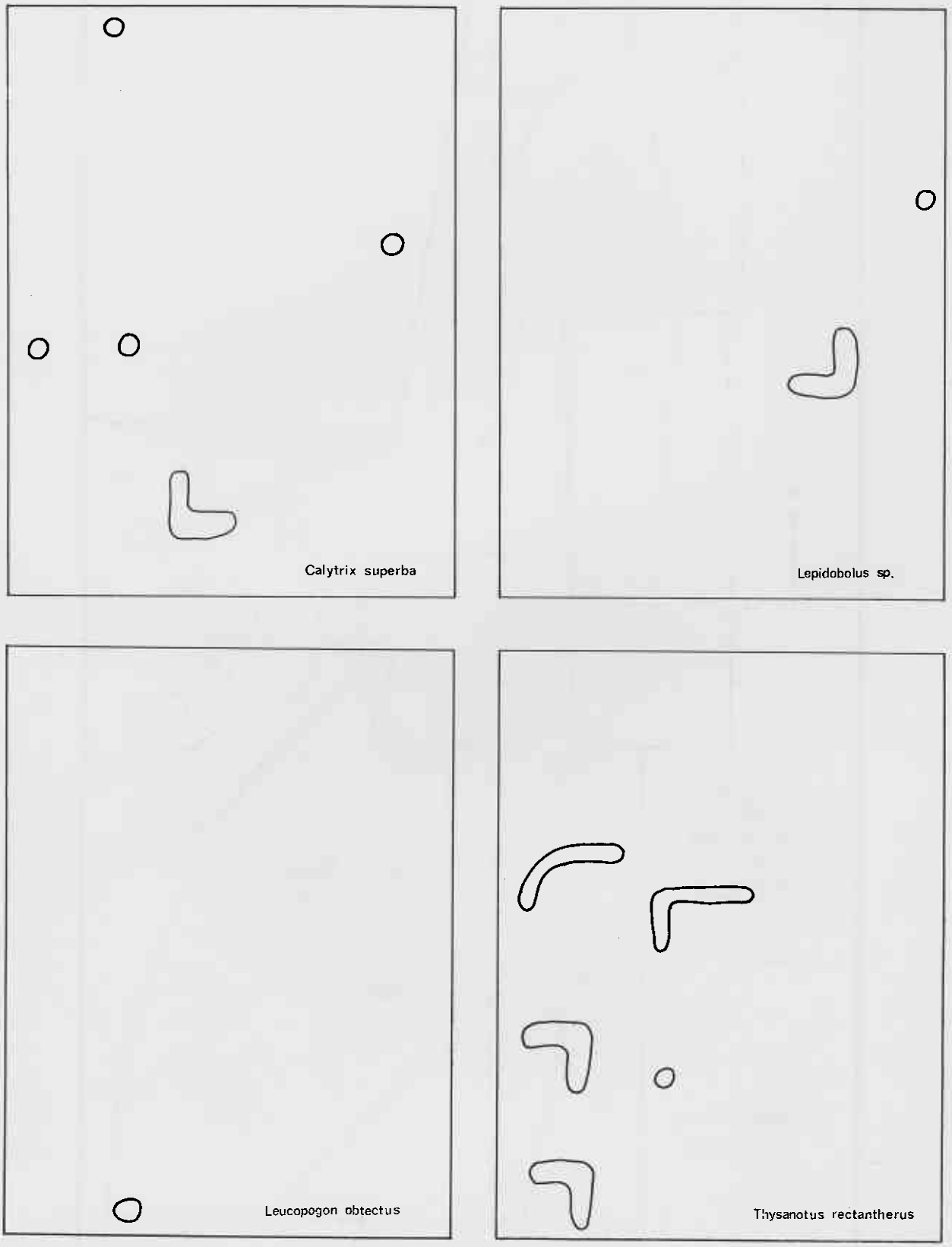


Figure 8—Maps of study area showing the approximate distributions of four poorly known or rare species of plants. Each map covers same area as shown in Figure 3.

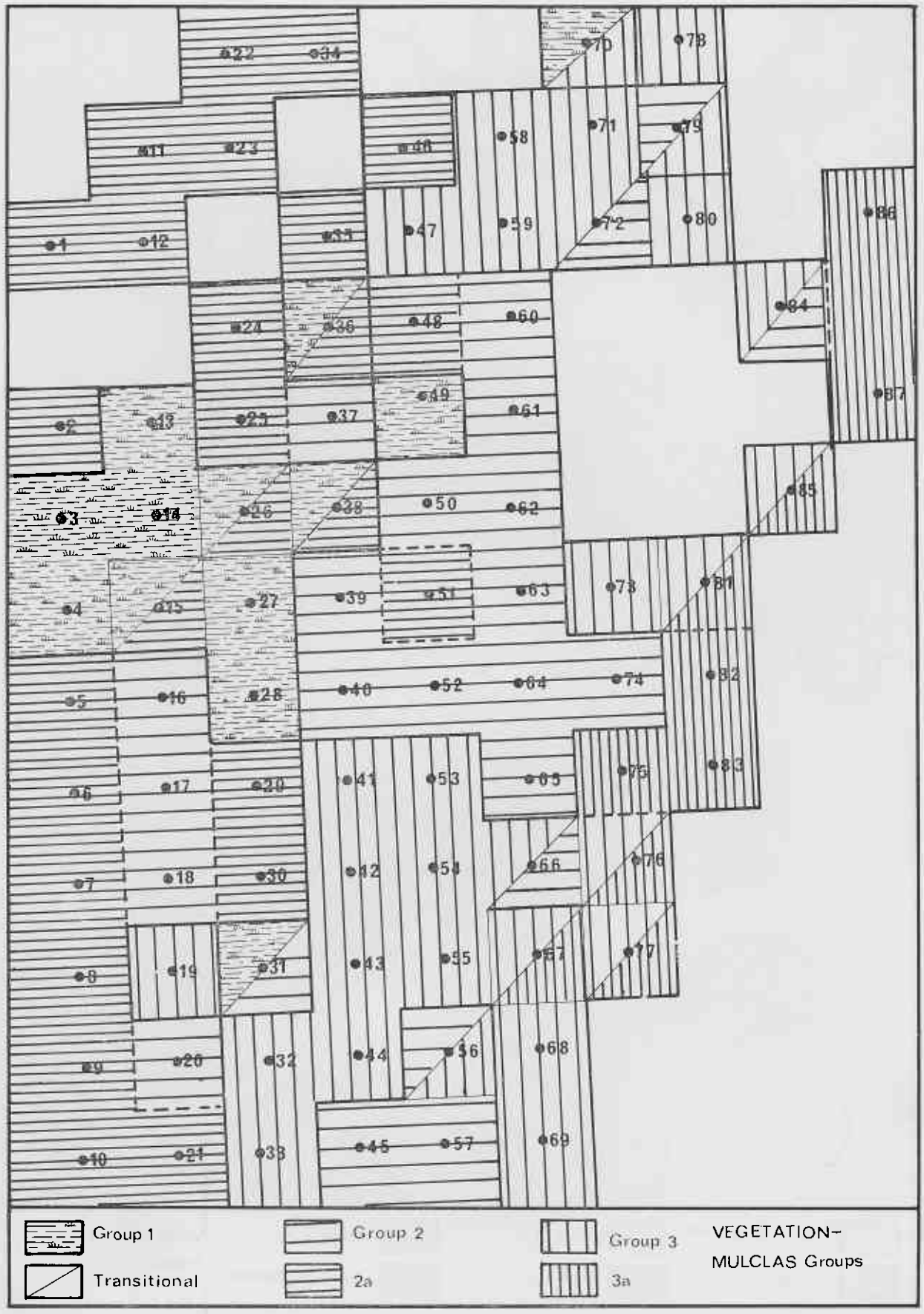


Figure 9—Map of study area showing the geographic disposition of the three major groups and two subgroups of vegetation derived from analysis of the floristic composition at 87 sample sites.

