FORESTS DEPARTMENT OF WESTERN AUSTRALIA

REPRINT NO.19

Reprinted, with permission, from 1979 Environmental Workshop, Bunbury, Vol. 1. Australian Mining Industry Council.

Development of the Ecosystem after Mining.

by

J.R. Bartle and S.R. Shea.

DEVELOPMENT OF THE ECOSYSTEM AFTER MINING

J.R. Bartle* and S.R. Shea**

*Research Officer, Dwellingup, Forests Department of WA

**OIC, Dwellingup Research Station, Forests Department of WA

1. INTRODUCTION

The recognition that rehabilitation following mining should be aimed at reconstruction of an ecosystem represents a major conceptual advance. Although such a concept may appear obvious to many members of this workshop it has been our experience that rehabilitation has been frequently based on engineering rather than ecological principles. Implicit in the objective of ecosystem development is the recognition that rehabilitation should be based not only on an understanding of the interactions between plants, animals and the environment but also that the area which is rehabilitated should be sustainable in perpetuity. While the objective of ecosystem development is admirable it must be recognised that we rarely have sufficient knowledge to redevelop any ecosystem. Natural ecosystems, particularly forests, are characterized by great diversity, complex interactions and long cycles of development, senescence and regeneration. The land manager is thus forced to undertake rehabilitation on an operational scale before he has the opportunity to test the consequences of his decisions.

In this paper we have used the rehabilitation of the jarrah forest following bauxite mining as a case study to illustrate an evolutionary approach towards ecosystem development following mining.

2. THE JARRAH FOREST ECOSYSTEM

The choice of methods for rebuilding an ecosystem after disturbance will invariably have to be made with incomplete knowledge. All sources of information should therefore be thoroughly analyzed to enable the land manager to make the best informed decisions possible. For this purpose the way in which the native ecosystem functioned prior to disturbance could serve as a model. This is not to suggest that the native system is necessarily superior to any other, only that it provides an available example of a successful system.

Two broad conceptual approaches are used in the analysis of ecosystems. The holistic approach, as typified by the Hubbard Brook Study (Likens *et al.*, 1977), where the system is characterized by its input and output budgets, is not as useful as the analytical approach, where the real relationships between plants, animals and the environment are examined. This latter approach provides insights into the relative importance of environmental factors which act as selection pressures in the evolution of a particular community. The identification of these selection pressures provides a basis for planning the redevelopment of the ecosystem.

2.1 Summer Drought

The climate of the jarrah forest is characterized by extreme summer drought. Less than 10% of annual rainfall occurs in the five summer months November to March. During this period evaporation greatly exceeds rainfall. The reverse applies during the five winter months May to September when 80% of annual rainfall occurs. During these months surplus water is available for recharge of soil profiles and stream flow.

A large proportion of the winter rainfall excess in the jarrah forest is retained in the soil profile. This results from the following factors:

(i) Deep weathered profile ranging from 20 to 30 m deep (Dimmock *et al.*, 1974; Herbert *et al.*, 1978) and underlain by basement granite, which is considered to be impermeable.

(ii) General moderate to low relief.

(iii) Wide occurrence of very permeable surface soils and absence of overland flow on these soils.

(iv) Conductive channels in the subsoil clays which result in rapid and deep vertical recharge (D.H. Hurle, personal communication; Bartle and Shea, 1978).

(v) Slow lateral drainage in subsoil clays. Using a hydraulic conductivity of 4x 10^{-2}m·day^{-1} (Peck *et al.*, 1978) and a ground water table gradient of 5% indicates that lateral flow velocity is less than 1 m per annum.

In the presence of deep stored water, two modes of adaptation to summer drought are possible:

(i) The development of characteristics (for example, deep root systems) which permit utilization of stored water.

(ii) Reduction of water consumption.

Though many jarrah forest species may use elements of both alternatives the dominant species, jarrah, relies heavily on adaptations which permit water consumption (Bartle and Shea, 1978).

