

Habitat alteration caused by an introduced plant disease, *Phytophthora cinnamomi*: a potential threat to the conservation of Australian forest fauna

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ABSTRACT

While the impacts of the introduced plant pathogen *Phytophthora cinnamomi* on Australian forest flora are well documented, its possible indirect impacts on fauna through changes to floristics and plant structure are less clear. We reviewed the literature on the responses of forest animal communities to the presence of *Phytophthora cinnamomi*, finding some evidence of declines in abundance and distribution of mammals and invertebrates. Mammals were mostly affected by reductions in shelter and food, while invertebrates probably declined because of changes in litterfall patterns. Mammal declines could in turn disrupt important ecosystem processes through reductions in burrowing and digging which are vital in soil turnover and plant propagation. Trends were less clear in birds and herpetofauna, where some authors speculated on possible impacts but there were few convincing studies. Overall, the review indicated that for a range of forest fauna serious impacts were either occurring or were plausible but not yet demonstrated. This scenario calls for a blend of precautionary and preventive measures on the part of management authorities, including quarantine, chemical control, review of fire practices and hygienic implementation of roadworks, drainage and logging. Without such precautionary and preventive management, *Phytophthora cinnamomi* has the potential to significantly reduce the diversity of forest fauna.

Key words: *Phytophthora cinnamomi*, dieback, root-rot fungus, jarrah, precautionary principle, key threatening process.

Introduction

When the available data used in decision making processes are limited but grave risks to the environment are predictable, management should adopt a precautionary approach to minimise the likelihood of irreversible environmental damage (O'Riordan *et al.* 2001, Calver 2002). Rather than awaiting detailed scientific studies of the risks, the precautionary approach requires immediate action to protect the environment. This could involve prohibitions on particular activities, stringent enforcement of quarantine measures or rigorous monitoring of activities with provision to halt them if impacts lie outside prescribed guidelines (Deville and Harding 1997). When risks are well known and grave, a preventive approach is appropriate, involving explicit action to minimise or avert the known risk (Calver 2002). Often, this requires an adaptive management strategy whereby the continued monitoring data from well-designed surveys, and audits of the environmental management system allow for modifications that prevent detrimental effects. This chapter examines these approaches to terrestrial forest fauna management using the plant disease *Phytophthora cinnamomi* as a model of a scenario where high ignorance and high risk prevail.

The plant conservation threat from *Phytophthora cinnamomi*

Phytophthora cinnamomi is a soil-borne pseudofungus belonging to the Class Oomycetes or 'water moulds' in the Kingdom Chromista. It is pathogenic to many plant species within Australia's forest ecosystems (Lewis and Colquhoun 2000,

Barrett 2001). Its growth, reproduction and spread are favoured by free water in the soil or ponding on the soil surface. Consequently, the movement of infested water and soil play a key role in the spread of this pathogen, and in contrast to other pathogens of natural ecosystems, human activity is critical in the spread of *P. cinnamomi* in infested soil. Road building, logging, wildflower picking, bush-walking, four-wheel driving, firebreak management and planting diseased nursery stock are examples of how *P. cinnamomi* can be inadvertently introduced and spread (Underwood and Murch 1984). Rain, topography and soil-type can increase the risk of spread and highly susceptible species can act as reservoirs for the continued growth of the pathogen (Marks and Smith 1991, Colquhoun and Hardy 2000). The epidemic of plant death caused by *P. cinnamomi* is recognised as one of 13 Key Threatening Processes to the Australian Environment (Commonwealth *Environment Protection and Biodiversity Conservation* (EPBC) Act 1999, Environment Australia 2001) and is now acknowledged as a potential threat to the wellbeing of fauna in a range of communities across the continent, including Australia's forest communities.

Jarrah dieback, dieback and cinnamon fungus are names commonly used for the disease caused by *P. cinnamomi* but they should be avoided as they cause confusion with particular localities or other plant diseases. This review follows the terminology outlined in the 'Threat Abatement Plan for the root-rot fungus *Phytophthora cinnamomi*' (Environment Australia 2001) and uses the binomial *P. cinnamomi* to describe the pathogen and *Phytophthora* dieback to describe the effect of the disease on plants.