Figure 10—Map of the study area showing the boundaries of vegetation units as determined from examination of aerial photographs.

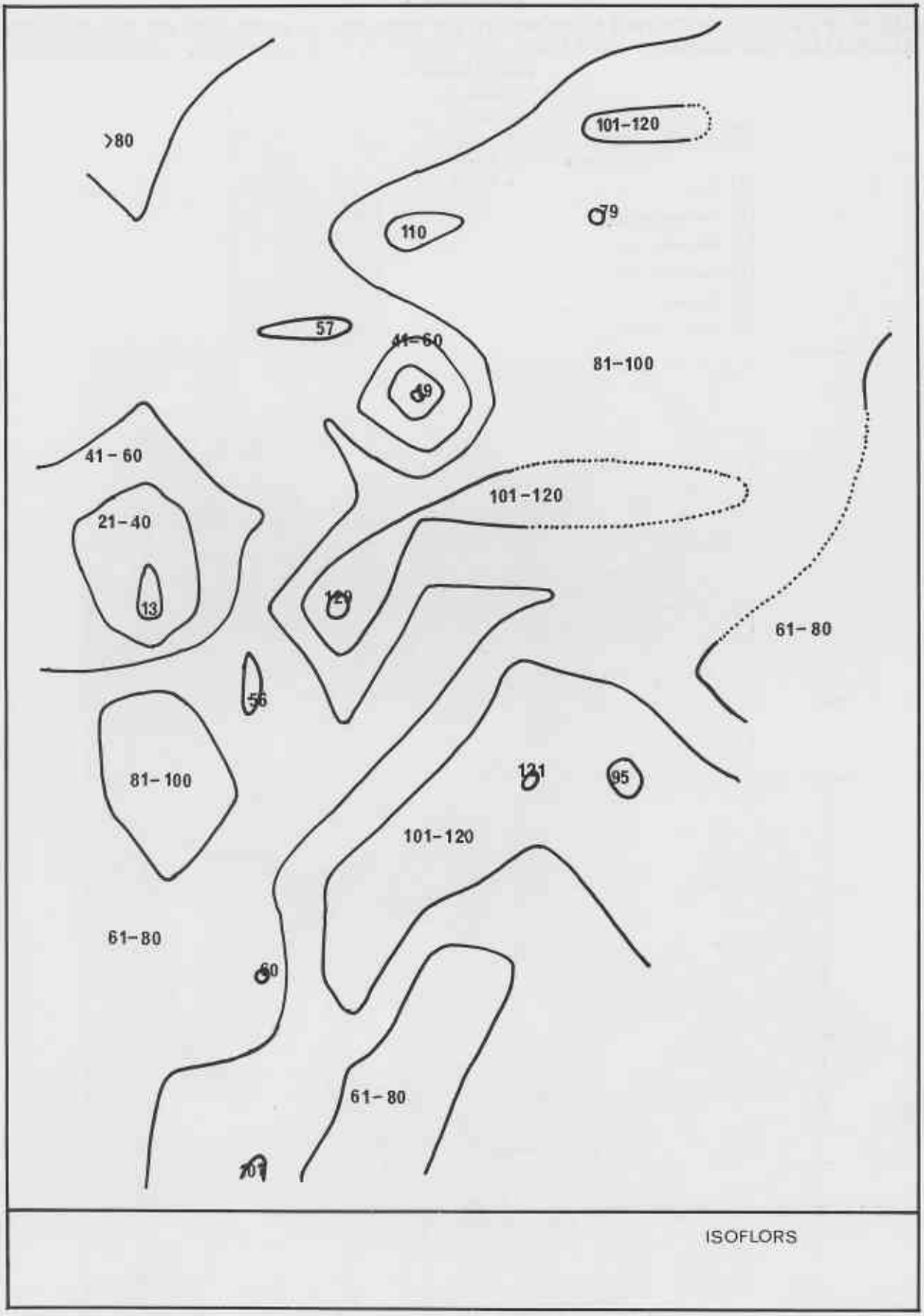


Figure 11—Isoflor map of the study area showing areas of greatest and least concentrations of species as determined from relevé records made at each of the 87 sample sites.

APPENDIX I

SOILS MAP OF VACANT CROWN LAND SOUTH OF ENEABBA AS PREPARED BY THE WESTERN AUSTRALIAN DEPARTMENT OF LANDS AND SURVEYS FOR ASSESSING AGRICULTURAL SUITABILITY.

APPENDIX II

RESULTS OF ANALYSES OF SOIL FROM FIVE SITES IN THE ALLIED ENEABBA PTY. LTD. LEASE AREA.

DATA ARE REPRODUCED FROM ALLIED ENEABBA (1978) WITH PERMISSION.

Location: 99090mN 99150mE (Allied Eneabba Pty Ltd metric grid).
Topography: Broad flat swale.
Parent Material: Bassendean Sand, Quaternary eolianite.
Profile Drainage: Impeded.
Native Vegetation: Low heath with *Conospermum triplinervium, Eremaea beaufortioides, E. violacea, Pileanthus filifolius, Melaleuca acerosa, Hibbertia crassifolia, H.* aff. *hypericoides.*

Morphology:

No.	Depth (cm)	
13	10	Brown (10 YR 4/3) single grain sand, 15% root material, organic staining.
14	25	Brownish yellow (10 YR 6/8) single grain sand, 5% root material, decreasing organic mottling.
15	60	Brownish yellow (10 YR 6/6) sand minor clay, 1% root material.
16	100	Yellowish brown (10 YR 5/6) sand with minor clay. Contacts transitional.

Laboratory Data:

Physical Analyses (sampled 15th May, 1977).

No.	Percent Moisture Retention — Atmospheres Suction Pressure					Percent Available	Na Cl % by Conductivity	Moisture % on Collection	Particle Size (mm) — Percent in stated fraction				
	1/10	1/3	1	3	15				>2	2–·2	·2–·02	·02–·002	<·002
13	4·0	2·8	2·1	1·9	1·5	2·5	·01	4·7	·21	81·35	15·37	2·87	0·20
14	3·6	2·6	2·1	1·9	1·7	1·9	·01	5·5	·21	71·06	26·60	2·13	0·00
15	5·9	4·5	3·7	3·6	3·1	2·8	·01	6·9	·78	69·01	27·29	2·92	0·00
16	7·3	5·0	4·4	4·3	4·0	3·3	·01	7·0	·00	66·28	29·07	4·65	0·00

Chemical Analyses (sampled 12th October, 1977).

