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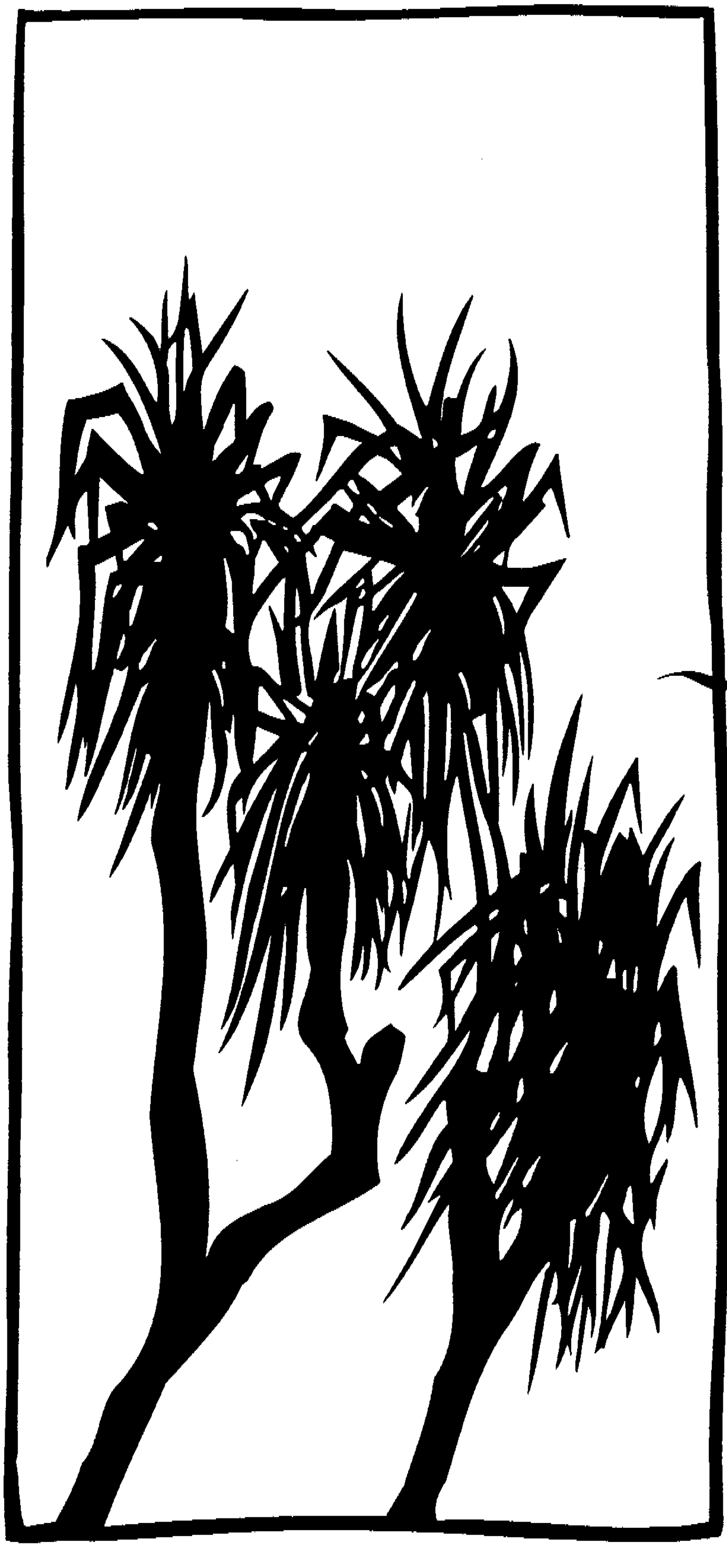

A review of revegetation techniques in the tropics

M Chandrasekaran, N Ashwath & P Waggitt

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By
M.Chandrasekaran
N. Ashwath
P. Waggitt

Office of the Supervising Scientist

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Revegetation Techniques in the Tropics

Abstract

This review examines current literature on revegetation techniques available for use in the tropics. These include vegetation surveys, surface preparation techniques, seed technology, microbial inoculation, use of top soil, use of fertilisers and amendments, weed control, species selection, fire tolerance, return of fauna and criteria for assessment of revegetation success. The report comments on the current state of knowledge for each of these topics and suggests preferred options in certain areas. The report goes on to summarise the available information relevant to the rehabilitation of the Ranger Uranium Mine in the northern Territory of Australia. Finally the report identifies further research that will be needed to achieve successful revegetation at Ranger. The report concludes with a list of over 120 references and a bibliography of other source materials.

1. Introduction

Revegetation is one of the most important components of rehabilitation. The final vegetation cover is the basis by which many people will judge the success of rehabilitation, thus revegetation assumes great importance. This importance is confirmed by the substantial effort and resources being used to support a wide range of research programs in the Alligator Rivers Region and elsewhere. In particular much work is being undertaken by both Energy Resources of Australia- operators of the Ranger Uranium Mine (ERA) and the Environmental Research Institute of the Supervising Scientist (ERISS), assisted by officers from the Office of the Supewrvising Scientist (OSS), into establishing what are the most successful and appropriate techniques to be used in revegetation programs.

The purpose of this document is to gather available data on revegetation techniques in the tropics. The report also will assess how much of this information is applicable to Ranger Uranium Mine and identify areas where further information is required to meet the needs of a successful revegetation program at Ranger.

1.1 Why revegetate?

In order to be able to select the most appropriate methods for revegetation, it is first necessary to establish what is the end purpose of the revegetation. Regardless of why or how the land has been disturbed it is important to have a final land use or vegetation type agreed before the revegetation work is begun. This is to ensure that the objectives of the work are clearly defined and understood by all parties, the mining company, the regulator and the landowner. In this way an appropriate program can be formulated and applied.

Revegetation may be undertaken for a variety of reasons. These include erosion control, screening, aesthetics establishment of a productive land use (such as grazing, tree or arable cropping) re-establishment of a natural/native ecosystem or conversion of the site to a commercial or recreational use. All of these have been attempted at one time or another on disturbed land with varying degrees of success. Most of the available literature relates to work done in temperate zones but this report attempts a review of the revegetation practices in the seasonally humid tropics.

There is a range of topics that may influence the selection of any particular revegetation method and these are briefly considered below.

1.1.1 Purpose

The end use of the land at Ranger, as set down in the Commonwealth Rehabilitation Goal and Objectives (OSS, 1992), is to return the site to a condition as similar as possible to that of the surrounding Kakadu National Park. This will require extensive work on the establishment of native species with the emphasis on local species. However, the operators of the mine have suggested that there may be other options which should be investigated, depending on the wishes of the traditional owners of the land.

The options mentioned have include fish and/or emu farming, and another possibility could be the establishment of a recreational facility. Obviously the final choice of revegetation techniques will depend on the selected final land use option. For example, many forms of agriculturally productive land use will require a final land surface free from major irregularities and with a surface texture suitable for the establishment of crops and use of machinery.

1.1.2 Climate

The climate of the Alligator Rivers Region is typical of the seasonally humid tropics. The annual rainfall at the Ranger site is approximately 1500 mm and most of this rain falls between November and April. The dry season is from May to August, with transitional stormy periods associated with both the beginning and the end of the season. The intensity of rainfall can be severe and as a consequence erosion rates can be high. Rapid establishment of vegetation soon after completion of earth works and landform reshaping will reduce the erosion risk considerably.

1.1.3 Cost

All aspects of the Ranger uranium mining operation are required to be carried out in accordance with the principle of 'best practicable technology' (BPT). This is defined in the Environmental Requirements (ERs) which are used to regulate environmental protection. The ERs are set down as a schedule to the Uranium Mining (Environment Control) Act 1979 of the Northern Territory. As cost is one of the elements of BPT, comparisons of costs or cost/benefit ratios should be made for every technique that may be an option in a given situation. This will assist in the determination of what BPT is for a particular situation.

1.1.4 Nature of disturbance

The nature of the way the ground has been cleared or disturbed, as well as the way it may have been partially or previously restored is likely to restrict the range of revegetation techniques that may be used. An open cut mine with waste rock dumps will obviously require a different revegetation strategy to a strip mine, and sand mining may be revegetated using yet another set of techniques.

Furthermore, surfaces that are too steep, too rocky or too wet will not be well suited to the use of machinery for cultivation and planting, although they may still need to be revegetated. Land which has simply been cleared by scraping with a bulldozer will require different revegetation techniques to a waste rock surface.

1.1.5 Nature of substrate

The type of material that is to be used as a planting medium will also affect the choice of revegetation technique. Returned topsoil may require a different revegetation method to waste rock or an area spread with low grade or sub-soil materials. Certain substrate materials may require amelioration, either chemically or physically, before revegetation processes can begin.

1.2 Vegetation surveys of Ranger and Nabarlek Lease Areas

Surveys from undisturbed areas in terms vegetation density and abundance are essential, as these are used to set standards to measure the success of revegetated areas following mining. A vegetation survey for trees and shrubs has been carried out at the Nabarlek project site (QMPL 1988) . However, no data are available for ground cover species such as grasses, forbs and sedges. Heath and Partners (1979) surveyed vegetation types in the Ranger Project area and classified the vegetation into different groups or species complexes. Ranger carried out a vegetation survey of the Land Application Area and determined density and abundance for upper storey, mid storey and ground cover species (Ranger, 1987). This survey indicated that *Eucalyptus tetrodonta* was dominant in the top stratum, *Petalostigma pubescens* in the mid-storey, and *Sorghum intrans* formed the abundant ground cover. A vegetation survey on lowland woodlands of the Ranger Lease Area identified 46 tree species (> 1.5 m in height; Brennan 1992). These species were present at an average density of 868 stems/ha. Of these, 31 species were also found to grow on rocky hills outside the Ranger site. The structural distribution of these species, based on height, is given in Table 1. OSS has completed the vegetation survey for species < 1.5 m including ground cover species and the data now are being processed. Preliminary analysis suggested that there were 200 ground cover species (with height < 1.5 m) present in the vicinity of Ranger mine site (K. Brennan. pers.com.).

Table 1 Structural distibution of tree species at Ranger

Height Class	Stems/ha
1.5 - 5 m	612
5 - 10 m	148
>10 m	

In a summary of vegetation analyses from 10 x 10 m quadrats (upper storey species >1m in height) from undisturbed sites in the Land Application Area (Ranger, 1987), the relative dominance of 24 species was listed on a scale of 100% ranging from 0.02% to 25.5%. There are only twelve species with a relative dominance of >2.0%, and these represent a total relative dominance of about 96%. Only 6 of the 24 listed species have a relative dominance value of >8% which accounts for about 80%. The corresponding value for these six species in the understorey (<1m in height) was about 23 % (using 5m x 5m quadrate).

1.3 Characterisation of waste rock dump (WRD) soils

1.3.1 Formation of soils on Ranger WRD

A generalised scheme of mine soil development on Ranger WRD was given by Fitzpatrick and Milnes (1988), who described the morphological, physical and chemical properties of WRD soils and identified seven types of soils formed on the WRD over a five year period. These include lithosolic soils with minimal pedogenic development, soils with stony/gravelly lags and vesicular crusts and weak development of a B horizon, polysequal soils indicative of erosion events on the dumps, and pseudo-acid sulphate soils characteristic of waterlogged situations. The sequence of soil development on the WRD is Lithosols, followed by soils with gravel lags and vesicular crusts, then Polysequal soils and finally Pseudo-acid sulphate soils. The development of soil texture progresses from bouldery and stony, to gravel, to clay.

1.3. 2 Physical properties:

Armstrong (1986) listed the physical properties of WRD soils as:

(i) high degree of heterogeneity, (ii) rapid weathering, (iii) poor structure upon weathering, with a high bulk density, (iv) a high proportion of clay. Physical conditions likely to limit plant growth on the WRD soils include water deficit (Emerson and Hignett 1988) and low infiltration (Fitzpatrick and Milnes 1988, Riley et al. 1993)). In general mine soils have a high content of rock fragments (>30%), and a high bulk density of 1.5 to 1.8 g/cm^3.

Fitzpatrick et al (1989) compared disturbed mine soils with undisturbed natural soils and stockpiled topsoils at Ranger. This study indicated that fine particles in most mine soils dispersed on wetting. Variation in soil texture result from local surface water erosion of fine particles, leading to marked soil structure changes with time. The Geomorphology Section of ERISS has carried out a number of rainfall simulation experiments to assess erodibility of WRD soils. These studies concluded that the WRD soils have extremely low infiltration rates compared with natural soils (Riley et al, 1993).

1.3.3 Chemical properties

Ranger mine soils have near neutral pH values and high concentrations of soluble and exchangeable magnesium (13 cmol/kg). Magnesium dominates the exchangeable complex (>95%) and is formed during the weathering of chlorite schist (Milnes 1988). The pseudo-acid sulphate soils that form in the furrows of reshaped and ripped WRD soils have higher concentrations of soluble and exchangeable potassium, clay and silt content than other soil types. The very high ratio of Mg to Ca in the soil solution could affect nutritional availability for some plant species (Milnes, 1988) and this aspect is currently being examined by OSS (Ashwath et al. 1993). Fitzpatrick and Milnes (1988) concluded that soil factors on the WRD soils that will influence plant growth are stoniness and pseudo acid sulphate conditions.

Armstrong (1986) reported that based on a three year trial, the WRD soils have a high degree of heterogeneity, Ca/Mg imbalance, and low levels of organic matter. Fitzpatrick et al (1989) reported that the morphological, chemical and mineralogical properties of WRD soils have features in common with natural undisturbed soils in the surrounding landscape, but are distinguishable in terms of their pH, lower organic carbon content, higher content of labile minerals, and consequently their higher concentration of some plant nutrients.

The Revegetation Research Section at ERISS investigated chemical properties of a number of soil samples collected from Ranger, Nabarlek and Coronation Hill mine sites and other natural habitats within the ARR, in order to identify the chemical factors that may limit plant growth on waste rock dump soils. Overall, mine soils differ from natural soils by having higher pH, EC (at Ranger only) cation exchange capacity, Mg and SO_4 concentrations and lower total nitrogen and organic carbon. The Ranger mine spoil has higher total, exchangeable and water soluble Mg, higher total phosphorus compared to other mine spoils or natural soils (Ashwath et al. 1993). A number of soil samples have also been analysed for plant available nutrients in connection with mycorrhizal studies (Brundrett et al, 1992a, b).