Phytophthora cinnamomi was first identified in Australia in the early 1930s. Although there has been some debate over its origin, it is now generally accepted that *P. cinnamomi* is of Asian origin (Zentmyer 1988). In 1965 *P. cinnamomi* was identified as the pathogen causing 'jarrah dieback' in the jarrah *Eucalyptus marginata* forests of Western Australia (Podger et al. 1965, Podger 1968). However, symptoms of *Phytophthora* dieback were observed in many south-eastern forested regions in the 1950s (Weste 1974, Marks and Idzak 1977, Ward et al. 1978, Marks and Smith 1991). *Phytophthora cinnamomi* is now widespread in Australia and occurs in a variety of vegetation communities in Western Australia, Tasmania, Victoria, South Australia, New South Wales and Queensland (Figure 1) (Podger and Ashton 1970, Newhook and Podger 1972, Weste and Taylor 1971, Weste 1974, Shearer and Tippett 1989, Wills 1993, Weste 1994).



Figure 1. Distribution of positive results from a number of soil isolations for *Phytophthora cinnamomi* in Australia.

Phytophthora dieback disease

The development of the plant disease that causes *Phytophthora* dieback requires a number of factors that must operate in concert. These are; (i) the presence of the pathogen, (ii) the presence of susceptible host plant species and (iii) environmental conditions that favour infection and subsequent reproduction and spread of the disease. Removal of any one factor from the system and *Phytophthora* dieback will not occur.

Two mechanisms have been recognised as fundamental to the spread and presence of *P. cinnamomi* over large areas of forested communities in Australia. These are the autonomous and passive mechanisms that spread an existing infection throughout the immediate landscape, and the creation of totally new areas of infection by the transfer of infective material, usually through human activity (CALM 2000). Both mechanisms of spread are intimately linked to the life-history of *P. cinnamomi* (Figure 2).

The body of *P. cinnamomi* consists of threadlike mycelial strands that grow in the soil or host plant tissue. In warm, moist conditions the mycelia reproduce asexually to produce both chlamydospores and sporangia. The thick

walled chlamydospores are resting spores and will, under optimum conditions, germinate to produce mycelia and/or sporangia. Sporangia are formed under warm wet and well-aerated conditions to produce zoospores.

The microscopic and motile zoospores are the major infective propagules in the *P. cinnamomi* life cycle. They are chemotactically attracted to plant roots, where they encyst and germinate; this results in autonomous spread of the pathogen. In susceptible hosts they will colonise the plant tissues. Zoospores are also passively spread long distances down hill in moving water.

Chlamydospores develop under unfavourable environmental conditions. They are capable of surviving for long periods within dead plants and can lead to spread of the pathogen (and the disease it causes) to entirely new locations through the movement of infected soil or plant material. It is now recognised that any human activity that favours the movement of infected soil or plant material, such as road construction, logging and earthmoving, is the most significant cause of the rapid distribution of the pathogen over large parts of southern and eastern Australia. In Western Australia, it is undeniable that "most diseased areas occur along the more used roads, though logging has evidently spread the pathogen further" (Forests Department 1973) and that "this fungus was spread by a range of forest uses, including roading, logging, mining, wildflower picking, bee-keeping and recreation" (Abbott and Christensen 1994, p. 115). All these activities share indirectly in the current and future impacts of the pathogen (Colquhoun and Hardy 2000). Minor vectors that spread the pathogen include footwear, feral and domestic animals and, potentially, native fauna (Marks and Smith 1991, Niewand et al. 1995)

Following the infection of plants by the pathogen, the mycelia invade the roots, causing tissue necrosis that leads to rotting of the roots and collar, found just at the soil level, of the plant. This limits the plant's water supply and leads to its death.

Host range

Phytophthora cinnamomi has a wide host range, although its pathogenicity to different hosts varies. It affects mainly woody perennial species (Colquhoun and Hardy 2000, Weste et al. 2002), while herbaceous perennials, annuals and geophytes remain largely unaffected (Kennedy and Weste 1986, Podger and Brown 1989, Wills 1993). The pathogen is known to infect many Australian native species (Weste 1974, Phillips and Weste 1984, Tippett et al. 1985, Weste and Marks 1987, Tippett et al. 1989, Marks and Smith 1991, Wills 1993). The most susceptible plant families are the Proteaceae, Fabaceae, Dillineaceae and Epacridaceae (Wills 1993, Weste 1994, Wills and Keighery 1994). In the Brisbane Ranges, Victoria 50-75% of species are susceptible (Weste and Taylor 1971), in the Grampians 26% of understorey species were eliminated and 28% were greatly reduced and the flora was changed from one dominated by insect-, mammal- and bird pollinated plants to one that is dominated by wind-pollinated plants (Kennedy and Weste 1986). In Tasmanian cool-temperate rainforest, 30% of species present (142 spp.) were highly