No.	Material	Kg/m³	% Oven Dry Weight			ppm Oven Dry Weight											
			Ign Loss	Ash	Insol. Residue	N	P	Avail P	K	Fe	Ca	Mg	S	Cu	Zn	Mn	Co	Mo
201	Aerial parts	·670	....	16·64	13·41	5 400	103	16	66	3 178	3 960	699	632	3·8	10·5	62	1·2	<·04
202	Roots 0–25 cm	1·430	....	24·47	20·46	4 600	148	21	20	4 674	5 163	612	487	3·2	18·8	68	1·7	<·05
203	Roots 25–50 cm	·550	....	26·51	21·58	5 000	126	16	20	7 264	7 582	742	424	2·1	16·7	59	1·9	<·06
101	Soil* 0–25 cm	412·500	1·6	....	....	....	361	2	140	12 000	357	1 400	100	4·0	42·0	315	5·0	<·2
102	Soil* 25–50 cm	412·500	1·8	....	....	....	400	2	163	13 100	395	381	130	6·0	47·0	254	4·0	<·2

* Bulk density of 1 650 kg/m³ estimated.

Location: 99090mN 9887OmE (Allied Eneabba Pty Ltd metric grid).
Topography: Low broad dune flank.
Parent Material: Bassendean Sand, Quaternary eolianite.
Profile Drainage Restricted.
Native Vegetation: Destroyed by spillage from tailings dam.

Morphology:

No.	Depth (cm)	
17	10	Greyish brown (10 YR 5/2) single grain sand, 30% root material plus organic staining.
18	25	Light brownish grey (10 YR 6/2) single grain sand, 10% root material plus organic staining.
19	55	Brown (10 YR 5/3) single grain sand, 2% root material, minor organic staining.
20	60+	Very pale brown (10 YR 7/4) hard pan, yellowish iron oxide with sand grains, with brownish yellow (10 YR 6/8) mottles

Contacts transitional. The profile is overlain by 5 cm of clay sediment derived from the recent (September, 1976) overflow of a tailings dam.

Laboratory Data:

Physical Analyses (sampled 17th May, 1977).

No.	Percent Moisture Retention — Atmospheres Suction Pressure					Percent Available	Na Cl % by Conductivity	Moisture % on Collection	Particle Size (mm) — Percent in stated fraction				
	1/10	1/3	1	3	15				>2	2–·2	·2–·02	·02–·002	<·002
17	3·8	1·4	1·4	1·6	1·4	2·4	<·01	2·1	·75	72·82	23·69	2·49	0·25
18	3·2	1·4	1·2	1·4	1·4	1·8	<·01	2·3	·47	69·22	27·45	2·39	0·47
19	3·3	1·6	1·4	1·4	1·2	2·1	<·01	3·5	1·09	58·34	36·18	4·39	0·00
20	4·3	2·5	2·1	2·1	1·8	2·5	<·01	3·4	2·11	58·78	34·88	4·23	0·00

Chemical Analyses (sampled 12th October 1977).

No.	Material	Kg/m³	% Oven Dry Weight			ppm Oven Dry Weight											
			Ign Loss	Ash	Insol. Residue	N	P	Avail P	K	Fe	Ca	Mg	S	Cu	Zn	Mn	Co	Mo
204	Aerial parts	·830	....	9·89	6·28	4 500	103	9	78	1 889	7 417	107	439	2·1	5·8	37	·9	<·02
205	Roots 0–25cm	3·940	....	24·33	20·36	3 100	39	6	16	2 798	11 678	462	535	2·2	12·2	50	1·5	<·05
206	Roots 25–50 cm	1·115	....	21·58	19·10	2 400	142	5	23	3 021	4 726	561	432	2·4	13·6	47	1·3	<·05
103	Soil* 0–25 cm	412·500	1·5	....	....	....	405	8	114	8 200	351	190	60	2·0	38·0	196	3·0	<·2
104	Soil* 25–50 cm	412·500	0·5	....	....	....	344	5	95	10 300	195	114	140	3·0	34·0	262	3·0	·2

* Bulk density of 1 650 kg/m³ estimated.

APPENDIX II—*continued*

Location: 98480mN 98540mE (Allied Eneabba Pty Ltd metric grid).
Topography: Low broad dune ridge.
Parent Material: Bassendean Sand, Quaternary eolianite.
Profile Drainage: Free.
Native Vegetation: Low heath with *Banksia hookerana, B. sphaerocarpa, Conospermum triplinervium, Eremaea beaufortioides, E. violacea, Melaleuca acerosa, Hibbertia crassifolia, H.* aff. *hypericoides.*

Morphology:

No.	Depth (cm)	
1	6	Light brownish grey (10 YR 6/2) single grain loose sand, 7% root material, organic staining.
2	14	Yellowish brown (10 YR 5/6) single grain loose sand, 2% root material, minor organic staining.
3	30	Yellowish brown (10 YR 5/8) single grain loose sand, 1% root material, trace organic staining.
4	100	Brownish yellow (10 YR 6/8) single grain loose sand, ·5% root material, no organic staining. Contacts transitional throughout.

Laboratory Data:

Physical Analyses (sampled 15th May, 1977).

No.	Percent Moisture Retention — Atmospheres Suction Pressure					Percent Available	Na Cl % by Conductivity	Moisture % on Collection	Particle Size (mm) — Percent in stated fraction				
	1/10	1/3	1	3	15				>2	2–·2	·2–·02	·02–·002	<·002
1	3·4	2·2	1·7	1·4	1·2	2·2	<·01	4·6	·21	78·75	17·70	2·09	1·25
2	3·0	2·0	1·6	1·4	1·2	1·8	<·01	5·1	·21	78·52	17·56	1·03	2·68
3	3·0	2·0	1·5	1·4	1·2	1·8	<·01	2·7	·40	70·00	28·00	1·00	·60
4	3·2	1·9	1·6	1·4	1·4	1·8	<·01	3·0	·18	59·47	39·41	·94	·00

Chemical Analyses (sampled 12th October 1977).

No.	Material	Kg/m³	% Oven Dry Weight			ppm Oven Dry Weight											
			Ign Loss	Ash	Insol. Residue	N	P	Avail P	K	Fe	Ca	Mg	S	Cu	Zn	Mn	Co	Mo
207	Aerial parts	·560	....	8·60	5·44	6 200	117	9	103	1 204	6 020	1 445	286	2·5	8·5	45	0·6	<·02
208	Roots 0–25 cm	2·380	....	27·51	24·57	3 600	46	10	26	3 851	6 025	688	610	2·5	21·2	35	0·8	<·06
209	Roots 25–50 cm	1·195	....	19·39	16·23	3 900	31	6	34	3 956	7 388	853	481	4·3	14·0	22	·8	<·04
105	Soil* 0–25 cm	412·500	1·6	....	....	....	82	1	105	7 300	303	100	90	2·0	30·0	92	3·0	<·2
106	Soil* 25–50 cm	412·500	1·0	....	....	....	86	5	103	9 500	168	81	220	2·0	30·0	100	4·0	<·2

* Bulk density of 1 650 kg/m³ estimated.

