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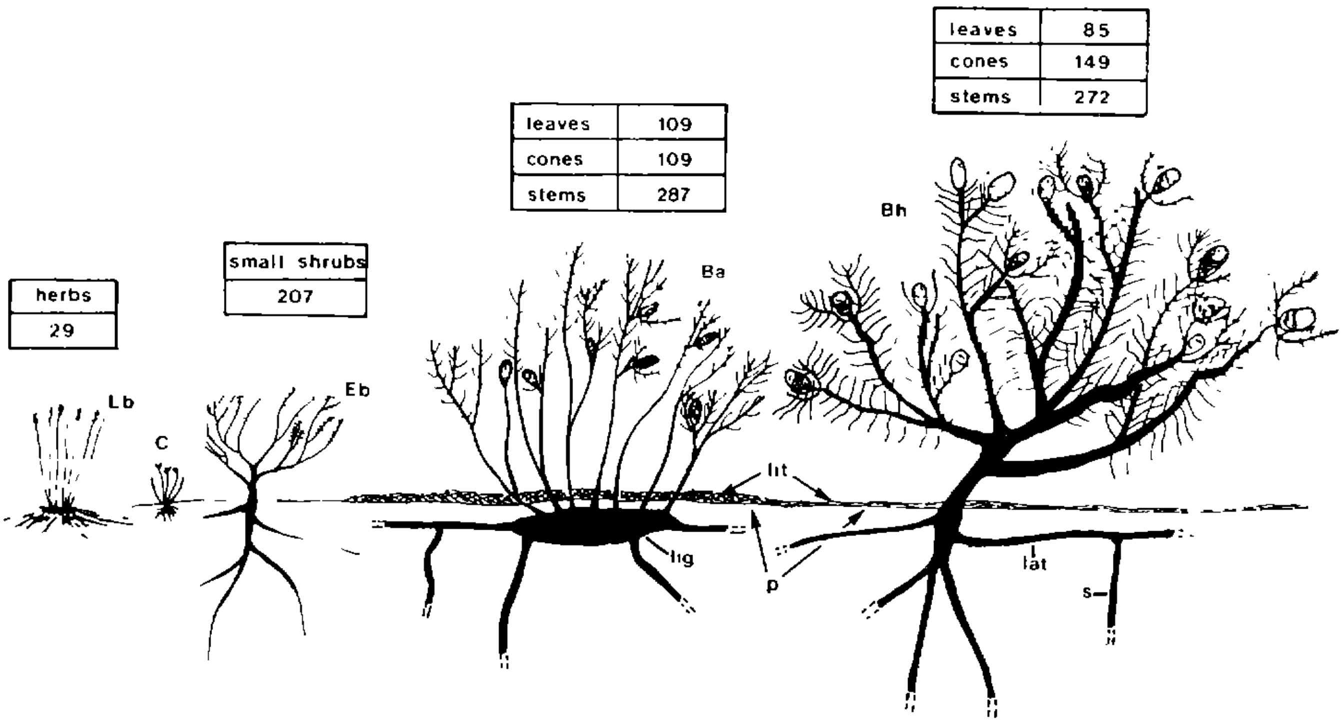

SCHEMATIC SECTION THROUGH A 12 yr OLD
Banksia HEATH COMMUNITY SHOWING MASS ALLOCATION
($g\ m^{-2}$) OF AERIAL AND BELOW-GROUND PARTS

Edited by
Byron Lamont and Barrie Low

1985

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Introduction

At the last informal meeting of the sponsors and researchers associated with the WAMPRI-ARGS project on nutrient cycling in heathland and rehabilitated mine sites at Eneabba, it was decided to widen the scope of the next meeting. Contributions were sought which would set the current research programme in a wider ecological context. For the first time since the biomass-nutrient research began in February, 1984, we were also able to consider some of the results of small projects within the overall programme. Most time was allotted to Barrie Low who has been an honorary research fellow working on the programme in 1984 and is soon to return to the Cape, South Africa. With his wide experience in South Africa in the area of nutrient cycling, we are now in the position of being able to compare the nutrient and biomass relations of two ecosystems which are both ecologically-equivalent and in which the same methods of analyses have been used.

Invitations were extended to research and administrative personnel who are currently active in the Eneabba region. In all, 17 people attended, including Suzanne Williams currently spending three weeks on the programme on an ANZAAS student scholarship. Apologies were received from David Bell, Robin Lea, John Marshall, John Riches and Richard Taylor. The meeting was considered a valuable exercise by the participants and tentative plans were made to hold another in mid-1985.

Byron Lamont
11th December, 1984

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The Flora and Vegetation of the Crown Land South of Eneabba

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Abstract

In this paper we attempt to summarise available information on the pre-mining situation to provide a background for discussions on the effect of mining. The vegetation is described in relation to important physiographic features of the area. The similarities between vegetation and floristic patterns emphasize the critical role of substrata in influencing species distributions. However, there are also important differences. Problems with floritistic studies require further attention. In particular it is recommended that a few key species be selected for examination of complete soil profiles. Over 500 vascular plant species have so far been collected from the area. However many of these have not been recorded from rehabilitation blocks. A classification of species in terms of regeneration characteristics is provided to permit further analysis of this problem. A number of other issues requiring study are also identified.

Introduction

The area around Eneabba is renowned for its contribution to the botanical importance of south-western Australia. The kwongan (shrub-dominated) vegetation is floristically rich; included are many rare and geographically restricted plant species. The two heavy mineral sands mining operations are presently taking place on the South Eneabba Nature Reserve (C27886 & C31030) and adjacent vacant Crown land. Reconciliation of these conflicting interests led to the development of rehabilitation programmes, the objective of which was the return of native vegetation. This objective has proved difficult to achieve, particularly since little was known of the ecology of the area, let alone horticultural aspects of the species, when operations began nearly 10 years ago. Early studies were focussed on the static ecological patterns of species distributions but now more emphasis is being placed on the dynamic aspects of the communities - the ecosystem processes. In this paper, we attempt briefly to summarize available information on the ecological relationships recorded prior to mining in order to provide the background for discussions on the rehabilitation studies.

Physiography of the area

The heavy mineral sands deposits south of Eneabba occur in unconsolidated Quaternary sediments. These have been mainly derived from the reworking of the underlying Mesozoic Yarragadee and Cockleshell Gully Formations. Alluvium from more active rivers than at present and colluvium from the abatement of the marine scarp to the east and south-east have been added to these deposits. Wind action has developed dunes over part of the area, some over 10 m higher than the relatively flat interdunal areas.

The deposits are principally sandy but are often associated with clay and gravel, often in layers. The depth of these deposits over the Mesozoic sediments varies considerably as the schematic west-east cross-section (Fig. 1) illustrates. This section can be divided into four units:

1. Lateritic uplands and shallow colluvial slopes in the east.

2. Dune and interdunal areas (including the area of the principal mineral sands deposits), with some winter-wet depressions which are relicts of more active drainage systems.

3. A shallow sand plain in the vicinity of the Brand Highway which appears to be underlain by a ferrugineous, indurated layer formed by groundwater enrichment.

4. The Rocky Spring complex which is a combination of exposures of the ferrugineous layer and Mesozoic sediments, with varying amounts of a very shallow sand and gravel mantle.

In addition, there are variations in the north-south direction. The major differences appear to be in the height of the dunes which are greatest in the vicinity of the northern boundary of Reserve 31030 and are lower further to the north. Comensurate with this, it appears that the interdunal areas to the north have a deeper, sandy A horizon than those in the south.

Vegetation

There appears to be a relationship between geomorphology and vegetation. While the precise nature of this relationship has yet to be fully elucidated, the principal influence appears to be the depth of sand over the clay/gravel layer illustrated in Fig. 1. This layer must <u>inter alia</u> affect water relations and root penetration.

The lateritic upland with a dense gravel layer at the surface has an Open heath/Low open heath often dominated by **Dryandra** sp. aff. **falcata.** In places where the lateritic duricrust has fractured, **Eucalyptus tetragona** can be an important tall shrub/mallee. Where colluvial sands cover the slopes of these uplands, a Low open heath, often with **Banksia grossa** and B. **attenuata**, occurs. In (presumably) deeper sands **Jacksonia** sp. aff. **eremodendron** can form High shrubland or Open scrub > 2 m tall.