1.3.4 Biological properties:

Moen and Kimber (1989) studied WRD soils and natural soil from native woodlands nearby with the view to determining patterns of bacterial occurrence and their characteristics for the genera *Pseudomonas, Thiobacillus* and *Bacillus*. They reported marked differences between genera and between sites. *Thiobacilli* were predominant on WRD soils but lowest in native soils. Based on D/L amino acid ratios for *Thiobacilli*, clear differences have been shown between the characteristics of the WRD micro flora and those from the native soil site. High proportions of bacilli at some sites was attributed to recent burning. With a knowledge of the D/L ratio of the amino acids from bacteria growing under optimum conditions, an assessment of the degree of stress a particular environment places on the bacteria can be made.

Milnes (1989) based on short term glasshouse experiments concluded that Ranger mine soils had fewer symbiotic micro-organisms (rhizobia and mycorrhizal fungi) than natural undisturbed soils. The ERISS has undertaken a collaborative research project with Jasper and Brundrett of the University of Western Australia and investigated plant-mycorrhizal associations in disturbed and undisturbed soils of the ARR (Brundrett et al 1992, a, b). The results indicated that the disturbed soils had fewer spores and lower diversities of endomycorrhizal fungi compared to undisturbed natural sites. Where the mine sites were densely revegetated, the endomycorrhizal infectivity/spore numbers were greater than those found in climax natural vegetation. However, the diversity of endomycorrhizal fungi was less than in natural sites.

1.3.5 Rhizobia and Mycorrhizal fungi

Reddell and Milnes (1992) reported that rhizobia and mycorrhizal fungi were ubiquitous components of soil biota in undisturbed soils of Kakadu National Park, but were absent or scarce in stockpiled soils and on WRD soils. Nitrogen and phosphorus omission experiments revealed that P was the most limiting element in the woodland and stockpile soils, while both N and P were limiting in WRD soils. This is interesting to note, as the WRD soils are reported to have higher available phosphorus than native soils (Milnes, 1989). Reddell and Milnes (1992) found that upon application of basal nutrients (except N), inoculation of *Acacia holosericea* seedlings with rhizobium corrected nitrogen deficiency in WRD soils. However, under conditions where both nitrogen and phosphorus were deficient, inoculation of *A. holosericea* with both rhizobium and VAM fungi only partly overcame the negative growth effects of phosphorus deficiency. The possibility exists that other nutrients not examined in the study may limit plant growth on WRD soils. The study recommended that rehabilitation strategies implemented on WRD soils, with or without spreading stockpiled top soils. Such strategies will need to ensure that deficiencies of phosphorus and other nutrients are corrected, and that viable populations of mycorrhizal fungi and rhizobia are introduced during early phases of vegetation development.

Two significant research projects have been established by ERISS to collect, isolate and maintain rhizobia and mycorrhizal fungi (involving a consultancy with the University of WA) from native plant species, and to understand plant-microbial interrelationships in these ecosystems. This research isolated rhizobia from sixty-seven leguminous species found at Ranger, Nabarlek, Gimbat, and two hill sites in the ARR (Mt Cahill and Buk Buk). The species represent 26 forb, 29 shrub, 3 tree and 9 vine species. A total of 624 isolations have been made from the collected nodules which yielded approximately 500 rhizobial isolates (McInnes and Ashwath, 1992). These isolates will be tested against their host plants to identify highly effective strains.

Soil cores and top soils from 32 locations in the ARR from both disturbed and undisturbed sites have been bioassayed and chemically analysed. Various new and novel techniques were adapted to isolate as many VAM fungi as possible from the ARR soils. The soils were also assessed for mycorrhizal species diversity (number of species) and spore density. Potential new species and strains have been isolated and are being characterised and multiplied (Brundrett et al 1992a, b). Currently 70 pure strains of VAM fungi and 5 strains of ectomycorrhizal fungi are available (Ashwath et al. 1993a).

ERA's consultants (CSIRO Minesite Rehabilitation Research Group) have established field trials on Ranger WRD to study the benefits of inoculating transplanted seedlings and to examine strategies for mycorrhizal spreading/distribution on newly revegetated sites. Also being studied is the return of fauna, mainly termites, from adjacent infested areas. To encourage faunal migration termite susceptible deadwood logs have been placed and termite resistant *Eucalyptus* sp seedlings have been planted. Termites were caught using pitfall traps. Tissue rolls have been placed next to the pitfall traps. When wet, these rolls become susceptible to fungal attack, which in turn will attract the termites. The authors understand that these results are not publicly accessible.

1.4 Revegetation field trials on WRD soils

In early revegetation trials (Ranger, 1987), Ranger used seed mixes which included only 9 of the listed 24 species for upper storey vegetation, and 7 of the 23 under storey species. Several significant upper storey species (*Xanthostemon paradoxus*, *E.bleeseri)* and the predominant understorey species *P. pubescens* were not included in these trials. It would be useful to rate the ease with which these native species can be established on the WRD soils. For example, by grouping them into those which can be readily established, those which can be established with minimal effort, and those which are difficult to establish.

In Ranger's 1982 WRD trials, application rates of complete fertiliser were combined with two different application rates of either gypsum or lime. There was a positive response to higher levels of gypsum in the growth of shrubs and the density of ground cover. The gypsum and lime treatments increased the level of exchangeable calcium in the soil. However, the Ca/Mg ratio on the soil exchange complex was still significantly lower than the critical value to prevent soil structural problems due to clay dispersion. Ranger (1987) concluded that establishment and growth of native species on the WRD was not affected by low levels of plant nutrients or by Ca/Mg imbalance. Acacias dominated the trial area with *Acacia holosericea* being the most prominent. *E. tetrodonta* failed to establish at all on the WRD soils, despite this being the dominant upper storey species in undisturbed areas. Exotic grass species disappeared after the second year possibly due to lack of plant nutrients and shading by trees and shrubs. The 1984 trial investigated the relationship between native trees, shrubs and exotic ground cover species at three levels of fertiliser, lime and gypsum application. The results indicated that as a group, acacias and eucalypts showed no variation in species richness or species density at different levels of fertiliser application. Eucalypts responded to high fertiliser by becoming more species diverse, although the stand was less dense. For acacias, diversity (no. of species/plot) appeared to be independent of fertiliser application. Native ground cover species also appeared to be independent of fertiliser application, whilst exotic ground cover species showed a positive correlation to fertiliser application (Ranger, 1987).

The 1982 trials included 4 species of *Acacia*, 4 species of *Eucalyptus* and 1 species of *Grevillea*. Acacias and *Grevillea pteridifolia* became dominant. *E. porrecta* and *E. miniata* performed best among the eucalypts. *E. latifolia* germinated well, but was competed out during later stages, and *E. tetrodonta* failed to establish at all. From the 1982 and 1984 vegetation trials it can be inferred that the species that can be established easily or with minimal effort on the WRD soils are: *A. dimidiata, A. holosericea, A. mountfordiae, A. oncinocarpa, A. auriculiformis, Grevillea pteridifolia* and *M. viridiflora*.

Those which are difficult to establish in WRD soils include: *E. latifolia, E. tetrodonta, E. miniata, Cochlospermum fraseri, Terminalia pterocarya, Melaleuca symphyocarpa, E. tectifica, Leptospermum longifolium, M. nervosa* and *E. camaldulensis*.

2.1 Seed technology

The success of a revegetation program is primarily dependent upon the quality of the seed used. This in turn depends on several processes, including time and method of seed collection, processing techniques, storage conditions and seed treatment procedures.

2.1.1 Time of Seed collection

In the top end of Australia, most native species produce seeds either during the second half of of Wet season (February-April) or towards the end of the Dry season (September-December). While most ground cover species mature during February-April, the majority of trees and shrubs mature in September-December. The time of seed maturity differs from species to species with some species taking up to 4 months to mature (eg *E. porrecta*) whereas others mature within a short period (eg Acacias). The seed maturity will also be influenced by the onset and distribution of rainfall. At present, little information is available on the flowering and seed maturity of a number of local native species except those collected by staff from ERISS (N. Ashwath unpublished).

Armstrong (1986), based on Ranger's 1982 and 1984 revegetation trials on the WRD, reported that the use of fresh native seed was essential for successful revegetation, and recommended that ideally seeds should be collected between June and November of the preceding year to establish vegetation in the early Wet season of the following year. At Nabarlek consistent germination failure of *Grevillea pteridifolia* was found to be associated with infestation of the seed by a small native wasp (QMPL, 1990). To overcome this problem it was recommended that the collection to be done only from those sites which showed a low rate of infestation by this wasp.

2.1.2 Method of collection

Methods of seed collection differ from species to species and the purpose for which the seed is collected. Hand picking and careful processing of seeds are essential for research work, while for general purposes manual or semi-mechanised methods are employed.

A cherry-picker may used to collect seeds from tall trees, or the seed bearing branches may be lopped to facilitate the collection of fruits, capsules, cones or other seed bearing structures. The lopping can be achieved using tree loppers, by shooting branches with a rifle (Kabay and Lewis 1987), sawing branches using a commando saw (Hinz 1990a) or using a bow and an arrow to pull a rope over a branch to break it.

Seeds from ground cover species can be collected manually or by using lawn mowers (eg grasses) or commercial vacuum harvesters (eg KimSeeds vacuum harvesters). Commercial harvesters have limited application in collecting native plant seed because of the occurrence of these species in mixed stands, usually with indeterminate maturity, and the rugged surface conditions of the habitats.

Where seed pods of most species remain attached to the plant, such as in the banksias of the heathlands in Eneabba, Western Australia, the entire vegetation may be harvested using a hay harvester. The vegetative material is chopped into 10 cm bits and spread over the reshaped area. This material acts both as a mulch and a seed source (M. Jeffries et al, 1991, Brooks and Jeffrey 1990).

Large seeds such as those of *Owenia, Planchonia careya, Syzygium*, *Planchonella* etc can be picked up from the ground manually, or may be gathered using vacuum harvesters.

2.1.3 Seed processing

Several methods are used to process native plant seed. These methods vary from species to species and they include (i) sun-drying the capsules and pods or oven drying at <40^{0}C, (ii) threshing using commercial threshers (especially applicable to leguminous species), (iii) cleaning seed using commercial seed cleaners, (iv) macerating after soaking the fruits in water, (v) manual processing, (vi) burning seed cones, etc.

The method of seed processing is highly specific to species. The methods relevant to Top End tree and shrub species are described by Hinz (1990b), and those used for other species are explained in Langkamp (1987). Great care is needed in processing to minimise damage and to ensure that clean and viable seeds are obtained. For eucalypts, seed bearing branches can be enclosed in bags (eg hessian or polypropylene fertiliser bags) or in trays which can then be dried at <40^{0}C in an oven or in open sun. This assists in the separation of seed and chaff from capsules (B. Gunn; pers. comm.). In most eucalypts, the seed and the chaff can be separated by sieving and winnowing. However, in species such as *E. camaldulensis* and *E.herbertiana* seeds are not easily distinguishable from the chaff (Hinz 1990b).

The method described above can also be used for many other native species, including legumes which dehisce pods readily,eg *Petalostigma* and many other forbs. In some species, such as *Petalostigma,* care should be taken to cover the tray containing fruits, or enclose fruits in bags to prevent the seed escaping from the containers during dehiscence (N. Ashwath; pers. comm.).

Commercial seed threshers such as those produced by KimSeed (Australian Revegetation Corporation, W.A.) can be used for separating seed from pods of acacias and many other legumes (Peter Foot; pers. comm.). The threshed material can then be put through a seed cleaner to separate seed from broken pods and to sort seeds of different size or quality (B. Gunn; pers. comm.).

In some species (eg *Terminalia, Planchinella, Planchonia*) seed are covered by fleshy material. The seed can be separated from the fleshy material by soaking the fruits in water (for various periods) and mascerating or rubbing the fermented seed against a hard surface whilst washing with running water. In some species, such as *Owenia vernicosa,* it is extremely difficult to separate the seed from the corky outer cover. At present methods are unavailable to process, and store or germinate these seeds (M. McLaughlin 1993).

Seeds of species such as *Alstonia spectabilis* contain furry structures which make it difficult to separate these seeds by sieving. Vacuuming seed from drying trays is found to be effective for this species (Kabay and Lewis 1987). The same technique can be applied to separate seeds of *Cochlospermum fraseri,* the seeds of which contain lint.

Microwaves set on 'defrost' for sixty seconds, can cause pods to open rapidly in *Pinus* species whereas in *Banksia,* 'barbequing' the seed pods for an appropriate amount of time and rapidly cooling the pods in cold water will assist in the release of seed (Kabay and Lewis 1987).

No improved methods of seed processing have been developed for native grasses. However, available seed threshers can be used after appropriate modification. Unless the demand for native plant seed increases, it is unlikely that the techniques of seed processing will be improved. As a consequence, most of the native plant seed processing will be carried out by manual methods. Manual methods of processing grass seeds include beating the dried seed bearing material with a cane, squeezing seed heads between the hands or feet, rubbing seed heads on the floor and or by winnowing, blowing the chaff and debris using a pedestal fan, (Ashwath et al 1994).

2.1.4 Seed treatment

Immediately after separation and prior to storage, seeds should be treated to prevent attack by insects. There are a number of methods that can be followed. These include: fumigation with chemicals, treating the seed with insecticides and exposure (1-2 days) of the seed to CO_2 prior to storage (B. Gunn, CSIRO; pers. comm., Hinz 1990a). Among these methods, treatment with CO_2 seems to be very effective for tropical native species (N. Ashwath; pers. comm.) and this method is being followed by the ERISS for storing seeds of a wide range of local native species, including trees, shrubs, grasses, forbs and sedges. Although this method has been found to be very effective for the storage of orthodox species, its application for treating recalcitrant species has not yet been tested. It is suspected that prolonged treatment of recalcitrant species with CO_2 may affect their germination percentage (B.Gunn; per. comm.).

Ranger's 1982 and 1984 revegetation trials on WRD suggested that there was no need to scarify fresh *Acacia* seed. Any hard or dormant seed that remains in the soil may germinate in later years or following fire (Armstrong 1986). Little is known about fungicidal treatment of seeds prior to sowing. Studies conducted by ERISS indicated that the majority of 70 native species tested had either nil or very low (<20%) germination (Ashwath et al, 1992). Germination of some species was improved significantly with simple treatments such as soaking in boiling water (eg acacias). These results suggest the need to investigate suitable seed treatment methods for native plant species. Further studies are underway to investigate seed treatment methods for selected herbaceous species, grasses, trees and shrubs.