Location: 100000mN 100300mE (Allied Eneabba Pty Ltd metric grid).
Topography: Broad flat swale.
Parent Material: Bassendean Sand, Quaternary eolianite.
Profile Drainage: Restricted.
Native Vegetation: Low heath with *Xanthorrhoea reflexa, Eremaea beaufortioides, E. violacea, Melaleuca acerosa, Hibbertia crassifolia, H.* aff. *hypericoides, Conostylis dielsii.*

Morphology:

No.	Depth (cm)	
5	7	Grey (10 YR 5/1) single grain sand, 20% root material, strong organic staining.
6	16	Pale brown (10 YR 6/3) single grain sand, 7% root material, moderate organic staining.
7	33	Pale brown (10 YR 6/3) single grain, minor dispersed clay, 2% root material, organic mottling.
8	48	Yellowish brown (10 YR 5/4) single grain, minor dispersed clay, 2% root material, minor organic mottling.
	205	Brownish yellow (10 YR 6/8) hard pan, brittle indurated clay mottles, roots rare.
	238	Brownish yellow (10 YR 6/6) clayey grit, 25% coarse angular quartz in fine clayey sand matrix.
		Contacts in upper half of profile are transitional.

Laboratory Data: Physical Analyses (sampled 16th May, 1977).

No.	Percent Moisture Retention					Percent Available	Na Cl % by Conductivity	Moisture % on Collection	Particle Size (mm)				
	Atmospheres Suction Pressure								Percent in stated fraction				
	1/10	1/3	1	3	15				>2	2–·2	·2–·02	·02–·002	<·002
5	4·4	2·8	2·0	1·8	1·4	3·0	<·01	4·2	·22	77·48	21·12	1·18	0·00
6	3·4	2·2	1·5	1·4	1·2	2·2	<·01	3·4	·21	74·47	24·26	1·06	0·00
7	3·6	2·2	1·6	1·4	1·2	2·4	<·01	4·7	·20	66·73	31·06	2·01	0·00
8	4·5	3·0	2·4	2·2	1·8	2·7	<·01	6·4	·54	64·39	33·27	1·80	0·00

Chemical Analyses (sampled 13th October, 1977).

No.	Material	Kg/m³	% Oven Dry Weight			ppm Oven Dry Weight											
			Ign Loss	Ash	Insol. Residue	N	P	Avail P	K	Fe	Cu	Mg	S	Cu	Zn	Mn	Co	Mo
210	Aerial parts	·690	....	13·13	10·20	5 800	114	12	63	1 838	7 497	880	675	2·2	8·3	38	·9	·05
211	Roots 0–25 cm	1·510	....	27·65	23·53	3 800	147	12	30	4 922	7 300	747	514	3·0	18·8	76	1·9	<·06
212	Roots 25–50 cm	·610	....	29·13	24·91	2 600	121	10	29	5 389	6 554	787	428	2·3	23·6	85	2·0	<·06
107	Soil* 0–25 cm	412·500	1·0	....	....	....	488	5	95	12 500	254	114	80	2·0	42·0	327	4·0	<·2
108	Soil* 25–50 cm	412·500	1·3	....	....	....	562	5	125	14 300	259	133	110	2·0	51·0	358	4·0	<·2
109	Pisolites 25–50 cm....	2·690	6·4	....	....	....	376	2	286	35 600	200	243	140	3·0	47·0	196	9·0	<·2

* Bulk density of 1 650 kg/m³ estimated.

APPENDIX II—*continued*

Location: 101370mN 100150mE (Allied Eneabba Pty Ltd metric grid).
Topography: Broad flat swale.
Parent Material: Bassendean Sand, Quaternary eolianite.
Profile Drainage: Restricted.
Native Vegetation: Low heath with *Xanthorrhoea reflexa, Conospermum triplinervium, Eremaea beaufortioides, E. violacea, Pileanthus filifolius, Melaleuca acerosa, Hibbertia crassifolia, H.* aff. *hypericoides, Conostylis dielsii.*

Morphology:

No.	Depth (cm)	
9	10	Very dark greyish brown (10 YR 3/2) sandy, single grain, 15% root material, organic staining.
10	40	Yellowish brown (10 YR 5/6) sandy, minor clay, 3% root material.
11	70	Yellowish brown (10 YR 5/6) sandy, increasing clay, 1% root material.
12	100+	Brownish yellow (10 YR 6/8) hard packed clayey sand, roots rare (red brown mottles 95–100 cm). All contacts are transitional.

Laboratory Data:

Physical Analyses (sampled 16th May, 1977).

No.	Percent Moisture Retention — Atmospheres Suction Pressure					Percent Available	Na Cl % by Conductivity	Moisture % on Collection	Particle Size (mm) — Percent in stated fraction				
	1/10	1/3	1	3	15				>2	2–·2	·2–·02	·02–·002	<·002
9	8·2	6·6	5·2	5·0	4·6	3·6	<·01	5·4	·19	80·46	17·41	1·94	0·00
10	5·6	4·4	3·7	3·4	3·0	2·6	<·01	6·7	·38	74·81	22·72	1·90	0·19
11	3·6	2·6	2·0	1·8	1·6	2·0	<·01	6·3	1·89	74·29	20·05	3·53	0·24
12	8·6	6·7	5·2	4·9	4·4	4·2	<·01	3·6	·48	67·88	26·57	4·83	0·24

Chemical Analyses (sampled 14th October, 1977).