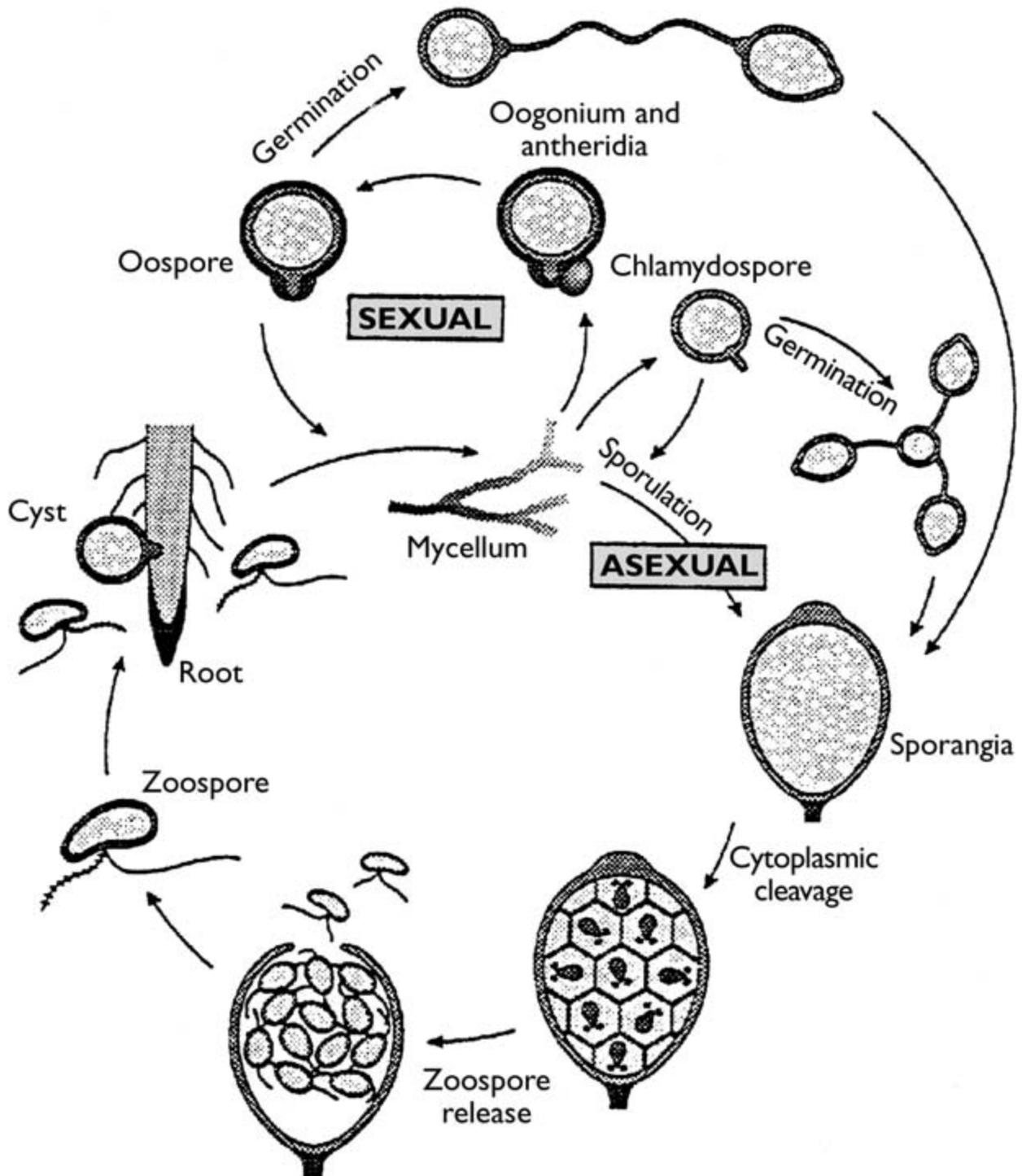


Figure 2. Life-cycle of *Phytophthora cinnamomi* (from Hardham 1999). The sexual stage is extremely rare as there is predominantly only one mating type.

susceptible (Podger and Brown 1989) and in the Stirling Ranges, Western Australia 36% of species were sensitive to *P. cinnamomi*, 10% were highly sensitive and 48% of woody perennials highly susceptible (Wills 1993).

