A REVIEW OF RESEARCH PERTINENT TO THE ESTABLISHMENT OF REHABILITATION FORESTS ON BAUXITE MINE PITS IN THE NORTHERN JARRAH FOREST OF W.A.

A. DAVEY
RESEARCH OFFICER
W.A. F.D.

CONTENTS

A REVIEW OF RESEARCH PERTINENT TO THE REHABILITATION OF BAUXITE MINE PITS IN THE NORTHERN JARRAH FOREST.

INTRODUCTION.

A public forest engages in many management activities to provide society with an array of products and services. The management problem for a public forest is to determine how much of each product and service should be provided (Chang and Buongiorno 1980; Alston 1972). In the case of a forest containing a considerable percentage of land affected by mining, this will largely depend on the ability of both managing and mining organizations involved to restore or re-create each service.

This "ability to re-create" will depend on

a) Land-use priorities and policies as perceived by the forest managers,

b) the effectiveness of the acquisition of a scientifically based understanding of the environmental/ecological processes at work in the ecosystem before, during and immediately after mining, and

c) the technological, logistical and political ability of all organizations involved to apply this knowledge as a rehabilitation strategy in order to produce or steer the ecosystem towards that end which will achieve the optimal balance of potential land-uses in perpetuity.

In this review it is intended to analyse all research and thinking to date on the rehabilitation of bauxite mining in the Northern Jarrah Forest of Western Australia in the light of the above three points. By drawing on records of experiences in rehabilitation from throughout the world it is hoped that facets of rehabilitation which have been overlooked or which show need for an increase of research can be identified and addressed.

BACKGROUND OF REGION.

The Northern Jarrah Forest exists at an elevation of between 275 and 380 metres (Harvey 1978) being situated on the Darling Range which is based on a shield of Precambium granites and gneisses (Mulchay 1960), over-lain by the weathered "pallid zone", an acidic white kaolinitic clay of low permeability (Stewart et al 1972) and extremely high bulk density (1.57gm/cc) (Shea, Herbert and Bartle 1978). The pallid zone contains a considerable store of salt (Burvill 1947) despite its weathered, infertile nature, and may be as deep as 30 metres (Stewart et al, op.cit.). Overlying this is a lateritic cap dominated by oxides of aluminium and iron.

The region has a distinctive mediterranean climate with large inputs of salt in rainfall. It experiences a summer drought with only 10% of the rainfall occurring over 5 months (Spriggins et al 1979). The rainfall is highest in the Western regions of the Darling Range, tapering off sharply in an Easterly direction. The dry sclerophyll forest, dominated by Jarrah (E.marginata) which occurs throughout the region, is adapted to consume a large proportion of the water stored deep in the soil profile (Havel 1975b, Shea et al 1975).

The area is infected with the pathogenic fungus Phytophthora cinnamomi, the causal agent for Jarrah Dieback Disease which is widespread throughout the forest (W.A. Forests Dept. 1972).

The major long term land-use for the region is as a water catchment (Bartle and Shea 1978). Secondary land uses include timber production, the conservation of flora and fauna, and science/education (W.A. Forests Department 1977). Mining of bauxite commenced at Jarrahdale in 1965 (Harris 1978). The earliest forms of mining rehabilitation were not ripped, and contained little landscaping of mine faces. Nursery reared monocultures of Phytophthora resistant trees including species such as E.maculata, E.saligna and Pinus pinaster were planted in rows.......no understorey of any description was applied. Later rehabilitation involved battering down of pit faces and deep ripping. Current rehabilitation involves extensive ripping and site landscaping, with particular attention being given to understorey establishment, both by double stripping of topsoil and direct seeding of understorey species (Fox et al 1982).

Mining, although a transitory land use, has a great and permanent influence on the landscape, ecology, and hence land-use strategies of the region. Of the 3000ha of jarrah forest currently free of, and "protectable" from, dieback, Alcoa propose to remove 1000ha through mining. It is estimated that dieback shall affect a further 1000ha (Alcoa 1978). Bartle (1976) considered that the combination of dieback and mining has the potential to degrade 90% of the entire Northern Jarrah Forest. This indicates that extensive rehabilitation is required if the region is to remain a multiple-use forest, particularly with respect to the maintenance of a viable water production area.

To date, all mining has been confined to the Western, high rainfall region of the Darling Range, where the overriding hydrological aim is to maintain high levels of water production while keeping erosion, and hence turbidity in check. Rehabilitation of the intermediate and eastern zones pose a completely different problem. In this area, the aim is to produce a system which will prevent water from entering the groundwater. To achieve this with vegetation, we require a system which will intercept, take up and transpire the maximum of incident rainfall.

CONCEPTS OF MINESITE REHABILITATION
- THE ECOLOGICAL APPROACH

For many people the rehabilitation of a minesite simply involves the implementation of landscaping treatment, and/or the establishment of some for of vegetation on the mined area. However, rehabilitation planning is far more complex than this, involving the integration of factors as diverse as the engineering aspects of post-mine site manipulation, estimation of the potential of the area to sustain different plant and animal communities (along with a projection of the successional outcome of the site/vegetation/management interactions), and the perception of socio-economic expectations which the community has of that land.

The huge gap between the raw mine pit surface and the finnished rehabilitated vegetation complex of greatest value to society can only be successfully bridged by rehabilitation strategies based on firm ecological principles.

Rehabilitation has been frequently based on engineering rather than ecological principles (Bartle and Shea 1979). Although the parameters for measuring the success of rehabilitation may be based on engineering (or water quality) the methods used must have a firm ecological base if the success is to be long-lived.

Woodwell (1978) outlined some unifying goals to which research in rehabilitation, landscape planning and ecology should be directed.... these were to develop systems that :-

(I) are tight and do not leak toxins (to which we can add nutrophying substances),

(II) operate on minimal subsidies of exogenous energy and other resources,

(III) have the potential for stability over decades.

Work towards developing ecosystems based on these principles is still rare. Different approaches to revegetation range from complete non-intervention in the natural recolonization process, to the major reconstruction and amendment of sites with subsequent artifial plantings (Skaller 1981). In choosing which of these two approaches to adopt, a number of factors must be considered (Ferrel 1974 and Skaller 1977) including regeneration time, development stages, plant and animal diversity, possible land uses (and their priority), general landscape aesthetics and management goals. In an area as socially important (for water supply) as the N.J.F., environmental liability, at least in the short term, favours vigorous management of the vegetation. Bartle and Shea (1978) state that the objective of rehabilitation research is to determine the affects of ecosystem disturbance on land use and to devise rehabilitation techniques that will restore land use values.

In the early days of rehabilitation in the N.J.F., the principle aim of rehabilitation during the first six years after mining, was to produce a viable, commercial, P.c. resistant forest (Shea and McCormick 1975). Minimum requirements of rehabilitation in the N.J.F. have been greatly expanded since that time, and currently it is prescribed that rehabilitated areas must:-

- have the capacity to withstand summer drought, periodic fire and the presence of P.c., the capacity to produce water, timber and lanscape values without heavy demands on organic fertilizers in the long term.

THE DIEBACK PROBLEM

Phytophthora cinnamomi, the causal organism of jarrah dieback (Podger 1972), not only destroys jarrah, the major overstorey species of the region, but also a majority of the understorey species (Titze and Palzer 1969). Forest destruction by P.c. has caused discharges of saline groundwater into the reservoirs which supply over 80% of the water for the south-west of the state (Shea et al 1975).

Of the 2 million hectares of government-controlled jarrah forest, it is estimated that 10% are infected with P.c. (W.A. Forests Department Report 1972). Throughout the forest area there are numerous examples of the association between the disease occurrence and earthmoving activities (Shea and Bartle 1978, Shea 1975); and Bartle (1976) estimates that together, mining and dieback have the potential to degrade 90% of the N.J.F. landscape.

In the rehabilitation of bauxite pits, the simplest, most obvious way to reduce the impact of P.c. on the new vegetation is by selecting species resistant to the disease.

While heightening the problems within the bounds of the pit itself, the association between earthworks and P.c. is such that the selection of resistant species within the pit has by no means had any perceptable impact on the spread of dieback from the pit and through the surrounding forest. To determine how the risk of this spread can be lessened, it is necessary for us to gain some understanding of what environmental factors combined to produce a high dieback-risk situation. P.c. weakens the tree or host plant by attacking transport tissue in the roots, inducing water stress (Podger 1968) and impairing the ability of the roots to absorb nutrients (Shea and Hopkins 1973).

P.c. spreads rapidly in the presence of high soil moisture (Shea 1977, Shea 1979, Bartle and Shea 1979, Christensen 1975), with the most rapid rates of spread occurring downslope in association with water flow (Shea and Dillon 1979). High soil temperatures also increase the spread of infection (Shea 1979, Christensen 1975, Shea 1977, Bartle and Shea 1979). Zoospores are considered to be the main agent of rapid spread and infection (Christensen 1975) and the combination of high soil moisture and temperatures increase sporulation and zoospore motility. Because of the dependence of P.c. on suitable soil temperatures and moisture conditions, the destruction of the canopy (Christensen 1975) and impedence of drainage produced by mining can cause a significant increase in the capacity of P.c. to sporulate (Shea 1979). Hence if water is allowed to flow out of the bauxite pits, the surrounding forest into which it would flow would be placed at a great risk.

As well as being susceptible to P.c., many plants act as hosts to the organism, building up the inoculum potential of the disease (and hence placing the adjacent forest at risk) for some time before succumbing to it. Proteaceous understorey plants appear to be the most instrumental in acting as hosts for P.c. (Weste 1974, Shea and Malacjczuk 1977, Shea and Hopkins 1973).

Insects, particularly termites, have also been implicated in the spread of the disease (Keast and Walsh 1979). Zentmeyer (1965) reports that bacteria have been shown to stimulate P.c. sporangial reproduction. Hence a large proportion of buried organic matter in a waterlogged soil may aid P.c. infection by increasing the activity of bacteria.

The literature was conflicting as to the effect of soil pH on the virulence of P.c.. Halsall and Forrester (1977) reported an inhibition of sporangia production and zoospore infectivity at a low pH, while Rummery and Howes (1978) reported an increase in P.c. production, also at a low pH.

By increasing the proportion of legumes, erradicating susceptible hosts, and creating less favourable physical and microbiological environments for the pathogen, controlled burns of high intensity are considered conducive to the control of P.c. spread (Shea and Malcjczuk 1977, Shea 1975, Shea et al 1976 and 1979, Glossop, Bell and Shea 1980, Ritson and Shea 1979, Shea 1979). This is currently practiced throughout the N.J.F. including areas surrounding pits. Repeated burning may however increase the susceptibility of the forest to P.c. by removing the litter layer from and blackening the soil, hence increasing the soil temperatures. Shea (1979) estimates that such an effect would last for approximately 2 years.

In revegetating pits, the current practice is to seed heavily with legumes. This gives a three way protection against dieback by:

a) providing a heavy shade to keep the soil temperatures low (Shea 1977),

b) by fully occupying the pit to the exclusion of potential proteaceous invaders,

c) by increasing the level of fertility of the soil (Shea 1979).

Alexander et al (1978) further suggest that exudates from Acacia pulchella depressed the production of sporangia and growth of mycelia of P.c.. Acacia pulchella is a major component of the understorey seed mix used on bauxite pits.

Like understorey species, tree species are being chosen for their apparent resistance to P.c.. A number of eucalypt species have demonstrated the ability to survive and grow on P.c. infected sites (Podger and Batini 1971). It has generally been observed that Monocalypt species of eucalypt are more susceptible to P.c. than Symphyomyrt eucalypts (Pittaway 1981). However, although a species appears unaffected by P.c., it does not necessarily follow that it isn't a host. P.c. may infect a host but because of host resistance have little impact on it (Marks et al 1972, Kassaby et al 1977). It should be noted that many species labelled as dieback "resistant" are still badly infected by the disease (eg. E.calophylla-Havel 1979). "Nil mortality" is often confused with "resistance" in the literature, hence a more careful screening of potential pit species may be in order to determine degrees of resistance.

P.c. inoculation of species already growing on pits may be the easiest way to screen species for their resistance to P.c. in the pit environment. There is evidence that some eucalypt communities have co-existed with P.c. for a very long time (Pratt and Heather 1972). Such communities would be a suitable place to look for species and indeed provenances with a P.c. resistance suitable for rehabilitation in the N.J.F.

A number of studies have shown that mycorrhizae are effective deterrents to Phytophthora infection (Marx and Davey 1967, Marx 1967 and 1972). Mycorrhizae vary from place to place, and because different tree species prefer different mycorrhizae, perhaps we should be incoculating introduced tree species with the suitably matched mycorrhizae introduced from the same area as the tree species. Tree species previously regected for rehabilitation due to their poor performance or P.c. susceptibility may exhibit quite different performance if in association with the appropriate mycorrhizal fungus.

Alcoa (1978) is undertaking to rehabilitate all dieback affected areas within the envelope of its mining operations. To this end, Alcoa is funding the Forest Improvement Rehabilitation Scheme (FIRS). The aim of this scheme which is administered by the W.A. Forests Department has been to rehabilitate "graveyard" or highly susceptible dieback sites back to a tall forest. However, it must be noted that catchments which are severely affected by dieback can yield 10-15% more runoff than heavily forested catchments. As these areas are all in a water MPA, in a state that has limited water resources, it has been suggested that a form of vegetation with lower water demands should be encouraged rather than a tall forest (Shea et al 1975).

In many places these FIRS operations have failed. Alcoa has stated (Alcoa 1978) that it "is prepared to make a committment to rehabilitate to standards agreed with the state government any degraded sites within its envelope of operations." In the light of the failure of many of these FIRS operations the current prescriptions for the FIRS programme appear to be inappropriate. Many areas shall need to be replanted once the prescription is amended. Research into this area is of the utmost urgency as, despite these failures, areas continue to be rehabilitated to the same inadequate standards.

HYDROLOGICAL AIMS OF REHABILITATION

A) THE WEST.

Conacher (1979) and Mulchay et al (1973) forecast that Perth's present water supply will become inadequate in the near future. The Public Works Department consider that the water resources of the Metropolitan zone of the south-west Western Australia (with the exception of the Murray) will be fully committed by the year 2000 (P.W.D. 1977). It is therefore of the utmost importance that the water resources of the Darling Range are protected. Only the short rivers rising in the high rainfall areas have catchments which yield water of sufficiently low salinity as to be suitable for agricultural, domestic, and industrial applications (Bettenay and Mulchay 1972). As such, the western zone is almost entirely classified as a Water Supply Management Priority Area. Bartle (1976) describes management of a water supply MPA as involving the following:-

(I) design of harvesting or silvicultural practices to maximize water production while protecting water quality.