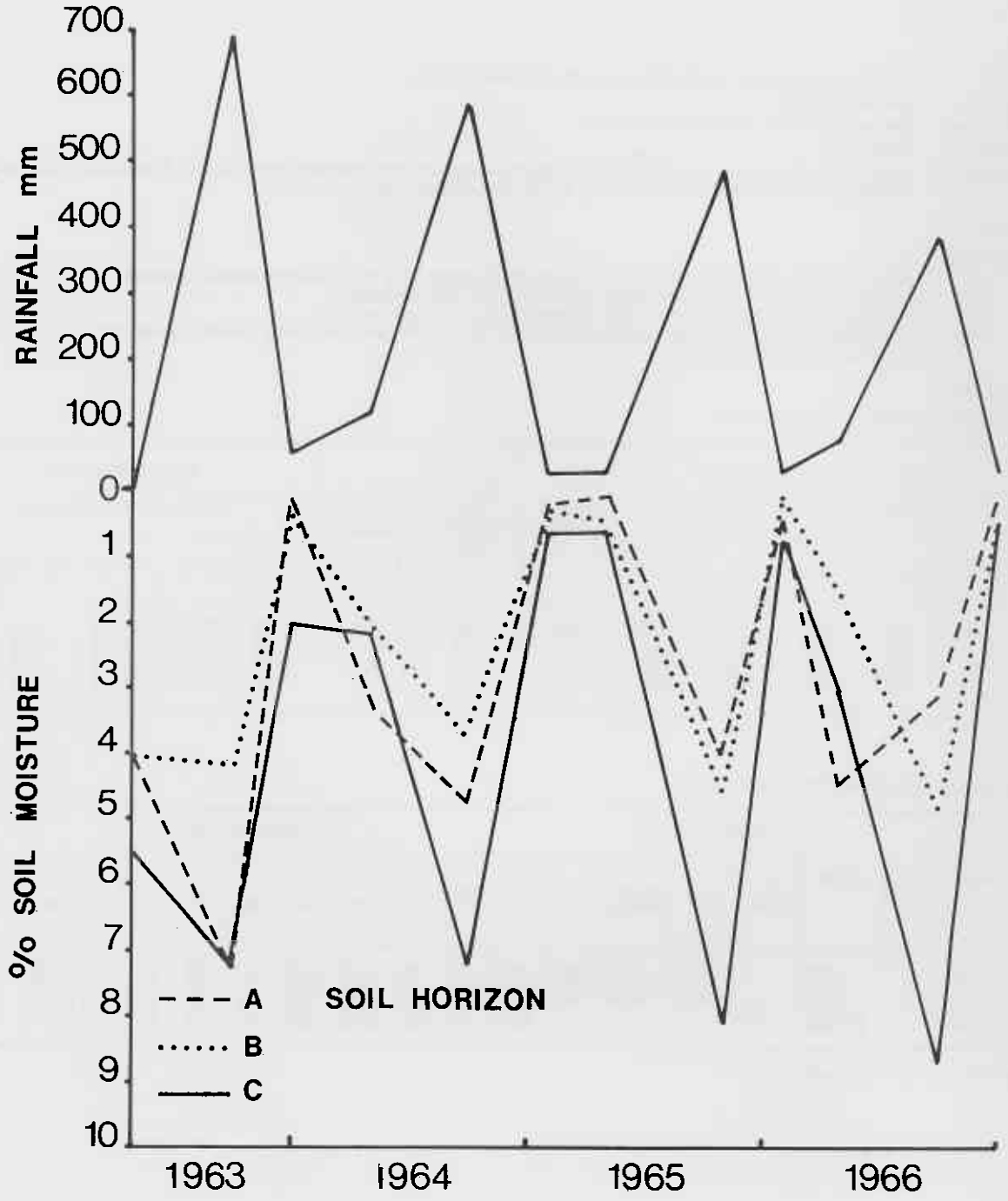
No.	Material	Kg/m³	% Oven Dry Weight			ppm Oven Dry Weight											
			Ign Loss	Ash	Insol. Residue	N	P	Avail P	K	Fe	Ca	Mg	S	Cu	Zn	Mn	Co	Mo
213	Aerial parts	·740	....	10·15	7·30	5 500	10	2	74	1 553	7 359	1 015	828	1·9	7·3	52	0·8	<·03
214	Roots 0–25 cm	2·200	....	24·67	20·38	3 800	16	11	20	4 860	8 215	641	659	2·2	67·8	76	1·7	<·05
215	Roots 25–50 cm	·300	....	23·78	20·40	3 700	92	11	22	3 924	5 018	642	637	2·4	21·4	57	1·9	<·05
110	Soil* 0–25 cm	412·500	1·9	....	....	....	250	3	114	14 100	243	133	100	2·0	47·0	308	3·0	<·2
111	Soil* 25–50 cm	412·500	2·3	....	....	....	206	3	165	14 900	227	152	60	2·0	42·0	277	4·0	<·2

* Bulk density of 1 650 kg/m³ estimated.

APPENDIX III

FIGURE ILLUSTRATING THE RELATIONSHIPS BETWEEN RAINFALL AND % SOIL MOISTURE CONTENT FROM A LOCATION IN UNDISTURBED KWONGAN ABOUT 12 KM NORTH OF ENEABBA

Three soil moisture readings (Speedy Moisture Test) were taken from each of the three recognised soil horizons on each visit and mean values are shown. Data are from Forests Department (1962) and Hart and Glover (1970).



APPENDIX IV

RESULTS OF ANALYSES OF SOILS FROM 31 SELECTED SITES WITHIN THE STUDY AREA.

Site No.	Depth (cm)	% Clay (< ·002 mm)	% Silt (·02–·002 mm)	% Fine Sand (·2–·02 mm)	% Coarse Sand (2–·2 mm)	% Gravel (> 2 mm)	% Available Moisture	% Organic Carbon
2	0–16	1·36	·70	12·10	85·84	....	1·4	0·53
	85–102	2·44	·10	19·43	78·03	....	0·8	0·09
11	0–15	·73	·52	25·91	72·84	....	1·7	0·47
	55–65	·99	1·15	21·91	75·95	....	1·1	0·09
	90–100	3·46	·66	28·09	67·79	....	1·4	0·09
13	0–18	1·19	·87	16·70	81·24	....	1·4	0·52
	40–50	1·30	·65	21·75	76·26	·04	1·3	0·06
	85–100	1·27	·57	27·76	59·77	10·63	2·1	0·07
16	0–14	1·57	1·52	20·67	76·23	....	2·1	1·26
	30–43	1·76	·75	23·90	73·59	....	0·9	0·18
	88–104	3·70	·31	28·81	67·18	....	1·1	0·10
17	0–13	2·21	1·56	20·80	75·43	....	2·0	0·46
	92–104	5·31	·98	32·45	61·26	....	1·7	0·14
21	0–18	2·01	·75	18·86	78·38	....	1·5	0·45
	93–107	3·36	·51	28·21	67·92	....	0·9	0·09
22	0–18	2·41	1·15	25·44	71·00	....	2·4	0·52
	35–40	1·40	1·32	34·51	62·77	....	1·6	0·26
	72–80	9·74	1·90	33·77	53·48	1·11	3·1	0·15
	90–100	14·74	1·58	29·05	44·74	9·89	4·0	0·17
25	0–16	1·93	·60	15·31	82·16	....	1·2	0·52
	80–102	2·46	·63	22·91	74·00	....	1·0	0·08
27	0–20	1·31	·79	9·84	88·06	....	1·5	0·64
28	0–21	·94	1·19	16·47	81·21	·19	2·0	0·53
	61–76	1·44	·74	25·59	72·13	·10	1·7	0·09
	90–105	1·76	·70	39·87	57·38	·29	1·7	0·08
33	0–13	3·47	1·53	32·88	62·18	....	2·6	0·59
	47–64	20·11	2·96	28·23	48·70	....	4·0	0·27
	90–102	13·36	5·63	35·18	45·69	·14	3·5	0·14
34	0–20	1·21	·89	23·45	74·45	....	1·6	0·55
	39	1·44	·47	30·21	67·88	....	1·5	0·22
	90	6·81	·81	37·80	54·58	....	1·6	0·22
37	0–18	2·00	1·05	12·27	84·68	....	2·0	0·63
	80–98	3·06	·37	23·99	72·58	....	1·5	0·10
39	0–8	2·21	·72	15·91	81·16	....	1·9	0·54
	44–59	4·87	·73	20·54	73·86	....	1·4	0·17
	92–102	6·29	·97	22·67	70·07	....	1·5	0·09
42	0–12	1·35	1·71	32·28	64·66	....	2·1	0·37
	31–45	2·73	·78	42·01	54·48	....	1·8	0·26
	92–104	16·90	3·22	24·63	48·20	7·05	4·9	0·20
43	0–14	2·15	·94	35·14	61·77	....	2·0	0·43
	27–54	3·52	·85	42·60	52·87	·16	1·7	0·14
	77–83	24·71	5·70	29·39	40·14	·06	7·1	0·23
	97–104	24·64	3·56	29·40	42·40	....	6·5	0·11
47	0–15	....	1·31	28·99	67·62	....	2·6	0·40
	82–95	20·00	2·87	22·08	42·87	5·18	4·4	0·20
	95–103	20·55	2·14	24·80	45·86	6·65	4·5	0·14
50	0–15	2·23	·60	14·45	82·72	....	1·3	0·21
	90–106	4·97	·47	27·24	67·32	....	1·1	0·07
53	0–11	4·01	1·27	31·66	63·06	....	2·2	0·38
	94–106	13·75	5·44	31·20	47·13	2·48	4·7	0·19
54	0–19	1·76	·93	28·79	68·36	·16	2·0	0·43
	26–41	2·48	1·01	45·60	50·49	·42	2·0	0·24
	90–100	8·64	3·99	25·31	42·75	19·31	5·0	0·34
59	0–14	2·15	·70	25·03	72·12	....	2·1	0·44
	87–105	10·62	·99	32·33	56·36	....	2·0	0·13
60	0–9	2·41	·77	16·22	80·60	....	2·1	0·70
	90–104	5·89	·96	28·33	64·82	....	1·5	0·10
61	0–10	1·49	·51	12·98	85·02	....	1·1	0·72
	91–105	2·71	·80	22·76	73·73	....	1·0	0·30
62	0–12	2·21	·73	23·80	73·26	....	1·7	0·66
	30–47	3·22	·72	33·48	62·58	....	1·0	0·08
	92–105	4·25	·69	33·19	61·87	....	1·1	0·18
64	0–11	2·68	·72	24·00	72·60	....	1·8	0·30
	29–47	5·00	·84	28·81	65·35	....	1·3	0·18
	91–105	7·33	1·26	33·66	57·75	....	1·6	0·09

