SCOPE ITEM 6

REHABILITATION OF *PHYTOPHTHORA*-DEGRADED PLANT COMMUNITIES IN SOUTH-WEST WESTERN AUSTRALIA

D.I.L. Murray

1 OBJECTIVE

The purpose of this document is to address Scope Item No. 6 for the *Phytophthora* and *Diplodina* Canker project (1997/98). This entails a review of factors likely to be important for the *in situ* rehabilitation of *Phytophthora*-damaged native plant communities and the associated restoration of habitat structure for dependent flora and fauna. A limited literature search was conducted using CD ROM TREE CD (1973-present; CAB International) to locate relevant publications. It is emphasised that a comprehensive review of the subject area could not be attempted within the period of time allotted for completion of this study.

2 INTRODUCTION

Several species of *Phytophthora* have been causally associated with dieback disease of native plant communities in the South West Land Division (SWLD) of Western Australia. These soil- or water-borne, root-infecting fungi include *P. cinnamomi, P. citricola, P. cryptogea,* (syn. = *P. drechsleri*), *P. megasperma* var. *megasperma, P. megasperma* var. *sojae* and *P. nicotianae* (Shearer *et al.*, 1991). While interactions between the various pathogens and native plant communities have differing degrees of significance, there is no doubt that *P. cinnamomi*, the cause of epidemic dieback of jarrah and other components of the indigenous flora (Podger, 1972), is by far the most important *Phytophthora* sp. in terms of the magnitude of damage that it inflicts on a broad spectrum of hosts in the SWLD. Accordingly, this document focuses on consideration of *P. cinnamomi* and its impact on native vegetation in Western Australia.

P. cinnamomi has been the subject of extensive research in Western Australia for more than a quarter of a century. During this period, considerable knowledge has accumulated regarding the distribution (Shearer, 1994), pathology and life cycle of the fungus, particularly in relation to the northern jarrah forest environment (Shearer & Tippett (1989). The pathogen has been reported to infect more than 900 species of higher plants many of which are important components of Western Australian plant communities (Zentmyer, 1980; Shearer & Hill, 1989; Shivas, 1989).

P. cinnamomi has a widespread though disjunct distribution, not only in the jarrah forest, but also in *Banksia* woodlands of the Swan Coastal Plain and kwongan communities on the northern and southern sandplains. The fungus occurs in an area extending south from Eneabba, inland beyond Dryandra, and around the south-west corner of the State continuing adjacent to and along the coast past Esperance in the east (Shearer, 1994). Podger (1972) reported that *P. cinnamomi* was killing most of the overstorey and shrub layers in *Banksia* woodlands. More recently, Hill (1990) and Shearer & Dillon (1996a; 1996b) studied the impact of *P. cinnamomi* in *Banksia* woodlands on the Swan Coastal Plain and listed many species as susceptible to the fungus. Wills (1993) assessed the susceptibility of native flora in the Stirling Range National Park and found that the pathogen was causing mortalities in 36% of 330 species examined. Many Declared Rare or Priority Flora are killed by the fungus in affected woodland or heath communities.

3 DEGRADATION OF PLANT COMMUNITIES

Significant alteration of floristic composition and reduction of structural complexity are consistent features of forest, woodland and sandplain communities following establishment of *P. cinnamomi* and natural progression of disease in susceptible vegetation. For example, in healthy jarrah forest, species of Proteaceae, Myrtaceae, Epacridaceae, Papilionaceae, Dilleniaceae and Xanthorrhoeaceae constitute a major segment of the understorey and shrub layers. *B. grandis* and many other of these species are killed by *P. cinnamomi* and their loss, together with mortality of jarrah, culminates in a marked decrease in floristic diversity (Shearer & Tippett, 1989). In terms of structural change, forest dieback sites infected 20-50 years ago have often become open woodlands bearing regrowth marri and a relatively simple ground cover dominated by sedges where a complex assemblage of mainly dicotyledonous species once prevailed.