(II) manage existing land uses on catchments so as to minimize the risk of siltation, turbidity, salinity and biological pollution.

(III) avoid land-use changes where they prejudice water values or potential storage sites.

The problem of forest degredation due to jarrah dieback is widespread throughout the Northern Jarrah Forest. While such degredation may, in some instances, result in a slight increase in stream turbidity (Shea et al 1975), the water yield from such degraded areas is greatly increased (Havel 1975, Shea et al 1975, Batini et al 1980, Ritson and Shea 1979, Bartle and Shea 1979, Bestow 1976). Where such areas are degraded to such a degree that there is a threat of erosion and turbidity, there is an obvious need for urgent rehabilitation. However, rehabilitation of degraded sites which pose no threat to water quality (back to a tall closed forest) would appear to be contrary to the guidelines for management of a water supply M.P.A. Ritson and Shea (1979) suggested that areas on the western side of the scarp devastated by P.c. are best left untreated, in a degraded state, thereby allowing a low-water-use, sparse marri woodland to develop.

Bestow (1976) reported that, while the annual discharge of salt had increased by 36% due to the removal of jarrah forest by mining and dieback, at the same time the amount of water being shed increased even more, leading to an overall dilution of the salt in the water yielded. Considering the probability of increases of salinity with the advent of mining in the eastern zone, it is important that a silvicultural mechanism be developed for the west such that water production in the western zone can be increased in a short period of time for dilution of saline water from the east.

The Forests Department has considered the use of a woodland or heath plant community as a means of maximizing water yielded from a rehabilitation site. A factorial experiment is currently being organized to evaluate the appropriate rehabilitation procedures necessary for these (Bartle pers.comm.). At this point of time, the policy for rehabilitation of bauxite pits is to aim towards a tall forest wherever this is attainable.

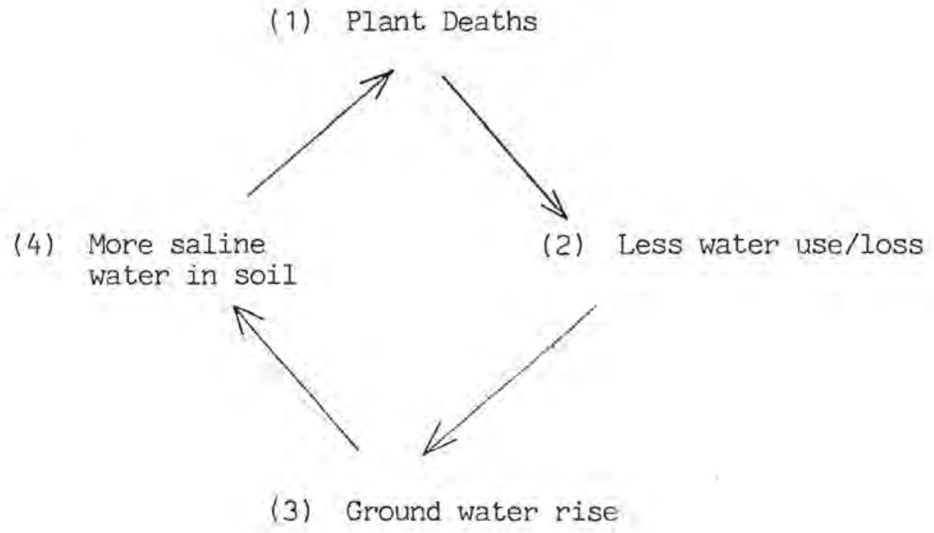
B) THE EAST.

The confined pallid zone aquifer is considered to be the main repository of salt in the landscape (Bettenay et al 1964). Total amounts of salt stored in the soil profiles of the N.J.F. tend to increase with decreasing rainfall, in an easterly direction (Burvill 1947, Dimmock et al 1974. Shea et al 1978), and may exceed 500,000 Kg/Ha in the East (Herbert and Shea 1977, Batini et al 1976). These large salt accumulations are readily mobilised by changes in the soil moisture regime (Stewart et al 1972, Lowe 1979). A large proportion of the winter rainfall excess in the Jarrah forest is retained deep in the soil profile (Bartle and Shea 1979). The native jarrah forest has the ability to consume a large proportion of the water entering and stored in the soil profile (Havel 1975a, Shea et al 1975, Grieve 1955, Doley 1967), keeping the water table below the areas of massive salt accumulation in the upper soil profile. Removal of this vegetation inevitably results in some period of reduced water consumption, excess water yield, and saline discharge (Wood 1924, Peck 1978).

Although in the past, clearing and increasing soil salinity have mainly been related in agricultural land, the proposed expansion of bauxite mining into the drier eastern zone poses new problems in revegetation and management. From a water management point of view, the aim of rehabilitation in these eastern areas will be to enhance interception of the rainfall by both the above and belowground components of the vegetation before it swells the ground water table.

Havel and Sanders (1974) carried out a preliminary investigation into the effect of bauxite mining on ground water hydrology in the less-salt-sensitive western zone (at Del Park). They found that the water table had risen 3m in the pit centre and 6m below the pit as a result of clearing. If mining extends to the intermediate and low rainfall zones, it is feared that the resultant removal of vegetation cover will cause significant stream salinity (Bartle and Shea 1978, Herbert et al 1977, Peck and Hurle 1972, Shea and McCormick 1975).

If the problem of saline discharge becomes apparent on rehabilitation in the eastern zone, we may expect that, without drastic correction, the severity of the problem shall increase exponentially. If salt becomes mobile in the upper soil profiles, we may expect the following cycle to become apparent:-



To prevent excessive salinization of the water resources of the bulk of Western Australia's population, much research is required into the hydrological implications of the various rehabilitation techniques proposed for the eastern zone. Alcoa has been prohibited from commercial mining in these low and intermediate rainfall areas until it can demonstrate its ability to mine and rehabilitate these areas in a successful and hydrologically viable manner.

ECOSYSTEM ESTABLISHMENT

Barrow (1979) states that the two fundamental requisites of a rooting medium as:-

a) being able to support the plant, and
b) being capable of allowing root penetration.

Of these two requisites, the first is the most difficult to quantify and hence, for us as rehabilitation managers, to attain.

To give the new association between plant and soil its greatest ecological resilience, the medium must be able to support the plant physically and nutritionally throughout all foreseeable future environmental and management (silvicultural) regimes. The medium must also be able to meet the changing demands of the plant throughout its development. If the medium can support the plant to reproduction, and subsequently lend similar support to the new generation of plants thus produced (and so on in perpetuity) we then have an ecological association between vegetation and medium of the highest resilience. The attainment of this is the ultimate goal of rehabilitation. The implicit first step in striving for this goal is the meticulous matching of environment and plant from the outset.

If the vegetation chosen has requirements beyond that which the medium can sustain, then the medium shall rapidly run into a deficit. To maintain support for the vegetation in such a situation the land manager has to "bail out" the medium with water, nutrients, physical ameliorants or whatever......the greater the "medium deficit", the greater the input and hence expense required.

If, on the other hand, the vegetation chosen has resource requirements far lower than the medium is capable of delivering, this leaves the vegetation wide open for competition from invader species, necessitating an intensive input from the land manager in the form of, for example, scrub control.

The mid point of these situations, where an ecological balance is reached, being situated on a razor's edge, is impossible to to attain, but by exercising care in the two basic approaches to rehabilitation, namely,

a) ameliorating the site (medium) before establishment, and

b) chosing species associations for rehabilitation (Hunter 1973),

the costs involved in artifially maintaining a system in its balanced state can be kept to a minimum.

Although, this review, the site amelioration and vegetational factors shall be discussed separately, the interdependence of these two factors is fundamental to rehabilitation planning, and the proximity of this association to the "point of balance" must be weighed with each rehabilitation amendment contemplated.

A. SITE AMELIORATION

1) SOIL HANDLING:

Before the bauxite can be mined, the overlying soil is scraped back and pushed to one side. In the past, several different methods have been employed in the Northern Jarrah Forest for handling this overlying soil. These methods fall into two broad categories: Bulk Stockpiling, and Double Stripping.

a) Bulk Stockpiling: This involves the removal of the overlying soil as one component (without the separation of overburden and topsoil) and stockpiling it adjacent to the pit (for around one year) for replacement over that same pit following mining and landscaping. Bulk stockpiling leads to conditions which are deleterious to the survival of plant propagules by altering the soil chemical and physical properties. Soils become anaerobic, causing a loss of organic matter and disrupting microbial populations (Hunter and Currie 1956, Miller and Cameron 1976), and many seeds, if buried deeply, may not have the reserves to reach the surface even if they do not germinate (Floyd 1976, Heydecker 1973). Since topsoil is a valuable source of native seed, double stripping has been developed to overcome these stockpiling problems.

b) Double Stripping: This involves the separate removal and direct return of the top 5cm of topsoil over a lower stockpiled layer (Tacey and Glossop 1980). In this method, the topsoil is stripped off one pit and directly transported to and spread over another, already-mined pit. The overburden is then scraped off the pit to be mined and stockpiled.

After mining, the overburden is respread and topsoil which has been just scraped off the next pit to be mined is immediately transported to this pit and spread over the overburden. Double stripping is the most useful method for ensuring that the naturally present seed is not buried too deeply (Tacey and Glossop 1979).

Felton (1976) states that in open and dry sclerophyll forest types, mechanical disturbance can provide a suitable seedbed for fire-dependent species in the absence of fire. Floyd (1962) states that mechanical clearing produces a superior seedbed to fire. Hence, if topsoil is placed in such a position that the propogules it contains are shallow enough to germinate, many fire dependent species can take advantage of this seedbed preparation. Double Stripping places the topsoil in such a location. Double Stripping has been shown to increase species diversity (Tacey 1978, Tacey and Glossop 1980, Glossop 1981), density (Tacey 1978) give a more even spacial distribution of species (Tacey and Glossop 1980), improve erosion control, reduce seed costs and, unlike stockpiling, would have little effect on physical and chemical soil factors (Tacey and Glossop 1980). Double Stripping is now widely used by Alcoa in all three mining areas. The one problem with double stripping is that it necessitates the transportation of soil from one area of the forest to another. This aids the spread of Phytophthora. Where this may pose a threat to the surrounding forest, the stockpiling method is used instead.

The next process in pit rehabilitation is ripping.

2) RIPPING:

The Northern Jarrah Forest has a deep, weathered "pallid zone" in its soil profile, ranging from 20-30 metres deep (Dimmock et al 1974, Herbert et al 1977). The normal hydraulic conductivity of the pallid zone clays is very low (Bartle 1976), however the high concentration of conductive channels caused by roots growing through to pallid zone in the native jarrah forest allows water to readily penetrate (Bartle and Shea, 1978 and 1979). The traffic of heavy machinery over the pit floor during mining and topsoil handling tends to block these channels and further compact the upper region of the pallid zone, thereby preventing infiltration, leading to overland flow, erosion, turbidity and acting as a barrier to root penetration.

Ripping of bauxite pit floors in the Northern Jarrah Forest has evolved from "nil", leaving a compacted layer impervious to roots (pre 1974), to a regime of ripping with a two metre winged tyne which uplifts and completely fractures the soil to a depth of around 1 - 2 metres.

In the past, the construction of large, steep, untrafficable banks has been used to control erosion on the pits (Shea and Bartle 1976). The majority of pits rehabilitated by Alcoa have been designed for the complete containment of water within the pit. This containment policy is most beneficial to the surrounding forest in terms of dieback protection, as it allows the water to infiltrate through the soil of the pit floor, rather than run overland. Another method of handling water on pits is called the Grade Bank System

(Riches 1979). This system is designed to direct the excess water (runoff) to the edge of the pit where it is discharged into a drainage channel, which empties directly into a natural watercourse. This system is generally accompanied by an increase in turbidity. The grade bank system produces a more trafficable pit as all internal structures are designed to retain a minimal amount of free water. The grade bank system is considerably cheaper to construct than a pit designed for water retention. If grade banks are to be used, it is essential that an effective way be found to disperse the water, once off the pit, without causing undue turbidity. Research in this area is required.

Many pits have been over-designed hydrologically, as it was originally thought that surface flow over the pits during a large rainfall event would be massive (Riches 1979). Even in "flash" rainfall events (for example, January 1982) both contour and grade-bank systems withstood the test. It is now generally accepted that pits are far more porous than was originally thought, hence erosion and turbidity problems are less significant because of this overdesign in water handling structures.

Where runoff and erosion does occur in mining areas, (for example on areas outside pits, such as roadsides), the turbidity can be controlled by collections of drains, silt traps and spillways (Shea and Bartle 1976, Branson 1975), or mulching (Shea and Bartle 1976, Meyer et al 1970, Olsen 1980).

Today, using a winged tyne for ripping, a smoother and more permeable pit floor is constructed. After ripping, the infiltration capacity of the pit floor was around 15 - 20mm per day compared with 5 - 10mm before rehabilitation (Alcoa 1978). The winged tyne is also the answer to accessability of the pits. Using this to rip the contour, and then cross-ploughing with a tractor produces a flat surface with extremely high infiltration capacity (Croton 1982 pers. comm.).

Ripping is also important in assisting root penetration. Jarrah, by virtue of the fact that its roots have the ability to penetrate the pallid zone, has the ability to tap water deep down in the soil profile (Kimber 1974). Planting seedlings into overburden spread over a compacted, unripped bauxite pit floor at Jarrahdale led to windthrow because of the inability of the tree roots to penetrate this compacted clay floor (Tacey 1979, Shea et al 1975). The roots of a diverse range of species growing on bauxite pits have been found to be almost entirely restricted to the overburden (Shea and McCormick 1975). Since 1974, deep ripping has been used in an effort to enhance root penetration of this compacted pallid zone (Tacey 1979, Harris 1978). Although Tacey (1979) reported that there is no evidence to show that deep ripping affects either tree survival, tree form or tree diameter, it must be noted that his studies were performed on trees in the early stages of their growth. Any impact on tree performance is more likely to become evident when the size and demand of older trees outstrips the resources available to their limited root systems.