APPENDIX IV

RESULTS OF ANALYSES OF SOILS FROM 31 SELECTED SITES WITHIN THE STUDY AREA—*continued*

Site No.	Depth (cm)	% Clay (< ·002 mm)	% Silt (·02–·002 mm)	% Fine Sand (·2–·02 mm)	% Coarse Sand (2–·2 mm)	% Gravel (> 2 mm)	% Available Moisture	% Organic Carbon
65	0–12	3·45	·99	26·32	69·24	....	2·0	0·38
	35–46	10·52	1·42	32·81	55·25	....	2·4	0·28
	92–103	12·98	3·56	30·39	53·07	....	3·9	0·19
71	0–8	1·48	1·09	22·52	74·91	....	2·0	0·66
	55–70	1·53	·75	29·86	66·22	1·64	2·1	0·13
	83–87	20·55	2·26	21·00	54·99	1·20	3·9	0·22
	90–98	14·01	2·71	19·68	43·98	19·62	5·1	0·22
74	0–9	2·69	1·12	24·52	71·67	....	1·8	0·44
	90–102	8·07	1·68	36·47	53·78	....	1·6	0·13
76	0–14	1·77	·85	23·30	74·00	·08	1·9	0·68
	34–49	3·25	1·31	20·34	42·00	33·10	3·0	0·28
	90–102	7·15	4·69	33·50	50·50	4·16	6·4	0·19
77	0–18	1·19	·08	27·39	66·53	4·81	2·8	0·37
	88–102	24·17	2·46	36·02	34·97	2·37	6·4	0·14
79	0–11	3·61	1·33	20·76	74·30	....	2·3	0·46
	90–102	10·16	2·16	31·87	55·81	....	2·7	0·15

APPENDIX V

LIST OF SPECIES RECORDED FOR THE ENEABBA STUDY AREA.

Those marked with an asterisk (*) are represented by voucher specimens at PERTH.
Those of uncertain determination and represented by a voucher have the initials and number of the collector indicated.

*Acacia auronitens Lindl.
* „ ? barbinervis Benth. EAG 796
* „ blakelyi Maiden
* „ fagonioides Benth.
* „ lasiocarpa var. lasiocarpa Benth.
* „ latipes Benth.
* „ saligna (Labill.) Wendl.
*Actinostrobus acuminatus Parl.
*Adenanthos cygnorum Diels
* „ drummondii Meisn.
*Alexgeorgea arenicola Carlquist
Amphipogon ? strictus R.Br.
* „ turbinatus R.Br.
*Amyema miquelii (Lehm. ex Miq.) Tieghem
*Anarthria sp. indet. 1. RJH 771360, 771380
„ sp. indet. 2.
*Andersonia gracilis DC.
* „ heterophylla Sond.
*Angianthus humifusus (Labill.) Benth.
* „ pusillus Benth.
*Anigozanthos humilis Lindl.
„ manglesii D.Don
Apiaceae indet. 1.
„ indet. 2.
*Arctotheca calendula (L.) Levyns
*Arnocrinum preissii Lehm.
*Astroloma cf. microdonta F.Muell. ex Benth.
* „ pallidum R.Br.
* „ ? serratifolium (DC.) Druce RJH 790073
* „ stomarrhena Sond.
* „ xerophyllum (DC.) Sond.
*Baeckea grandiflora Benth.
*Banksia attenuata R.Br.
„ candolleana Meisn.
* „ hookerana Meisn.
„ menziesii R.Br.
* „ sphaerocarpa R.Br.
* „ sp. 1. EAG 975
* „ sp. 2 RJH 771510
* „ sp. 3.
* „ sp. 4. RJH 771569
* „ sp. 5. EAG 857
*Beaufortia bracteosa Diels
* „ elegans Schau.
*Beyeria brevifolia (Muell. Arg.) Benth.
*Boronia coerulescens F.Muell.
* „ purdieana Diels
* „ ramosa (Lindl) Benth. subsp. anethifolia (Bartl.) P. G. Wilson
„ sp. indet. 1. RJH 771378
*Brachycome iberidifolia Benth.
*Briza minor L.
*Bulbine semibarbata (R.Br.) Haw.
*Burchardia umbellata R.Br.
*Burtonia conferta DC.
*Byblis gigantea Lindl.
*Caesia rigidifolia F.Muell. ex Benth.
Caladenia flava R.Br.
*Calandrinia corrigioloides F.Muell. ex Benth.
*Calectasia cyanea R.Br.
*Calocephalus priceanus Domin
*Calothamnus longissimus F.Muell.
„ quadrifidus R.Br.
* „ sanguineus Labill.
* „ torulosus Schau.
* „ sp. cf. villosus R.Br. RJH 771425
*Calytrix empetroides (Schau.) Benth.
* „ flavescens A.Cunn.
* „ strigosa A.Cunn.
* „ superba C. A. Gardn. & George
* „ tenuifolia (Meisn.) Benth.
Cassytha glabella R.Br.
„ pubescens R.Br.
*Casuarina humilis Otto & Dietr.
„ microstachya Miq.
*Caustis dioica R.Br.
*Centrolepis pilosa Hieron.
*Chorizandra enodis Nees
*Comesperma acerosum Steetz.
* „ calymega Labill.
* „ drummondii Steetz.
*Conospermum acerosum Lindl.
* „ crassinervium Meisn.
* „ incurvum Lindl.
* „ nervosum Meisn.
* „ triplinervium R.Br.
Conostephium preissii Sond.
*Conostylis aculeata R.Br.
* „ androstemma (Lindl.) F.Muell.
* „ aurea Lindl.
* „ crassinervia J. W. Green
* „ neocymosa S. D. Hopper
* „ teretifolia J. W. Green
* „ sp. 1. RJH 771121
* „ sp. 2. RJH 771497, EAG 961
* „ sp. 3. aff. crassinervia J. W. Green
* „ sp. 4. aff. aurea Lindl. RJH 771497
* „ sp. 5. EAG 631
*Conothamnus trinervis Lindl.
*Corynotheca ? micrantha (Lindl.) Macbride RJH 771228
*Crassula colorata (Nees) Ostf.
* „ sp. RJH 790061
*Cryptandra glabriflora Benth.
* „ humilis (Benth.) F.Muell.
* „ tomentosa Lindl.
* „ sp. indet.
Cyperaceae indet. 1.
„ indet. 2.
„ indet. 3.
„ indet. 4.
„ indet. 5.
„ indet. 6.
*Dampiera carinata Benth.
* „ oligophylla Benth. var. juncea Benth.
* „ spicigera Benth.
* „ teres Lindl.
*Darwinia neildiana F.Muell.
* „ sanguinea (Meisn.) Benth.
* „ speciosa (Meisn.) Benth.
Dasypogon bromeliifolius R.Br.
Daviesia dielsii E. Pritz.
* „ divaricata Benth.
„ epiphylla Meisn.
* „ juncea Sm.
* „ sp. aff. nudiflora Meisn. RJH 771559
* „ ? pectinata Lindl. RJH 771317
* „ pedunculata Benth.
* „ quadrilatera Benth. ex. Lindl.
* „ striata Turcz.
*Diplolaena ferruginea P. G. Wilson
*Drosera ? bulbigena Morrison RJH 771353, 771406
* „ drummondii Lehm.
* „ erythrorrhiza Lindl.
* „ gigantea Lindl.
* „ humilis Planch.
* „ leucoblasta Benth.
* „ macrantha Endl.
* „ menziesii R.Br.
* „ paleacea DC.
* „ pallida Lindl.
* „ ramellosa Lehm.
* „ sp. aff. banksii R.Br. ex DC. RJH 771136