Similarly, the structure and floristic diversity of *Banksia* woodlands are degraded by infections of *P. cinnamomi* on the coastal sandplain. Dominant tree species such as *B. attenuata*, *B. ilicifolia*, and *B menziesii* are killed in some areas leaving scattered eucalypts and a shrub layer in which species richness may be significantly diminished together with reductions in plant biomass of up to 90% (Shearer & Hill, 1989). *P. cinnamomi* is primarily a pathogen of woody perennials, whereas annuals, geophytes and herbaceous perennials are usually unaffected by the fungus (Zentmyer, 1980; Wills, 1993). Increased abundance of the latter plant forms can thus be expected as the floristic composition of an affected community changes after disease establishment.

Wills (1993) studied the ecological impact of *P. cinnamomi* in the Stirling Range National Park and pointed out that changes in habitats induced by modification of community structure or composition may adversely affect plants that are not directly attacked by the pathogen. This was illustrated by reference to *Stylidium scandens* which appears to be resistant to *P. cinnamomi*. Specimens of the triggerplant were common in healthy areas of the park but absent in adjacent, diseased sites. *S. scandens* is usually found in dense understorey beneath healthy stands of jarrah and it was suggested that its absence in infested areas was due to loss of canopy shading associated with understorey mortalities. Various components of the flora, resistant to

P. cinnamomi but sensitive to specific habitat alterations, may also be indirectly disfavoured by the results of pathogen activity while others, for example, introduced annuals, may benefit from such disturbance.

There is no doubt that degradation of native plant communities, caused by *P. cinnamomi*, has the potential to severely affect the abundance and composition of associated faunal populations (Wilson *et al.*, 1994). A decrease in canopy cover would be expected to directly impact on habitat availability for avifauna or arboreal marsupials. Changes to floristic composition in the overstorey, understorey and/or shrub layers might result in the loss of specific food (e.g., seeds, pollen or nectar) or habitat requirements (e.g., shelter from predators). Reduction in canopy together with thinning or removal of ground cover, leaf litter and exposure of soil surfaces may equate with severe alteration to, or local loss of habitat for some small ground-dwelling animals including litter invertebrates. Conversely, fauna adapted to more open habitats may be favoured (Wilson *et al.*, 1994). In exposed situations, the soil biota are likely to be affected by increased fluctuations in sub-surface temperatures as are soil microorganisms. The latter, including *P. cinnamomi*, may also be influenced by changes in floristic composition at least in the vicinity of plant roots (Murray *et al.*, 1985; Murray, 1987).

Indirect effects of *P. cinnamomi* on pollinators may further exacerbate the decline of relatively rare *Banksia* spp. and other animal-pollinated plants in some affected communities. For example, the local survival of two species of nectarivorous possums, *Cercartetus concinnus* and *Tarsipes rostratus*, are threatened by loss of nectar sources as a result of dieback disease in the Stirling Range National Park. If populations of the possums diminish in infested areas, this in turn could adversely affect the reproductive activity of remaining plants (Shearer *et al.*, 1991; Wills, 1993; Wills & Keighery, 1994). Further examples of interactions between pathogen, flora and fauna are cited by Shearer (1990) and Shearer *et al.*, (1991). Associations of this nature would be an important consideration in regard to rehabilitation of degraded communities.

4 REHABILITATION OF PLANT COMMUNITIES

With the exception of minesite studies, the literature search conducted at the onset of this work failed to locate any reports of *in situ* rehabilitation of *Phytophthora*-degraded native plant communities in Western Australia or elsewhere. Although mining activities obviously result in major physical disruption of the environment some aspects of bauxite mine rehabilitation are of interest in relation to the restoration of native plant communities devastated by *P. cinnamomi.*