3) MULCHES.

Several research projects have been conducted by Alcoa on the suitability of mulches as a physical aid to rehabilitation. Olsen (1980) found that any increase in the depth of mulch over 3-5cm caused a marked reduction in seedling emergence.

Because of their expense and the difficulty in achieving the desired evenness and thickness of spread, the use of mulches in the Northern Jarrah Forest minesites has tended to be confined to the revegetation of steep slopes and roadside banks.

4) NUTRITIONAL CONSIDERATIONS OF ESTABLISHMENT.

"The forest floor is the control gate through which pass almost all the nutrients taken up by the primary producers and most of the energy fixed by them as well. This regulatory role of the forest floor may be particularly important in ecosystems that have a low total nutrient capital. The long term stability of these ecosystems should be a central theme of forest ecology research" (Richards 1981).

a) Requirements For Establishment.

The highly weathered and leached nature of many Australian soils has led to the development of a wide range of nutrient deficiencies in forest soils (Hill and Lambert 1981).

The soils of the N.J.F. are no exception.

Struthers (1964) characterized soils being "toxic" to the existance of vegetation as either:-

a) very highly acidic, or
b) very highly saline, or
c) with limited or quickly depleted amounts of calcium and magnesium, or
d) having high levels of aluminium, iron or manganese salts.

Considering the soils of the N.J.F. in the light of the above points, after mining, the pH of the surface soil varies from 3.5 to 5 (Davey unpub.). The soil varies from moderately saline in the west to very saline in the east (nearly 10^6kg/Ha - Dimmock, Bettanay and Mulchay 1974), and the soils are dominated by the presence of iron and Aluminium ions. Although all mining spoils in the N.J.F. share a poor nutritional status, the N.J.F. soils are by no means homogeneous, thereby complicating nutritional studies.

The lowering of the soil pH after mining poses several possible problems to rehabilitation:-

- few species thrive in soils of low pH, the number of viable species declining rapidly as the pH approaches 4 (Limstrom 1960, Chadwick 1973). This applies to both agricultural legumes (Bengston et al 1973) and Australian natives (Koch 1980).

- Low pH reduces microbial activity (Schwyzer 1966, Harvey 1966).
- As pH drops the availability of P decreases in bauxitic soils (Rummery and Howes 1978).
- Aluminium becomes available for uptake as the pH drops below 5 (Otchere-boateng and Ballard 1981, Riley 1973, McLean 1976, Garrels and Christ 1965, Coleman and Thomas 1967).
- After mining, residual bauxite may become mixed with the acidic pallid zone.
- High levels of aluminium in plants can upset the nutrient metabolism within plants. Such affects can be as subtle as a slowing of the growth rate, and as spectacular as the collapse of a root system (Plucknett 1961, Jackson 1967, Foy and Brown 1964, Howard 1957, Riley 1973).

Very little has been studied concerning the aluminium uptake in jarrah forests. The most exhaustive study of metal plant analysis conducted (Hingston, Dimmock and Turton 1980) considered 6 metal ions, but excluded aluminium. Jarrah obviously thrives in this local environment. It may be adapted to high levels of aluminium (having evolved in this environment) by dumping excess aluminium into the cell interstices. Alternatively, jarrah may not have come into contact with readily available aluminium in the past (the native N.J.F. topsoil being considerably less acid than the bauxite/pallid-clay mix of the mined areas).

This needs further investigation.

An outstanding feature of Australian soils is their low phosphorus content (Wild 1958, McColl 1969, McColl and Humphries 1967). The strong phosphate fixing capacity of lateritic soils is well documented (Mulchay 1960, Gilkes, Scholz and Dimmock 1973, Rummery and Howes 1978, Barrow 1979). The more acid the soil, the greater the fixation of phosphorus (Rummery and Howes 1978). As the pH of N.J.F. topsoil is decreased markedly by mining from around 6.2 to 6.5 in its unmined state (Hingston et al 1980) to around 3.2 to 5 in the mined state (Davey 1982 unpub.), phosphorus is far more strongly adsorbed, and hence less available after mining.

Eucalypts are well adapted to low phosphorus levels. Once phosphorus is in the tree it tends to be recycled biochemically to suit the needs of the tree (Feller 1980, Attiwill 1980 and 1981, Attiwill et al 1978, Specht and Groves 1966). The phosphorus fixing ability of N.J.F. soils is such that jarrah has the ability to remove around 80% of phosphorus from its leaves prior to senescence (O'Connell et al 1978). This recycling ability is all very well for an established tree in an established forest ecosystem, but before canopy closure, heavy nutritional demands are made on the soil (Miller 1981). At this stage, supplementary nutrient inputs may be necessary to support growth.

The levels of available phosphorus and nitrogen are considered to be of the utmost importance in influencing the success of eucalypt plantations (Kaul et al 1966, Cameron 1981).

Following clearcutting, high soil temperatures, mineralization activity and water throughflow greatly increase the potential for leaching of soil nutrients (Charley 1981). Similar conditions exist on a freshly landscaped minesite. Hence, of the large amount of nutrients applied to a bauxite pit, the majority of phosphorus applied would be adsorbed, and a large proportion of the other nutrients would be leached out of the soil after a short period, given that the timing of nutrient applications corresponds with the early to mid wet season. The application of a second dose of nutrients as the first dose was approaching depletion would enable the continuity of nutrient uptake by the plants, throughout and hopefully beyond the first growing season.

Tacey (1979) showed that two surface applications of fertilizer (applied at 3 and 9 weeks after planting) resulted in significantly better tree growth than one application alone. Today this double application of fertilizer (MAP) is still practiced.

Research into the use of alternative forms of nitrogen and phosphorus may solve problems of nitrogen leaching and phosphorus fixation. Dissolution rates of nitrogenous fertilizers can be reduced by coating granules with sulphur i.e. sulphur coated urea (Allen, Hunt and Terman 1971). Rummery and Howes (1978) experimented with granular superphosphate compressed into briquettes, 3cm in diameter by 3cm high. The objective is to place concentrated, slow-release briquettes in close proximity to each tree. The phosphorus is available to the plants over a 1 to 2 year period, even in soils with an extreme phosphorus fixing ability, as the extremely high concentration of phosphorus around the briquette exceeds the fixing capacity of the soil. The use of such methods in the N.J.F. rehabilitation has not yet been considered.

To date, the role of minor nutrients in the establishment of rehabilitation has been given little consideration, yet micro-nutrient deficiencies have been reported for soils throughout Australia (Hill and Lambert 1981). The geological laterizing process removes almost all of the alkalis and minor elements (Prider 1966), yet to-date, prescriptions for the fertilization of bauxite rehabilitation sites have only specified the use of nitrogen and phosphorus.

In many cases, huge applications of nitrogen and phosphorus have been used without any attention to the effect this may have on the level of minor nutrients. Applications of excessive amounts of these major nutrients can induce or accentuate deficiencies of Boron (Hill and Lambert 1981), Copper (Ruiter 1969, Will 1972) and Zinc (Stoate 1950, McGrath 1978). Hence, the over-liberal application of major nutrients in an effort to "green up" a rehabilitation site may be counter-productive without adequate attention to minor nutrients.

This does not mean to say that we should concentrate our research resources on pinpointing the exact, optimum levels of each nutrient for application on bauxite pits. Even in quite restricted areas of apparently uniform geology and subdued relief, the range of variation of particular nutrient elements remains high (Ward 1979). Fluxes and levels of availability of elements in forest ecosystems are similarly spacially heterogenous (Charley and Ward 1981). Hence, trials aimed at pinpointing optimum levels of nutrient additions for bauxite pits would be of application only to the area of that trial, given the heterogeneity within as well as between pits.

Attiwill (1980) has studied the nutrient and biomass development of an E.obliqua forest for 22 years in search of an understanding of its nutritional requirements. Obviously, given the large number of species used in both mixture and monoculture on the bauxite pits and the pressing needs of the current rehabilitation programme, such a meticulous study is out of the question.

b) Understorey and Nutrition.

"Ecosystem management techniques must strive to be non-polluting and low in energy cost. Towards this end, techniques which allow natures own regulatory processes to work for man may prove important" (Skaller 1981).

The "fertility" of a site is often taken as the level of nutrients in that site as measured at a particular point of time. To a forest manager or ecologist however, true "fertility" would be better defined as the nutritional ability of a site to develop, support and sustain a forest ecosystem over decades, or even centuries. Injections of chemical nutrients, while they may raise the former type of fertility, have little positive effect on the latter "true" fertility, and may even have a negative effect. Mineralogical fertility is often transitory and short lived. Biological fertility tends to be regulated, and sustained (Ellenberg 1964, Hofman 1968, Jahn 1972, Maldague 1970).

Micronutrients such as Boron (Tiffin 1972), Manganese (Lamb 1976) and Calcium (Attiwill 1980) are considered as being fairly immobile in a tree. Hence, if an injection of nutrients is used in the absence of understorey species, of the small amount which is taken up by the tree seedlings most will be tied up in old wood (Hingston et al 1979, Lambert 1981) where it will remain as long as that plant organ is retained by the tree (alive or dead). Since the longevity of Eucalypt plants is far greater than that of understorey (Pook et. al. unpub. 1982, Groves 1968) and the decay rates of eucalypt litter extremely slow by world standards (Pressland 1982, Lee and Correll 1978, Hatch 1955, Birk 1979, Bray and Gorham 1964) we cannot rely on nutrient cycling from eucalypt litter fall for the supply of micronutrients to a pure young stand of eucalypts.

Litter fall is a very important link in the process of nutrient cycling (Ovington 1962, Newbould 1967), and although internal cycling of major nutrients (Nitrogen, Phosphorus, Potassium) readily occurs in eucalypts (Hatch 1964), external cycling takes place only very slowly due to the relative longevity of retention of eucalypt parts previously mentioned. Clearly then, a young eucalypt monoculture will contribute little to the nutrient cycling, soil biulding and long-term fertility of rehabilitation on a bauxite pit.

What is more, a continual input of micronutrients is required as the tree grows, as eucalypts are not capable of redistributing such elements within the tree once they have been initially assimilated.

A mixed understorey, because of its species diversity and large number of individuals, tends to occupy the soil more rapidly than eucalypts. Hence, the understorey has the ability to capture a sizeable proportion of any large injection of nutrients which would otherwise escape a solitary stand of eucalypts. Being composed of comparatively short-lived species, a mixed understorey also tends to be far more dynamic than eucalypts in terms of growth, death and litter fall. Whearas litter fall in a eucalypt forest is strongly seasonal (McColl 1966, Webb et al 1969, Ashton 1975, Specht and Brower 1975, Rogers and Westman 1977, Birk 1979, Bray and Gorham 1964), a well mixed understorey, because of its diversity, will tend to drop litter all year round and even out the litter fall of the plant community as a whole. Little by little, through abscision of leaves, twigs and roots (Waid 1974, Coleman 1976) and plant death, the understorey shall return its captured nutrients to the soil, thereby converting a massive pulse of fertilizer into a prolonged, even, trickle of nutrients.

Grier and Logan (1977) emphasized the importance of large woody material in an ecosystem as a buffer from perturbations in nutrient levels by acting as large reservoirs of nutrients. The lack of such "large compartments" in an ecosystem may result in high sensitivity to changes and variations in nutrient levels, even if such variations are short term (Jordan and Kline 1972). Eucalypts drop very little of the larger woody components before they reach maturity. Hence, in order to attain such a buffer as soon as possible, understorey mixes should include some of the larger, woody, fast growing, short-lived species such as the taller acacias and albizzias. Up until 1980, such species were included in the understorey mix for N.J.F. rehabilitation. This practice has been abandoned because of a conflict with the Forests Department's Fire Protection Policy. This shall be discussed further in a future review entitled Ecosystem Management.

c) Agricultural Understorey and Green Manures.

Shea and Kitt (1976) report that some native legume species have the ability to fix nitrogen at a level equivalent to that of a commercial agricultural crop. Because it takes them some time to become established, maximum nitrogen fixation by natives may not be achieved for a number of years after planting. In comparison, Shea and Bartle (1976) report than an agricultural legume crop was fully established a matter of weeks after sowing. Annual plants also tend to have a higher concentration of nutrients than perennials (Parrish and Bazzaz 1982).

Early in natural vegetation succession, nitrogen fixing plants are present, and they are replaced by other plants that utilize the accumulated nitrogen (Stevens and Walker 1970). It is common practice in minesite rehabilitation to utilize an accelerated successional process where an initial cover crop is later replaced by the desired vegetation (Plass 1968, Coaldrake 1973, Martinick 1976, Alcoa 1978).

A number of objections have been raised concerning the combination of an agricultural legume with a native understorey. Annuals tend to hoard nutrients, leading not only to mutual antagonism between annuals, but also reducing the availability of nutrients to other perennials on the same site (Harper 1977, Shea and McCormick 1975). This could be overcome by digging in the annuals before planting and sowing the perennials.

The organic layer produced by an agricultural crop tends to be relatively shallow. Decomposition of organic matter tends to be concentrated in the 0-10cm layer, preventing the formation of a deeper topsoil. Mineral retention also occurs in this layer, thereby preventing the roots from going deeper (Woods 1958). Again this problem could be overcome by growing the agricultural crop for one season, and then ploughing it in and seeding with natives the following season. This method does not necessitate a second ripping.

Because ripping is not necessary for the growing of grasses providing topsoil is present (Morgan 1974), the crop can be sown straight onto the reshaped pit surface. Ripping therefore need not take place until just prior to native understorey seeding/planting.

It has been claimed that digging-in a crop has a negative effect on nitrogen for at least several years (Nichols pers.comm. 1982). Such is the case for a non-nitrogen-fixing straw, the proportion of nitrogen being assimilated into microbial cells being very high when the carbon: nitrogen ratio is high, such that if insufficient nitrogen is present in the plant material, nitrate and ammonium ions shall be depleted (Grey etal 1971) and hence not available for plant growth. If, on the other hand, plant material high in nitrogen is incorporated in the soil, the nitrogen status of the soil is vastly improved (Cundell 1977).

Ellis (1971) has related an increase in site productivity to a gradient of decreasing bulk density, and increasing organic matter, cation exchange capacities, water holding capacity, and nutrient content. Digging in a nitrogen-fixing agricultural crop can rapidly improve all of the above factors.