The interdunal areas usually have a shallow grey sand layer (10-20 cm) over deep layers of gravel and clay. These areas support a Low open heath usually lacking species dominance. Where the sand appears to be generally deeper (as in the nothern part of the area), **Beaufortia elegans** and **Hakea brachyptera** may be dominant. The vegetation on the dunes appears to respond to the depth of sand. On the crest of many of the dunes **Banksia hookerana - Xylomelum angustifolia** Shrublands are found. Between the latter and the Low open heath (and on the top of some low dunes) the vegetation appears to be dominated by other **Banksia** species including B. **attenuata**, B. **candolleana** and B. **grossa**. The vegetation of winter-wet depressions is very variable and it appears that the effectiveness of the clay alluvium to create

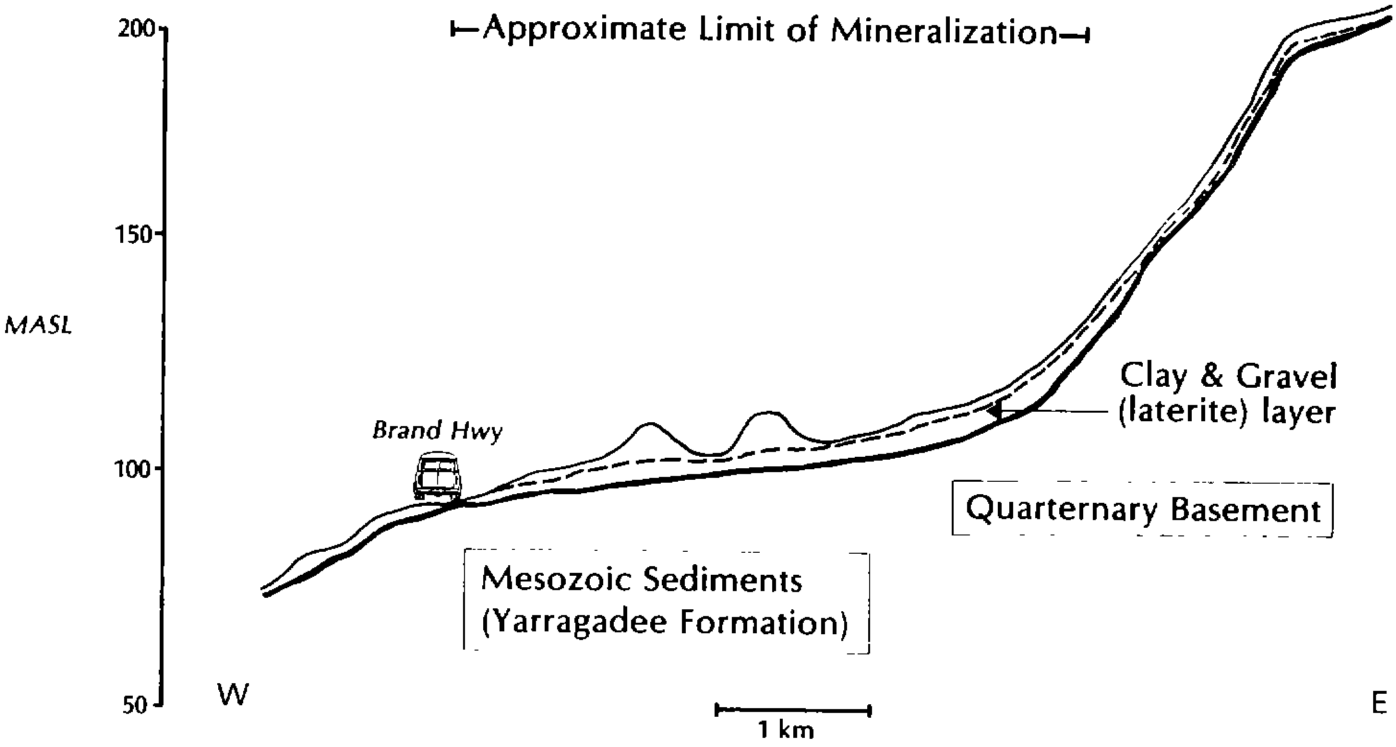

Fig.1. Schematic east-west section through landforms at Eneabba. See text for more details. MASL = metres above sea level.

waterlogged conditions during the winter is important in differentiating between plant communities. The wettest area appears to be a clay pan which has a Low open woodland of **Eucalyptus rudis** over a herbland with aquatics growing in the surface water. **Melaleuca ?hamulosa** Open scrub fringe this area. Other wet depressions may be dominated by species such as **Calytrix flavescens**, **Calothamnus quadrifidus** and **Verticordia densiflora**. The vegetation fringing these wet depressions are part of this system, being dependent on the increased moisture status.

The sandplain in the vicinity of the Brand Highway is dominated by **Eucalyptus todtiana** Low open woodlands. Here **Adenanthos cygnorum** (> 1 m tall) is usually the most important shrub species but is often accompanied by many Banksias which may be very important on the deeper sand. It appears, however, that the species composition of these **Banksia** dominated areas is different from that of the dunal area. Where the ferrugineous layer is probably less than 1 m below the surface, **Eucalyptus todtiana** is less important and **Adenanthos cygnorum**, often with **Banksia leptophylla**, is the major component of the vegetation. **Nuytsia floribunda** is usually conspicuous here, more so than in any other part of the Eneabba area. Where the ferrugineous layer is close to the surface, but still covered by yellow sand, **Dryandra sessilis** can be an important shrub species. Winter wetlands are present here but are very poorly understood. One example is an area which is dominated by **Ecdeiocolea monostachya** and forms a mixed Sedgeland/Low open heath.

The Rocky Spring complex is the least understood vegetation in the Eneabba area. It includes several woodland types dominated by **Eucalyptus accedens**, **E. wandoo**, **E. loxophleba**, **E. todtiana** and **Banksia prionotes**. Also included are many different tall shrub and mallee communities dominated by species such as **Allocasuarina campestris**, **Dryandra sp. aff. patens**, **Melaleuca sp. aff. acerosa**, **Labichea lanceolata**, **Melaleuca hamulosa**, **Eucalyptus drummondii** and **E. eudesmioides**. Many of these indicate a response to the exposed clayey Mesozoic sediments and the amounts of sand and gravel which overlay them in most places.

Preliminary photo-interpretation of the whole area has been undertaken with a view to providing a vegetation map. So far over twelve distinct vegetation types have been recognized; undoubtedly more will be identified as development of the map proceeds. These photo-units follow the scheme already presented by Hopkins and Hnatiuk (1981) where six units were mapped. The additional units which have been mentioned above, are to be found on the lateritic plateau to the east of that study area and further to the west, including the Rocky Spring complex.

Floristics

Just as it is important to appreciate the relevance of studies of particular plant communities to those of the mining areas, it is equally important to have a context for the studies of individual species. Aspects of this have been dealt with in the three main studies of the south Eneabba area by Lamont (1976), Hopkins and Hnatiuk (1981) (and Hnatiuk and Hopkins 1981) and Elkington and Griffin (1984). The reader is referred to these papers for detailed information on field and numerical analysis techniques and major results. Here we merely highlight some important features of the results with particular reference to the 1981 publications.

A variety of techniques have been used to elucidate the ecological basis of plant species distributions. Invariably studies have shown that soils are important. However the relationships are not clear-cut as many of the species seem to occur on a wide range of soil types. At Eneabba only some 15% of the species recorded were noted by Hnatiuk and Hopkins (1981) as being apparently restricted to one or two soil/habitat types and of these, many occurred occasionally in other habitats. In summary, there is low fidelity and constancy to soil type. Part of this reflects the generally complex nature of kwongan (e.g. the heterotoneity, see Hopkins and Griffin 1984). A major problem in improving our knowledge of the soil-plant relationships lies in our ability to adequately assess the soil profiles. At present, the soils classifications used are to a large extent inappropriate, dealing with soil groups on a macro-scale. In addition it is often impractical to sample the whole soil profile that any individual plant might be exploiting. Comprehensive study of soil profiles under a few key communities is regarded as a priority.