The efficiency of jarrah, and other jarrah forest species, in annually depleting water recharge results in the accumulation of salts. These salts arrive in trace amounts in rainfall. Exports of salts is constricted by the low level of water which escapes from jarrah forest profiles. Though salt input and loss in jarrah forest catchments reach an equilibrium this equilibrium only occurs in many catchments following the accumulation of large quantities of salt (Peck and Hurle, 1973; Peck, 1977 and 1978). The size of this storage is related to rainfall as this determines the amount of water flow passing through soil profiles. In the high rainfall (1200 mm per annum) western zone of the forest, where perennial streams occur and stream yields are approximately 15 to 20% of rainfall, total storage is of the order of 10^4 kg·ha^{-1}. In the drier (800 mm per annum) eastern forest stream yields are less than 2% and storages may exceed 10^6 kg·ha^{-1} (Dimmock *et al.*, 1974; Batini *et al.*, 1978 ; Herbert *et al.*, 1978; Johnson *et al.*, 1979). The removal of jarrah forest can result in reduced water consumption, accumulation of ground water, mobilization of stored salts and salting of streams (Williamson and Bettenay, 1979). Forest removal in the high rainfall (1150 to 1250 mm per annum) western forest has caused increased salt flow but no significant deterioration in water quality. Bauxite mining is currently confined to this zone of the forest.

2.2 Soil Conditions

The soil environment of the jarrah forest plays an important role in shaping the ecosystem. Dimmock *et al.* (1974) and Herbert *et al.* (1978) have reported some characteristics of jarrah forest profiles observed in extensive coring studies, viz. bulk density averages 1.6 g·cc^{-1}, pH is in the range of 5.3 ± 0.5 and peak salinity concentrations of 0.37% were observed.

Each of these parameters is at a level which is considered severely limiting to root growth. In addition, the whole profile is highly weathered and deficient in most major, and many minor, nutrient elements. In spite of these limitations the profile supports a dense forest.

The inhospitable nature of this environment is ameliorated to some extent by the occurrence of the conductive channels in the clay subsoil previously mentioned. Excavation has revealed that these channels are usually well defined continuous ducts up to several centimetres in diameter and occupied by living and dead roots (Bartle and Shea, 1978; D.H. Hurle, personal communication). Fine root proliferation occurs within these channels but does not extend far out into the clay matrix except in the zone above the water table (Kimber, 1974). The full utilization of such a specialized system may require specific adaptations in tree development and root habit.

2.3 Fire

There is abundant evidence that fire is a natural factor of the jarrah forest ecosystem (Wallace, 1966). The regular occurrence of long periods without rain corresponding with high temperatures and the accumulation of inflammable fuels with regular opportunities for ignition by natural factors (e.g. lightning) and by aboroginal man, indicate that the occurrence of fire at periodic intervals before the arrival of white man were inevitable (Hallam, 1975).

Both the fauna and vegetative components of the jarrah forest ecosystem are adapted to fire (Christensen and Kimber, 1975). For example, jarrah is able to survive high intensity fire because of specific adaptations, for example, lignotuber and thick bark. It is impossible to precisely define the frequency, intensity and season of fires in the jarrah forest before the coming of white man. It is possible to manipulate the fire regime by management (Shea *et al.*, 1979), but it is unlikely that fire could be excluded from any redeveloped ecosystem in the jarrah forest for prolonged periods. Thus the characteristics of the natural ecosystem which permit it to survive fire must be considered in development of the alternative ecosystem following mining.

2.4 *Phytophthora cinnamomi*

In addition to the natural factors in the jarrah forest environment the impact of an introduced factor - *Phytophthora cinnamomi* (Rands) - on the development of the ecosystem following mining must be considered. *Phytophthora cinnamomi* is an introduced soil-borne pathogen which is the causal agent of the disease called jarrah dieback (Podger, 1972). This pathogen has the capacity to kill the majority of the vegetative components of the jarrah forest ecosystem. *Phytophthora cinnamomi* is primarily distributed in soil carried on vehicles. Hence any land use activity which results in the disturbance of soil has the potential to spread the pathogen and consequently the disease (Shea, 1975). In addition to the effect on distribution of the fungus, land use activities which result in destruction of the canopy and impedence of drainage can cause a significant increase in the capacity of the fungus to sporulate (Shea, 1979). This results in a greater intensification of the disease.

The presence of *P. cinnamomi* in the jarrah forest places additional constraints on the development of an ecosystem following mining. For example, the species used to rehabilitate mined areas must be resistant to this pathogen since it is inevitable that *P. cinnamomi* will be widely distributed as a consequence of the extensive earth moving operations which occur when mining takes place. Thus a large number of the species in the jarrah forest, including jarrah, cannot be used to rehabilitate mine sites because of their susceptibility.