The use of an agricultural crop as an understorey in rehabilitation has only been practiced experimentally in the N.J.F. due to fears that crops and associated weeds may invade the surrounding jarrah forest. There is no evidence of invasion around any of the trials, probably due to the low level of phosphorus in the native soils (Stace et al 1968, Alcoa 1978). Kirkton (1965) reports that legumes can be removed from any phosphorus deficient soil by simply witholding phosphorus applications.

In a comparison of a number of agricultural legume crops as an initial stage in bauxite pit rehabilitation, Shea and Bartle (1976) found that purple vetch gave a thick cover in the first year of its development, and unlike most other agricultural legumes, was neither a heavy, nor a hardy seeder. Hence it is readily replaced by native vegetation over subsequent seasons. Further trials with purple vetch and perhaps other agricultural legumes should be conducted as it may be of benefit where, for fire protection purposes, thick native understorey is prohibited.

d) Microbiota and Nutrients.

Undisturbed or natural soils contain bacteria, fungi, and an assemblage of arthropods which make up the soil community. The soil community is a complex organization of interdependent species which process dead plant material and convert it into mineral soil, fix nitrogen, redistribute soil particles, enhance aeration, and generally affect the structure of a soil (Witkamp 1971). Mine spoils usually lack this biological soil community (Alcoa 1978).

Although processes of organic matter distribution, and hence the release of nutrients for recycling in soils are due mainly to the soil biota (Cundell 1977, Balicka and Sobieszczanski 1964, Lee et al 1981), little attention has been paid to the re-establishment of such beneficial organisms in local rehabilitation. These include rhizobia, actinomycetes and mycorrhizae.

Mycorrhizae are extremely important in enhancing root uptake-of-nutrients (Balicka and Sobieszczanski 1964, Bowen et al 1974, Fogel 1976, Tinker 1975, Powell 1976, Cundell 1977, Barrow 1979).

Such is the importance of mycorrhizal relationships that allelopathic effects have been ascribed to the direct suppression of mycorrhizae by chemical leachates (Del Moral et al 1978). As an added bonus, a number of studies have shown that mycorrhizal roots are more resistant to Phytophthora cinnamomi than non mycorrhizal roots (Marx 1967).

Mycorrhizae will invade from surrounding native forest, but will spread fairly slowly and tend to lack diversity (Bengston et al 1973). Mycorrhizae can be introduced into a site by introducing infected humus or mulch (Harvey et al 1981, Ettershank et al 1978, Bengston et al 1973, Trappe 1977), rotting wood from an infected site (Harvey et al 1976, 1978, 1979 and 1981, and Kropp 1982) or by infected soil, either straight into the field, or via the nursery (Trappe 1977), although such practices must meet hygiene specifications before being considered.

On a visit to the N.J.F. to study mycorrhizae on the rehabilitation areas, Trappe (pers.comm.) noted the vast diversity and proliferation of mycorrhizal fruiting bodies in the dense and diverse rehabilitation (such as that found in the "Jungle plot" at Jarrahdale), compared with their relative absence from eucalypt monocultures in the same region.

Clearly then, a diverse, dense understorey is the answer to stimulating mycorrhizal development in an area of rehabilitation.

In some circumstances, the establishment of a helpful microbial population may be aided by a simple injection of nutrients, for example, the addition of phosphate to increase the nitrifying activity of bacteria (Alexander 1965, Finch et al 1971, Skujins 1973). In other circumstances, the establishment of symbiotic microbes may be more difficult; for example, the salt intolerance of nitrifying bacteria is well known (Alexander 1965, Finch et al 1971, Skujins 1973, Cundell 1977). This could preclude their establishment in the eastern saline zone.

The bulk of the soil microbial population is immobile and inactive (and hence not cycling nutrients) for much of the time due to a lack of substrate (Gray and Williams 1971). A vegetation cover which ensures an adequate injection of nutrients and plant matter, whether it be an agricultural crop, a dense mixture of native legumes, or some combination of both, is essential for the maintenance of activity and diversity of symbiotic microbes and hence for nutrient cycling. Even in the presence of copious quantities of inorganic nutrients, a site with no understorey or with understorey capable of limited (in time and/or quantity) litter fall, could be considered to be void of the long term and sustainable "true fertility" described in the introduction to this section on nutritional considerations.

e) An Alternative Approach to Rehabilitation/Nutrition.

When planning for the rehabilitation of a site, there is always a tendency to firstly choose the vegetation species we would like to see in a rehabilitation area, and then amend the nutrition of that site to support our species choice. This is, to a large degree, the way rehabilitation in the N.J.F. has proceded to date. This approach is quite acceptable where the benefits reaped from the final product (e.g. sawlogs) offset the cost of additional input of nutrients and management required. However, where the major landuse is, for example water production, or some similarly non-timber-oriented product, the economics of this practice become questionable. A more sensible approach might be to firstly gain an understanding of what sort of vegetation-cover the site is nutritionally capable of maintaining, and then to choose an appropriately matched species mixture. Bevege (1978) in highlighting the benefits of exercising care in choosing species mixtures gives the example of admixed eucalyptus litter being more rapidly incorporated into the soil in the presence of high nitrogen acacia litter. Several workers (Hannon 1956, McColl 1969, Meakins 1966, Turton 1977) record large differences in the nutrient content of foliage of different species growing on the same site. Such variation can lead to different rates of incorporation of litter, different rates of nutrient cycling, and hence different vegetation carrying capacities depending on the species mix involved.

B. SPECIES SELECTION.

In W.A., jarrah has evolved in an environment which, although uniformly unfavourable for forest growth (Shea et al 1978, Spriggins et al 1979) contains many sites of widely varying ecology (Havel 1975). Because jarrah occurs over such a wide geographical range, crossing numerous ecological boundaries including those of soil type, aspect and topography, the initial impression one has of the region is usually that of relative uniformity and similarity throughout. While the dominance of jarrah throughout the landscape covers the area in a uniform clothing, the area is by no means of uniform site quality.

Jarrah has the ability to send its roots deep down through the pallid zone of the soil profile where it encounters water (Grieve 1955, Doley 1967, Kimber 1974, Shea and McCormick 1975, Shea et al 1975, Bartle 1976). As a result, jarrah has the unique ability of being able to maintain high transpiration throughout the summer (Grieve 1955, Doley 1967). This gives jarrah a competitive advantage over other local species which is why it dominates the landscape wherever the water table is deep (Havel 1975). Even in the higher rainfall zones, differential adaptation to moisture stess plays a fundamentally important role in determining present day species pattern. Wherever this stress is greater, the species pattern become more distinct (Florence 1982, Pook et al 1966). Because jarrah handles the most critical environmental problem, that of water supply, so effectively, it is able to transcend a multitude of lesser environmental boundaries. If we are able to introduce a species over the same range of environment that we find jarrah, then we would have to find a species which can handle this overriding restraint of water with the same proficiency as jarrah. To date, such a species has not been found (Shea and McCormick 1975), hence, as a first approximation for selecting species we must look towards those species which handle this fundamental restraint as well as possible. We must then screen these species for their ability to overcome the other, lesser environmental restraints which, although of little significance to jarrah, become all important as site delimiters for these species of lesser ability. After water, soil type is one of the factors most often addressed for an explanation of eucalypt distribution (Moore 1961, Beadle 1962, Winterhaulter 1963, Parsons and Specht 1967). Flexibility of root form could be one characteristic that might determine the success of replacement species (Dell and Bartle 1982). Hence, it appears that we shall require a suite of species if we are to successfully occupy the ecological range of jarrah.

It is often difficult to determine whether a tree species is deeply rooted in its natural habitat, let alone predict its root habit in a completely foreign rehabilitation situation. Many authors appeared naive as to the degree of contribution to the trees biomass of roots. For example, Feller (1980) showed surprise at the findings of Ashton (1975) that Eucalyptus regnans roots extended below 50cm in the soil, and states "in view of these points it is likely that root biomass has been underestimated somewhat". Shea and McCormick (1975) analysed the fine root development of a number of the earlier species planted on bauxite pits and found that despite ripping, roots were almost entirely restricted to the overburden. Studies of the root systems of species currently used are underway (Colquhoun), and show more promising penetration lower down the soil profile.

Mining produces changes of great magnitude in the soil structure and chemistry. The hydrologic characteristics of the soil shall also be changed to a greater or lesser extent depending on the depth of overburden, degree of compaction of the subsoil, and effectiveness of ripping. Hence, the overruling environmental restraint, the amount of water available for plant growth and its seasonal distribution through the soil profile will be changed to some extent. In addition, we have already discussed how the spread of P.c. by the mining operation precludes the successful reintroduction of jarrah as a minesite rehabilitation species. Clearly, the site has undergone a dramatic tranformation through the mining operation. Revegetation is therefore not simply a matter of replanting local species (Spriggins et al 1979).

Bartle (1978) states that a species is constrained ecologically to occupy a particular niche. In the simplest case, this constraint may be purely geographical (e.g. that between Western and Eastern Australian species), in which case we need only relocate the species to introduce it into the new area. A species may also be excluded from a certain area by competition from other species within that area; although this area may be climatically and edaphically more suitable to the species than that in which it is found. When transferred to this new area, and aided by an artificial reduction of the competition, it can display impressive performance (Spurr and Barnes 1973). In a mined area, this competition is usually already artificially reduced by the removal of the original vegetation. In some instances, the removal of this competition is all that is required for the hitherto-excluded species to colonize a new site (eg. E.patens, E.megacarpa - Havel 1979; and E.calophylla - Bartle 1976, invading disturbed jarrah sites). Spriggins et al (1979) state that "introduced species may be superior to local species or even essential for revegetation". They also state that reliable performance from replanted vegetation will only come from species well matched to the environment. Such matching involves detailed ecological analysis and experimentation. Bartle and Shea (1978) and Spriggins et al (1979) suggest that the selection of tree species for rehabilitation of degraded areas in the N.J.F. should be based on a two step approach:-

(I) Theoretical selection based on knowledge of the ecosystem of origin, and

(II) Emperical evaluation of those species chosen for the new environment.

This is basically the approach to selection which has been undertaken for rehabilitation of the N.J.F. to date. This practice could be improved further by initially choosing species by a fairly broad theoretical selection, and then carrying out the above mentioned two steps at a provenance rather than a species level. The concept of provenance based selection procedures shall be discussed further as this section progresses.

Cooper (1970) describes the steps in a theoretical analysis of tree species suitability as follows:-

(I) Definition of major characteristics of the new environment, eg. rainfall distribution, max. and min. temps etc.

(II) Determination of the extent to which some of these characteristics may be modified by management (eg. fertilizer, ripping practices).

(III) Identification of specific adaptations which will help a plant survive in the new environment.

(IV) Exploration of comparable environments for potentially adapted species.

Originally all monocultures, around 1979 mixtures of species were introduced to reduce the impact in the event of the failure of a rehabilitation species. Although towards the end of their rotation, they become harder to manage as a commercial forest than monocultures, well chosen mixtures often exhibit "overyielding", i.e. better performance and total productivity than monocultures. The range of habitat tolerance of a tree community increases with the number of component species (Trenbath 1974). Eucalypts often occur in mixtures in natural stands in Australia (Chilvers 1972, Hall et al 1970, Pryor 1953).

Many species from the two largest subgenera of the eucalypts (Pryor and Johnson 1962), Monocalyptus and Symphyomyrtus have been grown on the bauxite pits in the N.J.F.. As has been found in many other exotic eucalypt plantings (King and Krugman 1980, Pryor 1953) the symphyomyrts tend to exhibit far better performance and survival than the monocalypts. In addition, Pittaway (1981) and Shea (1979) found the monocalyptus species they studied far more susceptible to P.c. than the symphyomyrtus species. E.maculata from the subgenes Corymbia is another promising species.

Until recently, most species selection for rehabilitation in the N.J.F. have been on a trial and error, emperical and often intuitive basis; species choice repeatedly revised on the basis of a rapid subjective estimation of the above ground vigour of existing plantations at a very early age. Such estimations of tree growth during early stages of tree development can yield no information on root development and soil occupation (Shea and McCormick 1975) and may not accurately indicate future survival, let alone future growth rates. Thus, the evaluation of the performance of introduced tree species before they reach maturity must be approached with caution (Bartle and Shea 1978). Spriggins et al (1979) stated that species selection tended to be based on previous performance and theoretical prediction, and rapidly revised as new information became available. As a result, the rehabilitated forest has emerged as a patchwork of species, some successful, many not, over the landscape.

Often species were adopted or disguarded on the basis of a "once off" trial. A species may have been shunned because it was tried once in 1964 and did not perform. As little attention has been given to selecting provenances and keeping provenance records of species planted on individual pits, we can only surmize that many of the species which failed and were rejected were raised from seed of a provenance in an environment completely at odds with that of the N.J.F.. This can indeed be demonstrated for some species. For example, E.camaldulensis is the most widespread member of its genus in Australia (Hillis 1966) and thrives in plantations throughout the world (Del Moral 1970, Pryor 1976), even in the most inhospitable environments such as untreated mine spoils (Onosode and Redhead 1973). Why then has it failed in the N.J.F.? Like most eucalypts, the performance of E.camaldulensis has been found to be extremely provenance dependent (Hillis 1966, Onosode and Redhead 1973, Sands 1981, Hart 1982, Moreshet 1981). Limited nursery records show that at least one provenance of E. camaldulensis tried in the early days in Western Australia rehabilitation was from a tropical area. As such it was adapted to a period of maximum rainfall coincident with the hottest months. Hence, a tree genetically adapted to a wet summer was introduced into a climate where, for the hottest 6 months of the year, it experienced only a fraction of the annual rainfall. Clearly a species should not be judged by the performance of seed from one provenance, especially where this provenance was chosen at random. Until recently, the importance of recognizing genotypic variation between different provenances of the one species has been ignored. Even now, rather than being based on the best provenance possible, seed selections tend to be limited to whatever provenance happens to be in good supply on the shelf at the present time. Although the above practice may seem expedient, the enormous phenotypic variation between provenances of one species of eucalypt are such (Cameron 1981, Pryor 1972) that the additional expenditure and time delay necessary to secure seed from an optimal provenance are justified.