APPENDIX V—*continued*

*Dryandra bipinnatifida R.Br.
* „ carlinoides Meisn.
* „ kippistiana Meisn.
* „ nivea (Labill.) R.Br.
„ shuttleworthiana Meisn.
* „ tortifolia Kipp. ex R.Br.
* „ tridentata Meisn.
* „ vestita (Kipp.) Meisn.
* „ sp. aff. falcata RJH 771286

*Ecdeiocolea monostachya F.Muell.

Elythranthera brunonis (Endl.) George

*Eremaea acutifolia F. Muell.
„ beaufortioides Benth.
* „ violacea F.Muell.

*Eriostemon pinoides P. G. Wilson
* „ spicatus A.Rich.

*Eucalyptus accedens W. V. Fitzg.
* „ drummondii Benth.
* „ jucunda C. A. Gardn.
* „ rhodantha Blakely & Steedman
* „ rudis Endl.
* „ tetragona (R.Br.) F. Muell.
* „ todtiana F. Muell.

*Exocarpos sparteus R.Br.

*Gastrolobium obovatum Benth.
* „ pauciflorum C. A. Gardn.

*Geleznowia verrucosa Turcz.

*Gen. nov. aff. Ecdeiocolea RJH 771364

*Glischrocaryon aureum (Lindl.) Orch.

*Glossostigma diandrum (L.) O. Kuntze

*Gompholobium aristatum Benth.
* „ knightianum Lindl.
* „ shuttleworthii Meisn.
* „ tomentosum Labill.

*Goodenia caerulea R.Br.
* „ filiformis R.Br. var. minutiflora F.Muell.

Goodeniaceae indet.

*Grevillea acrobotrya Meisn.
* „ didymobotrya (Endl.) Meisn.
* „ eriostachya Lindl.
„ leucopteris Meisn.
* „ polybotrya Meisn.
* „ rudis Meisn.
* „ shuttleworthiana Meisn.
* „ synapheae R.Br.
* „ sp. aff. eriobotrya Lindl. EAG 815

*Haemodorum paniculatum Lindl.
* „ spicatum R.Br.
* „ sp. RJH 771355

*Hakea auriculata Meisn.
* „ brachyptera Meisn.
* „ candolleana Meisn.
* „ cinerea R.Br.
* „ conchifolia Hook.
* „ costata Meisn.
„ flabellifolia Meisn.
* „ incrassata R.Br.
* „ lissocarpha R.Br.
* „ obliqua R.Br.
* „ prostrata R.Br.
* „ ruscifolia Labill.
* „ smilacifolia Meisn.
„ stenocarpa R.Br.
* „ trifurcata (Sm.) R.Br.
* „ sp. EAG 2162

Helipterum cotula (Benth.) DC.

*Hemiandra pungens R.Br.

Herb indet. 1.

Herb indet. 2.

*Hibbertia acerosa (R.Br. ex DC.) Benth.
* „ crassifolia (Turcz.) Benth.
* „ huegelii (Endl.) F. Muell.
* „ polystachya Benth.
* „ subvaginata (Steud.) F. Muell.
* „ sp. aff. furfuracea (R.Br.) Benth. RJH 771310

*Homalosciadium homalocarpum (F. Muell.) Hj. Eichler

*Hovea stricta Meisn.

Hybanthus floribundus (Walp.) F. Muell.

*Hydrocotyle scutellifera Benth.

*Hypocalymma xanthopetalum F. Muell. var. linearifolium

*Hypochoeris glabra L.

*Isopogon adenanthoides Meisn.
* „ linearis Meisn.
* „ sp. aff. tridens F. Muell. EAG 881

*Isotoma pusilla Benth.

*Jacksonia floribunda Endl.
* „ hakeoides Meisn.
* „ restioides Meisn.
* „ ulicina Meisn.

*Johnsonia pubescens Lindl.

*Lachnostachys eriobotrya (F. Muell.) Druce

*Lambertia multiflora Lindl.

*Lasiopetalum drummondii Benth.

*Laxmannia omnifertilis Keighery
* „ sessiliflora Dcne. ssp. irwinensis Keighery

*Lechenaultia biloba Lindl.
* „ hirsuta F. Muell.
* „ stenosepala E. Pritz.

*Lepidobolus chaetocephalus F. Muell.
* „ sp. AJMH s.n.

*Lepidosperma pubisquameum Steud.
* „ scabrum Nees
„ sp. 1. RJH 771550
„ sp. 2. RJH 771377

*Leptomeria empetriformis Miq.

*Leptospermum erubescens Schau.
* „ spinescens Endl.