2.1.5 Seed storage

The methods of storing tropical orthodox seed include, storage in an air conditioned room (Hinz 1990a, D. Hinz; per.comm.) or in a cool room (1-3 °C) at low (~50%) relative humidity. Loss of seed viability during storage is a very common phenomenon. Care is therefore essential to prevent contamination of seed from moisture due to an increase in relative humidity of the storage room. The seed can also be vacuum packed and stored in a cool room (Hinz 1990a). QMPL (1990) identified that seeds of nine species cannot be stored for any length of time, and therefore plans to omit these from the proposed seed mixes to be used for revegetation at Nabarlek. The important requirements for seed storage are listed as:

- relatively low temperatures (19 to 23°C)

- very low humidity
- regular fumigation of the seed store.

The limited number of studies that have been carried out on storage of native plant seed, have been concentrated on trees and shrubs and very little attention has been paid to storage of native grass seed and other ground cover species. This situation is unlikely to change in the near future as the emphasis for using native grasses in revegetation programs has been very low.

There are a number of recalcitrant species (eg *Persoonia, Terminalia, Buchanania, Ficus*; Hinz 1990a) in the Top End, some of which are required to be included in revegetation programs due to their bush food value (P.Bailey; pers. comm.). Suitable techniques are presently unavailable to store these species. Similarly, seed storage conditions for a number of economically useful trees and rainforest species are not known. A recent international workshop on Tropical Tree Seed Research has identified that the research on storage procedures for recalcitrant and orthodox species at ultra low moisture content (3-5%) is a high priority (Schaefer et al 1989). At present, very little information is available on storage requirements for a large number of tropical native species, especially those which have fleshy seeds. Some techniques that are now available for storing recalcitrant crop species (Chin and Roberts 1980) may be useful to local native species. ERISS is currently investigating storage properties of a range of native plant seeds (N. Ashwath; pers. comm.).

2.1.6 Seed testing/germination

Seed testing includes testing the seed for seed filling and/or for seed germination. Seed filling can be examined by determining the proportion of fully developed seed in a seedlot. This can be achieved either by dissection of seed, visual examination or by X-radiography (Simak 1989). Adoption of X-radiography does not involve sample destruction and it is rapid and economical. ERISS used this technique to determine the proportion of filled seed and their viability in *Xanthostemon paradoxus* and the proportion of filled seed in *Terminalia pterocarya* (McLaughlin 1993), both of which are common in the ARR. Its applicability in testing other native species has yet to be tried.

Local native plant species have developed specific mechanisms which enable them to protect themselves from bush fire and predating insects, and to ensure that the seed will germinate only when the conditions for seedling growth are optimum. This is achieved by various mechanisms, including a hard seed coat, immature seed and physiological attributes. These mechanisms have been discussed separately for the members of the families Myrtaceae (Turnbull and Doran 1987), Order Fabales (hard-seeded species, Cavanagh 1987), Poaceae (Whalley 1987) and of other families (Fox et al. 1987). Although these studies make some reference to tropical species, very little information has been provided for the species that commonly occur in Kakadu National Park and its environs (see Appendices of Langkamp

1987). Nevertheless, studies at ERISS tested the germination characteristics of 82 local native plant species representing 47 genera and 20 families (Ashwath et al 1994, McLaughlin 1993, McIntyre 1993, Gray 1993) and developed suitable techniques to overcome germination problems in many of the local native species for which no data were previously available .

The techniques that were found promising are:

- leaching in running water (*Livistona*)
- hot water treatment (*Acacia spp* and some other legumes)
- scarification
- nicking (*Cochlospremum fraseri, Acacia spp*)
- dry heat

These studies also identified constraints in seed germination in a number of local native plant species, particularly *Owenia* and some grasses and legumes. ERISS is presently carrying out investigations on methods to induce germination in these species. Comalco has undertaken a number of studies on seed technology and native plant regeneration in connection with the revegetation of their bauxite mine at Weipa(Foster 1985a).

At Nabarlek good field germination results were recorded for the hard or large eucalypt seeds, such as *E.miniata* and *E.tetrodonta.* However, germination of paper-like seeds such as *E.clavigera* was poor although they showed good germination in the nursery (Hinz, 1989). Ranger in its field trials on the WRD in 1992 sowed seeds of 19 native species in shallow rip lines 20 m long and 5 m apart. Of these species, *M. symphyocarpa, E. tectifica, Leptospermum longifolia, A. mountfordeae, M. nervosa* and *E. camaldulensis* failed to germinate, whereas *Cochlospermum fraseri, E. tetrodonta, E. miniata* and *Terminalia pterocarya* recorded very low germination. The acacias germinated well, and subsequently dominated the site (Ranger, 1987).

2.1.7 Seed rates

Seed rates and seed mix used will differ from one mine site to another depending on the species composition of adjacent undisturbed sites and the cultural practices adapted (eg use of top soil, provision of protective irrigation). At Nabarlek, a seed mix of trees and shrubs will be used at rates varying from 0.6 to 1.1 kg/ha depending on the site type (QMPL 1990). No such seed mixes have apparently yet been worked out for use at Ranger. However, in trial plots seed rates of up to 1 kg/ha of native tree and shrub species, and 3 kg/ha of exotic ground cover species(consisting of a mixture of rhodes grass and stylosanthes) have been used in the past (Armstrong 1986). Foster (1985a) has calculated the required seed rate for native species using the formula

seeding rate (g/ha)= density (stems per ha)/[germinants per gram x field success rate] where density of each species is calculated as total density of stems per ha/total number of species, and field success rate as number of stems per ha/[(seeding rate (g/ha) x (germinants/g)].

2.2 Nursery techniques

2.2.1 Selection of growing containers

A variety of containers made of plastic, biodegradable substances (eg. Jiffy pots), polystyrene and clay are available for raising seedlings in the nursery. The size, shape and colour also differ markedly. When selecting the pot size, care should be taken to match the requirement of the species to be used, growth period in the nursery, potting mix used, maintenance regime, available resources, method of transplanting, cultural methods (eg irrigation), soil characteristics and climatic conditions.

While the above factors are variable, the most important aspect that should be kept in mind in raising seedlings is that the seedlings should not be left in the pots for too long. This is to prevent pot-bound conditions developing. Furthermore, emphasis should be placed in using containers that will encourage roots to grow downwards rather than in circles. The three types of pots that will prevent root circling are shown in Figure 1 (Ryan et al 1986). These pots have corrugations on the inside which will assist in directing the roots downwards. Experiments in Queensland have shown that the seedlings raised in the Queensland Forestry Tube generally develop more quickly and are more robust than those raised in the Hawaiian Dribbling Tube (Ryan et al 1986).

2.2.2 Potting mix and mechanisation of pot filling

The composition of potting mix will vary markedly depending on the location, available local resources and the method of pot filling (manual or mechanical). The composition to be used will also depend on the pot size and the species to be grown. It is desirable to formulate the potting mix sothat it is free draining and does not fall apart when the seedling is separated from the pot (except in biodegradable pots). The use of pasteurised local top soil is recommended in a potting mix to ensure that the seedlings are provided with local micro flora in the nursery.

Queensland Forestry Department uses 1 part of peat moss and 2 parts of vermiculite to raise seedlings of native species (Ryan et al 1986). Although this gives a sterile medium, it has two disadvantages:

- it is difficult to rewet when dry
- it loses moisture rapidly and shrinks differentially in clay soils under dry conditions

Alcoa, which raises about 2 million seedlings every year, uses a potting mix consisting of pine bark, jarrah sawdust and sand (1:1:1) (J. Gardner; pers. comm.). This mixture is filled into germination trays by a machine and the mix is pasteurised at 65-70 ^{0}C for 1 hour. The trays are seeded using a seeding machine and transferred to an open nursery where they are watered by automatic spray irrigation.

No suitable potting medium has been developed for raising local native species in the ARR. Trials at Nabarlek (QMPL 1988) indicated that the 'native tubes' (long square pots, 120 x 50 x 50 mm) were superior to other, round, pots. The potting mix used was local sandy lateritic top soil and peatmoss (ratio not given; QMPL 1990). Ranger Uranium Mine has raised seedlings of some native trees and shrubs using a variety of potting mixes and also tested the use of waste rock material to raise seedlings in the nursery. Arnhem Nursery in Darwin recommends the use of peat moss/cocopeat and coarse sand (1:1) with some top soil to raise local native species. The limited trials at ERISS confirm that the cocopeat, sand and top soil mixture (1:1:1) provides an excellent growth medium for a wide range of native species (N. Ashwath; pers. comm.).

2.2.3 Micro-propagation

Native plant species that are difficult to germinate and/or establish in the nursery due to abnormalities in seed development (eg. parthenocarpy, apomyxis) or due to difficulty in seed collection or poor seed production, can be propagated in large numbers via vegetative means. This technique involves excision of somatic tissues whether it be a leaf, stem or other parts of the plant and transferring it aseptically on to a tissue culture medium containing protein, carbohydrates, minerals, salts and hormones to induce roots and to promote shoot growth. The rooted plants are then transferred into pots containing ordinary potting medium. Mature plants produced by this technique can then be transplanted into the field.

This technique overcomes difficulties in germination and produces large numbers of genetically similar plants from a single plant or plant part. It is particularly important in genetic improvement of plants where single mutant or tolerant plant can be multiplied very quickly. This would be impossible to achieve using traditional techniques. This technique also assists in the development of uniform clones which is an essential requirement in commercial operations such as eucalypt plantations in Brazil.

Alcoa has established a large scale micro propagation unit to multiply species in jarrah forest that are difficult to propagate using traditional methods (Landline 1992). These include many sedges and rushes which propagate through roots and produce virtually no seed. Alcoa also uses this method to multiply tree seedlings that are resistant to jarrah die back and tolerant to salinity and waterlogging, for both its own use, and to supply to other mining companies and commercial markets. As far as the authors are aware, the above technique has not been used in the Top End of northern Australia for multiplication of native species.

Micro propagation technique is extremely important in ecosystem restoration where the establishment of a wide range of native species is required, but the propagation techniques of these species are not understood. Furthermore, this technique makes the restoration work less expensive as the costs of alternative methods of establishing some native species are very high.

2.2.4 Inoculation

The most effective means of ensuring that the established plants are infected with beneficial microbes such as rhizobia and mycorrhizal fungi, is to inoculate seedlings of these species raised in the nursery, or to coat the seeds that are directly broadcast in the field with microbial cultures. This method is widely practiced in agro forestry (Dr. P. Dart; pers. comm.) and forestry practices (Dr. N. Malacjzuk pers. comm.). In the US, where large areas of abandoned mine sites are revegetated by Federal Government agencies, planting of Pinus seedlings and inoculation of these with ectomycorrhizal fungi (*Pisolethus tinctorius*) is common.

Inoculation of seeds or seedlings is extremely important in mining operations where top soil is not used. This is because mine spoils generally lack sufficient number and types of beneficial microbes (Reddell and Milnes 1992) which are essential to promote plant growth and long term supply through fixation of atmospheric nitrogen. In addition, microbes assist in the uptake of phosphorus and other nutrients by plants.

Seeds can be inoculated by placing them in a rotating cement mixer containing peat moss containing rhizobia (Dr. P. Dart, pers. comm.) or resin beads containing spores of mycorrhizal fungi (Dr. N. Malajczuk, Dr. D. Jasper; pers. comm.). Alternatively, seeds can be pelleted with substances containing microbial inocula and/or fertiliser (Jasper; pers. comm.). The latter technique needs greater care as fertilisers may inhibit survival, growth or functioning of the microbes. Seedlings may be inoculated in the nursery by :

- raising them on soils that contains known strains of microbes
- adding the inoculum to the nursery, or
- dipping the seedlings (bare rooted seedlings) in a slurry containing microbial inocula immediately before transplanting.

In the Top End of northern Australia very little work has been done in developing appropriate cultures of microbes and the techniques of inoculating these on to native plant seed or seedlings. At present, ERA's consultants (CSIRO) are in the process of developing ectomycorrhizal fungi for use in mine site revegetation. ERISS has also collected several strains of rhizobia/bradyrhizobia and endomycorrhizal fungi (OSS 1992). None of these research projects has yet produced cultures/techniques that can readily be used in the field. In Western Australia, Dr. D. Jasper and his team have been working in developing inoculation production techniques and field testing of selected range of endomycorrhizal fungi. Again, these research results have not been tested in the field.

2.2.5 Hardening of seedlings

In the Top End climatic conditions (heat, desiccation and light intensity) are so severe that they have the potential to cause 100% failure in the establishment of transplanted seedlings (QMPL, 1988). Special care therefore needs to be taken when seedlings are transplanted. This includes hardening of seedlings prior to transplanting. Hardening is achieved by gradually exposing the seedlings in the nursery to field conditions such as heat, high light intensity, low humidity, drought, salinity, acidity, alkalinity, heavy metal toxicity, waterlogging, frost, etc. Seedlings that are hardened this way will build up physiological tolerance while in nursery, and thus they will be better able to cope with field conditions when transplanted. Hardening is particularly important in mine site revegetation as most revegetation practices do not include protective irrigation and the mine spoils usually have less stored water than natural soils. Hardening can also be achieved by increasing potassium supply and trimming roots and cutting part of the foliage.

2.2.6 Use of bare rooted vs containerised seedlings

Although bare-rooted seedlings are commonly used in silvicultural practices in some parts of the tropics (eg India for *Eucalyptus hybrid* and *Casuarina equisetifolia*), the success of seedling survival is very much dependent on the season during which the seedlings are transplanted and the after care provided. Given that the climatic conditions are very harsh in the Top End, use of bare seedlings is unlikely to give satisfactory results. If for any reason bare-rooted seedlings are used, then extra care should be taken in preparing seedlings, hardening, excavating and in providing after care.

2.2.7 Transplanting

Various techniques can be employed to transplant seedlings in the field. These include manual, semi-mechanised or fully automated methods. The selection of appropriate method depends on site conditions, available after care, number of seedlings to be transplanted and expected success.

Important points to remember in transplanting native plant seedling include:

- loosening circled roots
- trimming excessive roots
- placing the seedling at an appropriate depth (to reduce the chances of seedling death due to collar rot)
- compacting the soil around the seedling to encourage soil-root contact
- providing protective irrigation immediately after transplanting
- reducing leaf area to minimise transpirational loss during the initial establishment phase.

Time of planting also plays an important role in the success of transplanted seedlings in the tropics. The success will be highest if the seedlings are transplanted after midday rather than early in the morning (Ashwath; pers. comm.). This is because the seedlings that are transplanted after mid-day will have shorter periods of exposure to intense sun, heat and low humidity. Further, this will allow the seedlings to be exposed to longer periods of cool weather (whole night and early morning) which will assist in their establishment.