3. IMPACT OF BAUXITE MINING

3.1 Bauxite Pits

Bauxite ore occurs in discontinuous pods of varying size on the flanks of the ridges. Ore may occupy up to 20% of the landscape in the high grade western areas though the average over the whole Alcoa lease is 6%. Ancillary works for mining increases the cleared area by about 30% (Alcoa of Aust., 1978).

Mining involves the removal of vegetation, stripping and stock piling of approximately 40 cm of topsoil and the excavation of approximately 4.5 m of bauxite. Rehabilitation commences with earth works to reshape the sharp pit features into gentle grades harmonious with the surrounding landscape. Topsoil is replaced on the pit floor and ripping to 2 m depth on 2 m centres is carried out to break the compaction of the pit floor. Current revegetation procedure involves planting 625 tree seedlings per hectare (4 m x 4 m spacing) with a spot application of 200 g per tree 12:52 fertiliser and the aerial application of 1 $kg \cdot ha^{-1}$ of mixed native forest shrub species (predominately leguminous species) with 300 kg·ha^{-1} superphosphate (Bartle *et al.*, 1978). Carryover of native seed in replaced topsoil is possible by separate stripping of the upper 5 cm of top soil and immediate respreading. This process is currently being applied where practical. (Tacey, 1978).

The pit form is retained as an internally drained depression. Ripping of the pit floor is done on the contour and throws up ridges some 30 cm in height providing surface depression storage. This appears sufficient to contain all rainfall in average seasons. In-pit holding banks and downslope sumps provide extra temporary storage volumes for wetter periods.

3.1 Impact on the Landscape

The impact of bauxite mining is not confined to the mine pits, because of its effect on spread and intensification of jarrah dieback. The disease is widespread in the forest but principally confined to the more susceptable valley floor sites (Shea, 1975). It is estimated that approximately 10% of the forest is infected. Infection is most extensive in the western high rainfall forest. Rigid hygiene and quarantine have been introduced to minimize spread of the fungus in infected soil. Natural spread of the disease is rapid downslope but slow upslope (Shea and Dillon, 1979).
Where bauxite mining operations are located in forest areas which have already been severely degraded by *P. cinnamomi* the impact of mining on the forest vegetation is not significant. Where bauxite mining operations are located in healthy forest areas, however, the impact on the forest ecosystem within the 'envelope' of mining operations will be severe because:

(i) Bauxite deposits occur on freely drained upland sites which are less susceptible to the disease. These sites generally only have low levels of infection and often carry high quality forest. The potential for control of the disease on freely drained upland sites by manipulation of the soil environment is greatest (Shea and Malajczuk, 1977; Shea *et al.*, 1979).

(ii) The location of mining activity high in the landscape maximizes the potential for distribution of the disease since the fungus is rapidly transmitted downslope.

(iii) Although actual mining is restricted to less than 20% of the landscape, the probability that the fungus will be distributed throughout the forest located within the 'envelope' of the mining operations is high, because of the extensive disturbance caused by activities such as road and conveyor belt construction.

(iv) The fungus is favoured by high soil moisture levels. The disruption of drainage on the pits (free water accumulates in rip lines and on the lower sides of pits) and in the adjacent forest creates environmental conditions which favour fungus survival and sporangial production. Major increases in disease intensification following mining and road construction have been observed at the older bauxite mine sites at Jarrahdale.

Bartle (1976) studied the combined impact of mining and jarrah dieback in a typical catchment located in the western high rainfall zone of the forest and estimated that only 12% of the forest would remain unaffected (Table 1).

TABLE 1

Impact of *P. cinnamomi* in the post-mining landscape

Protectable	-	12%
Potentially exposed	- pits	27%
	- down slope forest	33-26%*
Old infected forest on valley floor		28-35%*

* Range indicates change observed during mining

4. POST-MINING ECOSYSTEM

4.1 Historical Review

Bauxite mining rehabilitation in the jarrah forest has become increasingly more sophisticated as the objectives of rehabilitation have been more clearly defined and our understanding of the ecosystem has developed. The close relationship between research groups within the managing authority (W.A. Forests Department) and the company (ALCOA) and the managers responsible for rehabilitation works has ensured that new approaches to rehabilitation have been rapidly implemented on an operational scale.