Bartle and Shea (1978) emphasized the importance of ensuring the environmental range of an introduced species is compatible with the N.J.F. environment, however the introduction of a species cannot procede with this information alone. The knowledge that a species has a range which extends into a environment similar to the N.J.F. is of no value, if the seed source obtained is from the provenance at the other end of its environmental range. Hence it is of the utmost importance that we not only match our species range with the target environment (Bennett 1970, Mooney 1974, Bartle 1978, and Sayn-Wittgenstein 1970), but also select provenances from the appropriate part of that range.

Although early successional species have broad overlapping niche occupation and are hence extremely adaptable, higher order plant species such as trees show far more niche differentiation (Parrish and Bazzaz 1982). Hence once we have selected our provenance of tree we must take care with its placement within the pit. Like the original forest (Florence 1982), pits too can contain a matrix of different ecological niches. If we are to ensure optimal placement of our selected tree stock within this pit environment, the new environment must be understood in terms of edaphic, topographic, climatic and biotic factors. Obviously, we cannot afford to carefully map a site for all of the above factors and then locate each individual tree to be planted on a pit. Hence, we must determine which site factors are limiting more important and match species accordingly (Jones 1969). It is also desirable to include wide diversity within each life form so that for each ecological response unit (set of different environmental and ecological conditions-Cook 1976), there is a range of species and genetic stock, some of which will be adapted to, and hence successful in this particular environment (Parrish and Bazzaz 1982, Bartle 1978).

SPECIES SELECTION AND FIRE.

If it is feasible (economically and in practicality) to exclude fire from a pit, we may choose to use more fire sensitive tree species. In less intensively managed multiple use forests, fire resistant mixtures of species would be preferable. Early bauxite rehabilitation in the N.J.F. consisted of such moderately fire sensitive monocultures. It was soon recognized that the cost of managing and maintaining such unnatural systems would be prohibitive over an extended period of time. Hence a more ecologically resilient mixture of tree species along with a diverse understorey was used from the late 1970's.

There is abundant evidence that fire is a natural component of the jarrah forest ecosystem (Wallace 1966, Hallam 1975).

Both the flora and fauna of that ecosystem are adapted to fire (Christensen and Kimber 1975). Hence, since we must expect and indeed encourage the occurrence of fire in the native forest adjacent to rehabilitated pits, we must be able to manage fire within the pits themselves and should chose our tree species appropriately. Many species have exacting fire requirements (Gill and Ingwersen 1976, Scotter 1972, Levyns 1966, Martin 1966, Hendrickson 1972, Specht et al 1958, Willis 1962, Garnet 1971, Gill and Groves 1981, Gill 1968, 1974, and 1981).

Fire intensity and bark thickness are the principle factors determining the severity of fire damage to an individual tree in any fire event (Gill 1981, McArthur 1962, 1967 and 1968, Chattaway 1953, Cremer 1962). Gill and Ashton (1968) revealed wide species variation for the penetration of bark by heat. Although many eucalypts regenerate after fire by the germination of seed (Shea et al 1979), successful regeneration after fire in a dry sclerophyl forest is primarily from lignotubers rather than seed (Christensen and Kimber 1975) due to a combination of factors including seed burn and dessication.

The deep root system of jarrah is based on an extended period as a lignotuber (Campbell 1956, Kimber 1974, Florence 1982); a trait which appears well adapted to the local environment. Some Eucalypt species, although they have the ability to develop rapidly on the bauxite pits (e.g. E.diversicolor), lack lignotubers (Gill 1975). Hence the early performed merits of such species must be carefully evaluated in the light of the cost of intensive fire protection requirements.

Many fire resistant eucalyptus species respond to even a mild fire by producing copious epicormic shoots throughout the bole (Jacobs 1955, Cremer 1972). The epicormic knob beneath each of these shoots causes considerable timber degrade (Jacobs 1955). If it is intended to impose a burning regime in rehabilitation, and if some degree of commercial timber production is proposed from rehabilitation (however so distant) it should be ensured that such species are excluded from rehabilitation.

Tolerance to fire is the result of-

a) resistance to the fire and
b) recovery from the fire
(Gill and Ashton 1968).

However, when screening species for rehabilitation, we must consider more than the ability of an individual tree to survive one fire event. A third measure of fire tolerance should be added, mainly the ability to repeat recovery over a series of fires and throughout the life of the tree. For example, in many species of eucalypts, lignotubers appear to become ineffective as growth continues through maturity (Gill 1975). Similarly, Gill (1975) informs us that bark recovery varies with tree age. If damaged bark is not fully recovered before the onset of another fire, damage to woody tissue shall be far more severe and, depending on species, recovery of bark after fire can take from as little as 3 years (for smooth barks - Jacobs 1955) to 20 years (for stringy bark - Wallace 1966). Changes in fire intensities and frequency can thereby cause major changes in the species composition of Australian native vegetation (Floyd 1966).

Hence when concocting "melting pot" of plant species, we should ensure that the mix of species is compatible with the fire regime we intend to use. For convenience, this regime should be similar to that of the surrounding forest.

SPECIES SELECTION AND HYDROLOGY

As mentioned previously, the hydrological aims of rehabilitation in the high rainfall west are completely different from those in the low rainfall, potentially high salt discharge east. Because of its value as a water resource, the western rehabilitation should not unduly deplete this water resource. As such, the choice of tall, dense forest species would seem inappropriate for the rehabilitation of this area as transpirational water losses would be great. Some species (e.g. E.maculata) are purported to be of good form when planted in sparse stands. More research and appropriate field trials are required on such species. The use of woodland species in the west has also been suggested. Hydrologically, it would appear that they should be ideal being of low leaf area and transpirational capacity. However, consider the usefullness of a woodland-based rehabilitation system in the light of the following points exogenous nutrient inputs into mining rehabilitation throughout the world follow a similar pattern. The initial injections of nutrients are massive in terms of dose and regularity, the majority of nutrients being applied in the first five years of growth. If the ecological vegetation type is such that the individuals are widely spaced, and/or root occupation of the upper layers of soil in the early stages is very limited, then an extremely large proportion of the applied nutrients will escape this plant community. Eventually, when the organization responsible for the rehabilitation ceases its operations in the area, nutrient application cease. From that point on the plant community has to rely on the recycling of whatever nutrients it has managed to capture in those early years for the further development and perpetuation of its various vegetational components. Woodland ecological systems are, by their nature, extremely sparse, slow to develop and have an extremely slow turnover of organic matter and hence nutrients (Charley and Cowling 1968, Bevege 1978). Hence if a woodland is required on a pit it should be aimed for in the long term only. Initially a temporary ecosystem should be produced which is more dense, develops more quickly and can more readily capture and cycle the nutrients applied. The choice of a woodland community as the basis for a one step rehabilitation programme amounts to the forfeiture of site potential.

The species choice for the rehabilitation of the east is governed by concepts quite removed from those of the west. The ideal replacement species in the east would act hydrologically very similarly to jarrah i.e. in order to survive it must not close down transpiration during periods of moisture deficit in the upper soil profile, but rather gain its moisture from deep down in the soil profile. Some prospective species do appear to have a deep root system (e.g. E.maculata), but their performance falls far short of that of jarrah. Another possibility, although less satisfactory, would be the selection of a species which had sufficient leaf area and/or surface root system to intercept and dicipate that majority of incident water (by evapotranspiration) before the water soaks below its root zone. To date, most such species considered have been drought sensitive. We cannot afford to rely on one species for rehabilitation of the east, because in the case of a collapse of that vegetation, the unintercepted rain would quickly swell the ground water to dissolve and mobilize salt deposits higher in the soil profile, possibly causing the collapse of the surrounding vegetation which would in turn lead to the release of yet more salt, and so on.

A "dual-forest-type" system is under consideration for the rehabilitation of the eastern zone. This approach uses (as a temporary measure) a rapid-growth, high leaf area species (e.g. E.diversicolor to intercept and use a maximum of water in the early years of rehabilitation), undersown by and understorey of slower-growing, more deeply rooted species which would subsequently replace the temporary, faster-growing, species. During 1977 a programme of research was initiated into the diurnal and seasonal fluctuations in xylem pressure potential and leaf diffusive resistance of eucalypt species to determine their suitability for rehabilitation, particularly of the eastern zone. The major difficulty in using this technique concerns ways of accounting for differences in canopy density (Bartle and Shea 1978).

The final species choice for the east shall be based on the hydrological species evaluations which are being performed throughout the N.J.F. by personnel from Forests Department, Alcoa, and the Metropolitan Water Board, as well as on the performance of species in the various arboreta, both established and planned, in the intermediate and low rainfall areas. In the search for suitable rehabilitation species for the east, large, retractible vapour sampling envelopes have been set up around single trees in the jarrah forest by John Bartle of the Western Australian Forests Department for the intensive measurement of whole-tree transpiration. Although the system has proved of insufficient resolution to quantify transpirative differences between species, it is extremely useful for comparing the transpiration patterns of prospective rehabilitation species with that of jarrah. Collection of the baseline data on jarrah transpiration patterns is well underway.

ADDITIONAL INFORMATION ON UNDERSTOREY COLLECTION AND ESTABLISHMENT

(See Also Sections on The Dieback Problem, Soil Handling and Nutrition)

The aim of rehabilitation should be to achieve a steady state of litter production, water use, litter fall and nutrient cycling. True succession always tends towards this (Bellefleur 1981). The aims of the ecosystem manager should be to maintain the fluency of ecological processes wherever possible (Webb 1970). In a vegetational monoculture, perturbations in litterfall, soil moisture and soil temperature are accentuated and readily cause changes in structure of soil biota, making the attainment of this steady state quite impossible. The role of the understorey in evening out the litterfall and hence reducing nutrient perturbation caused by the seasonality of tree litterfall and exogenious injections of nutrients has already been mentioned. Many studies have highlighted the importance of encouraging a diverse community of micr-organisms (Jehne and Thompson 1981, Balicka and Sobieszczanski 1964, Trappe pers.comm., Harvey et al 1981, Cundell 1977, Lee et al 1981) and larger invertebrates (Birk 1979, Majer 1978 and 1980, Berg 1975, Kabay and Nichols 1980, Kabbay and Nichols 1980) for the establishment and maintenance of soil building and nutrient cycling processes. The understorey mix should be sufficiently diverse so as to encourage maximum diversity in the soil biota.

To a large degree, understorey species choice has been governed by the presence of P.c. which has the ability to destroy not only jarrah, but man understorey species (Titze and Palzer 1969). Some other understorey species enhance the spread and infectivity of P.c.. Native species have been most commonly used in rehabilitation owing to the ease with which their seed is collected (Shea and Kitt 1976). Proteaceous natives are avoided as they tend to provide an opportunity for the survival and spread of P.c. (Shea and Hopkins 1973, Shea and Malajczuk 1977). Current species mixes include a wide variety of leguminous natives. Legumes have been found most favourable for the control of phytophthora (Shea 1979). Further information on the influence of P.c. on the choice of understorey species has been already discussed in the section on "The Dieback Problem".

Understorey seed must be sown in early winter. At this time, ant and bird predation of the seed is low, and the seed has a long time to establish before the onset of dry soil conditions (Bartle et al 1978). Because competition from dense understorey could affect the survival and growth of eucalypts (Cunningham and Cramer 1965 and Floyd 1966), current thinking favours the seeding of understorey species along with the planting of eucalypt species. However, where direct seeding of eucalypts has been carried out concurrently with the seeding of the understorey experimentally in the N.J.F., development of the eucalypt has been quite satisfactory, a good example being the "Jungle Plot" at Jarrahdale where, at one point, seeded eucalypts are growing clear of the exceptionally dense understorey.

CONCLUSION

This report has outlined the more important problems inherent in ecosystem establishment and how they relate to bauxite mining in the Northern Jarrah Forest of Western Australia. By critically reviewing local research to date and drawing on international experience and knowledge in broader ecological process studies, possible solutions to these problems have been discussed.

We are now at the point where only a small percentage of the more pressing problems have been resolved satisfactorily, despite the fact that mining has been progressing for the past two decades. Over that period, the prescription for ecosystem establishment has evolved with research findings. The offsping of the "shotgun" marriage between extremely urgent applied research and ongoing, ever accellerating mining is thousands of hecatares of rehabilitated forest consisting of a patchwork of ages, different landscaping, nutritional and biological treatments and containing a multitude of overstorey species sometimes in monoculture, often in one of many possible species-mix permutations.

The management problems posed by such a conglomeration are profoundly complex.

A future report shall consider these management problems and the ecological basis behind both them and their possible solutions. Research into this area has only just begun.

BIBLIOGRAPHY

Alcoa (1978). Wagerup alumina project. E.R.M.P. Alcoa of Australia.

Alexander, M. (1965). Microbial ecology. John Wiley and Sons, New York: 424-429.

Alexander, R., Croft, K.D., Kagi, R.I., and Shea, S. (1978). Saponins of Acacia pulchella. Aust. J. Chem., Vol. 31: 2741-2744.

Allen, S.E., Hunt, C.M. and Terman, G.L. (1971a). Nitrogen release from sulfur-coated urea, as affected by coating weight, placement, and temperature. Agron. J. 63: 529-533.

Alston, R.M. (1972). Forest goal and decision-making in the Forest Service. USDA For. Service Inter-mountain For. and Range Exp. Sta. Res. Rep. INT-128.

Ashton, D.H. (1975). Studies of litter in Eucalyptus regnans forests. Australian Journal of Botany 23: 413-434.

Ashton, D.H. (1975b). The root and shoot development of Eucalyptus regnans. F. Muell. Aust. J. Bot. 23: 867-887.

Attiwill, P.M. (1968). The loss of elements from decomposing litter. Ecology 49: 142-145.

Attiwill, P.M. (1980). Nutrient cycling in a Eucalyptus obliqua forest. IV. Nutrient uptake and nutrient return. Aust. J. Bot. 28(2): 199-222.

Attiwill, P.M. (1981). Energy, nutrient flow and biomass. Aust. For. Counc. 1981 Nutrition Workshop: 131-144.

Attiwill, P.M., Baker, T.G. and Adams, M.A. (1981). In "Managing the Nitrogen Economies of Natural and Man-Made Forest Ecosystems" CSIRO Div. L.R.M. (Rummery and Hingston (Eds)).

Attiwill, P.M., Guthrie, H.B. and Leuning, R. (1978). Nutrient cycling in a Eucalyptus obliqua (L'Herrit) forest. 1. Litter production and nutrient return. Aust. J. Bot. 26: 79-91.