2.3 Surface preparation techniques

The success of revegetation depends on plants becoming well established in a short time. The conditions in the seedbed or planting area are very important in this regard. Creation of a good seedbed is of vital importance in agricultural situations where great emphasis often placed on creating a good tilth, or fine crumb structure, in the seed bed prior to planting. In revegetation work the final land surface is usually not a prime soil material. Often at mine sites the final surface is a mixture of rocks and fine weathering products. In order for seeds to germinate they require good contact with the soil to maximise opportunities to take up moisture and nutrients; also they need cover as protection from desiccation by wind and sun and attack by birds and insects. Also there is a need to create a suitable rooting zone for plants (Bell, 1993).

Moisture is often a limiting factor on disturbed mine sites. Bulk density of mine soils may be higher although water holding capacity is often less than for a 'natural' soil (Davies et al, 1992). Surface preparation work such as ripping or contouring is often used in agriculture to improve the infiltration and water holding characteristics of the soil or growth medium (eg , Kamprath et al, 1979; Ibrahim and Miller, 1989; Arora et al, 1993). Deep ripping to 800 mm on restored minesites in Illinois produced improved crop yields as a consequence of improved root growth resulting from the lowering of soil bulk density by comparison with less cultivated soils (Bledsoe et al, 1992). Ripping experiments carried out at Ranger Uranium Mine have shown that there are beneficial effects from ripping but they are relatively short lived. Ripping improves infiltration of water but the fissures become choked with fine materials within the first season; also silt sized materials may form a surface crust following cultivation operations (Riley et al, 1993). The spacing of rip lines should be such that no ground remains unturned. Research work at RUM by OSS in 1992 used lines approximately 1 to 1.5 metres apart (Riley et al, 1993). Ripping on the contour can also act as a rainwater harvesting and erosion control technique which increases the quantity of water held in the root zone (Hudson, 1981). This effect will again be relatively short lived if surface crusting and fissure-filling occur. Use of disc harrows in Kakadu National Park borrow pits has been reported as increasing seedling growth by more than 100% when compared to scarifying and chain harrows (Setterfield et al 1993). However, these results were obtained on soil, or soil-like surfaces, rather than a waste rock surface. The timing of cultivation is also important. Ripping and other cultivation after seeding may bury seed at too great a depth for germination to be successful (Glossop, 1982).

Rehabilitation trials at Weipa in 1986-87 showed that the plant density of native vegetation increased from 520 stems/ha to 6800 stems/ha, and species numbers from 8 to 33 in the uncultivated and cultivated areas, respectively (Dahl and Foster, 1989). Further trials were carried out at Weipa during 1988 into different methods of seedbed preparation using three types of cultivating equipment and top soil stripped over a range of stripping times. Seedling establishment was more successful in cultivation trials with disc harrows, scarifier tines and trailing chains showing 93 %, 58 % and 42 % more seedlings respectively than the control. The reasons for this were that,firstly, cultivation produced a rough soil surface which provided favourable niches for the seed to fall into and get covered with the soil; secondly, it reduced competition from native grasses. In contrast, the untreated control had a smooth, crusted soil surface which offered few favourable sites for seed germination. Trials at Nabarlek suggest that if seed is sown immediately after ripping, good seed-soil contact develops thorough soil resettling, and the need for covering the seed by raking etc. is avoided (Hinz 1989).

Ranger's procedure for the establishment of native vegetation and exotic grass cover species on the WRD involves tine seeding of exotic grass, followed by broadcasting of a native seed mix, then harrowing and application of fertiliser and lime/gypsum (Ranger, 1987). No details were provided to describe the surface preparation procedures.

2.4 Use of top soil

A review of the use of topsoil in revegetation in the Alligator Rivers Region was undertaken by (Ashwath et al. 1992b) for an OSS internal report (unpublished). Grundy and Bell (1981) reported a comprehensive survey on all aspects of the use of topsoil in minesite reclamation. Their opinion was that wherever possible topsoil should be preserved for use in revegetation work during the rehabilitation program. The procurement, transport, storage and use of topsoil in revegetation are topics that have given rise to a great amount of literature (eg Bransden, 1991; Davies et al 1992; Grundy and Bell, 1981). The mainconcern when using soil appears to be to minimisation of both damage during the relocation phases and time spent in storage. Topsoil stored for any significant period of time undergoes changes which are generally not beneficial; structure breaks down (Setterfield et al 1993), seed viability decreases (Richards and Calder, 1978) and there is a decline in some of the micoflora population (Setterfield et al 1993). The extreme species richness of native shrubland vegetation near Eneabba, Western Australia, presents a major problem in the restoration of sites following mineral sand mining (Bellairs and Bell, 1993). Fresh soil from undisturbed sites contained 56 to 128 seeds/m^2 compared to only 10.5 seeds/m^2 in the surface 2.5 cm from a three year old stockpiled top soil.

Soil is seen as a valuable source of planting material such as seeds and other propagules which must be carefully managed (Hinz, 1981). However, the same topsoil may also be the source of annual forbs and grass seeds that can out compete tree seedlings in the early stages of rehabilitation and dominate the vegetation population (AMIC, 1994). The timing of topsoil operations may also be important. At Gove in the Northern Territory, Richards and Calder (1978) found that topsoil stripped late in the dry season, after seed set, gave the best establishment results. This observation was borne out by work at Weipa (Foster and Dahl, 1990) who found up to three times greater seedling establishment on rehabilitation sites using topsoil collected in the late dry season when compared to material collected in the early dry season.

Results from a bauxite mine rehabilitation monitoring program at Weipa in 1988 indicated the effect of using topsoil stripped at three time periods (April to June, July to Mid October, mid October to December) on the success of sown native tree and shrub species (Dahl and Foster, 1989). The results were found to be 4300, 1600 and 12000 stems/ha for early, mid and late year topsoil stripped areas, respectively. The improved result from late year stripping was due to retention of most of the soil structure and reduced competition from grass through killing the germinating native grass seeds from the first rains of the wet season.

2.4.1 Top soil collection methods

In Comalco's bauxite mining rehabilitation program at Weipa, soil from a nearby new mine area is stripped by a pair of caterpillar 657B self loading push-pull scrapers and relaid on the worked out mine area. The front machine loads subsoil while the rear machine pushes, then the rear machine loads the top soil further along the cut while the front machine pulls. The depth of cut is about 20-30 cm and the length of cut about 60 metres. The first machine spreads its load of subsoil directly on the mine floor. The second machine then spreads its load of top soil directly on top of the subsoil layer. The whole operation takes about 4 to 6 minutes. Estimates indicated that the scraper operators are able to return between 60-90% of the A horizon to the top of the new soil profile while relaying soil to an average depth of 50 cm. As most of the viable seed and vegetative propagules occur within the top 20-50 cm, special care is taken to ensure that the darker A horizon is relaid over the red coloured B1 horizon. The above technique of fresh soil replacement has been found to be successful and ensured a quick cover of grass and herb species (Foster, 1985b). Such a degree of success was not found on stockpiled soils. Moreover, stockpiled soils were frequently infested with weed species, particularly *Passiflora foetida.* Stockpiled soil at Weipa is respread using elevating scrapers and then ploughed to breakdown larger clods. In 1984, the cost of stockpiled topsoil was $2400/ha, which in 1994 terms is possibly close to $5000/ha. Topsoil also has value as a source of microbial inoculum for species such as rhizobia and mycorrhizal fungi and actinomycetes. There are also likely to be populations of soil invertebrates. Finally, soil is also a source of nutrients for plant growth.

2.4.2 Topsoil storage

The quantity and value of these resources and properties decrease with increase in storage time for the soil, as does the physical condition of the soil (Grundy and Bell, 1981). There is also a risk that weed seeds may increase as a proportion of the total viable seed population during storage (Bransden, 1991). For these reasons the most successful users of soil are likely to be those who are able to separate soil as topsoil and subsoil and reuse the materials in the appropriate order, unmixed, either immediately after stripping or certainly within one growing season (Semalulu and Barnhisel, 1992). At the Nabalco bauxite mine, Gove NT, land is cleared carefully prior to mining but the soil is not stripped until after regrowth of ground covers has reached the seeding stage (D. O'Keefe, pers. comm). This ensures that when the material is stripped and placed there will be a good supply of native plant propagules planted in the restored land surface. However, at Gove the area mined and the area stripped are essentially the same. In most open cut operations the pit is a much smaller area than that covered by the waste rock piles. In other words there will not be sufficient soil obtained from the initial clearing operation to return to the final land surface except as a relatively thin layer. Certainly there will not be enough topsoil to cover the entire site and the use of subsoil materials as surface cover is not recommended. This is because lateritic soils of northern Australia, particularly sub-soils, are known to have a large capacity to fix phosphorus (Bell, 1985, Koch, 1985). Nor is it usually possible or appropriate to collect topsoil from other areas to provide growth medium for a reclaimed site.

ERA's revegetation trials at the Light Industrial Area in Jabiru East on plots with and without top soil, indicated that the initial establishment of vegetation was much better on those plots which had received top soil. Even the spear grass *Sorghum intrans,* which is considered hardy, was unable to establish on plots which did not receive top soil. This suggests that in spite of its reduced biological properties, stockpiled top soil may assist in accelerating the initial vegetation establishment process. Any assessment on the use of stored top soil should be based on its overall merits rather than a single attribute.

2.5 Direct seeding vs tube stock

The use of tube stock usually results in quicker establishment and uniform growth. However, the cost of using tube stocks in broad-acre planting is exorbitant. This is especially so when no economic return is anticipated from the site being restored. In addition, use of tube stock will have certain disadvantages, such as development of shallow rooted plants, and stem forking (J. Gardner, Alcoa; pers. comm.). The latter was observed in jarrah forest established on a rehabilitated bauxite mine. Although the real cause of stem forking is not known, the available data suggest that this may be the case if tube stock is used.

Recognising the significance of direct seedling in achieving the targets of the Billion Tree Planting program , the Greening Australia organised a conference exclusively on direct seeding (Greening Australia 1990). The proceedings of this conference contains a great deal of valuable information on all aspects of direct seedling with native plant seed.

Trials at Nabarlek (QML, 1990) suggested that the use of tube stock cannot be relied upon for successful revegetation and that direct seeding gives better results. Of the five species tested as tube stock, all except *Erythrophleum chlorostachys*. *E. tetrodonta* and *E. miniata* grew well in the nursery in all pot sizes used. However, once planted out in the field, their survival and growth rates were poor: although root growth continued, shoot growth appeared to cease. Overall, large tubes proved uneconomical. Of the small tubes used, best results were obtained from a long square tube (120 x 50 x 50 mm) with large holes in the bottom. These pots, known as " Native tube," reduced the root balling effect, and gave a field survival rate of 90 % compared to 30 to 50% for round tubes of similar capacity. Other strategies which contributed to the successful establishment of tube stock included i) planting in January and February - the wettest time of the year, ii) use of hay mulch and good grass cover to protect the seedlings against high temperature, iii) using soil in the pot which was similar to that found in the field, iv) use of sun and moisture hardened seedlings in contrast to well watered and well fertilised plants.

At Nabarlek, use of tube stock will be limited to *Melaleuca viridiflora* in wet areas as it is considered that the tube stock of other species will not survive without irrigation (QML, 1990).

Preliminary transplanting trials conducted by ERISS (Ashwath, unpublished data) on a natural soil using large plastic bags (2 litre capacity) proved very satisfactory (>90% survival) for the 16 species examined. ERA has achieved good success on their WRD for a range of native species used in a mycorrhizal fungi study. These trials were, however, provided with protective irrigation.

2.6 Soil surface stabilisation

A major concern in minesite rehabilitation is to ensure stabilisation of the land surface at the earliest possible stage. This has the dual benefit of reducing erosion hazard and providing a stable environment in which vegetation can become established. Tatzenko (1985) reviewed a number of techniques used for stabilisation of batters in the Top End of the Northern Territory. These included hydro mulching, hay mulching, mesh mulching and rock mulching.

Hydromulching, also known as hydroseeding, is a technique in which seed, fertiliser and mulch are applied in one operation. This technique is often used on steeper slopes where it is necessary to protect the soil surface from erosion and establish permanent vegetation cover quickly. This is particularly important where the slope has been topsoiled and there is a risk of soil being washed off by heavy rain. Most commonly grass and ground cover species, usually agricultural varieties, are sprayed over the surface of the area in a mixture of water and mulching material, often with a starter dose of fertiliser. The mulch is usually wood fibre or paper slurry and may incorporate a sticky substance to improve adhesion to the slope. This technique has been used by RUM on waste rock surfaces, some of the outer batters on the tailings dam and on other earth embankments. However, it is relatively costly and is really only of value on areas where quick establishment is essential (Hudson, 1981). GEMCO at Groote Eylandt also uses hydro mulching and the mulch medium is composed of commercially available wood fibre pulp.

Hay mulching is a technique in which a layer of hay is applied to the treated area to provide protection to the seed, fertiliser and the soil surface from the action of wind and water. The hay is tacked down to form a cohesive mat, through the use of a binding agent. The most commonly used binders are biodegradable anionic bitumen emulsions (such as Terolas) or various polymer binders. Hay mulching has been used effectively by QMPL at Nabarlek to revegetate and stabilise a variety of areas throughout the mine site. The hay mulching technique is used extensively for the revegetation and stabilisation of road cuttings and embankments, particularly where only limited maintenance is desired.

Mesh mulching involves application of an open weave mesh to the surface which has been prepared, seeded and fertilised to provide physical condition until a vegetative cover is established. The type of mulch used (eg. gap between the strands of the weave, synthetic or natural fibre) will depend on site specific conditions. The major cause of failure of the mesh mulches is incorrect anchoring of the edges of the mesh, particularly in overlap areas where two rolls join.

Rock mulching is a technique whereby the area to be protected against is covered with a continuous layer of rocks. This method has been used successfully throughout the Top End on a variety of mine structures ranging from tailings dam and retention pond batters to drainage lines. In the Rum Jungle Rehabilitation Project rock mulch has been used to improve the long term stability of the reshaped batters and drainage lines.

Elsewhere other amendments have been tried as surface stabilisers. Sopper (1993) reports on the use of fly ash mixed with sewage sludge and refers to his earlier work with sludge alone. In both cases the amendment was applied to steep slopes made from coal waste. The resulting, stabilised, surfaces were then hydro seeded with grasses and legumes in a series of trials. The conclusion was that the treatment was successful as a topsoil substitute and enabled steep slopes to be quickly revegetated without the need for regrading to shallower batters. It is unlikely that such techniques would be of value in the ARR where the areas to be revegetated are great. There is no source of fly ash and the supply of sludge is insufficient locally and further supplies are located far from the site to be rehabilitated. Neither is there a cheap and plentiful source of material, such as straw or woodchips, suitable for use as a conventional mulch treatment.