Leucopogon conostephioides DC.
* „ hispidus E. Pritz.
* „ leptanthus Benth.
* „ obtectus Benth.
* „ striatus R.Br. RJH 771131, 771553
„ sp. 1.
„ sp. 2.
„ sp. 3.
„ sp. 4.
* „ sp. 5. EAG 1012

Liliaceae indet. 1.
„ indet. 2.

*Logania spermacocea F. Muell.

*Lomandra caespitosa (Benth.) Ewart
* „ hastilis (R.Br.) Ewart
* „ preissii (Endl.) Ewart
„ sp. aff. glauca (R.Br.) Ewart ssp. collina (R.Br.) A. Lee
„ sp. 1.

Loxocarya cinerea R.Br.
* „ fasciculata (R.Br.) Benth.

*Lyginia barbata R.Br.

*Lysinema ciliatum R.Br.

*Macarthuria australis Hueg. ex Endl.

Macropidia fuliginosa (Hook.) Druce

Macrozamia riedlei (Fisch. ex Gaud.) C. A. Gardn.

*Melaleuca acerosa Schau.
* „ hamulosa Turcz.
* „ rhaphiophylla Schau.
* „ trichophylla Lindl.
* „ uncinata R.Br. ex Ait.
* „ sp. 1. EAG 1368
* „ sp. 2. RJH 771339

Mesomelaena stygia (R.Br.) Nees var deflexa Kükenth.
* „ „ „ „ „ pseudostygia Kükenth.
„ tetragona (R.Br.) Benth.

*Microcorys sp. RJH 771501

*Microtis orbicularis Rogers

*Millotia myosotidifolia (Benth.) Steetz.

*Mirbelia spinosa Benth.

*Monotaxis grandiflora Endl.

*Myriocephalus appendiculatus Benth.

*Myriophyllum integrifolium Hook. f.

APPENDIX V—*continued*

*Neurachne alopecuroidea R.Br.
Nuytsia floribunda (Labill.) R.Br.
*Olax benthamiana Miq.
* „ phyllanthi (Labill.) R.Br.
Orchidaceae indet. 1.
„ indet. 2.
*Oxylobium capitatum Benth.
*Patersonia juncea Lindl.
*Pentaschistis airoides (Nees) Stapf.
*Persoonia acicularis F.Muell.
* „ angustiflora Benth.
„ sp. 1. aff. sulcata Meisn.
Petrophile drummondii Meisn.
* „ ericifolia R.Br.
* „ inconspicua Meisn.
„ linearis R.Br.
* „ macrostachya R.Br.
* „ media R.Br.
* „ serruriae R.Br.
* „ striata R.Br.
*Philydrella pygmaea (R.Br.) Caruel.
*Phymatocarpus porphyrocephalus F. Muell.
*Pileanthus filifolius Meisn.
*Pimelea angustifolia R.Br.
* „ leucantha Diels
* „ sulphurea Meisn.
*Pityrodia bartlingii (Lehm.) Benth.
* „ hemigenioides (F. Muell.) Benth.
* „ verbascina (F. Muell.) Benth.
*Platysace xerophila (E. Pritzel) L. Johnson
Poaceae indet. 1.
„ indet. 2.
„ indet. 3.
„ indet. 4.
„ indet. 5.
„ indet. 6.
*Podotheca angustifolium Less.
* „ gnaphalioides Grah.
*Poranthera microphylla Brongn.
*Prasophyllum macrostachyum R.Br.
* „ ovale Lindl.
Pterostylis sp. 1.
*Ptilotus gaudichaudii (F. Muell.) J. M. Black.
*Restio sphacelatus R.Br.
*Scaevola canescens Benth.
* „ humifusa de Vriese
„ paludosa R.Br.
„ phlebopetala F. Muell.
„ sp. 1.
*Schoenus curvifolius (R.Br.) Benth.
* „ subbarbatus Kükenth.
* „ sp. 1. aff. pleiostemoneus F. Muell. RJH 771480
* „ sp. 2. aff. pedicellatus (R.Br.) Benth. RJH 771468
„ sp. 3. RJH 771442
„ sp. 4.
„ sp. 5. RJH 771108
* „ sp. 6. EAG 2145
*Scholtzia involucrata (Endl.) Druce
* „ laxiflora Benth.
* „ umbellifera F. Muell.
* „ sp. cf. parviflora F. Muell. EAG 982
Scirpus marginatus Thunb.
„ sp. 1. RJH 771404
„ sp. 2.
„ sp. 3.
* „ sp. 4. RJH 771540
*Silene gallica L. var. anglica (L.) Clapham
*Sphaerolobium scabriusculum Meisn.
„ sp. EAG 1003
*Stackhousia brunonis Benth.
„ dielsii Pampanini
*Stachystemon axillaris George
*Stipa compressa R.Br.
* „ variabilis Hughes
Stirlingia latifolia (R.Br.) Steud.
* „ simplex Lindl.
Strangea cynanchicarpa F.Muell.
*Stylidium adpressum Benth.
* „ brunonianum Benth.
* „ calcaratum R.Br.
* „ crossocephalum F. Muell.
* „ dichotomum DC.
* „ diuroides Lindl.
* „ inundatum R. Br.
* „ junceum R.Br.
* „ macrocarpum (Benth.) Erickson & Willis
* „ maitlandianum E. Pritz.
* „ miniatum Mildbr.
* „ perpusillum Hook.f.
* „ piliferum R.Br.
„ repens R.Br.
„ sp. 1.
*Synaphea polymorpha R.Br.
*Templetonia biloba (Benth.) Polhill
*Tetraria octandra (Nees) Kükenth.
*Tetratheca confertifolia Steetz.
*Thelymitra antennifera (Lindl.) Hook.f.
* „ campanulata Lindl.
*Thryptomene mucronulata Turcz.
* „ prolifera Turcz.
*Thysanotus dichotomus (Labill.) R.Br.
* „ patersonii R.Br.
* „ pauciflorus R.Br.
* „ rectantherus N. H. Brittan
* „ sparteus R.Br.
* „ spiniger N. H. Brittan
* „ ? tenellus EAG 672
* „ teretifolius N. H. Brittan
* „ triandrus (Labill.) R.Br.
„ sp. 1.
„ sp. 2.
*Trachymene pilosa Sm.
*Tribonanthes uniflora Lindl.
*Tricoryne elatior R.Br.
*Trifolium subterraneum L.
*Triglochin procera (R.Br.) Buch.
*Ursinia anthemoides (L.) Poir.
*Verreauxia reinwardtii (de Vriese) Benth.
Verticordia chrysantha Endl.
* „ chrysostachys Meisn.
* „ densiflora Lindl.
„ grandiflora Endl.
* „ grandis Drumm.
* „ sp. aff. nitens (Lindl.) Schau. RJH 771142
* „ ovalifolia Meisn.
* „ pennigera Endl.
„ stelluligera Meisn.
* „ sp. 1. RJH 771443
*Villarsia capitata Nees
*Wahlenbergia capensis (L.) A. DC.
*Waitzia paniculata F.Muell. ex. Benth.
*Wurmbea dioica (R.Br.) F. Muell.
Xanthorrhoea reflexa Herbert
*Xanthosia huegelii (Benth.) Steud.
Xylomelum angustifolium Kipp. & Meisn.
indet. 1.
indet. 2.
indet. 3.

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