Baker, T.G. and Attiwill, P.M. (1981). Nitrogen in Australian eucalypt forests. Aust. For. Counc. Nutrition Workshop: 159-172.

Balicka, N. and Sobieszczanski, J. (1964). The role of the microflora in reclaiming waste land after coal mining in Turoszov. Reczn. Naukro In Ser. A. 88A: 711-722.

Barrow, N.J. (1979). Soil development after mining. In: Proceedings of Australian Mining Industry Council 1979 Environmental Workshop, Bunbury, September 1979.

Bartle, J. (1976). Rehabilitation of the Seldom Seen Catchment, Jarrahdale. A Project 5 Report, Dwellingup Res. Sta., W.A. Forests Department.

Bartle, J.R. (1978). Choosing trees for specific purposes. Proc. Workshop. Integ. Ag. and For. 1977.

Bartle, J.R., McCormick, J. and Shea, S.R. (1978). Direct seeding of native species – a technique for revegetation of disturbed jarrah (Eucalyptus marginata Sm.) forest.

Bartle, J.R., and Shea, S.R. (1978). Selection of tree species for rehabilitation of degraded areas in the northern jarrah forest. Proceedings: Rehabilitation of Mined Lands in Western Australia. Perth, 11th October, 1978.

Bartle, J.R. and Shea, S.R. (1979). Development of the ecosystem after mining. Forests Department Reprint No. 19.

Batini, F.E., Black, R.E., Byrne, J. and Clifford, P.J. (1980). An examination of the effects of changes in catchment condition on water yield in the Wungong catchment, W.A. Aust. For. Res. 10: 29-38.

Batini, F.E., Selkirk, A.B. and Hatch, A.B. (1976). Salt content of soil profiles in the Helena Catchment, Western Australia. For. Dept. W.A. Res. Pap. No. 23.

Bendle, N.C.W. (1962). Soil phosphate and the delimitation of plant communities in Eastern Australia. II. Ecology 43: 281-288.

Bellefleur, P. (1981). Markov models of forest-type secondary succession in coastal British Columbia. Canadian Journal of Forest Research 11(1): 18-29.

Bengston, G.W., Allen, S.E., Mays, D.A. and Zarger, T.G. (1973). Use of fertilizers to speed pine establishment on reclaimed coal-mine spoil. I. Greenhouse experiments. Ecol. and Reclam. of Devastated Land (Hutnik & Davis (Eds)).

Bennett, E. (1970). Tactics of plant exploration. In 'Genetic Resources in Plants'. I.B.P. Handbook No. 11. (Eds. O.H. Frankel and E. Bennett.) (Blackwell: Oxford).

Berg, R.Y. (1975). Myrmecochorous plants in Australia and their dispersal by ants. Aust. J. Bot. 23: 475-508.

Bestow, T.T. (1976). The effects of bauxite mining at Del Park on groundwater hydrology. Geol. Survey of W.A. Ann. Rept. 1975: 13-31.

Bettenay, E., Blackmore, A.V. and Hingston, F.J. (1964). Aspects of the hydrologic cycle and related salinity in the Belka valley, Western Australia. Aust. J. Soil Res., 2: 187-210.

Bettenay, E. and Mulcahy, M.J. (1972). Soil and landscape studies in Western Australia (2). Valley form and surface features of the south-west drainage division. J. Geol. Soc. Aust., 18: 4.

Bevege, D.I. (1978). Biomass and nutrient distribution in indigenous forest ecosystems. Queensl. Dept. For. Tech. Paper 6.

Birk, E.M. (1979). Disappearance of overstorey and understorey litter in an open eucalypt forest. Aust. J. Ecol. 4: 207-222.

Birk, E.M. (1979b). Overstorey and understorey litterfall in a eucalypt forest: spatial and temporal variability. Aust. J. Bot. 27: 145-156.

Bowen, G.D., Skinner, M.F. and Bevege, D.I. (1974). Zinc uptake by mycorrhizal and uninfected roots of Pinus radiata and Araucaria cunninghamii. Soil Biol. Biochem. 6: 141-144.

Branson, F.A. (1975). Natural and modified plant communities as related to runoff and sediment yields. Ecol. Studies 10. Coupling of Land and Water Systems, A.D. Hasler (Ed).

Bray, J.R. and Gorham, E. (1964). Litter production in forests of the world. Advances in Ecological Research 2: 101-157.

Burvill, G.H. (1947). Soil salinity in the agricultural areas of Western Australia. Aust. Inst. Agr. Sc. Jour., 13: 9-19.

Cameron, D.M. (1981). Influence of nutrition and provenance on growth of young eucalypts in south-eastern Queensland. Aust. For. Counc. Nutrition Workshop.

Campbell, J.B. (1956). Behaviour of a jarrah lignotuber. Institute of Foresters of Australia Newsletter 16: 2-3.

Carrol, E.J. and Ashton, D.H. (1965). Seed storage in several Victoria plant communities. Victorian Naturalist 82: 102-110.

Chadwick, M.J. (1973). Amendment trials of coal spoil in the north of England. Ecol. and Reclam. of Devastated Land (Hutnik and Davis (Eds)).

Chang, S.J. and Buongiorno, J. (1981). A programming model for multiple use of forestry. J. Environ. Mgmt. 13(1): 41-54.

Charley, J.L. (1981). Soil as a nutrient reservoir and buffer system. Aust. F.C.: 13-27.

Charley, J.L. and Cowling, S.W. (1968). Changes in soil nutrient status resulting from overgrazing and their consequences in plant communities of semi arid areas. Proc. Ecol. Soc. Aust. 3: 28-38.

Charley, J.L. and Ward, S.C. (1981). Plant-induced chemical patterns. Aust. For. Counc. Nutrition Workshop.

Chattaway, M.M. (1952). More about (Eucalyptus) bark. For. Prod. News Lett. C.S.I.R.O. Aust. No. 192.

Chilvers, G.A. (1972). Tree root pattern in a mixed eucalypt forest. Aust. J. Bot. 20: 229-234.

Chilvers, G.A. and Pryor, L.D. (1965). The structure of eucalypt mycorrhizas. Aust. J. Bot. 13: 245-249.

Christensen, P. (1975). Jarrah dieback, soil temperature and soil moisture regimes of some southern forest types. W.A. Forests Department Bulletin 88.

Christensen, P. and Kimber, P.C. (1975). Effects of prescribed burning on the flora and fauna of S.W. Australian forests. In: Managing Terrestrial Ecosystems. Kikkawa & Nix (Eds). Proc. Ecol. Soc. Aust. 9.

Coleman, D.C. (1976). In: 'The Role of Terrestrial and Aquatic Organisms in Decomposition Processes', eds. J.M. Anderson and A. Macfadyen: 417-434.

Coleman, N.T. and Thomas, G.W. (1967). The basic chemistry of soil acidity. In: Soil Acidity and Liming. Am. Soc. Agron. Pearson, R.W. & Adams, F. (Eds): 1-41.

Conacher, A.J. (1979). Water quality and forests in south western Australia. Aust. Geographer 14.

Cook, C.W. (1976). Surface mine rehabilitations in the American West. Environ. Conserv. 3: 179-183.

Cooper, J.P. (1970). Environmental physiology. In: 'Genetic Resources, in Genetic Resources in Plants – their exploration and conservation'. Frankel, O.H. & Bennett, E. (Eds).

Cremer, K.W. (1962). The effect of fire on eucalypts reserved for seeding. Aust. For. 26, No. 2: 129-154.

Cremer, K.W. (1972). Morphology and development of the primary and accessory buds of Eucalyptus regnans. Aust. J. of Botany 20(2): 175-195.

Chattaway, M.M. (1953). The anatomy of bark. I. The genus Eucalyptus. Aust. J. Bot. 1(2): 402-433.

Cundell, (1977). The role of microorganisms in the revegetation of strip-mined land in the western United States. J. Range Man. 30-4: 299-305.

Cunningham, T.M. and Cremer, K.W. (1965). Control of the understorey in wet eucalypt forests. Aust. For. 29: 4-14.

Dell, B. and Bartle, J.R. (1982). Root channels and root occupation of jarrah forest subsoils. In press.

Del Moral, R. and Muller, C.H. (1970). The allelopathic effects of Eucalyptus camaldulensis. The American Midland Naturalist, 83: 254-282.

Del Moral, R., Willis, R.J. and Ashton, D.H. (1978). Suppression of coastal heath vegetation by Eucalyptus baxteri. Australian Journal of Botany, 26: 203-219.

Dimmock, G.M., Bettenay, E. and Mulcahy, M.J. (1974). Salt content of lateritic profiles in the Darling Range W.A. Aust. J. Soil Res. 12: 63-69.

Doley, D. (1967). Water relations of Eucalyptus marginata Sm. under natural conditions. Ecology 55: 597-614.

Ellenberg, H. (1964). Stickstoff als Standortsfaktor, Ber. Dt. Bot. Ges. 77: 82-92.

Ellis, R.C. (1971). Growth of eucalyptus seedlings on four different soils. Australian Forestry, 35: 107-118.

Ettershank, G., Elkins, N.Z., Santos, P.F., Whitford, W.G., and Aldon, E.F. (1978). The use of termites and other soil fauna (micro-arthropods) to develop soils on strip mine spoils (in New Mexico). Res. Note, Rocky Mount. For. & Range Exp. Stat. USDA For. Serv. RM-361.

Feller, M.C. (1980). Biomass and nutrient distribution in two eucalypt forest ecosystems. Australian Journal of Ecology 5: 309-333.

Felton, K. (1976). Regeneration of cut-over areas of Tasmanian eucalypt forest. In: 'Woodchip Symposium Papers', 47th ANZAAS Congress, Hobart.

Ferrel, J. (1974). Vegetation rehabilitation for a limestone quarry. MS. Thesis, State Univ. NY, College of Environmental Science and Forestry, Syracuse, NY: 118pp.

Finch, P., Hayes, M.H.B. and Stacey, M. (1971). The biochemistry of soil polysaccharides. In: 'Soil Biochemistry', Vol. 2. McLaren, A.D. & Skyjins, J. (Eds): 258-319.

Florence, R.G. (1982). The Australian forests. Application of Vegetation Science, Jahn (Ed).

Floyd, A.G. (1962). Investigations into the natural regeneration of blackbutt E.pilularis. Div. For. Mgmt., For. Comm. NSW Res Note No. 10.

Floyd, A.G. (1966). Effect of fire upon weed seeds in the wet sclerophyll forest of northern N.S.W. Aust. J. Bot. 14: 143-156.

Floyd, A.G. (1976). Effect of burning on regeneration from seeds in wet sclerophyll forest. Aust. For. 39: 210-220.

Fogel, R. (1976). Can. J. Bot. 54: 1152-1162.

Fox, J.E.D., Majer, J.D., Sandford, P., Day, J.E. and Glossop, B.L. (1982). Plant species successfully recolonising rehabilitated bauxite mines. Mulga Research Centre (W.A.I.T.) Annual Report.

Foy, C.D. and Brown, J.C. (1964). Toxic factors in acid soils. 2. Differential aluminium tolerance of plant species. Proc. Soil Sci. Soc. Am. 28: 27-32.

Garnet, J.R. (1971). The Wildflowers of Wilson's Promontory National Park. Lothiam Publ. Co. and Field Naturalists Club of Victoria, Melbourne, Vic., 192 pp.

Garrels, R.M. and Christ, C.L. (1965). Solutions, minerals and equilibria. Freeman, Cooper & Co., San Francisco, CA.

Gilkes, R.J., Scholz, G. and Dimmock, G.M. (1973). Lateritic deep weathering of granite. Journal of Soil Science, 24: 523-536.

Gill, A.M. (1974). Towards an understanding of fire-scar formation: field observation and laboratory simulation. Forest Sci. 20: 198-205.

Gill, A.M. (1975). Fire and the Australian flora: a review. Aust. For., 38: 4-25.

Gill, A.M. and Ashton, D.H. (1968). The role of bark type in relative tolerance to fire of three Central Victorian eucalypts. Aust. J. Bot. 16: 491-498.

Gill, A.M. and Groves, R.H. (1981). Fire regimes in heathlands and their plant-ecological effects. Heathlands & Related Shrublands of the World. Specht, R. (Ed): 61-83.

Gill, A.M., Groves, R.H., and Noble, I.R. (1981). Fire and the Australian biota. Canberra, Australia; Australian Academy of Science. viii + 582.

Gill, A.M. and Ingwersen, F. (1976). Growth of Xanthorrhoea australis R.Br. in relation to fire. J. Appl. Ecol., 13: 195-203.

Glossop, B.L. (1981). Assessment of the floral composition achieved by two topsoil handling techniques used for rehabilitation of bauxite mined areas - preliminary study. Alcoa of Aust. Env. Res. Bul. No. 11.

Glossop, B.L., Bell, T. and Shea, S.R. (1980). Changes in the nitrogen and phosphorus levels in foliage and connecting branches of jarrah after intense fire. Aust. For. Res. 10: 105-111.

Gray, T.R.G. and Williams, S.T. (1971). Soil microorganisms. Longman, London. p. 240.

Gray, T.R.G. and Williams, S.T. (1971). In: Symposia of the Society for General Microbiology, No. XXI: 255-286.

Grier, C.C. and Logan, R.S. (1977). Old growth Pseudotsuga menziesii communities of a western Oregon watershed. Ecol. Monographs 47: 373-400.

Grieve, B.J. (1955). Studies in the water relations of plants. I. Transpiration of Western Australian (Swan Plain) Sclerophylls. J. Roy. Soc. West. Aust. 40: 15-30.

Groves, R.H. (1968). Physiology of sclerophyll shrubs in southeastern Australia. Proc. Ecol. Soc. Aust., 3: 40-45.

Hall, N., Johnston, R.D. and Chippendale, G.M. (1975). Forest trees of Australia. Aust. For. & Timb. Bureau, A.C.T.; A.G.P.S. 334pp.

Hallam, S.J. (1975). Fire and Hearth. Australian Institute of Aboriginal Studies, Canberra, Australia.

Halsall, D.M., and Forrester, A.I. (1977). Effects of certain cations on the formation and infectivity of Phytophthora zoospores. I. Effects of calcium, magnesium, potassium and iron ions. Can. J. Microbiol., Vol. 23: 994-1001.