4.1 MINESITE REHABILITATION

Alcoa of Australia Ltd. has been involved in open cut bauxite mining and subsequent rehabilitation of minesites in the jarrah forest since 1963 and 1966, respectively (Koch *et al.*, 1994; Ward *et al.*, 1997; Grant & Koch, 1997). At the Jarrahdale and Willowdale sites, mining occurs in predominantly dieback-affected forest (Colquhoun, 1992). Mining entails the removal of topsoil (5-15cm), overburden (0-1m), cemented caprock and bauxite ore to a depth of 2-5m. Pit walls are levelled during the initial stage of physical rehabilitation, and the overburden and topsoil are then replaced in that order before mechanical ripping to a depth of 1.5m (Nichols *et al.*, 1989; Ward *et al.*, 1996).

Early attempts at rehabilitation included the planting of exotic pines or eastern states eucalypts (resistant to *P. cinnamomi*) without understorey seeding or ripping of pit floors (Nichols & Bamford, 1985; Nichols *et al.*, 1989). The outcome of this approach was a single stratum of plantation-like vegetation with poor development of understorey or ground cover (Nichols & Bamford, 1985).

As rehabilitation techniques gradually evolved in tandem with increased understanding of pathogen-host-environment interactions, it became apparent that jarrah and other species considered susceptible to *P. cinnamomi* could be used for minesite rehabilitation. The re-establishment of these species was probably favoured, and the pathogen disfavoured, by alteration of environmental conditions including removal of caprock, reduced soil compaction and improved drainage associated with deep ripping (Colquhoun, 1992). It is interesting to speculate whether cost-effective methods for modification of the soil environment could be developed to accommodate the reintroduction of dieback-susceptible species in woodland, sandplain or unmined forest areas infested with the pathogen.

An objective of Alcoa's mine rehabilitation program is to establish a self-sustaining ecosystem (Ward *et al.*, 1997) with floral, faunal and soil characteristics of the indigenous jarrah forest (Nichols *et al.*, 1991). Since 1989, Western Australian native eucalypts including jarrah have been used exclusively for overstorey rehabilitation. Moreover, the current policy is to use only local species for the understorey seed mix that supplements the seed-bank in returned topsoil. To assist achievement of this objective, a seed collection provenance zone has been established for each mine (Koch *et al.*, 1994).

Mortality rates of reintroduced jarrah on minesites are low despite the presence of *P. cinnamomi*. At Eneabba, on the northern sandplain, highly susceptible species of *Banksia* have been used successfully in the rehabilitation of infested land mined by RGC Mineral Sands Ltd. (Colquhoun & Peterson, 1994). While the survival of sensitive host plants in these areas may be favoured by environmental disturbance associated with mining, it is also possible that insufficient time has elapsed (since revegetation) to allow the biomass of susceptible root tissue in the soil to attain a level conducive to rapid build up of pathogen inoculum.

Collins *et. al.* (1985) studied re-colonisation of restored bauxite minesites by birds and reported that older sites, lacking understorey or planted with pines, supported smaller populations and fewer species of avifauna than sites that had been revegetated using more advanced methods. Furthermore, population densities and numbers of species at the latter sites were similar to those recorded for healthy forest communities. Old sites rehabilitated only with overstorey trees were also unsuitable for most reptiles (Nichols & Bamford, 1985). There is evidence that as floral communities on rehabilitated minesites mature and plant diversity increases, animal species absent in the early stages of colonisation may return as specific habitat requirements become available. Examples include birds that nest in hollows or in the canopy of tall trees. According to Nichols *et al.* (1991), it is unnecessary and impractical to physically reintroduce fauna back into restored minesites as their successful establishment will be dependent on the existence of suitable habitats, a key element of which is vegetation.