A second major problem identified through the floristic studies at Eneabba is the disparity between the distribution of the physiognomic units of vegetation and the floristic units. There is some similarity; for example the Floristic Group 2 sites of Hnatiuk and Hopkins (1981) were predominantly the dune and swale units on the vegetation map. Yet the disparities were important too and emphasize the need to study species separately from vegetation.

The floristics of the Eneabba area may be regarded as rich, with over 500 species being recorded so far, 429 coming from the 20 km^2 area of the Hopkins and Hnatiuk (1981) study. Elements of the richness include local richness (alpha diversity), homotoneity or within stand variability (beta diversity) and habitat diversity (gamma diversity). These are discussed more fully in Lamont et al. (1984) and Hopkins and Griffin (1984). In particular it is of note that Eneabba is not the richest site in Western Australia but it still ranks highly on an Australian and even a World Scale. Other rich sites have rain forest vegetation, or in the case of the South African fynbos, the direct analogue to the kwongan, the areas have considerably more topographic, and thus habitat, diversity.

The floristics of the rehabilitation area

Although new rehabilitation techniques are still being developed and new species continually appear in the post-mine flora, it is clear that there are many species that are absent and others which occur very infrequently. The presence of these sparse species can be evidenced in the shape of the species-area curves from the rehabilitation blocks compared to one from an area of native vegetation (Fig. 2) - species-area relationships converge as the sample area increases but for samples of less than 100 m^2 the rehabilitation blocks are species poor.

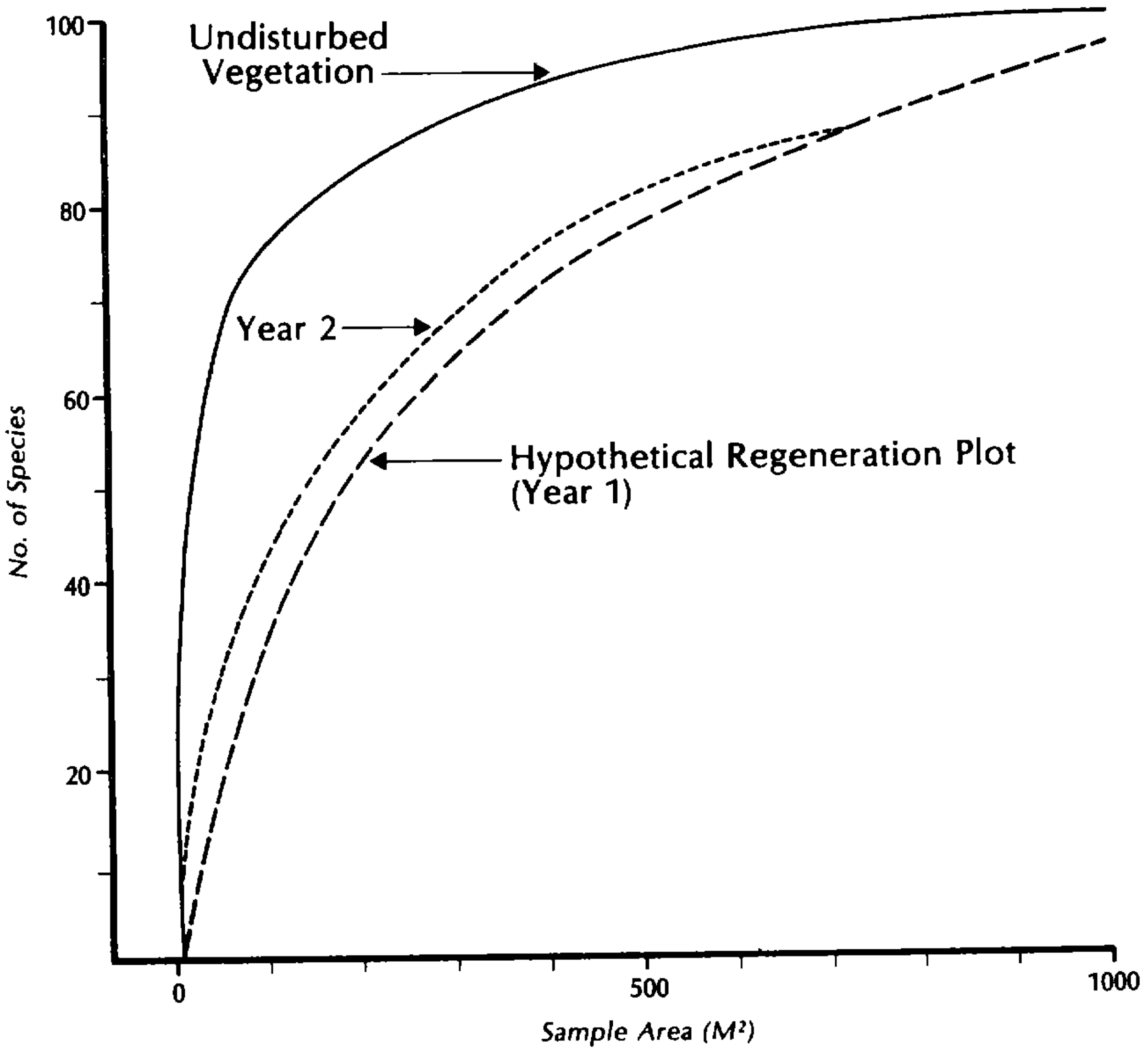

Fig.2. Species-area curves for undisturbed heath at Eneabba and rehabilitated plots after 1 and 2 years.

Two reasons can be advanced for the absence of certain species from rehabilitation areas. Firstly some of these species are recorded from native habitats outside the mining areas. For example, **Jacksonia** sp. aff. **eremodendron** of the shrublands on grey sands over laterite would not be expected to occur on the escarpment or coastal plain and thus should not be expected in the post-mine flora. Secondly, there are species for which present rehabilitation is probably not appropriate. In order to further understand these rehabilitation failures, we have developed a classification of regeneration characteristics of plant species. Five categories are presented in Table 1 together with some examples of species that are absent from, or sparse in, rehabilitation blocks. The classification should have immediate application in rehabilitation practices. For example, **Actinostrobus acuminatus** has seeds in woody fruits stored close to the ground, and these are unlikely to be collected by brush harvesting machinery; in any case they are not particularly abundant. A special programme of seed collection will have to be initiated to introduce plants into the rehabilitation area. In contrast, appearance of species such as **Baeckea** and **Scholtzia** will probably depend on correct handling of topsoil.

One particular suite of species missing from the rehabilitation blocks is that associated with the wetlands of the mining areas. Many of these herbs appear to regenerate predominantly from underground parts. The appropriate habitats are being created during rehabilitation; therefore it will be necessary to introduce wetland species into these habitats through vegetative means such as direct transplanting.

Future research

This meeting provides an appropriate forum for presenting some suggestions for future work. The following are based on our present perceptions of past work, and present and proposed studies, and should be regarded as personal views.

In the two major studies that we have been involved with over the past years, areas of concern have been identified and recommendations for future work have been made.

1. The importance of the wetland flora and the need for its adequate conservation was elaborated by Hopkins and Hnatiuk (1981).

2. The harvesting of brush material remains an important facet of rehabilitation programmes. The supply of suitable vegetation is limited. Two approaches to the problem of supply include repeated harvesting of the limited area and harvesting elsewhere. Either approach warrants further attention; both will require some further study along the lines already recommended by Griffin and Hopkins (1981).

3. The detailed relationships between selected groups of plant species and whole soil profiles, as already discussed, should be further investigated. Species that are known to have some edaphic control should be chosen for initial study.