Other agents have been used for soil stabilisation elsewhere in the world. Many have been employed to reduce dusting of fine materials such as silts and fine sand. Such agents have included epoxy resin, asphalt, polyethylene, urea-formaldehyde, butadiene, cement, lime, polyesters, polyvinyl alcohols and gypsum (Bridges, 1991). No reports have been found of any of these materials being used in commercial applications in the Top End.

2.7 Soil fertilisers and amendments

2.7.1 Fertilisers

Bell (1993) quoting information from Hannan and Bell (1993) on fertiliser requirements stated that most Australian native species have evolved under conditions of relatively low available amounts of nutrients, particularly phosphorus. Mycorrhizal associations enable these species to grow on australian soils satisfactorily. Some native plants, such as eucalypts, can exist under low nutrient levels but will respond positively to nitrogen and phosphorus fertiliser applications. Few data are available on the fertiliser requirements for re-establishing native plant species. Experience from bauxite and sand mining industries in Australia indicate that some fertiliser application will be necessary during initial establishment. While native vegetation must rely on the biological nitrogen fixation to meet their long-term needs, a starter dose of 10 to 30 kg/ha of nitrogen and 10 to 50 kg/ha of phosphorus is suggested as a guide (Foster, 1985b). Exotic pasture species, however, will require higher levels of nitrogen (30 to 40 kg/ha) and phosphorus (30 to 60 kg/ha) at establishment. At Gove native species are directly seeded along with rhodes grass (*Chloris gayana*) into replaced soil with an application of 36 kg/ha of phosphorus as superphosphate. Hinz (1981) found that rhodes grass disappeared after five years as the phosphorus status in the soil declined.

Bell (1993) considered that when topsoil is used in revegetation programs, it rarely requires any amelioration beyond the addition of nutrients. Where a pasture involving exotic grasses and legumes is being established, there will be both initial and continuing requirements to supply fertiliser. Where the establishment of a native ecosystem is envisaged, there may still be an initial need to apply low rates of nutrients, such as phosphorus, to assist rapid establishment. Overburden spoils at most mine sites in Australia are commonly deficient in plant nutrients such as nitrogen and phosphorus and therefore will require an initial application of fertiliser for the successful establishment of native vegetation.

Bell (1985), under glasshouse conditions, assessed the nutritional requirements for the establishment of nine native species from Weipa. Six species responded to phosphorus application and three did not. The three species which did not respond were relatively large seeded and it was suggested that the seed contained adequate amounts of phosphorus to meet plant needs at establishment. Also, the growth of the six of the nine species was increased by nitrogen application. While the species of *Melaleuca* and *Eucalyptus* tested by Bell (1985) responded to both nitrogen and phosphorus, *Grevillea pteridifolia* responded to neither treatment. Bell's (1985) trials also found that exclusion of potassium, copper and zinc had no effect on *Erythrophleum chlorostachys* and the *Acacia* species studied, but depressed the growth of *Melaleuca* and *Eucalyptus* species. He noted that different species have different nutrient requirements during the establishment phase and that the fertiliser mix used may influence the final species composition on a site.

The lateritic soils of northern Australia are known to have a large capacity to fix phosphorus (Bell 1985, Koch, 1985). To overcome this problem, high rates of phosphorus fertiliser application (>40 kg/ha) were considered essential during the first few years of seedling establishment and growth (Bell, 1985). An initial application of nitrogen is also considered necessary to ensure rapid establishment of vegetation cover. However, long-term nitrogen levels should be met by establishing legumes and other nitrogen fixing species (Marrs, 1989, Koch, 1985). Nitrogen fertiliser application rates should be kept below 50 kg/ha/year, as higher rates reduce biological nitrogen fixation (Skeffington and Bradshaw, 1981).

Richards (1981) in his rehabilitation trials at Gove noted that indigenous species were not responsive to fertiliser treatments and that high phosphorus application resulted in the exotic species, especially legumes, gaining a competitive edge over the native species. In unfertilised plots the native species have competed successfully against most introductions. In the 1972 species/fertiliser/site preparation trials at the bauxite mining site in Gove, five levels of phosphate to a maximum rate of 800 kg/ha were applied to areas sown with fifteen species (Richards and Calder, 1978). Re-analysis of the site after twenty years found that total phosphorus from superphosphate applications was continuing to act as a slow release phosphorus reservoir with no sign of being the supply depleted in the immediate future. Of the fifteen species originally sown in 1972, seven were absent from the site in 1992, three had very restricted occurrence, and five had spread extensively from the original sown sites (Richards et al, 1992).

Studies at Gove indicate that the widely used cover crop *Chloris gayana* for revegetation in the Top End becomes less vigorous and fades out approximately in five years due to competition by recolonising indigenous flora and lack of nutrients in the soil (Hinz, 1981). In coal mining rehabilitation work in Queensland, fertiliser is used to maintain the cover crop vigour at a level which is sufficient for erosion control but still allows native seeds to germinate and establish (Csurhes, 1988). Csurhes (1988) found that the growth rates of two native species *Acacia holosericea* and *Eucalyptus citriodora* increased following application of nitrogen and phosphorus in the absence of cover crop. However, the height of these species was reduced with increasing application of nitrogen and phosphorus in the presence of a cover crop.

Langkamp (1982) reported that for optimal growth of acacias on areas restored after mining in Groote Eylandt adequate phosphorus and molybdenum nutrition was essential. He also reported that, following complete fertiliser application to a *Eucalyptus tetrodonta* open forest, there were significant increases in dry matter production in the grass/forb and *Acacia aulacocarpa* components of the understorey. In revegetation work following sand mining on Fraser Island, use of phosphate fertiliser was a critical factor in tipping the balance between the desired heath/eucalypt community and the acacia dominated community (Davie et al. 1991).

In experiments on the revegetation of manganese tailings at Groote Eylandt in the Northern Territory grass seeds were sown at 5 kg/ha with 200 kg/ha of NPK mix (12:14:10); and legumes at 5 kg/ha with 200 kg/ha P, K and Mo mix (10:10:25) with and without their specific inoculum (Farnell, 1992). Of the eight species of grasses sown all except carpet grass established successfully in the tailings. Farnell (1992) considered that the critical factor in determining the growth of tropical grasses in high manganese and acid conditions is the high level of water soluble manganese. The growth of legumes in the tailings was poor due to their susceptibility to excess manganese. Farnell (1992) also tested rhodes and couch grass to NPK mix (12:14:10) applied at 200 kg/ha. He noted major response of rhodes and couch grass to phosphorus, but not to N and K applied individually. However, significant NP, PK and NPK interactions were evident.

Studies on the vegetation establishment on the bauxite residue at Gove best results were obtained when plants were fertilised with 1200 kg/ha of NPK (12:5:15) plus trace elements, and an additional 300 kg of super phosphate per hectare (Hinz, 1982)

On Comalco's bauxite mining rehabilitation program, at Weipa in north Queensland, 2-3 kg of native seeds are mixed with 500 kg of fertiliser and sown aerially (Dahl and Foster, 1988). The authors did not include data on rates per unit area and went on to express the view that fertiliser application rates at Weipa were based on scanty information, and that nothing was known about the effects of split vs single application. According to them plant nutrition is thought to be one of the principal factors influencing long-term stability in the rehabilitated plant community.

In Ranger's 1982 trials on the WRD, using nine native species, two application rates of complete fertiliser were combined with two different application rates of gypsum or lime. There was a positive response to higher levels of gypsum in the growth of shrubs and density of ground cover. The study concluded that establishment and growth of native species on the WRD were not affected by low levels of plant nutrients or Ca/Mg imbalance (Ranger, 1987).

Ranger's 1984 trials investigated the relationship between native trees, shrubs and exotic ground cover species at three levels of fertiliser, lime and gypsum application. The results indicated that, as a group, acacias and eucalypts showed no variation in species richness or species density at different levels of fertiliser application. Eucalypts responded to high rates of fertiliser application by increasing species diversity, and numbers of both acacias and native ground cover species appeared to be independent of fertiliser application; exotic ground cover species showed a positive correlation with fertiliser application (Ranger, 1987).

2.7.2 Amendments:

The poor structure and low hydraulic conductivity of fine bauxite refining residues (red mud) from alumina production are major factors hindering its revegetation. At the alumina refinery at Gladstone in central Queensland, two approaches to the reclamation of redmud were examined (Bell and Meecham, 1978). The first was to determine if the red mud itself could be suitably ameliorated to support plant growth; the second was to consider the use of a soil layer over the redmud as a growth medium. In the field trials no growth occurred in any of the treatments on the alumina refinery waste in the absence of applied soil. Maximum yields of pasture were recorded with at least 200 mm of soil cover and an application of 50 kg/ha of phosphorus, although establishment of all legumes was poor.

At Alcoa's redmud rehabilitation experiments in Western Australia plant cover and percentage dry weight yield of *Agropyron elongatum* increased with increasing levels of gypsum and sewage sludge amendment. An application of 77 t/ha gypsum and 144 t/ha sewage sludge produced the maximum beneficial effect on soil physical properties of red mud (Wong and Ho, 1991).

2.8 Weed control

Disturbed sites are prone to be infested by obnoxious exotic weeds which are better able to cope than native species with the hostile environment that occurs initially on disturbed sites. Also some exotic species are so aggressive that even if some native species establish on these sites, they will be out-competed by the exotic weeds.

Control of exotic weeds can be very expensive and is often a long term activity. The best strategy for weed management on a disturbed site is to minimise weed infestation and multiplication rather than resorting to eradication after they have established. This approach is currently being followed at Nabarlek, Ranger, Coronation Hill and Kakadu National Park for some selected weed species. To achieve effective weed control detailed planning, regular monitoring, frequent investigation of effective methods of control and a thorough understanding of weed biology are all necessary.

In a tropical climate, weed infestation usually occurs during the wet season. Disturbed sites have to be regularly monitored during the wet season to record the type of weeds that establish and the rate at which they spread. Depending on the nature of the weed and its spreading potential, some weeds may be allowed to establish on the site (in order to prevent invasion by aggressive species) while others can be eradicated prior to seed maturity. This approach is extremely important if large areas are to be kept weed-free. This will allow the use of available resources to be concentrated on eradication of more aggressive species. For example, Kakadu National Park (KNP) has a number of exotic weeds (Cowie and Finlayson 1986, Cowie and Werner 1987 and 1988, Brock and Cowie 1992). The eradication of two of these weed species *Salvinia molesta* and *Mimosa pigra* is a high priority at present (J. Russell-Smith, pers. comm.). Control of other weeds such as *Pennisetum polystachion, Hyptis*, *Sida* etc is considered a lower priority (I. Garven; pers. comm.).

Mining companies in the ARR have small areas on which to control weeds by comparison with KNP. However, mine sites are more prone to infestation by exotic weeds than undisturbed sites elsewhere in the Region. This is due to increased human and vehicular traffic within mine leases, and changes in the properties of disturbed soils viz soil nutrition (eg higher P on Ranger WRD) and water availability. The mining companies therefore adopt intensive methods of weed control. At Nabarlek, stockpiled clay, top soils and retention pond bunds are treated with herbicides (R. Hinz; pers. comm.) early in the Wet season. The areas are then monitored and any clumps left un-affected by herbicide are removed manually. Natural areas adjacent to disturbed sites may also be infested by exotic weeds such as mission grass (*Pennisetum polystachion*). These isolated plants are monitored during their flowering stage. Seed heads are bagged and the entire plant removed and burnt (P. Bailey; pers. comm.).

At Ranger, *Pennisetum polystachion* is commonly found on many disturbed sites (eg Jabiru East and some sites on waste rock dumps), and other weeds also appear occasionally. Burning is followed to control the former while the latter are eradicated by herbicide application and/or hand removal (C. Unger; pers. comm.). The waste rock dumps and RP2/RP4 areas are also infested with buffel grass (*Cenchrus ciliaris*), but no control measures seem to have been taken.

At Coronation Hill, rubber bush (*Calotropis procera*) occurs in isolated bushes and clumps. Use of herbicides and hand pulling are being employed to eradicate this species (J. Russell-Smith; pers. comm.).

Many studies have been carried out, or are currently underway to investigate eradication procedures for exotic weeds from range lands, pastoral lands and park lands of the ARR. These studies primarily concentrate on the control of *Mimosa pigra* (Harley 1992), *Salvinia molesta* (M. Julien and M. Storrs; pers. comm.), *Sida acuta* and *Pennisetum polystachion* (Mott 1980). The methods tested include biological methods such as the use of insects and fungi, and chemical methods (use of herbicides, salinity) and cultural methods (ploughing, burning).

An integrated approach is used to control exotic weeds within Kakadu National Park (KNP). This includes the use of quarantine procedures as well as mechanical, chemical and biological methods of control. Staff at KNP have identified four classes of plants for eradication. These include: class 1; *Mimosa pigra* and *Salvinia molesta*, class 2; introduced pastoral species (gamba grass, mission grass, para grass and calapo), class 3; rubber bush (*Calotropis procera*) and class 4; others (*Pennisetum polystachion*, rosella (*Hibiscus subdariffa)* and *Hyptis suaveolens*).

Class 1 weeds are being controlled intensively. *Mimosa pigra* is controlled by mechanical methods; *Salvinia molesta* is regulated by a quarantine method, also spraying using the herbicide Kammat and the release of weevils (*Cyrtobagous salvinae).* Among the Class 2 weeds, gamba grass (*Andropogon gayanus*), para grass (*Brachiaria mutica*) and calapo *Calapogonium muconoides*) are now beyond control. However, effective control of mission grass is being achieved by pulling out the clumps prior to seed maturity. The control of Class 3 weed (*Calotropis procera)* is achieved by cutting back the shoot and spraying the stubble with Garlon. The Class 4 weeds are controlled on an opportunistic basis using both mechanical and chemical (glyphosate) methods (Dr J. Russell-Smith; pers comm).

The Australian Nature Conservation Agency (ANCA) sponsored a study to assess the status of plants currently used in KNP, with the intention of minimising the spread of alien species. This study surveyed settlements in KNP and classified species as recommended and accepted , provisional or prohibited (Brock and Cowie 1992).

Studies to control *Salvinia molesta* using the weevil *Cyrtobagous salvinae* seem to be promising (M. Julien and M. Storrs; pers. comm.). However, this method is yet to be tested at field level. It is hoped that the integration of the biological method with a chemical method involving spraying of F100 (kerosene and Kammat mixture) will provide effective management of salvinia in natural billabongs of KNP. It is however, too early to predict the effectiveness of this method.