In 1966, when mining commenced, there was a minimal input to rehabilitation research because the existing and projected scale of mining was too small to justify a larger commitment. Initially there was no attempt to landscape the pits, site preparation was restricted to replacement of topsoil and an assortment of tree species was planted. As the scale of operations increased and as problems developed a number of modifications to the initial practices were made. The desirability of landscaping pits for aesthetic reasons and so that surface water control facilities could be built in became apparent. The development of windthrow in the young tree plantations led to the introduction of ripping the compacted pit floor to improve root penetration. The absence of regeneration of native shrub species in replaced topsoil, and the very slow natural recolonization from surrounding bush led to the investigation of direct seeding of shrubs and to alternative topsoil handling methods. Greater attention was given to species selection because of the poor performance and/or deaths of a number of the species which were initially used. The small starter application of nitrogen and phosphorus fertiliser used for tree establishment gave successful early growth but subsequent poor thrift and slowing growth rates indicated the need for further investigation of tree nutrition. The spread and intensification of jarrah dieback outside pit areas led to the concept of total catchment rehabilitation.

Some observed problems had immediate and obvious solutions which could be quickly incorporated into rehabilitation practice. Others were resolved by simple applied research. Still others indicated the need for fundamental research. Improved research was facilitated by the setting up in 1973 of a formal administrative structure to co-ordinate and stimulate research into the effects of bauxite mining. The structure is headed by the Hunt Steering Committee and its annual reports provide documentation for the points reviewed.

By the end of the first decade of rehabilitation a new generation of methods had been evolved. Landscaping of pits, including deep ripping on the contour and provision for surface water storage, became standard practice. The pit form was retained as an internally drained depression to avoid the alternative of opening the pits to surface drainage and having to combat turbidity and erosion problems. This method copes adequately with average rainfall, but there have been no exceptionally wet years recently to put it under the real test.

Revegetation practice now includes planting of mixed species of trees and undersowing with native shrub species. Leguminous species (mainly from the genus *Acacia*) predominate in these mixtures which may consist of up to 10 species. In addition "double stripped" topsoil is occasionally used. An application of phosphorus is included with the shrub seed mixture. Several benefits are expected to result from this more elaborate revegetation practice.

The resulting vegetation formation is generally acknowledged as an aesthetic advance. The diversity and density of the stand brings the benefit of stability in the event of failure of some species, it results in rapid soil stabilization as total surface cover is achieved within two years, and it encourages the recolonization of pits by fauna from the surrounding forest.

Other promising aspects of this revegetation practice which are currently under investigation include:

(i) The role of phosphorus fertilisation in stimulating legume growth and nutrient recycling.

(ii) The role of recycled nitrogen in eucalypt nutrition.

(iii) The effect of competition from the shrub layer on growth and root pattern development in eucalypts

(iv) The importance of *Acacia* species in the suppression of *P. cinnamomi* activity.

With the improved performance of in-pit rehabilitation attention has now been directed towards evolving a range of treatments to be applied over the balance of the post-mining landscape. The objectives of treatments currently being tested in operational trials are: to reduce or prevent the impact of *P. cinnamomi* in exposed and protectable portions of the landscape; to provide for a balance of long term timber and water production by thinning non-commercial trees; and to increase the tree cover on the old degraded part of the landscape.

4.2 Future Problems

Considerable progress towards the development of a viable ecocystem following bauxite mining has been made as a result of intensive research and rapid implementation of more desirable rehabilitation procedures as they have evolved. There are, however, many problems which have not been resolved and it is anticipated that as the age of rehabilitated areas increases and as the mining extends into relatively healthy forest these problems will become more apparent.

The effect of fire, either prescribed or uncontrolled, on areas which have been rehabilitated has received little attention. As has been observed, it is unlikely that it would be possible to perpetually exclude fire from the forest.

Recognition of the inevitability of fire was one of the factors behind the decision to eliminate *Pinus* sp. from rehabilitation plantings. The re-establishment of a diverse understorey of predominately legume species on bauxite pits has many advantages but one of the longer term consequences of this practice is a marked increase in fire hazard. The legume species which have been used are relatively short-lived (10 to 15 years) and following death they form a highly inflammable fuel. In the natural jarrah forest ecosystem legume species only regenerate following moderate to high intensity fire (Shea *et al.*, 1979). It is not known if the relationship between fire and legume regeneration on bauxite pits will be the same as in the natural forest (Majer, 1978). Similarly, the effect of fire on the large number of introduced tree species which have been planted on bauxite pits is not known. Even if a satisfactory fire regime can be evolved the costs associated with implementing that regime will, because of the high fuel loads and the diversity in structure and composition, be very high. Since fire will have to be used periodically these costs will be incurred repeatedly.