Table 1. Methods of reproduction

	Examples of Eneabba species at present absent from rehabilitation sites
WIND BORNE SEED e.g. Podotheca	Waitzia
BRADYSPORES (CANOPY STORAGE) e.g. Banksia Dryandra Hakea Melaleuca Eremaea	Actinostrobus acuminatus Petrophile macrostachya Some Hakea spp. Calothamnus sanguineus Xanthorrhoea reflexa
SHORT LIVED SEED IN SOIL e.g. Liliaceae Darwinia Verticordia Dampiera Andersonia Lysinema	Baeckea grandiflora Scholtzia laxiflora Verticordia spp. Pityrodia spp. Lachnostachys eriobotrya Eriostemon spicatus Tetratheca confertifolia
LONG LIVED SEED IN SOIL e.g. Acacia Daviesia Astroloma Some Goodeniaceae	Jacksonia restioides Leucopogon obtectus Adenanthos cygnorum
OTHER PERENNATING ORGANS e.g. Restionaceae Drosera Orchidaceae	Hypocalymma xanthopetalum Drosera erythrorrhiza Dasypogon bromeliifolius

4. The microclimate of rehabilitation sites is likely to be very different from that of native vegetation, even shortly after fire in the latter. This difference may have important consequences in terms of selecting surface treatments for optimal germination and establishment of plants as well as for example the soil fauna. R.J. Hnatiuk has some records for a native vegetation site at Eneabba.

5. The work so far carried out on nutrient pools and cycling provides a good basis for further studies. In particular, the effects of fire on nutrient pools and its role in nutrient cycling could now be studied along with such aspects as dynamics of plant species in relation to fire.

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Nutrient allocation in native heath and rehabilitated communities

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Introduction

The Eneabba region in southwestern Australia with its extensive heathland communities provides an excellent backdrop for the study of heath nutrient allocation and nutrient cycling. Certainly, on deep podsolized sands where leaching is marked, nutrient quantities are extremely low and moisture stress is particularly pronounced in the summer months. These environmental characteristics fit Specht's (1979) generalized definition for winter rainfall heaths.

Nutrient studies in coastal lowland heaths have recently received attention by Low (1983) in the Western Cape, where coastal fynbos is found on deep podsolized sands and under a similar annual rainfall to Eneabba (530 mm). This paper seeks primarily to provide a preliminary comparison between nitrogen and phosphorus pools in these two heath systems. In particular, it endeavours to ascertain if there are any intra-heathland dichotomies using nutrients as a basis for comparison. Further it seeks to examine N and P allocation in Eneabba heath and rehabilitated communities.

Methods

Aerial and below-ground plant material, and soils to a depth of 250 cm, were sampled in a 12 year old **Banksia** heath community 8 km south of Eneabba. Dry mass of the community was determined and sub-samples of plant and soil material were analysed for N and P using standard methods (Low 1983).

Results and Discussion

Dry mass and N and P allocation for the Western Cape (Kraaifontein) and Eneabba deep sands is given in Table 1. Also included are data from a sand heath at Keith, South Australia (Specht *et al*. 1958). All possessed similar aerial masses but varied in the amounts of N and P. Of particular note are the extremely low levels of P in the Australian heaths. This element is regarded as the major limiting factor to development of sclerophyll vegetation in Australia (Beadle 1966).

Due to the high proportion of lignotubers, below-ground masses were far greater in the Australian sites and this was also reflected in the quantities of nitrogen in each. However, P once again exhibited far lower amounts, by a factor of 2 to 3.

The Cape soil possessed greater amounts of total N and P than both its Australian counterparts. Of note is that, although soil nitrogen was more than 3 times greater in the Cape, nearly all Australian aerial and root nitrogen totals are higher than in the Cape community. Only the Eneabba aerial N pool is lower, by a factor of less than 2.

Table 1. Mass (g m^{-2}), and N and P pools (g m^{-2}) in 11-12 yr old heath vegetation at Kraaifontein, Cape, South Africa, Eneabba, W.A. and Keith, South Australia. Data presented for 0-180 cm depths.

	Kraaifontein			Eneabba			Keith		
	Mass	N	P	Mass	N	P	Mass	N	P
Aerial - live	1458	7,67	0,72	1033	3,72	0,18	1235	7,90	0,19
- dead	273	1,26	0,08	536	1,82	0,07	310	2,72	0,05
Total	1731	8,93	0,80	1569	5,54	0,25	1545	10,62	0,24
Roots - live	747	2,86	0,77	2388[a]	7,03	0,22	NA	NA	NA
- fibrous	269	2,35	0,12	695	2,65	0,07	NA	NA	NA
- dead	381	2,90	0,16	1850	8,11	0,08	NA	NA	NA
Total	1397	8,11	1,05	4933	17,79	0,37	7200[ba]	31,29[b]	0,49[b]
Soils - 0-15 cm	2115[c]	96,82	2,46	1879	21,09	1,19	1551	46,12	1,26
- 0-180 cm	11078	584,10	24,87	11733	97,75	13,40	6744[b]	173,34[b]	12,10[b]
Total	14206[d]	601,10	26,70	18235	121,10	14,00	15489	215,30	12,80

[a] Dominated by large rootstocks.

[b] Calculated from 0-76 cm data assuming similar decreases to the Eneabba profile.

[c] Organic matter.

[d] Includes soil organic matter.

This implies that Australian heaths are exceedingly adept at extracting N and P from the soil. Many of these heath plants are known to be actively mycorrhizal (Lamont 1982) and the Proteaceae were observed to produce more extensive proteoid root mats than those observed in the Cape (Low unpub. data).

By way of comparison the aerial N and P data are plotted in Fig. 1, together with those from other Eneabba heaths taken from Hopkins and Hnatiuk (1981). N/P values for the Australian heaths were high whereas coastal fynbos accumulated more P at the expense of N. Acquisition of large amounts of N in the **Banksia** community at such low concentrations of total soil N (101 ppm) is unexpected. Even mature **Banksia** leaves have N concentrations (approx. 5500-6500 ppm) similar to those in Cape fynbos (Low unpub. data), despite the latter possessing far greater quantities of soil N. This once again illustrates the remarkable efficiency of these plants in absorbing nutrients from a very infertile substrate. The presence of greater numbers of legumes in the Eneabba region compared with Cape coastal heath (Lamont *et al.* 1984, Low 1983) may form part of the answer if an extremely tight nitrogen cycle operates between this group, the soil and non-legumes such as the banksias. Fabaceae in this study always possessed high quantities of N and this is certainly true for legumes found in the Swan coastal plain (B. Dell unpub. data).

The **Banksia** heath soils may also be limiting nutrient uptake due to extremely high C/N (Fig. 2) and C/P ratios. High ratios induce microbial immobilisation of these nutrients particularly if suitable carbon energy sources are small. It is expected that much of the carbon is bound up in relatively inert compounds such as lignin, which may predominate due to the highly sclerophyllous nature of the vegetation. C/N ratios are in the order of 35 to 50 for Eneabba heath and 10 to 30 for coastal fynbos. A regression of carbon versus nitrogen for the Eneabba soils produced a straight line ($y = 226.81x - 6.76$, $p < 0.001$) which is typical of nutrient poor heath soils where total nutrients correlate directly with soil organic matter.

Faced with low soil nutrient levels and high carbon: element ratios at the surface, it is possible that banksias and other species exploit the B horizon for additional nutrients. Root penetration at depth is certainly pronounced. Growth by proteaceous seedlings on B horizon soil is vigorous and much of the root mass is composed of proteoid roots. Sesquioxide coatings on the B horizon soil particles probably act as exchange sites for certain nutrient ions, several of which (e.g. P and K) are present in higher amounts than the in topsoil (Low unpub. data).

Although the nutrient cycling part of the study will only be completed during 1985, preliminary data indicate an extremely low **Banksia** litterfall during the year coupled with very slow litter decomposition rates. This would effectively reduce nutrient loss from the plant. In addition, transfer of N and P from senescing leaves is in the order of 40 to 60% revealing that leaves dropped in the litter possess relatively low quantities of nutrients.

Considering now the rehabilitation situation following sandmining, a comparison of N and P pools is presented in Fig. 3.