4.2 INVENTORY

Determination and documentation of the pre-infection floristic composition and structure of *Phytophthora*-degraded plant communities are essential prerequisites to rehabilitation if conservation values are to be restored in affected areas. Disease-induced alterations to the jarrah forest understorey are not well documented (Shearer & Tippett, 1989) although the original work of Podger (1968), the site-vegetation relationships elucidated by Havel (1975a; 1975b) and more recent studies by Shearer & Dillon (1995) provide some indication of likely changes following disease establishment in forest areas. Alterations to floristic composition and structural complexity of *Banksia* woodland on the Swan Coastal Plain are reported by Shearer & Dillon (1996b). Further assessments of plant community structure and composition need to be undertaken for healthy areas of forest, woodland and sandplain, particularly those under imminent threat of infestation by *Phytophthora*. In some cases, extrapolation of results from healthy to adjacent diseased areas may be the only avenue available for determination of pre-infection community composition.

A comparison between pre- and post-infection assessments of animal populations can provide some idea of the success of a particular rehabilitation procedure as the disappearance of certain species in the latter assessment may indicate a lack of suitable habitats (Nichols *et al.*, 1991).

4.3 REHABILITATION STRATEGIES

Three options are available in relation to selection of appropriate plant species for rehabilitation of *Phytophthora*-damaged communities in forest, woodland or sandplain situations. These are:

1. Reintroduction of the native species eliminated previously by *P. cinnamomi*.

2. Introduction of non-local (surrogate) species.

3. A combination of 1 and 2.

The first option is essentially that adopted by Alcoa for minesite rehabilitation. If feasible, it is certainly the most attractive alternative since it should lead ultimately to the development of a similar native plant community to that existing before infection. This assumes that niches occupied by the original flora are still open, or could be made so by removal of annual weeds or other invaders prior to revegetation. Faunal recolonisation would proceed as suitable habitats again became available in the developing plant community. Various aspects of the reintroduction of native species are considered below, in greater detail.

If a decision is made in favour of using non-local or exotic flora (Option 2), it is important that certain properties are demonstrated for candidate plant species prior to their introduction to native communities. Selected species should be field resistant to *P. cinnamomi* and to any other significant pathogens or pests likely to be encountered. They should be site compatible in terms of climatic, edaphic and biotic factors but not likely to become invasive or weedy at any stage of development. Their response to fire and their ability to withstand grazing should not differ significantly to that of the original flora. Finally, each species should be phenotypically similar to that which it replaces in the community. Implicit in the last requirement is the need for introduced species to act as surrogates, to re-establish the structure and quality of habitats for dependent flora and fauna, thus ensuring the availability of adequate nutrition, shelter, reproductive or other necessary conditions at levels comparable to those prevailing before community degradation.

At some locations it might be expedient to use surrogate species to replace only those elements of a community that are particularly susceptible to *P. cinnamomi*, for example, various *Banksia* spp. This approach (Option 3), which would be expected to significantly reduce the quantity of pathogen inoculum available for infection of other hosts, might assist the reintroduction of relatively insensitive components of the native flora. Irrespective of which option is chosen, testing of candidate species under field conditions and monitoring in the long term would be needed to evaluate the efficacy of any rehabilitation strategy.

4.4 REINTRODUCTION OF NATIVE SPECIES

Reintroduction of susceptible native species into an area infested by *P. cinnamomi* is unlikely to be successful unless the environment can be manipulated to create conditions unfavourable for host infection or alternatively, the reintroduced plants can be protected by cost-effective application of a persistent, systemic fungicide such as phosphonate. A third possibility is the selection of genetic resistance to *P. cinnamomi* in the native species to be used for the rehabilitation process.

Manipulation of floristic composition by prescription burning was suggested more than two decades ago as a means of ameliorating the impact of *P. cinnamomi* in the jarrah forest (Shea & Malajczuk, 1977). Moreover, there is evidence that plant establishment in rehabilitated minesites can be enhanced by fire (Grant *et al.*, 1997) and it is possible that controlled burning may in some circumstances have a role to play in the restoration of degraded plant communities. However, physical alteration of the soil environment to a degree resembling that noted for mining operations would probably be prohibitively expensive.