The long term development of the ecosystem, particularly of trees, is unpredictable (Bartle and Shea, 1978): whether the new system will develop into tall forest comparable with jarrah; what volume of timber production will be achieved; whether the system will be self sustaining by being able to regenerate naturally; what thinning and management treatments might become necessary; what extremes of drought, flood, fire, pests and disease might do to the redeveloped ecosystem: these are not known. These considerations are long term, cannot be predicted in advance and may eventually indicate the need for basic change in rehabilitation methods. Furthermore, the manipulation of these ecosystems to provide for optimum land use is only likely to be resolved by trial and error over the long term.

In the western high rainfall forest the dependence on a trial and error approach to rehabilitation, although undesirable, has been tolerated because the consequences of failure have not been extreme. As mining proceeds into areas of predominately healthy forest, and specifically into forest areas with a high salinity hazard, this strategy will not be acceptable owing to the likely adverse consequences.
Several factors which will be critical in successful ecosystem development in the more eastern forest zones can be fore-shadowed.

Firstly, since *P. cinnamomi* infections can multiply the adverse effects of bauxite mining its control will form the single most important aspect of ecosystem development. There are some promising possibilities in *P. cinnamomi* control but long periods are required to evaluate this research (Shea, 1979).

Secondly, the identification of tree species able to duplicate the hydrologic role of jarrah and to survive in the post-mining ecosystem is necessary. Large screening trials of tree species have been undertaken. Fundamental research into all aspects of the jarrah forest hydrologic cycle is also underway. This should indicate the density and topographic distribution of trees that is required.

Thirdly, the pit drainage system currently used in the west may not be appropriate in saline areas. In the west the pits are rehabilitated such that water must infiltrate into the ripped floor from depression storages or from sumps. To use this procedure in the east may result in unacceptable disturbance to the saline ground water system. Opening the pits to surface drainage would require soil surface stabilization in the first year of rehabilitation and substantial engineered channel systems with their attendant maintenance problems (T.A.G. Report, 1978). Some preliminary investigation of water discharge systems has been carried out (Bartle and Tacey, unpublished data).

A fourth essential factor in developing an appropriate ecosystem is time. A strategy for the development of an ecosystem after mining in the saline zone could be devised using the best available information but the validation of its worth could take decades. A trial mining exercise has been proposed for this purpose (T.A.G. Report, 1978)

5. CONCLUSIONS

A consequence of the evolutionary strategy which has been adopted in the development of an ecosystem following bauxite mining is that it converts the landscape into a hotch-potch of treatments. This may be a very effective large scale experiment but it is not good land management. Inevitably, this approach to rehabilitation results in the creation of a number of substandard ecosystems which may require expensive retreatment at a later stage. The overall management of the landscape is also more difficult and costly when a number of diverse areas are present. Although there was no alternative to an evolutionary approach an earlier and larger commitment to research and integrated land use planning might have reduced the error component in this process of trial and error.

In general the evolutionary strategy as a means of developing the ecosystem after mining can be endorsed. However, it should be preceeded by intensive research and planning to maximize the rate of evolution of a rehabilitation strategy which results in the formation of a viable ecosystem which can be sustained in perpetuity. Where the consequences of failure to satisfactorily reconstruct an ecosystem are large, we believe, our relatively poor understanding of ecosystem development should be acknowledged and a conservative approach to the rate and scale of mining should be adopted.

6. REFERENCES

ALCOA OF AUSTRALIA (1978). Wagerup Alumina Refinery. Environmental Review and Management Programme.

BARTLE, J.R. (1976). Rehabilitation in the Seldom Seen Catchment. Report to the Project 5 Working Group of the Hunt Steering Committee.

BARTLE, J.R. and SHEA, S.R. (1978). Selection of tree species for rehabilitation of degraded areas in the Northern Jarrah Forest. Proceedings, Meeting on Rehabilitation of Mined Lands in Western Australia. Western Australian Institute of Technology pp 7-16.

BARTLE, J.R., McCORMICK, J. and SHEA, S.R. (1978). Direct seeding of native species - a technique for revegetation of disturbed areas in the jarrah (*Eucalyptus marginata* Sm.) forest. Proceedings, Meeting on Rehabilitation of Mined Lands in Western Australia. Western Australian Institute of Technology pp 99-100.

BATINI, F.E., SELKIRK, A.B. and HATCH, A.B. (1976). Salt content of soil profiles in the Helena Catchment, Western Australia. Research Paper 23, Forests Department of Western Australia.