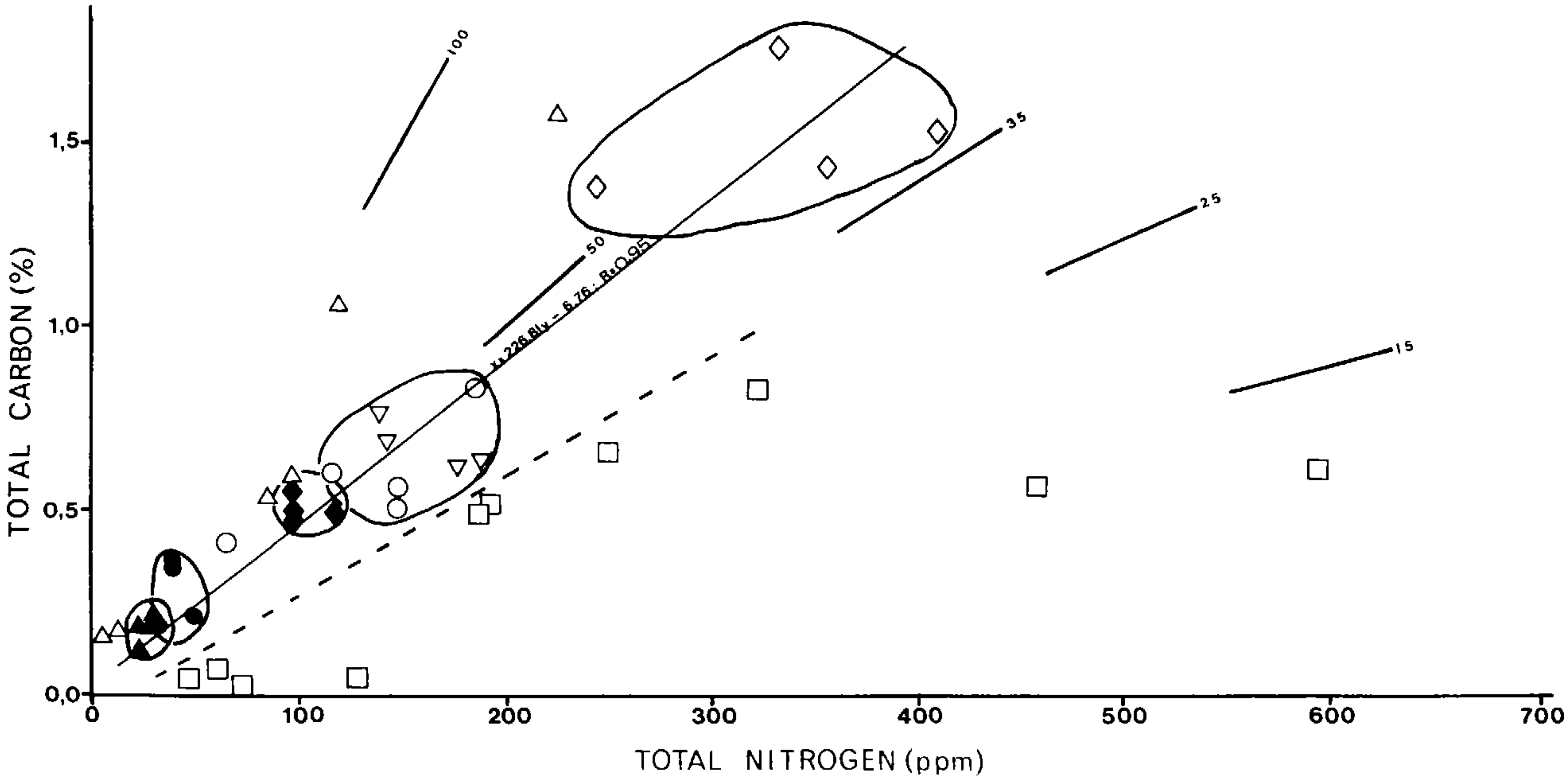

Fig. 1 Carbon : nitrogen relationships for Eneabba (◇ – laterite , ▽ – sand over laterite , ○ – sand over clay and ◆ , ▲ and ● – deep sand (A1 , A2 and B2 respectively) , rehab(△) and Cape coastal fynbos (□) soils . C/N ratios increase from right (15) to left (100).

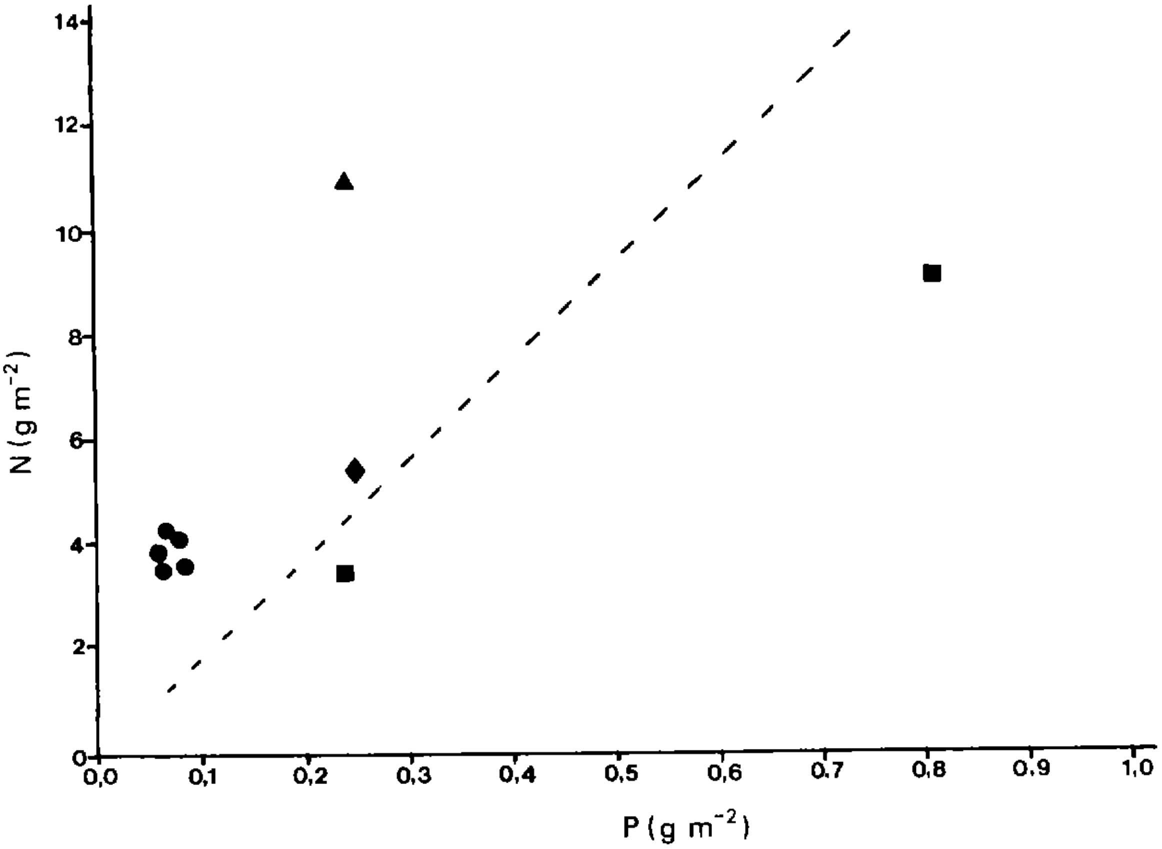

Fig. 2 Aerial nitrogen : phosphorus pools (g m^{-2}) for heaths at the study site (♦), other Eneabba communities (Hopkins and Hnatiuk 1981) (●) , Keith , South Australia (Specht et al . 1958) (▲) and Cape coastal fynbos (■) (Low 1983)

This reflects differences between the Banksia heath community and reconstituted Allied and AMC rehabilitation soil profiles prior to treatment and plant establishment.

Quantities of nitrogen in the sampled rehabilitated sites were lower by 573 kg/ha (Allied) and 679 kg/ha (AMC). Phosphorus levels on the other hand were greater by 232 and 97 kg/ha respectively. Deficits for both N and P (82.1 and 13.0 kg/ha) were reported for an Allied Eneabba profile when compared with kwongan heath (Anon. undated). Data from the latter study should be compared with caution as the methodology for N and P determination was different from that used in this paper.