Phosphonate is a non-toxic, systemic fungicide considered to be capable of controlling most species of *Phytophthora* including *P. cinnamomi*. The chemical is thought to enhance host resistance to the pathogen and it is reported to protect *Banksia* spp. from infection for at least four years after application (Shearer *et al.*, 1991). Therefore, phosphonate treatment would appear to be a potent tool for assisting the reintroduction of susceptible native plants into areas where previously they were eliminated by the pathogen.

High levels of genetic resistance to *P. cinnamomi* have been demonstrated to exist in *Eucalyptus marginata* (jarrah) and technology is now available for the micropropagation of selected lines that may be useful in the rehabilitation of degraded sites in the jarrah forest (McComb *et al.*, 1994; Stukely & Crane, 1994). Some evidence of resistance to *P. cinnamomi* has also been found for *Banksia coccinea* and *B. hookerana*, two species that are regarded as highly susceptible to the pathogen (McCredie *et al.*, 1985). Detection of genetic resistance and propagation of resistant lines of native species currently being destroyed by *P. cinnamomi* is possible. However, the time required to develop screening and propagation techniques will probably restrict the use of this approach to priority species under threat of extinction from the fungus (McComb *et al.*, 1994) at least in the short term.

There is evidence in the literature to suggest that, whenever possible, local provenance material should be used for revegetation programs (Taylor *et al.*, 1994; van Leeuwen, 1994; Coates & van Leeuwen, 1996). This is based on the premise that considerable genetic variation exists in a species (over its geographic range) which reflects not only the evolutionary history of the species, but also the ecological conditions to which it has been exposed. It follows that the population of a species best adapted to a particular locality will be that which evolved there. Accordingly, provenance seed from locally occurring species is likely to be most suitable for the rehabilitation of a degraded plant community (Coates & van Leeuwen, 1996). While accepting the validity of this argument, it is clear that local species did not evolve in the presence of *P.cinnamomi* and that susceptible taxa are not well adapted to coexist with the pathogen. If local provenance material is to be used for the reintroduction of susceptible native flora, then plants will require protection in the form of phosphonate application unless resistant lines can be identified. This probably represents the best strategy currently available for rehabilitation of native plant communities damaged by *P. cinnamomi*. As indicated earlier, populations of fauna should return as the plant community develops, assuming that there are no barriers to migration from surrounding areas.

5 OUTCOME

- This review represents a first step towards synthesis of the knowledge base required for *in situ* rehabilitation of *Phytophthora*-damaged native plant communities in Western Australia, and for the associated restoration of habitat structure that is essential for conservation of dependant flora and fauna.

6 REFERENCES

Coates, D.J. & van Leeuwen, S.J. (1996). Delineating seed provenance areas for revegetation from patterns of genetic variation. In: Proceedings of the second Australian native seed biology for revegetation workshop, Newcastle, NSW. (Eds. S.M. Bellairs and J.M. Osborne) pp. 3-14.

Collins, B.G., Wykes, B.J. & Nichols, O.G. (1985). Re-colonization of restored bauxite minelands by birds in southwestern Australian forests. In: Birds of eucalypt forests and woodlands: Ecology, conservation and management. Surrey, Beatty and Sons, Sydney, NSW. (Eds. A. Keast and H. Recher) pp. 341-354.

Colquhoun, I.J. (1992). Alcoa's dieback research direction. In: Dieback - What is the future? Northern sandplain dieback working party. Perth, WA. (Eds. M.J. Freeman, R. Hart and M. Ryall) pp. 15-21.

Colquhoun, I.J. & Petersen, A.E. (1994). The impact of plant disease on mining. *Journal of the Royal Society of Western Australia* **77,** 151-158.

Grant, C.D. & Koch, J.M. (1997). Ecological aspects of soil and seed-banks in relation to bauxite mining. II. Twelve year old rehabilitated mines. *Australian Journal of Ecology* **22,** 177-184.