Mimosa pigra occupies over 80,000 ha in the Top End. Infestation usually occurs in land areas of low economic value, so costly methods such as chaining, ploughing, burning and herbicide spraying are not practical (except in Kakadu National Park). The only economical way this species can be effectively controlled is via biological methods (except in KNP, G. Farrell; pers. comm.).

Intensive methods of weed control are still applicable on sites that have commercial importance such as tourism, conservation or crop production. These methods assist in rapid eradication and prevent further spread of mimosa from its primary infested areas.

Biological methods of controlling *Mimosa pigra* is being researched both by CSIRO and the Northern Territory Department of Primary Industry and Fisheries (DPIF) in Australia and many others overseas (see Harley 1992). In the Top End, the CSIRO Tropical Ecosystem Research Centre has made considerable progress (Dr G. Farrell; pers. comm.). Research results indicate that a single insect species is unlikely to prove totally effective in the control of mimosa. The trials, including up to six species of insects and two species of fungi, appear to be effective. Each species of insect affects a different aspect of the plant's life cycle and, as a result, contributes to the overall decline of the species. Presently, the insect *Carmenta mimosa* is proving to be very effective (G. Farrell; pers. comm.) whilst the potential of the other species and the fungi have yet to be tested on a field scale. The field studies indicate that the delay in the effectiveness of an insect-based control method can be attributed to the relatively slow rate at which the insects are spreading rather than any inability of the insects to attack plants.

A further example of biological weed control is found at the Nabarlek minesite. The weed spiny head sida (*Sida acuta*) is being controlled by an introduced beetle, *Calligrapha pantherina*. The beetle was introduced to the site in 1990 with the assistance of the Northern Territory Department of Primary Industry and Fisheries. To date the creature has performed well with effective control of the weed being established and maintained (P.Bailey, pers.com.)

2.9 Species

2.9.1 Species selection

The choice of species to be used in revegetation is influenced by its aim. If the aim is to restore the site to a woodland ecosystem, then only local native species can be used in the revegetation program. If the land is to be restored to agriculture, pasture or forest, then different principles apply. Likewise, the species to be used will differ if the land is to be returned to multiple uses involving forestry, woodland, pasture, animal production and recreation.

Regardless of the aims of revegetation, there is a need to match species to site conditions because disturbed sites are highly variable. The success of establishment, or ensuring that the established vegetation is viable in the longer term, will depend upon how well the species are matched to site conditions. The species-site matching is extremely important in the case of restoration of native woodland ecosystems where restoration requires the establishment of self-sustaining ecosystems. Greater emphasis should be placed on the use of local native species in ecosystem restoration (Bell 1984). This limits the range of species one could use in revegetation. Nevertheless, there is much natural variability within a given ecosystem and this provides an opportunity to select genotypes for specific site conditions. If a specific quality is not found within the local plant community (eg tolerance to heavy metals, salinity, acidity etc) and if the sites have these characteristics, then the use of tolerant non-local native species or even exotic species should be considered. This site-genotype/species matching principle applies even if a single species is to be established on the site (eg *Pinus radiata* or

Eucalyptus camaldulensis) as the provenances within a species may have marked differences in their adaptability and tolerance.

2.9.2 Species for land stabilisation

Some mining companies view revegetation practices in two distinct phases viz an initial phase and the final phase. Initial phase activities include establishment of vegetation that assists in the stabilisation of disturbed sites to minimise erosion, control dust and/or to build up organic matter on the site. Erosion control is usually achieved by establishing fast growing, often exotic grasses (Armstrong 1986). Often, due to lack of information on native grasses and unavailability of native plant seed on a commercial scale, exotic species such as couch, stylosanthes and rhodes grass are widely used. Trials at Ranger have shown that native grasses can be used to achieve surface stabilisation while some native species offer other advantages such as recurring growth, ability to grow well on unamended spoil, resilience to fire and other stresses, etc (Gray 1993, Ashwath et al 1994).

In sand mines (eg North Stradbroke Island), use of grasses is discouraged to prevent their competition with native species. In such conditions, the surface is stabilised by mulching or by establishing a cover of hybrid sorghum (sudax) which binds the soil and reduces wind velocity (P. Foot; pers. comm.). No grasses are used at Alcoa as the natural sites in jarrah forests do not have native grasses (J. Gardner; pers. comm.). In this instance surface stabilisation is achieved by direct sowing of native trees, shrubs and forbs at a higher plant density higher than that found naturally.

The desirable characteristics of the grasses to be used in surface stabilisation include their ability to establish well and grow on a disturbed site, soil binding nature, providing rapid plant cover, reduced competition with other species for water, nutrients and space etc. Ashwath et al (1994) listed some native grasses that are considered to have the best potential for use in surface stabilisation in the Wet-Dry tropics.

2.9.3 Species to promote soil development

Some rehabilitation workers believe that there is a need to establish succession species prior to introducing canopy species (A. Armstrong; pers. comm.). Succession species such as acacias grow fast, bind soil, and accumulate large amounts of litter contributing to the build up of organic matter. Furthermore, acacias fix nitrogen (which is often the most limiting nutrient in the savanna ecosystem) and thus enrich the soil within a short time. The disadvantage of using acacias are that they compete with other canopy species, are susceptible to fire and have relatively short life cycles.

Another group of rehabilitation workers and scientists question the need to include a successional phase in restoration. This group believes that succession is unnecessary and the canopy species can be introduced directly with appropriate cultural practices (P. Reddell; N. Ashwath, pers. comm.). There are already demonstrated examples at Weipa (Foster 1985b), Gove (Hinz 1981), RGC sand mine at Eneabba (Jeffries et al 1991) and Alcoa (Nichols et al 1991) that the canopy species can be established without going through a succession phase. We recommend this approach for restoration in the Top End and suggest the use of greater cultural care (eg seed treatment, fertiliser application, protective irrigation, weed control) to increase the success of restoration, and to accelerate this process. Care should, however, be taken with this approach to ensure that the species mixture is balanced by including seeds of at least the important functional groups such as legumes, ground cover species, shrubs and trees to serve both immediate and long-term needs of the ecosystem.

2.9.4 Species for problem sites

Disturbed sites, especially mine sites are noted for their problem soils. These include, sloping areas, compacted sites, saline soils, waterlogged sites, alkaline soils, sodic soils, acidic soils, infertile soils and soils characterised by abnormal levels of heavy metals (eg Pb, U). Presence of one or more of these conditions on a mine site requires the matching of species to site conditions.

The first step in this matching process is to identify sites with potential problems, diagnose the problem and then investigate if there are local native species that can cope with unfavourable soil conditions. If no suitable local native species are found, then consideration should be given to using non-local native species and exotic species. In selecting species for problem sites, care should be taken to assess all possible constraints and then evaluate if there are species/genotypes that can cope with these constraints. If no species are found that can tolerate all the constraints, then it is important to identify the constraint which is likely to affect the plant growth the most. In some cases the interaction between the factors may be far more significant in influencing plant growth than any of the stresses on their own. For example, if a site is exposed to both salinity and waterlogging, there is no point in selecting species tolerant either to salinity or waterlogging. This is because the effect of interaction between these two factors is more significant in influencing the plant growth than either factor individually (Barrett-Lennard et al. 1990, Morris, 1980, Aswathappa, 1994).

The available information on pH, salinity, and waterlogging tolerance of native plant species has recently been reviewed (Chandrasekaran 1994). It is clear from this report that most studies deal with trees and shrubs with hardly any studies on local grasses, legumes, and other forbs.

Relative tolerance of native tree and shrub species to salinity and acid soil indicated large inter species differences. The recorded LD50 (salt concentration required to cause 50% seedling mortality) values were 350 mol m^{-3} for *A. torulosa* and to 1850 mol m^{-3} for *A. maconochiana*. Acacias and melaleucas showed large variability to salinity tolerance compared to eucalypts indicating greater potential for selecting tolerant species from the former genera (Ashwath and Marcar 1994). The tolerance between provenances (within a species) also differ. For example, in *A. ligulata* and *A. leptocarpa*, there was a marked difference between the provenance for salt tolerance.

Grasses also exhibit large variation in their tolerance to salinity, with *Chloris gayana* exhibiting highest tolerance and *Setaria anceps* the least (Russell 1976). However, studies by Russell included mostly exotic species with little understanding of salt tolerance of native grasses. Tolerance to waterlogging, and salinity and waterlogging has been examined for 16 native tropical and subtropical trees and shrubs (Ashwath, unpublished). This study clearly illustrated that the combined effects of salinity and waterlogging caused a greater reduction in growth than either factor alone. In addition, the study also indicated that some species tolerant to waterlogging (eg melaleucas) maintained their salinity tolerance levels when exposed to combined effects. On the contrary salt tolerant species susceptible to waterlogging (eg acacias) were severely affected by the combined stress. Van der Moezel et al (1988) list information on the tolerance of salinity and waterlogging for a wide range of Western Australian native species.

Ashwath et al. (1993b) ranked a number of Acacia species for acid soil tolerance in yellow podsolic and gilgaied clay soils. The studies indicated that ranking order of species for acid soil tolerance differed with the soil type, which suggested the need to use more than one soil type to obtain a reliable ranking. The differences in species ranking order between the two soils were found to be related to the greater sensitivity of some acacia species tested to aluminium toxicity in the gilgaied soil than to manganese toxicity in the yellow podsolic soil. Ranger and Nabarlek mine spoils do not have sodium chloride induced salinity. However, Ranger spoil has $MgSO_4$ induced salinity and an imbalance of Ca:Mg ratios. Research at ERISS is currently looking at the effects of high $MgSO_4$ concentrations and high Mg:Ca ratios in the WRD soil growth on the germination of native plant species (Ashwath et al. 1993a).

2.9.5 Species for commercial purpose

The use of commercial species such as mangoes (*Mangifera indica*), neem (*Azadirachta indica*) and cashew (*Anacardium occidentale*), forestry species such as teak (*Tectona grandis*), Caribbean pine (*Pinus caribae*), Hoop pine (*Araucaria cunninghamii*) and pastures such as stylosanthes, siratro, pangola grass (*Digitaria decumbens*) on disturbed mine sites has been investigated at a bauxite mine in Weipa (Lawrie 1985). Research is being continued on this and in the establishment of local native plants. No conclusions have been reached as to the pros and cons of using commercial versus native woodland species.

2.10 Conservation vs commercial species

In deciding about the overall aim of revegetation, various aspects, including long-term use of the site should be considered and the proposal to use commercial over woodland species needs to be assessed thoroughly before any decision can be made. This is because commercial species require a very high level of care compared to native woodland species (Bell 1984). In addition, provision of this care cannot be sustained in the longer term unless net profits from the rehabilitated sites are high. Often such a venture may not generate enough produce to make it economically viable. Similarly, plants may produce enough yield, but the fruits or the grains may be predated by native fauna, thus forfeiting the entire investment. A typical example is the rice project at Humpty Doo near Darwin where rice production was shown to be possible, but adequate protection of the crop from magpie geese was impossible to achieve. Such ecological effects in assessing viability of species for commercial use should be borne in mind while considering plants for mine site rehabilitation. In addition, possible changes in the social habits of the traditional owners, public attitudes and political sensitivities need to be taken into account when making a choice of commercial species for mine site revegetation.

2.11 Return of Fauna:

Consideration of waste rock dumps as habitats for fauna is often a secondary concern to achieving surface stability through the development of a vegetative cover (Bell, 1993). However, there is evidence to indicate that soil and other fauna are important components of functioning ecosystems (Majer, 1989). Curry and Good (1992) reviewed the process involved in the restoration of soil fauna. Viert (1989), and Green and Salter (1987) discussed measures which can be adopted in rehabilitation programs to encourage the return of macro-fauna. Nichols *et al.* (1991) discussed issues related to faunal return on land revegetated with a native ecosystemafter bauxite mining in Western Australia. Monitoring of the return of vertebrate species into rehabilitated areas following sand mining near Eneabba in Western Australia has shown that their return is dependent upon the provision of food sources and shelter (Jefferies et al. 1991) . This was particularly evident in the nectar and pollen feeders which moved in and out of the rehabilitated areas from surrounding undisturbed vegetation, the animals following the flowering of certain species.

General fauna surveys at Alcoa's rehabilitated bauxite mining areas in the northern jarrah forests of Western Australia indicated that a high proportion of most fauna groups return to rehabilitated sites. Seventy-eight per cent of reptiles, 90% of birds, 100% of upland mammal species and 80-90% of ant and collembola species have been recorded (Nichols and Bamford 1985, Collins et al. 1985, Kabay and Nichols 1980 and Majer et al. 1984). Monitoring at Alcoa indicated that revegetated areas (only four to five years old) had bird species numbers and densities similar to those of undisturbed sites. However, the bird populations were mainly dependent on the revegetation techniques used; in particular the type of tree species used and the inclusion of ground cover and shrub understorey plants (Nichols and Watkins, 1984). Termite utilisation of Alcoa's rehabilitated bauxite mined areas in Western Australia indicated that the pattern of termite distribution depended on two interrelated factors; the termite species' food requirements and the floral and physical characteristics of the particular rehabilitated area (Nichols and Bunn, undated). Age of the rehabilitated site appears to be the most important determinant of species composition in the termite population . Nichols and Michaelsen (1985) published an inventory of fauna research including over 100 references in relation to mining in Australia covering the bauxite, coal, sand, iron ore, uranium and petroleum industries.

Studies undertaken at Groote Eylandt, Gove and Weipa indicate that ant species recolonise revegetated sites in the seasonally wet tropics at similar rates, and reach species numbers similar to those of adjacent undisturbed forest areas between 3.5 and 7.5 years after revegetation (Major 1983). The work of Reeders and Mortons (1983) and Reeders (1985) at Weipa bauxite mining operations showed that, of the 160 vertebrate species known to occur in the *Eucalyptus tetradonta* open forests, more than 73 per cent were in the revegetated areas. These included mammals, birds, lizards, snakes and frogs and the return ranged from 58% for mammals to 88% for frogs.

Andersen (1989) suggested that ants can be used as indicators of rehabilitation success on disturbed mine sites in Australia. The most interpretable results are obtained when ants are classified into functional groups based on their habitat requirements and their status in ant communities. Of the seven functional groups of Australian ants, four are considered to be useful for bio-monitoring purposes. Dominant species of the genus *Iridomyrmex* are aggressive and abundant in hot and open habitats. Opportunists are poor competitors and are characteristic of disturbed sites. Cryptic species occur where there is an abundance of soil-litter interface.