Higher P quantities in the rehabilitated subsoils (Fig. 3) probably correlate with higher clay levels there, whereas low N can be related to low OM concentrations and higher C/N ratios (Fig. 1) than in the native heath soils. P availability in high clay soils also poses problems, particularly where the clay mineral quality is poor and P fixation may consequently be high.

Rehabilitation procedures naturally include fertilisation practices which are designed to make up elemental deficits. From the preliminary data reported here it is apparent that, depending on the element concerned, these deficits may not always be present. In addition, more replication of samples is needed. Considerable variation within and between different rehabilitated soil profiles can be expected.

Further, alternatives to top-dressing with chemical fertilizers should be examined. This can be achieved through increasing the amount of topsoil returned to the site. Topsoils with higher organic matter contents display higher levels of N (Fig. 1) and P. In addition, increasing the amount as well as quality of mulch is seen as an important part of the rehabilitation programme. Mulch is regarded as being effective in its slow release of nitrogen (Anon. undated). However, much of the N is tied up in woody plant material as this forms the bulk of the mulch collected. The woody parts decompose slowly due to a high proportion of fibre and high C/N ratios and mulch-induced N deficiency is thought to occur (R. Black pers. comm.). Focus should thus be placed on enhancing the quality of mulch, for example through harvesting the upper (foliage canopy) parts of the native plant stratum at the expense of the woody bases and major stems.

Coupled with the above, more intensive investigations should be levelled at native species which cope well with infertile soils and moisture-stressed conditions. Beadle (1968) has shown that individuals of a species display high sclerophylly indices at low nutrient availabilities. It is thus to be expected that the highly sclerophyllous species found in the sand over clay, and the laterite communities, may have a greater survival success than those from deep sands, particularly in the conditions immediately following rehabilitation when the environment is at its most hostile. These species are invariably spinescent and thus have an added advantage of deterring herbivore activity (and therefore nutrient loss).

As the rehabilitation environment is not the same as that which

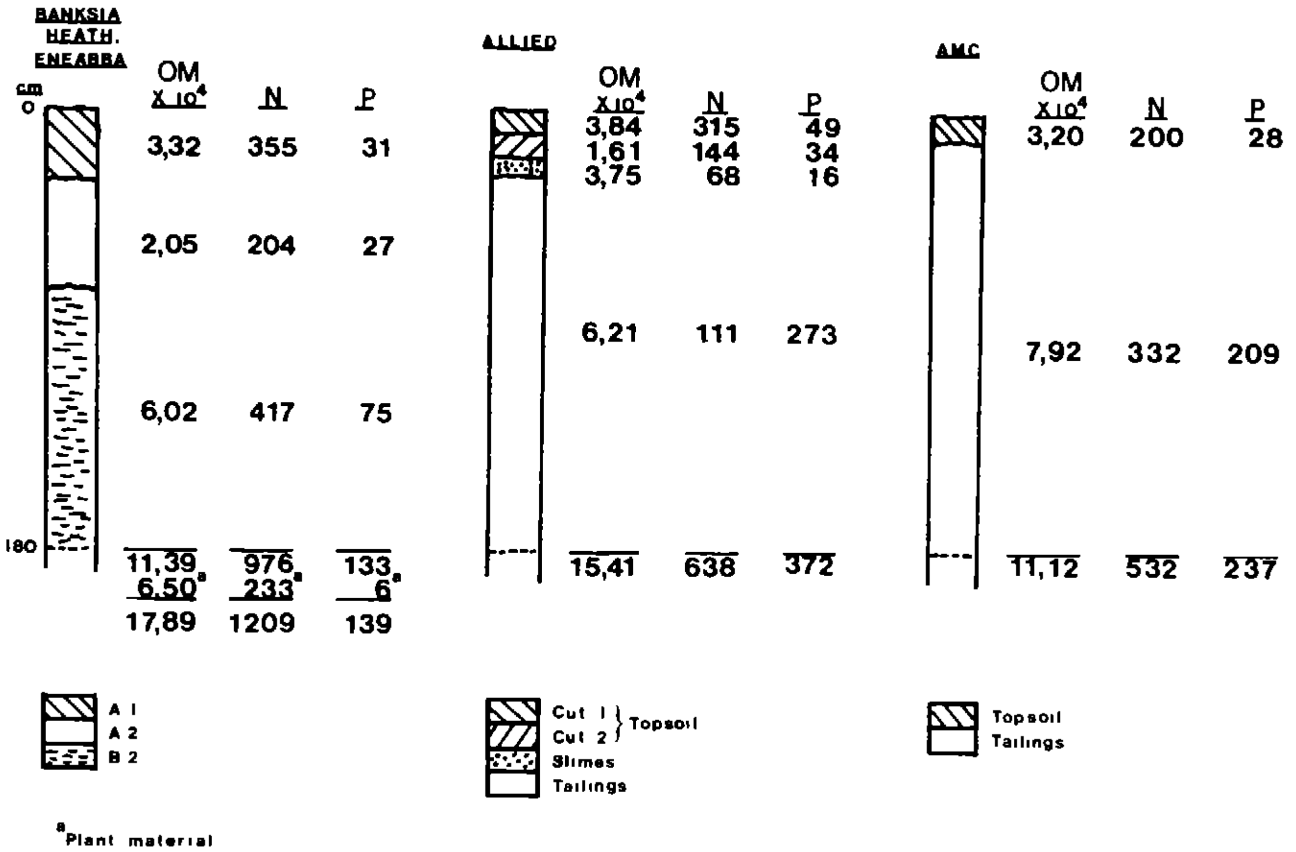

Fig. 3 Nitrogen and phosphorus pools (kg ha^{-1}) for the Eneabba site , and reconstituted profiles from Allied Eneabba and AMC .The latter two represent the pre-revegetation , unfertilized state.

exists prior to mining, there is no guarantee that it will suit species which grew there previously. Therefore emphasis should be placed on introducing species from the district which have high environmental tolerance levels rather than those which produce high numbers of seed (ease of collection) and high germination rates but which are otherwise less suitable.

To sum up, this study presents the first nutrient allocation data for a **Banksia** heath in southwestern Australia, hence providing a basis for direct comparisons with the rehabilitation plots at Eneabba. However, a more detailed analysis is required of low heath communities where mining is occurring and aerial N and P levels are even lower, in the order of 35-42 (N) and 6-9 (P) kg ha-1 (Hopkins and Hnatiuk 1981).

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The root systems, biomass and nitrogen and phosphorus contents of field and potted plants of *Banksia hookerana*, *B. menziesii* and *B. attenuata* from Eneabba

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Mature banksias at the deep sand study site

Three plants each of the three Banksia species dominating the vegetation on the dune crests were analysed. **B. hookerana** is a non-sprouter and 11 year-old shrubs, representing widespread establishment after the last fire, were selected. The two resprouters, **B. menziesii** and **B. attenuata**, bore 11-12 years regrowth, but were of unknown age. During April 23-30, 1984, the root systems of the selected plants were followed to their limits in the horizontal plane and to a depth of 1 (most sinkers) to 3 (tap roots) m. After mapping their positions the roots were harvested and separated into lateral, sinker and tap roots. The plants were further divided into lignotubers (absent from **B. hookerana**), leaves and stems (by age class) and cones. The dry biomass, nitrogen and phosphorus concentrations and contents of each fraction were determined as described elsewhere.

The plan views of the root systems provided (Figs. 1-3) show **B. hookerana** has a different type of root system to the other two species. Two of the three plants of both **B. menziesii** and **B. attenuata** examined lacked tap roots. Their place was taken by 'sinker' roots - the **B. menziesii** plant illustrated has 34 sinkers, while the **B. attenuata** has 25. Although the canopy radii were under 1 m, the laterals of **B. hookerana** reached up to 9 m long. These terminated in masses of proteoid roots, which

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Table 1. Biomass (g) of different fractions of three major Banksia spp. at Eneabba. Means of three plants.

Fraction	**B. hookerana**	**B. menziesii**	**B. attenuata**
Leaves - live	1161	994	869
- dead (on plant)	84	0	0
Litter	(804)	(2574)	(1396)
Stems	2257	2747	1973
Cones	1586	698	902
Roots - laterals	566	3794	3661
- sinkers	641	797	811
- tap	408	(303)*	(761)*
- lignotuber	0	1989	3225
Total (omitting litter)	6703	11221	11949

* mass of tap root for 1 plant only, as absent from other two

Table 2. Nitrogen (mg/g) and phosphorus (ug/g) content of young and old leaves of three Banksia spp.