Grant, C.D., Loneragan, W.A., Koch, J.M. & Bell, D.T. (1997). The effect of burning, soil scarification and seeding on the understorey composition of 12 year-old rehabilitated bauxite mines in Western Australia. *Australian Forestry* **60,** 16-23.

Havel, J.J. (1975a). Site-vegetation mapping in the northern jarrah forest (Darling Range). 1. Definition of site-vegetation types. Bulletin 86, Forests Department, Western Australia.

Havel, J.J. (1975b). Site-vegetation mapping in the northern jarrah forest (Darling Range). 2. Location and mapping of site-vegetation types. Bulletin 87, Forests Department, Western Australia.

Hill, T.C.J. (1990). Dieback disease and other *Phytophthora* species in the northern kwongan. In: Nature Conservation, Landscape and Recreation Values of the Lesueur Area. Bulletin No. 424, Environmental Protection Authority, Perth, WA. (Eds. A.A. Burbidge, S.D. Hopper and S. van Leeuwen) pp. 89-97.

Koch, J.M., Taylor, S.K. & Gardner, J.H. (1994). Research to maximise plant diversity in rehabilitated bauxite mines in the jarrah forest. In: National Workshop on Native Seed Biology for Revegetation. Perth, WA. (Eds. S.M. Bellairs and L. C. Bell) pp. 41-50.

McComb, J.A., Stukely, M. & Bennett, I.J. (1994). Future ecosystems - use of genetic resistance. *Journal of the Royal Society of Western Australia* **77,** 179-180.

McCredie, T.A., Dixon, K.W. & Sivasithamparam, K. (1985).Variability in the resistance of *Banksia* L.f. Species to *Phytophthora cinnamomi* Rands. *Australian Journal of Botany* **33,** 629-637.

Murray, D.I.L. (1987). Rhizosphere microorganisms from the jarrah forest of Western Australia and their effects on vegetative growth and sporulation in *Phytophthora cinnamomi* Rands. *Australian Journal of Botany* **35,** 567-580.

Murray, D.I.L., Darling, D.D. & McGann, L.R. (1985). Indirect effect of floristic composition on production of sporangia by *Phytophthora cinnamomi* in jarrah forest soils. *Australian Journal of Botany* **33,** 109-113.

Nichols, O.G. & Bamford, M.J. (1985). Reptile and frog utilisation of rehabilitated bauxite minesites and dieback-affected sites in Western Australia's jarrah *Eucalyptus marginata* forest. *Biological Conservation* **34,** 227-249.

Nichols, O.G., Koch, J.M., Taylor, S. & Gardner, J. (1991). Conserving biodiversity. In: Proceedings of the Australian Mining Industry Council Environmental Workshop, Perth, WA. pp. 116-136.

Nichols, O., Wykes, B.J. & Majer, J.D. (1989). The return of vertebrate and invertebrate fauna to bauxite mined areas in south-western Australia. In: Animals in primary succession - The role of fauna in reclaimed land. Cambridge University Press, UK. (Ed. J.D. Majer) pp. 397-421.

Podger, F.D. (1968). Aetiology of jarrah dieback. A disease of dry sclerophyll *Eucalyptus marginata* Sm. forests in Western Australia. M.Sc. thesis, University of Melbourne, Vic.

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. & Malajczuk, N. (1977). Potential for control of eucalypt dieback in Western Australia. In: Seminar Papers, Annual conference of Australian Nurseryman's Association Ltd., Hobart, Tas. pp. 13-19.

Shearer, B.L. (1990). Dieback of native plant communities caused by *Phytophthora* species - a major factor affecting land use in south-western Australia. *Land and Water Research News* **5,** 15-26.

Shearer, B.L. (1994). The major plant pathogens occurring in native ecosystems of south-western Australia. *Journal of the Royal Society of Western Australia* **77,** 113-122.

Shearer, B.L. & Dillon, M. (1995). Susceptibility of plant species in *Eucalyptus marginata* forest to infection by *Phytophthora cinnamomi. Australian Journal of Botany* **43,** 113-134.