Hannon, N.J. (1956). The status of nitrogen in the Hawkesbury sandstone soils and their plant communities in the Sydney district. I. The significance and level of nitrogen. Proc. Linn. Soc. NSW. 81(2): 119-143.

Harper, J.L. (1977). Population biology of plants. Academic Press, New York, USA.

Harris, J.A. (1978). Land rehabilitation after bauxite mining in the northern jarrah forest (Darling Range) of Western Australia. Unpublished Report, CCAE, Canberra.

Hart, A.J. (1982). 10 year results of river red gum (E. camaldulensis) provenance trials at 6 localities in agricultural areas. Forests Dept. Paper (Internal).

Harvey, P. (1966). A preliminary microbial study of Crown Mines "A" Sand Dump. Booysens. Johannesburg. B. Sc. (Honours) Thesis, Univ. of the Witwatersrand.

Harvey, A.E., Jurgensen, M.F. and Larsen, M.J. (1978). Seasonal distribution of ectomycorrhizae in a mature Douglas-fir - larch soil in western Montana. For. Sci. 24(2): 203-208.

Harvey, A.E., Larsen, M.J. and Jurgensen, M.F. (1976). Distribution of ectomycorrhizae in a mature Douglas-fir - larch forest soil in western Montana. For. Sci. 22(3): 393-398.

Harvey, A.E., Larsen, M.J. and Jurgensen, M.F. (1979). Comparative distribution of ectomycorrhizae in soils of three western Montana forest habitat types. For. Sci. 25(2): 350-358.

Harvey, A.E., Jurgensen, M.F. and Larsen, M.J. (1981). Organic reserves: importance to ectomycorrhizae in forest soils of western Montana. For. Sci. 27(3): 442-445.

Hatch, A.B. (1955). The influence of plant litter in the jarrah forest soils of the Dwellings region, Western Australia. Leafl. For. Bur. 70: 1-18.

Hatch, A.B. (1964). The interaction between forest floor dynamics and soil properties in Eucalyptus marginata Sm. forests. M. Sc. Thesis, Univ. Sydney.

Havel, J.J. (1975). Site vegetation mapping in the northern jarrah forest (Darling Range). I. Definition of site-vegetation types. F.D. of W.A. Bulletin No. 86. II. Location and mapping of site vegetation-types. F.D. of W.A. Bulletin No. 87. III. Relationship of site-vegetation types to land utilization. F.D. of W.A. Bulletin.

Havel, J.J. (1975b). The effects of water supply for the city Perth, Western Australia, on other forms of land use. J. of Landscape Planning, 2.

Havel, J.J. (1979). Identification of vulnerable communities and prediction of disease spread. Phytophthora and Forest Management in Australia.

Havel, J.J. and Sanders, C.C. (1974). Effects of bauxite mining in the Darling Range. Unpublished Inter-departmental Report.

Hendrickson, W.H. (1972). Perspective on fire and ecosystems in the United States. In: Fire in the Environment Symposium, Denver, U.S.D.A. For. Serv., Washington: 29-33.

Herbert, E.J., Shea, S.R. and Hatch, A.B. (1977). Salt content of lateritic profiles in the Yarragil catchment, Western Australia. For. Dept. W.A. Res. Pap. No. 32.

Heydecker, W. (ed) (1973). Seed Ecology. Butterworths, London.

Hill, J., Lambert, M.J. (1981). Physiology and management of micronutrients in forest trees in Australasia. CSIRO Div. For. Res. St. Lucia, QLD: 93-103.

Hillis, W.E. (1966). Variation in polyphenol composition within species of Eucalyptus L'Herit. Phytochemistry, 5: 541-556.

Hingston, F.J., Dimmock, G.M. and Turton, A.G. (1980). Nutrient distribution in a jarrah (Eucalyptus marginata Donn ex Sm) ecosystem in south-west Western Australia. Forest Ecology and Management 3: 183-207.

Hingston, F.J., Turton, A.G. and Dimmock, G.M. (1979). Nutrient distribution in karri (E.diversicolor) ecosystems in south-west Western Australia. For. Ecol. Manag. 2: 133-158.

Hofmann, W. (1968). Vitalität der Rotbuche und Klima in Mainfranken. Feddes Repertorium 78, 1-3,pp. 135-137, Berlin.

Howard, R.A. and Proctor, G.R. (1957). The vegetation on bauxitic soils in Jamaica. J. Arnold Arbor. 38: 1-41.

Hunter, G.D. (1973). Revegetation of mine wastes at Mt. Isa, Qld. Msc, Univ. Qld.

Hunter, F. and Currie, J.A. (1956). Structural changes during bulk soil storage. Journal of Soil Science, 7: 75-80.

Jackson, W.A. (1967). Physiological effects of soil acidity. In: Soil Acidity and Liming, Pearson, R.W. and Adams, F. (Eds). Am. Soc. Agron., Madison, Wis.: 43-124.

Jacobs, M.R. (1955). Growth Habits of the Eucalypts. Government Printer, Canberra.

Jahn, G. (1972). Forstliche Wuchraumgliederung und waldbauliche Rahmenplanung in der Nordeifel. Dissertationes Botanicae Bd. 16, Lehre.

Jehne, W. and Thompson, C.H. (1981). Endo-mycorrhizas in rainforests and woodlands at Cooloola, Queensland. Aust. For. Council Nutrition Workshop (Proceedings).

Jones, J.R. (1969). Review and comparison of site evaluation methods. U.S. For. Serv. Res. Pap. Rocky Mt. For. Range Exp. Sta. No. RM-51.

Jordan, C.F., and Kline, J.R. (1972). Mineral cycling: some basic concepts and their application in a tropical rain forest. Annual Review of Ecology and Systematics 3: 33-50.

Kabay, E.D. and Nichols, O.G. (1980). The use of rehabilitated mine areas in the jarrah forest by vertebrate fauna. Alcoa of Aust. Env. Res. Bulletin No. 18.

Kassaby, F.J., Fagg, P.C. and Marks, G.C. (1977). Survival in, and colonisation of, mountain forest soil by Phytophthora cinnamomi Rands in eastern Victoria. Aust. For. Res. Vol. 7: 173-183.

Kaul, O.N., Srivastava, P.B.L. and Bora, N.K.S. (1966). Nutrition studies on Eucalyptus. 1. Diagnosis of mineral deficiencies in Eucalyptus hybrid seedlings.. Indian Forester 92: 264-268.

Keast, D. and Walsh, K.G. (1979). Passage and survival of chlamydospores of Phytophthora cinnamomi Rands, the causal agent of forest dieback disease, through the gastrointestinal tracts of termites and wild birds. Applied and Environmental Microbiology 37(3): 661-664.

Kimber, P.C. (1974). The root system of jarrah (Eucalyptus marginata Sm). Forests Department of Western Australia Research Paper 10.

King, J.P. and Krugman, S.L. (1980). Tests of 36 Eucalyptus species in northern California. USDA Res. Pap. S.W. For. Range Exp. Stat. PSW-152.

Kirton, D.J. (1982). The effects of time on the plant availability of fertilizer phosphorous. Unpublished M.Sc. Thesis. Univ. of W.A.

Koch, J.M. (1980). Broadcast seeding trials at Collie, W.A. Landline 3.

Kropp, B.R. (1982). Rotten wood as mycorrhizal inoculum for containerized western hemlock. Can. J. For. Res. 12(2).

Lamb, D. (1976). Variations in the foliar concentrations of macro and micro elements in a fast-growing tropical eucalypt. Plant Soil 45: 477-492.

Lambert, M.J. (1981). Inorganic constituents in wood and bark of N.S.W. forest tree species. For. Comm. N.S.W. Res. Note. No. 45.

Lee, K.E. and Correll, R.L. (1978). Litter fall and its relationship to nutrient cycling in a South Australian dry sclerophyll forest. Aust. J. Ecol. 3: 243-252.

Lee, K.E., Warcup, J.H. and Hutson, B.R. (1981). The soil biota. Aust. F.C.: 65-78.

Levyns, M.R. (1966). Haemanthus canaliculatus, a new fire-lily from the Western Province. J.S. Afri. Bot. 32: 73-75.

Limstrom, G. (1960). Forestation of strip-mined land in the Central States. U.S. Dep. Agr., Forest Service, Agr. Handbook 166. 77 p.

Lowe, G.P.W. (1979). The value of the Murray River as a water resource. In: Water Resources and Land Management Issues in the Darling Range. F.D. Workshop, Sept. 1979.

Logan, R.S. and Grier, C.C. (1977). Old-growth Pseudotsuga menziesii communities of a western Oregon watershed: biomass distribution and production budgets. Ecological Monographs 47(4): 373-400.

McArthur, A.G. (1962). Controlled burning in eucalypt forests. Comm. Aust. For. Timb. Bur. Leaflet No. 80.

McArthur, A.G. (1967). The influence of fire on the productivity of hardwood forests in Australia. Aust. For. Res. 3: 24-35.

McArthur, A.G. (1968). The fire resistance of eucalypts. Proc. Ecol. Soc. Aust. 3: 83-90.

McColl, J.G. (1966). Soil plant relationships in a Eucalyptus forest on the south coast of N.S.W. Ecology 50: 355-362.

McColl, J.G. (1969). Soil plant relationships in a Eucalyptus forest on the south coast of N.S.W. Ecology 50: 354-362.

McColl, J.G. and Humphreys, F.R. (1967). Relationships between some nutritional factors and the distribution of Eucalyptus gummifera and E.maculata. Ecology 48: 706-771.

McGrath, J.F. (1978). Phosphate and zinc nutrition of young P.radiata D. Don in the Donnybrook sunkland. Res. Paper 34. Forests Dept. W.A.

McLean, E.O. (1976). Chemistry of soil aluminium. Commun. Soil Sci. Plant Anal. 7: 619-636.

Majer, J.D. (1978). The ecology of ants in relation to bauxite mine rehabilitation. Bull. Ecol. Soc. Aust. 8, 9.

Majer, J.D. (1980). A preliminary ecological survey of the Wagerup ant fauna. Alcoa of Aust. Res. Bull. No. 7.

Maldague, M.E. (1970). The role of soil fauna in the fertility of forest soils. Pub. Inst. Nat. Etude. Agron. Congo (Ser. Sci. 112: 245 pp).

Marks, G.C., Kassaby, F.Y. and Reynolds, S.T. (1972). Dieback in the mixed hardwood forests of eastern Victoria: Preliminary Report. Aust. J. Bot. Vol. 20: 141-154.

Martin, A.R.H. (1966). The plant ecology of the Grahamstown Nature Reserve. II. Some effects of burning. J.S. Afr. Bot. 32: 1-39.

Martinick, W.G. (1976). Basic considerations in vegetating areas affected by mining activities: In: Aus. I.M.M. Landscaping and Land Use Planning as Related to Mining Operations. Aus. I.M.M. Parkville, Vic.

Marx, D.H. (1967). The role of ectotrophic mycorrhizal fungi in the resistance of pine roots to infection by Phytophthora cinnamomi Rands. Diss. Abstr. 27(6)B. (Univ. N. Carol., Raleigh), Abstract: R.A.M., Vol. 46(1): 558.

Marx, D.H. (1972). Ectomycorrhizae as biological deterrents to pathogenic root infections. Annual Review of Phytopathology, Vol. 10: 429-454.

Marx, D.H. and Davey, G.B. (1967). Ectotrophic mycorrhizae as deterrents to pathogenic root infections. Nature, Vol. 213, No. 5081.

Meakins, J. (1966). The effect of understorey species on soil properties under mountain eucalypts. B.Sc.For. (Hons) Thesis, Aust. Nat. Univ. 68 pp.

Meyer, L.D., Wischmeier, W.H. and Foster, G.R. (1970). Mulch rates required for erosion control on steep slopes. Soil Sci. Soc. Amer. Proc. 34: 928-931.

Miller, H.G. (1981). Mineral cycling studies at the Macaulay Institute for soil research. Aust. For. Counc. Nutrition Workshop.

Miller, R.W. and Cameron, R.E. (1976). Some effects on soil microbiota of topsoil storage during surface mining. Coal Conference, St. Louis, Missouri, Argonne Nat. Lab. Illinois.

Mooney, H.A. (1974). Plant forms in relation to environment. In: Handbook of Vegetation Science: Part 6, Vegetation and Environment. Strain, B.R. and Billings, W.D. (Eds).

Moore, C.W.E. (1961). Competition between Eucalyptus melliodora and E.rossii at varying levels of exchangeable calcium. Aust. J. Bot. 9(1): 92-97.

Moreshet, S. (1981). Physiological activity in a semi-arid environment of Eucalyptus camaldulensis Dehn. from 2 provenances. Aust. J. Bot. 29(1): 11-16.

Morgan, G.W. (1974). Crop productivity as affected by depths of topsoil spread for reclaiming bauxite-mined lands in Jamaica. Trop. Agric. (Trinidad) Vol. 51(2).

Mulcahy, M.J. (1960). Laterites and lateritic soils in south-western Australia. J. Soil Sci. 11: 206-225.

Mulcahy, M.J., Bettenay, E., Churchward, H.M., Hingston, F.J., Peck, A.J. and Williamson, D.R. (1973). Study of Western Australian salinity problems. A preliminary report for A.W.R.C. Research Project 71/71. C.S.I.R.O. Div. of Soils, Perth.

Newbould, P.J. (1967). Methods for estimating the primary production of forests. IBP Handbook No. 2.

O'Connell, A.M. , Grove, T.S. and Dimmock, G.M. (1978). Nutrients in the litter on jarrah forest soils. Aust. J. Ecol. 3: 253-260.

Olsen, D.P. (1980). Utilisation of woodwaste materials as weed-free mulches. Alcoa of Aust. Env. Res. Note No. 5.

Onosode, A.T. and Redhead, J.F. (1973). The reclamation of land devastated by tin mining on the Jos Plateau, Nigeria. Ecol. and Reclam. of Devastated Land. Hutnik and Davis (Eds).

Otchere-Boateng, J. and Ballard, T.M. (1981). Effect of urea fertilizer on leaching of micronutrient metals and aluminium from forest soil columns. Canadian Journal of Forest Research 11(4): 763-767.

Ovington, J.D. (1962). Quantitative ecology and the woodland ecosystem concept. Adv. Ecol. Res. 1: 103-192.

Parrish, J.A.D. and Bazzaz, F.A. (1979). Differences in pollination niche relationship in early and late successional plant communities. Ecology 60: 597-610.