Year	**B. hookerana**		**B. menziesii**		**B. attenuata**	
	N	P	N	P	N	P
1	7.3	376	5.5	398	5.1	463
4	4.8	100	4.2	204	4.6	276
Litter	4.9	89	3.6	70	3.5	44

suggests the source of nutrients from the A horizon may be a considerable distance from the plant and that proteoid roots exploiting the litter beneath its canopy probably belong to those of other plants due to the intermingling of root systems.

The mean root/shoot ratio for **B. hookerana** was 0.32, **B. menziesii** was 1.51 and **B. attenuata** was 2.12. These differences are due to a greater leaf load in **B. hookerana**, a smaller stem load in **B. attenuata**, a much greater lateral root mass and presence of a lignotuber in the two resprouters (Table 1). There was much more litter under **B. menziesii** than under the other two species, especially in relation to their leaf load: this suggests that decomposition rates are especially slow in this species.

B. hookerana had the greatest concentration of nitrogen, but the lowest of phosphorus in its leaves (Table 2). **B. hookerana** was the most efficient at retranslocating P and N from its leaves before dropping them, although increase in leaf mass over time confounds the results. The youngest stems usually had the highest concentration of N and P. The cones of **B. attenuata** had much higher levels of P in them than the other two species whose concentrations were in the same order as the stems. **B. menziesii** had higher concentrations of N in its root system than the other two species, while only the sinkers and tap root of **B. hookerana** had lower P levels than in the other two species. The proteoid

Table 3. Nitrogen and phosphorus content of whole plants and litter beneath the three major Banksia spp. at Eneabba.

	B. hookerana	**B. menziesii**	**B. attenuata**
Total N (g)	19.03	35.31	20.61
Litter (g)	3.98	9.31	4.83
Leaves (%)	40.4	15.7	21.1
Stems (%)	27.5	28.2	15.3
Cones (%)	18.9	5.1	10.5
Underground (%)	11.3	51.0	53.1
Total P (mg)	577	686	1015
Litter (mg)	72	180	61
Leaves (%)	51.7	45.0	31.9
Stems (%)	22.5	9.9	5.5
Cones (%)	15.9	3.9	20.0
Underground (%)	9.9	41.2	42.6

roots were dead at this stage and their N and P concentrations were similar to those for the laterals. The surface soil possessed a total of 194 ug N/g soil and 5 ug P/g soil, an order of magnitude less than that in the roots.

B. **menziesii** had almost twice the total N content per plant as the other two, while B. **attenuata** had almost twice the total P content as the other two (Table 3). The litter beneath the plants represented a large proportion of external cycling of N and P, except for P under B. **hookerana** (12% of plant P) and B. **attenuata** (6% of plant P). On a percentage basis, there was much more N the leaves of B. **hookerana**, but much less in the underground parts, than in the two resprouters. Relative content of P in the leaves was higher than for N in the three species, but with the same pattern as for N described above. There was relatively less P in the underground parts and stems of the two resprouters than for N. B. **hookerana** and B. **attenuata** are serotinous (retaining seed on the plant indefinitely) and they had proportionately more of their total N and P contents present in the cones. The annual loss of N and P to dispersed seed has not yet been determined.

Pot trials with banksias in sand and rehabilitation soils

The three **Banksia** spp. were grown in grey sand from the dune study site above and in a red loam ('rich' soil) bearing York Gum (**Eucalyptus loxophleba**) vegetation from Watheroo National Park. Tailings from mine pits at Allied Eneabba (plus the company fertilizer applied at its standard rate) and Associated Minerals Consolidated (unfertilized) were also used. There were two seedlings per 9 l of soil per pot. Apart from the above treatments which received deionized water only, there were 16 combinations of nitrogen and phosphorus in a basal nutrient solution containing all other minerals. Only 4 treatments are described here: basal solution only (0N0P), basal solution plus 2 ppm P (as K_2HPO_4) only (0N2P), 100 ppm N (as NH_4NO_3) only (100N,0P) and both P and N (100N,2P). The pots were kept moist with deionized water and received 250-300 ml of nutrient solution on alternate weeks. They were grown in an unshaded glasshouse for 25 weeks during April-September, 1984.

All plants survived in all soils and treatments, although those in the AMC soil showed chlorosis and leaf curl. In comparison with the control treatment (deionized water only) shoots of B. **hookerana** grew larger in the 'rich' and AE soils and smaller in the AMC soil (Table 4). B. **attenuata** was smaller in the 'rich' soil but much larger in the AE soil. Fertilizing with N and/or P resulted in greater growth of B. **menziesii** and B. **attenuata**, while B. **hookerana** only responded positively to the basal solution. Root/shoot ratios on a dry mass basis were maintained at 0.5-0.9 in the control and nutrient-supplement soils (Table 4). They were 0.1-0.6 in the 'rich' and two rehabilitation soils. Values were particularly low in the AE soil and for B. **hookerana** in the 'rich' soil. Total root lengths were low in the 'rich' and AMC/AE soils compared with the controls (Table 4). Without summer irrigation, it appears that these seedlings would be much less drought tolerant than in their natural habitat even when supplemented with additional nutrients (equivalent to the effects of a bushfire?).

Table 4. Shoot mass, root/shoot mass ratio and root length of 6 month old seedlings of three **Banksia** species grown in various soil treatments.

Mean Dry Mass of Shoots (g):

	Soil			
	Control	'Rich'	AMC	AE
B. menziesii	1.00	0.74	0.92	0.82
B. attenuata	0.71	0.47	0.67	1.64
B. hookerana	0.79	1.24	0.40	1.25

	Treatment			
	ON,OP	ON,2P	100N,OP	100N,2P
B. menziesii	0.91	1.52	1.62	2.05
B. attenuata	1.02	1.23	1.21	1.44
B. hookerana	1.30	0.93	0.86	0.84

Mean Root/Shoot Ratio:

	Soil			
	Control	'Rich'	AMC	AE
B. menziesii	0.46	0.32	0.37	0.13
B. attenuata	0.64	0.61	0.28	0.09
B. hookerana	0.92	0.18	0.54	0.12

	Treatment			
	ON,OP	ON,2P	100N,OP	100N,2P
B. menziesii	0.56	0.38	0.50	0.56
B. attenuata	0.57	0.57	0.49	0.56
B. hookerana	0.64	0.69	0.72	0.87

Mean Root Length (m):

	Soil			
	Control	'Rich'	AMC	AE
B. menziesii	43	20	12	10
B. attenuata	40	12	16	11
B. hookerana	59	42	13	26

Table 5. Phosphorus concentration (mg/g) in shoots of 6 month old seedlings of three Banksia species.

	Soil			
	Control	'Rich'	AMC	AE
B. menziesii	0.34	1.03	6.83	0.50
B. attenuata	1.97	0.44	8.16	0.94
B. hookerana	0.88	2.00	4.20	1.56

	Treatment			
	ON,OP	ON,2P	100N,OP	100N,2P
B. menziesii	0.65	0.61	0.97	0.63
B. attenuata	1.22	0.70	1.07	1.59
B. hookerana	0.76	0.10	0.34	0.23

Table 6. Mean nitrogen and phosphorus concentration in treatment and other soils after the experiment.

	SOIL N (mg/g)	SOIL P (ug/g)
Control	17.7	0.88
'Rich'	92.8	69.60
AMC	25.6	42.40
AE	38.6	24.80
ON,OP	26.0	2.10
ON,2P	33.5	4.93
100N,OP	32.1	-
100N,2P	28.6	5.31

Nitrogen concentration in the shoots was higher in the 'rich', AMC, AE, 100N/OP and 100N/2P soils than in the control, ON/OP and ON/2P soils (Table 5). The phosphorus concentrations were erratic apart from the higher levels in B. menziesii and B. hookerana in the 'rich' soil and the extremely high levels in the AMC plants. The latter result casts doubt on the ability of proteaceous species to survive on this material and further work would be required to determine if the material used was exceptional or whether other treatments could be applied to raise the N/P ratio. Soil analyses after the pot trial confirmed that the Watheroo soil was relatively high in total N and P. The N levels of the rehabilitation soils were not much greater than in the control and N-supplemented soils, while the P levels, especially in the AMC material, were much greater (Table 6).