Using the composition and structure of ant communities, Anderson (1993) investigated the success of the restoration program at Ranger Uranium Mine. He noted a clear succession of ant species across revegetated sites within the Ranger lease which were dominated by*Acacia*. Initial colonisation was by ant species belonging to the genus*Iridomyrmex*, but as plant cover and litter increased these were replaced by the broadly adapted, opportunistic species *Paratrechina longicornis*. He found that ant colonisation was slow at isolated sites, with only twelve species present after eight years compared to 21 species after only four years at a site close to potential sources of recolonisation. However, he considered that heavy shade and litter produced by acacias were hampering further change. Results from a site where, two years after revegetation, a fire had broken the dominance of acacias and led to the establishment of a wide variety plants species which suggested that management practices like prescribed burning may encourage further colonisation by ant species. In addition, studies are also underway to monitor return of vertebrate fauna onto revegetated sites of Ranger (eg lizards; J. Bywater; pers. comm.).

In southern Australia, disturbed habitats such as old mine sites generally have few of the dominant *Iridomyrmex* and cryptic species compared with undisturbed sites, whereas the opportunists and generalised myrmecines are well represented. In contrast, abundant *Iridomyrmex*, and consequently a reduced representation of opportunists and generalised myrmecines occur in northern Australia where the open conditions of disturbed habitats are found (Andersen 1989). As rehabilitation progresses, it is expected that the mix of these functional groups of ants will approach that of undisturbed sites. As the characteristics of ant populations are dependent upon a wide range of ecological variables, the relative abundance of the functional groups of ants could provide a broad measure of success of rehabilitation. More site-specific information is needed in order to be able to use ants to assess rehabilitation success in a more detailed manner.

Although proposals have been made to use ants as bio-indicators of restoration success, to date little effort has been made to relate the number and diversity of ants with other terrestrial invertebrate fauna (eg spiders, collembola, beetles, silver fish etc) and the degree of disturbance. A collaborative study between the OSS and CSIRO is currently investigating the relationship between ants and soil-living invertebrates and foliage arthropods at 39 sites in the Jabiru region. The sites differ markedly in their plant composition, disturbance and other attributes. This study is also examining the functional role of ants in revegetation, eg seed removal and litter decomposition.

The rehabilitation of the uranium mine site at Rum Jungle in the NT was carried out between 1983 and 1987. Ryan (1987) reported that six species of daylight active ants were recorded on the rehabilitated surfaces at Rum Jungle. The increased number and diversity of ant species recorded was found to be related to the amount of vegetation cover, organic matter and build up of available seed on the new surface. Similar observations were noted by Majer (1983, 1985) in his studies of colonisation of rehabilitated sand mines by soil fauna. At least twelve months elapsed between final soil covering (rehabilitation) and the first recorded presence of ants at Rum Jungle. In addition, at Rum Jungle the first termite activity on the rehabilitated surface occurred in November 1986.

2.12 Fire management and fire tolerance

Aborigines have employed fire as a land management tool in the Northern Territory for over 30,000 years (Brown, 1987). Fires are used to promote conditions of improved access, food gathering and decreased risk of destructive and high intensity fire. This practice still continues with most areas of the Top End in the NT being burnt every 1-3 years. The effect of fire on open forest has been to create only two main strata, overstorey and ground cover, with little understorey. In the absence of fire, the understorey species give a multi-layered understorey capable of supporting a much higher intensity fire. However, if a fire occurs the normal single strata understorey is re-established. Langkamp (1982) reported that with the application of a complete fertiliser to a *Eucalyptus tetrodonta* open-forest on Groote Eylandt, significant dry matter increases were observed in the grass/forb and *Acacia aulacocarpa* components of the understorey. Following a burn of the understorey where fertiliser had been applied, significant increases of *A. aulacocarpa* only were found. The rehabilitation objectives at Groote Eylandt, following manganese ore mining, are to establish a stable ecosystem of native species. Brown (1987) reported that grasses while controlling erosion, also increase the risk of high intensity fires which destroy the seedlings of forest trees. The result has been the seeding of grasses at rates only just sufficient to control erosion. Couch grass is preferred to taller growing and more flammable Rhodes grass. He noted that through choice of appropriate treatments revegetated areas can be made to survive low intensity fires during the first dry season. High intensity fires in the late dry season were found to kill a high number of eucalypts than other species and such fires should therefore be excluded from revegetated areas for five years.

Bowman (1991) and Bowman et al. (1988) carried out a number of studies on the role of fire in *Eucalyptus* savannas and in monsoon rainforests in the Top End. Their studies also included management of fire sensitive vegetation communities, particularly *Callitis sp.* and sandstone flora.

Hinz (1990b) stated that fire had to be excluded from the revegetated areas in the Top End for at least the first three years of growth. Setterfield et al. (1993) reported that fire has devastated revegetation attempts of numerous borrow pits in the Kakadu National Park and suggested that methods of protecting borrow pits from fire need to be examined. It must be recognised that the need to protect the soil from erosion at the surface through a cover crop conflicts with the need to reduce the impact of fires and establishment of tree seedlings. Resolution of this conflict should be a major goal for future work.

At Weipa, revegetated sites are protected from fire for at least 10 years after establishment. By doing so, fire damage to young vegetation is avoided and the breakdown of leaf litter and its incorporation into the soil is encouraged, thereby replenishing soil organic matter which is a fundamental requirement for tropical soil fertility. Fire prevention measures include grading strategic fire breaks in and around revegetated areas; prescribed burning of surrounding native forests during May and June; and sowing fire resilient species in areas being revegetated.

Press and Wellings (1989) reported that CSIRO had undertaken a major program of research in the Kapalga Research Station in Kakadu National Park, to study the effects of different fire regimes on the flora and fauna. The available information, however, is limited only to mature climax vegetation and therefore may not be applicable to newly revegetated areas. Little information is available to assess the response of younger plant communities similar to those encountered on mine sites, to fire. *A. holosericea* and *A. mimula* seedlings are not able to resist fire and can not sucker after fire, whereas *A.torulosa* and *A.tropica* are fire resilient (QML, 1990).

In an attempt to assess the likely effects of fire on revegetated WRD sites, ERA burnt two-year old newly vegetated WRD areas consisting mainly of *Acacia* and *Eucalyptus* species about 3m in height (Ranger, 1987). Most of the eucalypt regrowth occurred from lignotubers and suckers following fire, with a few from the seed. The *Acacia* species did not tolerate fire as well as eucalypts. Those which survived were able to resprout from the seed pool in the soil (*A. holosericea* and *A. mountfordiae*). The projections from this trial are that longer intervals between burnings would promote the development of tree species particularly eucalypts, from the revegetated areas. Based on ERA's revegetation trials on the WRD in 1982 and 1984, Armstrong (1986) reported that *Acacia* seedlings can recover from fire during the first year, but eucalypt, melaleuca and grevillea seedlings can be killed by fire if not sufficiently developed.

Fire management is critical to successful revegetation, as fire will affect plant density and composition. Information is necessary to direct controlled burning and to understand the response between burnings in newly revegetated areas. Details are also required on fire modelling, including desirable flame height during burning (to prevent crown scorch), and optimum fuel load and moisture content in the fuel. If the fuel load is dominated by litter (other than grass), then successful burning under moist conditions can be carried out with flame heights of 1m or less (Ranger, 1987). ANCA undertakes regular control burning of native woodlands in the Top End during the early part of the Dry season aimed at keeping the fuel loads within acceptable limits.

It is also necessary to understand the mechanisms and strategies that the native plant species of the ARR have adopted to cope with seasonal burning. Such information will assist in the selection of plant species for establishment of sustainable plant communities on disturbed mine sites. Information on the use of appropriate burning strategies, i.e. whether to burn the whole area or to "patch burn" (leaving alternate strips of unburnt areas of certain width to provide niches for faunal survival) is presently unavailable and needs to be obtained for newly revegetated areas.

Other examples of the importance of fire in vegetation life cycles are found outside the tropics. For example, fire is an infrequent but a vital component in the life cycle of the mountain ash forest (*Eucalyptus regnans*) in the wetter (>1200 mm) parts of the highlands of Victoria. These tree seedlings only survive and grow in exposed soil with direct sunlight. In nature these conditions are only created by bushfires. Immediately after the fire, in a mature ash forest, seeds stored in woody capsules in the crowns of the trees is released onto the exposed soil surface. In the absence of fire, it is considered that mountain ash would disappear from a site within 500 years (Vertessy et al. 1994).

2.13 Monitoring and assessment of revegetation success:

The rehabilitation objective at Groote Eylandt following manganese ore mining is to establish a stable ecosystem with native species. The revegetated areas are monitored for germination, survival etc. during the first wet season. In addition, photographic records are also maintained. Longer-term assessments are done using line transect methods. About 30 quadrats, each 10 m^2 and evenly spaced along a 120 m transect are run through the area. Number of individuals, species site coverage etc are recorded. In addition, heights, breast height diameters, crown width for major tree and shrub species are recorded. Relative densities, dominance and frequencies, basal area, stocking and average height are estimated to enable monitoring of successional changes. Such studies provide feedback on treatments, for example, the intensity of competition between grasses, and trees and shrubs and fire risk from grasses. Repeated surveys are undertaken which provide information on how areas develop from their initial state. If succession is not disturbed by fire, then grass cover, eucalypt density, eucalypt to acacia ratio and site age are considered to be major determining factors. An index of success would require areas of 1 and 3 years of age with a eucalypt density of at least 1000 stem/ha and a eucalypt:acacia ratio of at least 1:1(Brown, 1987).

Basic rehabilitation monitoring at Alcoa's bauxite mining operations in Western Australia includes: tree survival, form, nutrition and growth; understorey establishment; and performance of erosion and drainage control works. Further, at selected sites more detailed monitoring is undertaken on specific characteristics such as biomass accumulation, nutrient cycling, plant and fauna succession, dieback incidence, insect damage, and a range of hydrological and hydrobiological parameters (Slessar and Foster, 1987). The main focus of post rehabilitation monitoring at Alcoa's operations is on tree nutrition, in addition to silvicultural treatments such as thinning and fire management.

Monitoring at Alcoa's rehabilitated areas to re-establish the jarrah forest ecosystem indicated that about 79% of the pre-mining species re-colonise on mined areas within the first year. Permanent vegetation monitoring plots in rehabilitated areas and control sites have been established and direct comparisons of a range of parameters (such as floristic diversity) and long-term floristic changes in the rehabilitated areas are made on a continuing basis (Nichols et al. 1991).

At Weipa, revegetated areas are monitored 6 months after treatment using belt transects.(Morton, 1983) A 0.5% sample of the area revegetated in the previous season is taken and species abundance and diversity are measured. Areas not satisfactorily revegetated are either re-fertilised or re-seeded and planted during the following season (Slessar and Foster, 1987).

Ryan (1987) reported that revegetation monitoring at Rum Jungle indicated that of the five species of *Eucalyptus,* three species of *Acacia* and one species of *Melaleuca*, all were able to penetrate the clay layer to varying degrees of success. This is not a desired outcome as any risk to the integrity of the clay cap will be inconsistent with the rehabilitation objectives

Davie et al.(1991) concluded from their observations that restoration of sites following sand mining on Fraser Island will require ongoing maintenance and monitoring for a number of years. They consider that, in sub-tropical and tropical environments, a longer time frame of 15-20 years is more appropriate than the more commonly adopted practice of five years, because of the longevity of the major competitive species.

McLaughlin and Jackson (1988) in conjunction with QMPL proposed a set of standards or release criteria for Nabarlek. The criteria proposed consisted of a mixture of qualitative and quantitative factors such as:

vegetation density similar to the adjoining area

species diversity

canopy cover

inflorescence production

vigour and health

ability to survive fire

presence of edible food species, etc.

Jackson (1989) in his review emphasised the need for quantifiable standards to set release criteria for mine rehabilitation in the seasonally wet tropics. He pointed out that the assessment of rehabilitation success so far has been based on macro plant features and little on the development of models or standards that will take into account a broad range of features to determine the self-sustaining status of an ecosystem.

Aronson et al. (1993 a and b) defined vital ecosystem attributes (VEA) as those characteristics or attributes that are correlated with, and can serve as, indicators of ecosystem structure and function. The VEAs relate primarily to vegetation, soils and micro organisms. As ecosystems undergo dramatic changes from wet to dry seasons, the VEAs related to ecosystem structure should be measured at the end of the rainy season for several successive years in the tropical regions. The VEAs related to ecosystem structure are:

i)Perennial and annual species richness

ii) total plant cover

iii) soil-borne seed bank

iv) aboveground phytomass

v) beta diversity (ie. extent of species replacement or biota change along environmental gradients)

vi) range of life form

vii) key stone species (ie. species that are critical to ecosystem structure and functioning eg. perennial nitrogen fixing legumes)

viii) microbial biomass, and

ix) soil biota diversity.

The VEAs that are considered to be related to the ecosystem functions are:

i) biomass productivity

ii) soil organic matter

iii) soil surface conditions

iv) maximum available soil water reserves

v) soil cation exchange capacity(:is highly sensitive to degradation and directly correlated with the overall soil fertility)

vi) coefficient of rainfall efficiency (is the amount of water infiltrates into middle and deep soil layers and thus reflects soil surface conditions and soil absorption capacity)

vii) rain use efficiency: is the slope of the relationship between annual rainfall and above ground phytomass production

viii) length of water availability period in the soil (this can be easily measured by successive tensiometer readings at different soil depths)

ix) nitrogen use efficiency

x) micro symbiont effectiveness and

xi) cycling indices.

The cycling index is the ratio of the amount of energy or an element recycled in an ecosystem to the amount of energy or elements moving straight through the system. Since ecosystems in a mature stage are considered to have a greater capacity to entrap and hold nutrients for internal cycling compared to a developing ecosystem, the achievement of a tighter nutrient cycle would indicate positive signs of ecosystem restoration.

They measured a number of quantifiable VEAs and evaluated the ecosystem degradation and the experimental responses of rehabilitation on vegetation, soils and plant-soil-water relations.

2.14 Natural Succession

A description of natural plant succession from field observations was made on 33 borrow pits at Nabarlek (QML, 1990). The pioneer species at Nabarlek are several Calytrix species and *Verticordia cunninghamii* followed by acacias then *Melaleuca viridiflora,* particularly in the moist low-lying areas. The observations at Nabarlek indicate that despite eucalypt seeds being dropped into borrow pits from the surrounding areas, poor soil conditions and lack of protection of seed make it difficult for seedling establishment.