Parrish, J.A.D. and Bazzaz, F.A. (1982). Competitive interactions in plant communities of different successional ages. Ecology 63(2): 314-320.

Parsons, R.F. and Specht, R.L. (1967). Lime chlorosis and other factors affecting the distribution of Eucalyptus on coastal sands in southern Australia. Aust. J. Bot. 15(1).

Peck, A.J. (1978). Salinization of non-irrigated soils and associated streams; a review. Aust. J. Soil. Res. 16: 157-168.

Peck, A.J. and Hurle, D.H. (1972). Chloride balance of some farmed and forested catchments in southwestern Australia. Wat. Resour. Res., 9(3): 648-657.

Pittaway, P. (1981). Plant growth analysis of three eucalyptus species growing in contrasting soil types. Aust. For. Counc. Nutrition Workshop (Proc.).

Plass, W.T. (1968). Tree survival and growth on Fescue - covered spoil banks. U.S. For. Serv. Res. Note NE-90.

Plucknett, D.L. (1961). Root growth in bauxite soils. Hawaii Fm Sci. 10: 8-9.

Podger, F.D. (1968). Aetiology of jarrah dieback. M.Sc.For. Thesis, Univ. of Melbourne: 292 pp.

Podger, F.D. (1972). Phytophthora cinnamomi, a cause of lethal disease in indigenous plant communities in Western Australia. Phytopath. 62: 972-991.

Podger, F.D. and Batini, F. (1971). Susceptibility to Phytophthora cinnamomi root rot of thirty-six species of Eucalyptus. Aust. For. Res. 5: 9-20.

Pook, E.W., Costin, A.B. and Moore, C.W.E. (1966). Water stress in native vegetation during the drought of 1965. Aust. J. Bot. 14: 257-267.

Powell, C. (1976). Mycorrhizal fungi stimulate clover growth in New Zealand hill country soils. Nature 264: 436-438.

Pratt, B.H. and Heather, W.A. (1972). A method for rapid differentiation of Phytophthora cinnamomi from other Phytophthora species isolated from soil by lupin baiting. Trans. British Mycological Society 59(1): 87-96.

Pratt, B.H., Heather, W.A. and Shepherd, C.J. (1973). Recovery of Phytophthora cinnamomi from native vegetation in a remote area of New South Wales. Trans. British Mycological Society 60(2): 197-204.

Pressland, A.J. (1982). Litter production and decomposition from an overstorey of eucalyptus spp. on two catchments in the New England region of N.S.W. Aust. J. Ecol. 7: 171-180.

Prider, R.T. (1966). The laterized surface of Western Australia. Aust. J. Sci., 28: 443-451.

Pryor, L.D. (1953). Genetic control in Eucalyptus distribution. Proc. Linn. Soc. N.S.W. 78, 8.

Pryor, L.D. (1972). The selection of eucalypts for regeneration. Appita 26(1): 35-38.

Pryor, L.D. (1976). The biology of eucalypts. Inst. of Biology's Studies in Biology No. 61: 82 pp.

Pryor, L.D. and Johnson, L.A.S. (1962). The status and significance of the hybrid Eucalyptus marginata Sm. x E.megacarpa F. Muell. Aust. J. Bot. 10(2): 129-133.

Public Works Department, W.A. (1975). Streamflow records of Western Australia to 1975. Govt. Printer, Perth, W.A.

Public Works Department, W.A. (1977). Stream flow records of Western Australia to 1975.

Richards, B.N. (1981). Forest floor dynamics. Aust. For. Counc. Nutrition Workshop.

Riches, J.H.R. (1979). The effects of mining and rehabilitation on water quality and turbidity. Proc. Aust. Mining Industry Council Environ. Workshop.

Riley, C.V. (1973). Chemical alteration of new strip-mine spoils by furrow grading revegetation success. Ecol. and Reclam. of Devastated Land, Hutnik and Davis (Eds).

Ritson, P. and Shea, S.R. (1979). Increasing soil yield. In: Water Resources and Land Management Issues in the Darling Range, F.D. Workshop, Sept. 1979.

Rogers, R.W. and Westman, W.E. (1977). Seasonal nutrient dynamics of litter in a sub-tropical eucalypt forest, North Stradbroke Island. Australian Journal of Botany, 25: 47-58.

Rummery, R.A. and Howes, K.M.W. (1978). Management of lands affected by mining. CSIRO Div. Land Res. Man. Workshop.

Ruiter, J.H. (1969). Suspected copper deficiency in Radiata Pine. Plant and Soil 31: 197-200.

Sands, R. (1981). Salt resistance in Eucalyptus camaldulensis Dehn. from three different seed sources. Aust. For. Res.11(2).

Sayn-Wittgenstein, L. (1970). Patterns of spatial variation in forests and other natural populations. Pattern Recognition 2: 245-253.

Schwyzer, H.M. (1967). Plant ecology and microbiology of "A" Sand Dump, Crown mines. B. Sc. (Honours) Thesis, Univ. of the Witwatersrand.

Scotter, G.W. (1972). Fire as an ecological factor in boreal forest ecosystems of Canada. In: Fire in the Environment Symposium, Denver. USDA For. Serv.: 15-24.

Shea, S.R. (1975). Environmental factors of the northern jarrah forest in relation to pathogenicity and survival of Phytophthora cinnamomi. W.A. For. Dept. Bull. No. 85.

Shea, S.R. (1977). Environmental factors of the northern jarrah forest in relation to pathogenicity and survival of Phytophthora cinnamomi. For. Dept. W.A. Bull. No. 85.

Shea, S.R. (1979). Forest Management and Phytophthora cinnamomi in Australia. Proceedings, Phytophthora cinnamomi Workshop, C.S.I.R.O., Canberra (in press).

Shea, S.R. (1979). Jarrah dieback....possible means of control. In: Water Resources and Land Management Issues in the Darling Range, F.D. Workshop, Sept. 1979.

Shea, S.R. and Bartle, J.R. (1976). Rehabilitation of bauxite mine sites in the northern jarrah (Eucalyptus marginata) forest. In: Workshop on Land Use and Stream Salinity. C.S.I.R.O.

Shea, S.R. and Dillon, M.J. (1979). Rate of spread of Phytophthora cinnamomi in the Eucalyptus marginata forest. Research Paper (in press), Forests Department of Western Australia.

Shea, S.R., Hatch, A.B., Havel, J.J. and Ritson, P. (1975). The effect of changes in forest structure and composition on water quality and yield from the northern jarrah forest. In: Managing Terrestrial Ecosystems. Kikkawa, J. and Nix, H.A. (Eds). Proc. Ecol. Soc. Aust. 9.

Shea, S.R., Herbert, E.J. and Bartle, J.R. (1978). An ecological approach to the active management of jarrah forest catchments in the south-west of Western Australia. Proc. Hydrology Symposium, Canberra. Inst. of Engineers: 155-162.

Shea, S.R. and Hopkins, E.R. (1973). Environmental factors in relation to distribution, intensity and control of jarrah dieback. Paper presented to 45th ANZAAS Congress, Aug. 1973.

Shea, S.R. and Kitt, R.J. (1976). The capacity of jarrah forest native legumes to fix nitrogen. West. Aust. For. Dept. Res. Paper 21.

Shea, S.R. and Malajczuk, N. (1977). Potential for control of eucalypt dieback in Western Australia. Seminar Papers. Aust. Nurserymen's Assoc. Ltd., Ann. Conf.

Shea, S.R., Malajczuk, N. and Kitt, R.J. (1976). Promotion of understorey native legumes - a possible method of control of P.cinnamomi in the northern jarrah forest of W.A. Aust. Plant Pathol. Soc. Newsl. 5.

Shea, S.R. and McCormick, J. (1975). Bauxite mining rehabilitation in the Darling Ranges. Dwellingup Res. Sta., W.A. Forests Department.

Shea, S.R., McCormick, J. and Portlock, C.C. (1979). The effect of fires on regeneration of leguminous species in the northern jarrah (E.marginata Sm.) forest. Aust. J. Ecol. 4: 195-206.

Skaller, P.M. (1977). Plant colonization and soil development in the Jamesville Limestone Quarry. Ph.D. Thesis, State Univ. NY, College of Environmental Science and Forestry, Syracuse, NY, 211 pp.

Skaller, P.M. (1981). Vegetation management by minimal intervention: Working with succession. Landscape Planning 8: 149-174.

Skujins, J. (1973). Dehydrogenase: an indicator of biological activities in arid soils. In: Modern Methods in the Study of Microbial Ecology, Rosswall, T. (Ed): 235-243.

Specht, R.L. and Brouwer, Y.M. (1975). Seasonal shoot growth of Eucalyptus spp. in the Brisbane area of Queensaland (with notes on the shoot growth and litterfall in other areas of Australia). Australian Journal of Botany 23: 459-

Specht, R.L. and Groves, R.H. (1966). A comparison of the phosphorus nutrition of Australian heath plants and introduced economic plants. Aust. J. Bot. 14: 201-222.

Specht, R.L., Rayson, P. and Jackman, M.E. (1958). Dark Island Heath. VI. Pyric succession: changes in composition, coverage, dry weight, and mineral nutrient status. Aust. J. Bot. 6: 59-88.

Spriggins, D., Haswell, D., Van Kepple, P. and Bartle, J. (1979). Reforestation technique and species selection. In: Water Resources and Land Management Issues in the Darling Range, F.D. Workshop, Sept. 1979.

Spurr, S.H. and Barnes, B.V. (1973). Forest Ecology. (Ronald: New York).

Stace, H.C.T., Hubble, G.D., Brewer, R., Northcote, K.H., Sleeman, J.R., Mulcahy, M.J. and Hallsworth, E.G. (1968). A hand book of Australian Soils. Rellim, South Australia.

Stevens, T.R. and Walker, T.W. (1970). Chronosequence concept of soil formation. Quart. Rev. Biol. Vol. 43(4): 333-350.

Stewart, G.A., Mulcahy, M.J., Costin, A.B., Fleming, P.M., and Charles, A.W. (1972). Ecological effects of bauxite mining in the Darling Range of Western Australia. Report to the Executive of CSIRO. CSIRO, Canberra: 35 pp.

Stoate, T.N. (1950). Bull. No. 30. Forestry and Timber Bureau, Canberra.

Struthers, P.H. (1964). Chemical weathering of strip-mine spoils. Ohio J. Sci. 64: 125-131.

Tacey, W.H. (1978). Establishment of diversity of jarrah forest flora on bauxite mined areas. In: Rehabilitation of Mined Lands in Western Australia. WAIT.

Tacey, W.H. (1979). Landscaping and revegetation practices used in rehabilitation after bauxite mining in Western Australia. Reclamation Rev. 2: 123-132.

Tacey, W.H. (1979). Sub-soil preparation and nutrition effects on the early growth of five eucalyptus species. Alcoa of Aust. Env. Res. Bull. No. 4.

Tacey, W.H. and Glossop, B.L. (1979). Regeneration of understorey flora on bauxite mined areas. In: Proc. of Aust. Mining Industry Council, Environmental Workshop.

Tacey, W.H. and Glossop, B.L. (1980). Assessment of topsoil handling techniques for rehabilitation of sites mined for bauxite within the jarrah forest of Western Australia. J. Appl. Ecol. 17(1): 195-201.

Tiffin, P.D. (1972). In: Micronutrients in Agriculture. Mortvedt, P.M., Giordano, P.M. and Lindsay, W.L. (Eds): 199-229. Soil Soc. Am. Inc., Madison, Wis., U.S.A. 666pp.

Tinker, P.B.H. (1975). Effects of vesicular-arbuscular mycorrhizas on high plants. In: Symbiosis, Jennings, D.H. and Lee, D.L. (Eds): 325-350.

Titze, J.F. and Palzer, C.R. (1969). Host list of Phytophthora cinnamomi Rands with special reference to Western Australia. Dept. Nat. Div. Forest Timber Bur. Tech. Note 1: 58 pp.

Trappe, J.M. (1977). Selection of fungi for ectomycorrhizal inoculation in nurseries. Annual Rev. Phytopathol. 15: 203-222.

Trenbath, B.R. (1974). Biomass productivity of mixtures. Adv. Agron. 26: 177-206.

Turton, A.G. (1977). Nutrient cycling in indigenous forest ecosystems. Paper presented at Symposium organized jointly by W.A. Forests Department and CSIRO Div. of Land Resources Management.

Western Australian Forests Department. (1975). Annual Report.

Waid, J.S. (1974). In: Biology of Plant Litter Decomposition. Dickinson, C.H. and Pugh, G.J.F. (Eds), Vol. 1: 175-211.

Wallace, W.R. (1966). Fire in the jarrah forest environment. J. Roy. Soc. W.A. 49: 33-44.

Ward, S.C. (1979). B.Sc.Hons. Thesis, Univ. New England, Armidale.

Webb, L.J. (1970). Fire environments in eastern Australia. Second Fire Ecology Symposium Papers.

Webb, L.J., Tracey, J.G., Williams, W.T. and Lance, G.M. (1969). The pattern and mineral return in leaf litter of three sub-tropical Australian forests. Australian Forestry 33: 99-110.

Weste, G.M. (1974). Phytophthora cinnamomi - the cause of severe diseases in certain native communities. Aust. J. Bot. Vo. 22: 1-8.

Wild, A. (1958). Aust. J. Agric. Res. 9: 193-204.

Will, G.M. (1972). Copper deficiency in Radiata pine planted on sands at Marhawhae forest. N.Z. J. For. Sci. 2: 217-221.

Willis, J.H. (1962). A Handbook to Plants in Victoria, Vol. I. Ferns, Conifers and Monocotyledons. 448 pp.

Winterhalder, E.K. (1963). Differential resistance of two species of Eucalyptus to toxic soil manganese levels. Aust. J. Sci. 25(8): 363-364.

Witkamp, M. (1971). Soils as components of ecosystems. In: Annual Review of Ecology and Systematics. Johnson, R.F. (Ed): 85-110.

Woods, F.W. (1958). Factors limiting root penetration in deep sands of south-eastern coastal plain. Ecology 38: 357-359.

Woodwell, G.M. (1978). Paradigms lost. Bull. Ecol. Soc. Am., 59: 136-140.

Zentmyer, G.A. (1965). Bacterial stimulation of sporangial production in Phytophthora cinnamomi. Science, Vol. 53: 1383-1387.