Shearer, B.L. & Dillon, M. (1996a). Susceptibility of plant species in *Banksia* woodlands on the Swan Coastal Plain, Western Australia, to infection by *Phytophthora cinnamomi* **44,** 433-445.

Shearer, B.L. & Dillon, M. (1996b). Impact and disease centre characteristics of *Phytophthora cinnamomi* infestations of *Banksia* woodlands on the Swan Coastal Plain, Western Australia. *Australian Journal of Botany* **44,** 79-90.

Shearer, B.L. & Hill, T.C. (1989). Diseases of *Banksia* woodlands on the Bassendean and Spearwood Dune Systems. *Journal of the Royal Society of Western Australia* **71,** 113-114.

Shearer, B.L. & Tippett, J.T. (1989). Jarrah dieback: The dynamics and management of *Phytophthora cinnamomi* in the jarrah (*Eucalyptus marginata*) forest of south-western Australia. Department of Conservation and Land Management Research Bulletin No. 3, Como, WA.

Shearer, B.L., Wills, R.T. & Stukely, M. (1991). Wildflower killers. *Landscope* **7,** 30-34.

Shivas, R.G. (1989). Fungal and bacterial diseases of plants in Western Australia. *Journal of the Royal Society of Western Australia* **72,** 1-62.

Stukely, M.J.C. & Crane, C.E. (1994). Genetically based resistance of *Eucalyptus marginata* to *Phytophthora cinnamomi*. *Phytopathology* **84,** 650-656.

Taylor, S.K., Luscombe, P. & Hill, G. (1994). Planning and designing seed mixes. In: Proceedings of Workshop 3 - Revegetation of minesites using appropriate species. Third International Conference on Environmental Issues and Waste Management in Energy and Mineral Production. Perth, WA. pp. 47-51.

van Leeuwen, S.J. (1994). Justification for the use of provenance seed in the rehabilitation of disturbed sites. In: Proceedings of Workshop 3 - Revegetation of minesites using appropriate species. Third International Conference on Environmental Issues and Waste Management in Energy and Mineral Production. Perth, WA. pp. 27-36.

Ward, S.C., Koch, J.M. & Ainsworth, G.L. (1996). The effect of timing of rehabilitation procedures on the establishment of a jarrah forest after bauxite mining. *Restoration Ecology* **4,** 19-24.

Ward, S.C., Koch, J.M. & Grant, C.D. (1997). Ecological aspects of soil seed-banks in relation to bauxite mining. I. Unmined jarrah forest. *Australian Journal of Ecology* **22,** 169-176.

Wills, R.T. (1993). The ecological impact of *Phytophthora cinnamomi* in the Stirling Range National Park, Western Australia. *Australian Journal of Ecology* **18,** 145-159.

Wills, R.T. & Keighery, G.J. (1994). Ecological impact of plant disease on plant communities. *Journal of the Royal Society of Western Australia* 77, 127-131.

Wilson, B.A., Newall, G., Laidlaw, W.S. & Friend, G. (1994). Impact of plant diseases on faunal communities. *Journal of the Royal Society of Western Australia* 77, 139-143.

Zentmyer, G.A. (1980). *Phytophthora cinnamomi* and the diseases it causes. Monograph No. 10. American Phytopathological Society, St. Paul, USA.

Acknowledgments

I thank Mr. John Gardner and Dr. I.J. Colquhoun of Alcoa of Australia Ltd. for providing access to library facilities and unpublished data.

CONTROL OF *PHYTOPHTHORA* AND *DIPLODINA* CANKER IN WESTERN AUSTRALIA

FINAL REPORT

TO THE THREATENED SPECIES AND COMMUNITIES UNIT

BIODIVERSITY GROUP

ENVIRONMENT AUSTRALIA

DECEMBER 1998

Department of Conservation and Land Management
Locked Bag 104, Bentley Delivery Centre, WA 6983