There are no details recorded in the ARR on faunal colonisation or vegetation composition and density with progressive natural plant succession, either in borrow pits or on abandoned mine sites. Preliminary observations of borrow pits, abandoned mine sites and cleared pastoral leases in the ARR by Ashwath and Brennan of ERISS have suggested that many of the native trees and shrubs have failed to establish on these sites despite their location in the midst of large areas of undisturbed climax vegetation. However, some success has been achieved in the establishment of native species on sites where some efforts have been made withland preparation and direct sowing. ANCA sponsored a study by CSIRO to investigate natural succession on borrow pits in Kakadu National Park, and to identify the strategies for revegetation of these sites. The study, by Setterfield et al (1993), identified more than 500 borrow pits in Kakadu National Park and in no case was vegetation establishment proceeding satisfactorily. Furthermore, the study found that the establishment of *Eucalyptus sp* was poor, and where woody recruitment was high the communities were dominated by short lived *Acacia sp.* The study identified that there was a need to promote the establishment of *Eucalyptus sp* and overstorey woody species. Revegetation was considered to be limited by the inadequate supply of propagules and that sowing seeds of appropriate species or use of top soil containing vegetative propagules was necessary to overcome the problem.

3 Revegetation methods used within the Alligator Rivers Region

Agencies within the ARR who are carrying out revegetation work include Australian Nature Conservation Agency (ANCA), ERA, and Queensland Mines Proprietary Limited (QMPL). The Oenpelli Council, who have responsibility for much of the area to the east of the Kakadu National Park boundary, do not have a recognised revegetation program although they are involved in weed eradication work with the Department of Primary Industries and Fisheries of the Northern Territory Government.

The agencies who are actively engaged in revegetation works are described below:

3.1 Australian Nature Conservation Agency (ANCA)

ANCA generally carry out little in the way of revegetation work themselves. New works, such as roads and bridges, are required to be rehabilitated by the contractor on a continual basis. The extensive program of highway construction in recent years has resulted in a series of approved revegetation practices which have to be followed by contractors. These involve erosion control works by contouring, use of native species, scarifying and/or ripping in old roadways and on compacted ground. A recent consultancy by CSIRO (Setterfield et al, 1993) has produced a strategy for rehabilitation of old borrow pits within Kakadu National Park. This document can be used as an operators handbook. The report provides a key for classifying borrow pits into six groups based on slope, previous treatment, availability of topsoil and potential to pond water. The report then details an appropriate rehabilitation strategy for each class. Most of the 'older' site revegetation work on borrow pits is subcontracted to local organisations. A further identified problem will be revegetation of the paddocks at the old Mudginberri Abbatoir site. These are extensive and were planted with exotic grass species. A new strategy is to be developed for their revegetation and subsequent incorporation into the park (J. Russell-Smith, pers. comm.).

At mine waste burial sites in the South Alligator Valley the final land surface was lightly scarified with the tip of a loader bucket and then native seed from a range of shrubs and trees was broadcast at the beginning of the wet season. Establishment after one season has been reasonable bearing in mind there was no fertiliser applied or subsequent management (P. Waggitt, pers comm).

3.2 Energy Resources of Australia-Ranger Uranium Mine (ERA)

ERA have carried out a series of revegetation operations within their lease boundary over the past few years. There are several areas where revegetation work has been undertaken. These include, Jabiru East, the Light Industrial Area, tailings dam seepage collector sumps and parts of the waste rock dumps.

At the tailings dam three sumps were backfilled with a mixture of waste rock from the bund walls and soil materials from stockpiles. The final surface was topsoil wherever possible. Native grass seed was broadcast and tube stock and seedling tree planting material was used. The work was undertaken at the end of the dry season and the growth to date has been reasonably good (P. Waggitt, pers. comm.).

At the Light Industrial Area the site was cleared of industrial debris and then ripped. Seeds of native species were spread although the composition of the mix did not reflect the surrounding vegetation in density and abundance. It is possible that the vegetation will adjust its composition with time to match the surrounding area more closely.

The waste rock dump sites were used for experimental work carried out jointly with CSIRO. The areas used were the flat surfaces where the landform was claimed to be at final design level. A range of treatments was put in place involving topsoil, irrigation and fertilisers. The details of this work have not yet been released.

Jabiru East was treated in much the same way as the Light Industrial Area. House sites and roadways were ripped up and native seed was spread. Again the composition of the mix was possibly not in balance with the surrounding vegetation; in particular, plants of *Acacia holosericea* are present in greater numbers than are seen in adjacent areas.

ERA use hydro seeding routinely in a variety of situations where quick establishment of vegetation is needed. One example is the bunds in the wetland filter of the RP1 catchment where some hydro seeding was carried out in 1992. Also a hydro seeding treatment was applied to a batter slope on the north-eastern face of the waste rock dump as part of a trial.

The objective was to compare bare ground with hydro seeding and hand seeding with *Acacia* species.

3.3 Queensland Mines Proprietary Limited (QMPL)

The final revegetation plan has been frequently updated since the mine operation began at Nabarlek in the Northern Territory. The most recent complete version was distributed in 1990. The compnay have already carried out revegetation work at several locations within the site in accordance with the revegetation plan as part of a progressive rehabilitation program.

QMPL has proposed a range of techniques for use in the revegetation of their minesite at Nabarlek. After contouring of the final landform the soils/land surface will be deep ripped and then seed mixes appropriate to the area hand broadcast. A final light scarifying of the surface will complete the sowing operation.

In the past both tube stock and native seed were used to establish vegetation. The use of tube stock has been discontinued as the success rate was variable and considered unacceptable in view of the high cost involved to raise trees in this way. Experience had shown that irrigation was essential for tube stock seedlings to survive transplanting. This was not considered to be a practical option when re-establishing native bushland (QMPL, 1990).

The use of exotic grass species (specifically rhodes grass) to provide initial surface stabilisation has been addressed by QMPL in its documentation but the final decision on whether to use the technique or not has yet to be made. The prediction is that the rhodes grass would provide a quick initial cover for erosion protection but be out competed by native species in a short period of about two to three years. This is because there would be no on-going nutrient supply at an adequate level for the exotic species.

Some species may be planted in greater quantities than are usually found in natural bushland. For example, during 1994 emphasis was given to planting seeds of a bush tucker plant, *Buchanania obovata*, to satisfy the wishes of the traditional landowners. These seeds were planted in areas where there was little risk of contamination from the mining operation (P.Bailey, pers comm).

In subsequent years fire will be kept out of new plantings as much as possible; erosion control works will be monitored and repaired or upgraded as necessary and reseeding will be undertaken in areas where there has been poor establishment. The length of this post rehabilitation maintenance period this not yet been determined.

4. Available information and information needs for revegetation at Ranger

4.1 Vegetation survey

Adequate data are available on vegetation composition, density and structure for the Ranger mine site. The data are also available from sites which may form analogues to Ranger WRD. These data may be used to set initial standards for revegetation at Ranger.

4.2 Characterisation of properties of WRD spoils

Sufficient information is available on chemical and biological properties of WRD. However, the information on plant available water, hydrology and soil development over time is yet to be collected.

Further research is required to overcome some issues in particular with reduced infiltration into the WRD. Research is needed to find out the extent of waterlogging (development of perched water table), if any, at depth within the WRD and the associated redox conditions.

4.3 Surface preparation techniques

Some data are available on ripping techniques, batter slope construction and protection of batters from erosion (eg hydro mulching). However, all these techniques have been tested without vegetation. The role of vegetation on the effectiveness of these techniques needs to be investigated.

Surface preparation techniques that provide good tillage and optimum conditions for germination and establishment of native plants (eg harrowing, tine seeding, etc) need to be investigated. Some of the surface preparation techniques that are being used at Weipa and Gove may be relevant and these may be tested for Ranger situation.

4.4 Seed technology

The available information on seed collection, processing and germination is probably sufficient for trees and shrubs, and scanty for ground cover species and grasses. Hardly any data are available for the long term storage of native plant seed. This is particularly true for ground cover species and those species with fleshy fruits. Very little data are available on propagation of vegetatively propagated native species.

Research is required on seed storage procedures, seed germination techniques (ground cover species) and vegetative propagation techniques. The extent of this research will, to certain extent, depend upon whether or not fresh top soil will be used for revegetation.

4.5 Fertiliser and amendments

Most native plants have the ability to cope with low soil fertility status, and often require only a low rate of fertiliser application for initial establishment. Some groups of plants (eg grevilleas) are very sensitive to high doses of fertilisers (eg P). As mine spoils differ from natural soils in their plant available nutrients, there is often a need to examine and establish plant responses to fertiliser to site specific conditions. Application of 100-250 kg/ha 'Tropigro' (10N:9P:7K) appears to be adequate for the establishment of exotic grasses at Ranger. However, the optimum dose for native plant species is yet to be determined.

Soil amendments such as gypsum and lime have been used at Ranger. Results of this study suggest the need to increase gypsum application rates to restore the balance Mg:Ca in the soil. The OSS study on native grasses revealed that while exotic grasses responded to gypsum application, growth of most native grasses remained unaffected.

Further research is required on the use of gypsum and/or other soil amendments to improve infiltration rates and to reduce Mg:Ca ratio in the soil. Since the long term nitrogen supply to plants must come from biological fixation, studies are needed to identify effective strains of rhizobia to meet this requirement.

4.6 Use of top soil

Stockpiled top soils at Ranger have been characterised for chemical and mycorrhizal properties. Field trials in the use of top soil at Ranger have shown that providing a thin layer of top soil will assist in establishing native plants such as acacias. Other trials have indicated that use of top soil may in fact accelerate initial vegetation establishment. The use of fresh top soil has also shown that it has increased weed infestation. The work carried out at Weipa ie. late season stripping of top soil, collecting and storing topsoil and subsoil separately and re-laying the soil so that the A horizon is above the B horizon, is all relevant to the Ranger situation.

Procedures for the collection (top soil and sub soil separately) and active management of top soil to preserve its benefits during storage are currently unavailable, and these need to be investigated. One of the major benefits of using top soil at Ranger is likely to be its value as a seed source. This being the case, the time of collection, depth of collection and cost of collection all need to be investigated.

4.7 Weed Control

Available information seems to be adequate at present. The research undertaken by CSIRO will further increase the knowledge on this topic.

4.8 Return of fauna

Some information is available on the invertebrate populations in natural, disturbed and waste rock dump habitats within the ARR. The rehabilitated sites at Ranger are also being examined for the return of invertebrate and vertebrate fauna (ants, termites, lizards, other soil fauna) and microbial biomass.

Further research is required to develop techniques by which return of fauna on to rehabilitated sites can be accelerated. How best the data on return of fauna can be used in the release criteria needs to be established.

4.9 Fire tolerance

Substantial data are available on the response of mature plant communities to fire in the Top End. However, the information on the responses of newly revegetated areas to fire is limited.

Responses of freshly revegetated sites to fire need to be understood and fire tolerance of seedlings of even major canopy species is not known. The strategies for fire management in a rehabilitated area are poorly understood. This information is important to develop release criteria.

4.10 Monitoring and assessment of revegetation success

Details of vegetation composition, density and structure are available for undisturbed plant community on Ranger Project Area. The same data are also available for analogue sites in the ARR. These data may be used to set the initial revegetation standards for Ranger. Sufficient information is also available on invertebrate and invertebrate fauna from undisturbed sites.

The vital ecosystem attributes (VEA) of these plant communities and the methods/monitoring procedures to assess the success of revegetation are not well understood at present. This needs to be developed in consultation with the Ranger TWG.

There is an urgent need to identify VEA, develop monitoring tools and establish predictive models to assess the success of restoration practices. There is also a need to identify bio indicators that may give an indication of the status of ecosystem health.

5. LITERATURE ON REVEGETATION TECHNIQUES IN THE TROPICS

5.1 Standing references

Proceedings of the Australian Mining Industry Council (AMIC) Annual Environmental Workshops, Landline (AMIC's publication), Mining and the Return of Living Environment (AMIC's), Proceedings of the North Australian Mine Rehabilitation Workshops, Mine Rehabilitation Handbook (AMIC's), Mining and the Environment (AMIC's), Office of the Supervising Scientist Research Summary and Reports, Today - the environment magazine (published by ASM Group Pty. Ltd. Mona vale, NSW), Environmental Research Notes (Alcoa, Perth), Environmental Research Bulletin (Alcoa, Perth),

5.2 Occasional publications

Arid zone field environmental handbook (Santos, Adelaide), Mine Rehabilitation - a handbook for the coal mining industry (NSW Coal Association), The Restoration of Land- A.D. Bradshaw and MJ Chadwick Blackwell scientific publications, Guidelines for effective rehabilitation of borrow pits in the Top End (CCNT), rehabilitation and erosion control guidelines for mineral exploration in the TopEnd (CCNT), How to collect native plant seed easily (CSIRO Forestry, Canberra), a list of plant species suitable for planting in the Top End (CCNT), Australian suppliers of tree seed (CSIRO Forestry, Canberra), Germination of Australian native plant seed (P.J. Langkamp), AFL Fertiliser Handbook (J. Glendenning, Australian Fertiliser Ltd; Sydney), Field guide to weeds in Australia (C. Lamp and F. Collet 1989), Drip irrigation for trees and shrubs (CCNT).

The NT Department of Primary Industry and Fisheries has produced a number of publications on various aspects relevant to Revegetation techniques and weed control. These include Agnotes, Tech notes, Technical Bulletins, Incidental Publications and Incidental Pamphlets (DPIF 1994). The titles of the publications useful in revegetation are listed below:

5.3 Agnotes

Termites in the home garden, potting mix ingredients, lawns1: lawn species suitable for use in the NT, weed control in Top End gardens, tests for seed, guidelines for grain and seed storage in the tropics, soil solarisation, tensiometers, improving soil structure and pH levels in Top End horticultural soils, several publications on cultivation of pasture species, including grasses that are commonly used in surface stabilisation and weeds. There are about 65 Agnotes on weed species including *Mimosa pigra*, *Salvinia*, mission grass, *Hyptis* and *Sida* and biological control of *Mimosa pigra*.

5.4 Technotes

Seed storage and particle board, the assessment and use of rock phosphates as fertiliser, analysis of common fertilisers and agricultural chemicals, germination and seedling growth of the annual weed *Pennesetum pedicellatum*, inoculation of grain legumes- is there a better way?, notes on seed production of some tropical grasses near Darwin, NT, seed production of

Stylosanthes hamata cv. Verano in the Douglas Daly district, NT, *Spinifex* communities and management for pastoral production in central Australia.

5.5 Technical bulletins

Ecology of the Hardman Basin in the NT, Pangola grass, nutritional problems of northern Australian soils, pastures in the Top End-a primer, *Mimosa pigra* in the NT and Grassland monitoring project *Mimosa pigra* Marrakai.

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