CHRISTENSEN, P.E. and KIMBER, P.C. (1975). Effect of prescribed burning on the flora and fauna of south-west Australian forests. Proceedings of the Ecological Society of Australia. 9, 85-106.

DIMMOCK, G.M., BETTENAY, E. and MULCAHY, M.J. (1974). Salt content of lateritic profiles in the Darling Range, Western Australia. Australian Journal of Soil Research 12, 63-69.

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

HERBERT, E.J., SHEA, S.R. and HATCH, A.B. (1978). Salt content of lateritic profiles in the Yarragil Catchment, Western Australia. Research Paper 32, Forests Department of Western Australia.

HUNT STEERING COMMITTEE (1978). Research into the effect of bauxite mining on the water resources of the Darling Range. Department of Industrial Development, Western Australia.

JOHNSTON, C.D., McARTHUR, W.M. and PECK, A.J. (1979). Distribution of soluble salts and water in soils of the Manjimup Woodchip Licence Area, Western Australia. Technical Paper (in press), Division of Land Resources Management, C.S.I.R.O., Australia.

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

LIKENS, G.E. BORMANN, F.H., PIERCE, R.S. EATON, J.S. and JOHNSON, N.M. (1977). Biogeochemistry of a Forested Ecosystem. Springer Verlag, Berlin.

MAJER, J.D. (1978). The importance of invertebrates in successful land reclamation with particular reference to bauxite mine rehabilitation. Proceedings, Meeting on Rehabilitation of Mined Lands in Western Australia. Western Australian Institute of Technology, pp 47-62.

PECK, A.J. (1977). Development and reclamation of secondary salinity. In: Soil Factors in Crop Production in a Semi-arid Environment. University of Queensland Press, St. Lucia, Queensland.

PECK, A.J. (1978). Salinization of non-irrigated soils and associated streams; a review. Australian Journal of Soil Research 16, 157-168.

PECK, A.J. and HURLE, D.H. (1973). Chloride balance of some farmed and forested catchments in south-western Australia. Water Resources Research 9, 648-657.

PECK, A.J., HEWER, R.A. and SLESSAR, G.C. (1977). Simulation of the effects of bauxite mining and dieback disease on river salinity. Technical Paper 3, Division of Land Resources Management, C.S.I.R.O., Australia.

PODGER, F.D. (1972). *Phytophthora cinnamomi*, a cause of lethal disease in indigenous plant communities in Western Australia. Phytopathology 62, 972-981.

SHEA, S.R. (1977). Environmental factors of the northern jarrah forest in relation to pathogenicity and survival of *Phytophthora cinnamomi*. Bulletin 85, Forests Department of Western Australia.

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

SHEA, S.R. and DILLON, M.J. (1979). Rate of spread of *Phytophthora cinnamomi* in the *Eucalyptus marginata* forest.

Research Paper (in press), Forests Department of Western Australia.

SHEA, S.R. and MALAJCZUK, N. (1977). Potential for control of eucalypt dieback in Western Australia. Seminar papers, Australian Nurserymen's Association Annual Conference, Hobart, 1977.

SHEA, S.R., McCORMICK, J. and PORTLOCK, C.C. (1979). The effect of fire on the regeneration of leguminous species in the northern jarrah forest of Western Australia. Australian Journal of Ecology 4.

SHEA, S.R., GILLEN, K.J. and KITT, R.J. (1978). Variation in sporangial production of *Phytophthora cinnamomi* on jarrah forest sites with different understorey compositions. Australian Forest Research 8, 219-226.

SHEA, S.R., PEET, G.B. and CHENEY, P. (1979). The role of fires in the management of forests in Australia. In: Fire and the Australian Biota (in press).

TACEY, W. (1978). Establishment and diversity of jarrah forest flora. Proceedings, Meeting on Rehabilitation of Mined Lands in Western Australia. Western Australian Institute of Technology, pp 87-92.

TECHNICAL ADVISORY GROUP (1978). Report to the Environmental Protection Authority on Bauxite Mining in the Darling Range. Bulletin 44, Department of Conservation and Environment, Western Australia.

WALLACE, W.R. (1966). Fire in the jarrah Forest Environment. Journal of the Royal Society of Western Australia 49, 72.

WILLIAMSON, D.R. and BETTENAY, E. (1979). Agricultural land use and its effects on catchment output of salt and water - Evidence from Southern Australia. Proceedings of the International Conference on the Agricultural Industry and its effects on Water Quality. Hamilton, New Zealand.