Ecosystems south of Eneabba - the importance of vegetation-environmental relationships

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In any ecological study, it is important to develop an understanding of the factors influencing the distribution of species and groups of species across the landscape. In an area like the northern sandplain this can be a formidable task because of the marked species richness. Previous studies have identified over 500 species of plants and recognized broad floristic patterns in the native heathland south of Eneabba (Lamont 1976, Hopkins and Hnatiuk 1981). Moreover, an association between these floristic patterns and the major soil units of the area has been identified.

These studies have provided an initial basis for interpreting the distributions of plants in the region. However, a clear picture of the specific environmental factors that influence the distribution and success of plant species in the native ecosystem is lacking.

In previous studies, relatively few species were shown to be strictly associated with particular soil types. From the analyses, plant species appeared to exhibit a rather continuous distribution across a substantial degree of environmental heterogeneity. Field observations, however, indicate that there is a recognizable gradient in species importance both within and between the major soil units and associated plant communities. This suggests that there are indeed certain environmental conditions influencing the distribution of these plant species.

One objective of current research is to investigate the influence of specific environmental factors on plant species distributions. By combining a botanical survey of the major vegetation types with the collection of specific soil and topographic variables, it is hoped that some of these relationships might be further elucidated. Information gained from this analysis will then be applied to a similar survey of rehabilitated areas.

Research and monitoring on the vegetation of rehabilitated areas at Eneabba has provided an important measure of the rate of return of species to these areas. It has also illustrated the effects of various rehabilitation treatments (mulch, fertilization, time of sowing, etc.) on species establishment. However, variation in the success of revegetation within rehabilitated blocks and even within specific rehabilitation treatments indicates that there are also inherent environmental conditions that influence the success of species establishment. Part of the current research programme will be to investigate the influence of soil and topographic factors on establishment of native plant species. By collecting environmental information from sites adjacent to established regeneration quadrats, relationships between specific soil and topographic factors and the success of native species will be analysed.

Information gathered from rehabilitated areas will then be combined with that from the native ecosystem to determine the relative success of a given species or group of species on rehabilitated sites can be related to the conditions under which they thrive in the native situation. For example, one might suspect that a certain suite of native species is successfully re-establishing itself on minesites because the post-mining soil and/or topographic condtions are analagous to those under which they do well in the native situation. On the other hand, areas which exhibit poor establishment may possess soil conditions totally unlike the native situation and therefore inhibit re-establishment. Such an analysis will also attempt to identify the native soil type(s) most closely represented in the rehabilitation situation and summarize the species which exhibit the greatest success under these conditions. By achieving a better understanding of these relationships, the environment created in the rehabilitated minesites may be controlled or ameliorated to create more ideal conditions for appropriate species.

Mycorrhizal investigations in rehabilitated areas - implications for Eneabba

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The involvement of the mining industry in research on endomycorrhizal fungi emanated from CSIRO studies on the Cooloola sand mass in Queensland. Here it was found that vegetation colonizing siliceous sands was preceded by a strong presence of vesicular arbuscular (VA) mycorrhizal fungal hyphae. Microprobe analyses showed that the fungal hyphae appeared to be utilising phosphorus and other nutrients bound by sesquioxide coatings on the sand grains, otherwise considered unavailable to vascular plants. These findings were considered to have great significance to post-mining rehabilitation.

Between September 1980 and August 1983 a collaborative project funded by fifteen companies through AMIRA was conducted by the CSIRO Division of Soils throughout Australia and Papua New Guinea. The obejctive was to examine the role of endomycrrhizal fungi in disturbed soils and mining wastes. The principal findings of this work indicated that:

1) Most of the plants in the native ecosystems examined were infected with symbiotic mycorrhizal fungi.

2) Few propagules of endomycorrhizal fungi survived mining processes.

3) Natural recolonization of mine wastes by endomycorrhizal fungi was slow.

4) Use of fresh topsoil markedly assisted the re-establishment of native symbionts, including endomycorrhizal fungi, in revegetation areas.

5) Different strains of endomycorrhizal fungi were associated with different soils and mine wastes.

6) Glasshouse experiments showed that mycorrhizal plants displayed better growth and extracted more nutrients than non-mycorrhizal plants.

7) Some strains of endomycorrhizal fungi were more effective in promoting plant growth and nutrient uptake than others.

8) Some strains might be able to act as biological filters of potentially toxic elements.

9) Management factors, such as cover crops and different litters, could affect the development of mycorrhizas and there were differences in the efficiency of fungal strains under different treatments.

10) Selected strains of endomycorrhizal fungi could be introduced in pellets to revegetation areas; native strains could be introduced in fresh topsoil.

Thus, this initial work has shown that endomycorrhizal fungi have an important role in the development of stable revegetation communities on mined lands. Further, there appears to be considerable scope for the selection of the most appropriate strains of fungi to suit particular post-mining conditions and for their deliberate introduction by artificial inoculation techniques. These aspects are to be the subject of a further project to be conducted at the Department of Science and Plant Nutrition, University of Western Australia under Dr A. Robson, also to be funded by AMIRA. Scheduled to commence early in 1985, this project will also have a broad-spectrum approach. Of importance is that AMC as co-sponsor will nominate Eneabba as one of the study areas.

It is not expected that all the answers will emerge from this three year project and we are still in the pioneering stages of this work. The CSIRO workers claim that mycorrhizal research is currently at the same stage as rhizobial research was 40 years ago. However, with the involvement of the University of Western Australia, there will be plenty of opportunity for many of the matters of detail to be filled out by student research at various levels.

Litter cycling at Eneabba with emphasis on the role of arthropods

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Two studies have been performed on the invertebrates of rehabilitated lands and kwongan at Eneabba. The first was that of Majer _et al._ (1982) who looked at the recolonisation by ants and also soil invertebrates in sand mines ranging from one to three years old and also in the heath. The second was that of Majer and Bergl (1984) who looked at the progressive recolonization of soil invertebrates in plots ranging from one to six years old and they related this to the structural properties of the soil. Some of the plots selected for this study were those also used in the earlier studies.

Measurements reported by Majer _et al._ 1982 suggested that there was a great deficit of nutrients in the rehabilitated areas when compared with the kwongan. Soil and litter micro-organisms and also micro-invertebrates are extremely important in litter breakdown and nutrient cycling. In view of the deficit of nutrients in the rehabilitated areas, the adequate recolonization by these components of the biota is clearly important for successful rehabilitation to occur. Both of the studies reported above have attempted to quantify the recolonization by soil and litter invertebrates, little work has been performed to relate the levels of these animals to the degree of decomposition however.

A very tentative investigation of decomposition has been performed in the rehabilitated areas and kwongan at Eneabba and more detailed studies have been performed in the rehabilitated bauxite mines further south (Majer unpublished data). The Eneabba study involved burying rectangles of calico in the ground and leaving them there for some months. After this period they were removed from the soil and their loss of tensile strength estimated with a tensiometer. Despite the fact that there was little loss of tensile strength in calico strips from the kwongan, those from the rehabilitated areas were highly decomposed. Further investigations which were performed suggested that this was due to physical rather than biological deterioration of the calico. The bauxite mine work involved placing jarrah leaves out in fresh bags for an 18 month period over two rainy periods. At the end of this period the loss of surface area of the leaves, the loss of nutrients and the loss of weight was measured. Decomposition in many of the bauxite mines appeared to be as great as in the forest and it is interesting to note that the mined area with the greatest decomposition was one which was not revegetated. The probable reason for this is that the leaves were not shaded or protected from the elements and hence physical decomposition became a major factor. Both of these studies illustrate the problem of estimating decomposition and nutrient cycling in the rehabilitated areas at Eneabba. This problem will be discussed in the presentation today.

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