Studies in Western Australia show that approximately 2000 of the 8000 - 9000 taxa in the southwestern botanical province are directly susceptible to infection by *P. cinnamomi* (Wills 1993, Komorek *et al.* 1994, Colquhoun and Hardy 2000). In Western Australia, Podger (1968) and Shearer and Dillon (1995, 1996) list 100 native

plant species from 23 families and 53 genera from which *P. cinnamomi* has been isolated after surface sterilisation of root material and plating onto selective agar. Overall, in Australia *P. cinnamomi* has been directly isolated from 56 families, 145 genera and 256 species (Podger 1968, Podger *et al.*, 1990, Weste 1995, Shearer and Dillon 1995, 1996). In addition, there are many records of dead and dying plants in known *P. cinnamomi* infested areas where no attempts have been made to recover *P. cinnamomi* or from which *P. cinnamomi* was not recovered (Wills 1993).

The most critical environmental factor that favours an outbreak of *Phytophthora* dieback appears to be rainfall. The disease is most likely to occur in susceptible vegetation communities where the annual average rainfall is greater than 600 mm. However, *Phytophthora* dieback may also occur in areas of rainfall between 400 to 600 mm if water-shedding conditions prevail, and recent surveys have identified *P. cinnamomi* causing death in dominant *Oxylobium* understorey in the subalpine ecosystems of the Barrington Tops National Park, New South Wales (McDougall et al. 2003). As a general rule, all high rainfall Mediterranean plant communities and low elevation temperate vegetation communities are prone to severe outbreaks of *Phytophthora* dieback (CALM 2000, Environment Australia 2001). However, *Phytophthora* should not be ruled out as the cause of plant death in lower rainfall areas or higher elevations. The areas where the disease is most virulent are the most likely source of material that will spread the pathogen to new locations.

Habitat alteration caused by *Phytophthora* dieback

The effects of large-scale *Phytophthora* dieback in susceptible plant communities are devastating (see Figure 3 for mass collapse of jarrah forest). Several studies have demonstrated that the disease results in decreased plant species richness, vegetation cover and alterations to the vertical structure, particularly in understorey species. The floristic characteristics of vegetation communities are altered through the loss of susceptible species and increases in resistant plants, such as sedges (Kennedy and Weste 1986), leading to a simplified understorey vegetation. In the Stirling Ranges of Western Australia, 85% of the Proteaceae are susceptible to the pathogen and the proteaceous elements of the vegetation are responsible for 40% of the projected foliage cover in healthy, non-infested sites. Herbaceous perennials, annuals and geophytes survive infestation by *P. cinnamomi* while 48% of woody perennials are susceptible to the disease (Wills 1993). Alteration to the vegetation structure can lead to additional floristic changes in vegetation, even where field resistant species occur. For example, species of *P. cinnamomi* field-resistant Stylideaceae

co-occur with jarrah trees in non-infested sites, however, they do not occur in sites where *Phytophthora* dieback has affected the tree strata (Wills 1993). In Western Australia, the potential for direct and indirect modification of the fauna habitat by *Phytophthora* dieback is apparent in the forest canopy and understorey.

This contrasts to one study conducted in the Brisbane Ranges in Victoria. In areas where large-scale *Phytophthora* dieback of the overstorey had occurred in the previous 10-20 years, recent *P. cinnamomi* spread did not affect the canopy cover or the availability of tree hollows (Newell 1998). This suggests that modification to vertebrate habitat was not occurring at this stratum. However, modification of the understorey, through the loss of *P. cinnamomi* susceptible species, did occur. Very susceptible species, such as the Austral Grass-Tree *Xanthorrhoea australis* (Figure 4) and *Dillwynia glaberrima* have been shown to regenerate in the Brisbane Ranges 20 to 30 years after the initial *P. cinnamomi* infestation that killed these species (Weste and Ashton 1994, Weste 1997, Weste and Kennedy 1997), which suggests that understorey habitat may regenerate. Similar regeneration of the *X. australis* has been recorded in the Grampians (Weste et al. 2002). It is far too early to judge if the regeneration observed in Victorian dry sclerophyll forest can be sustained and fauna habitats return to a pre-disease state. The conditions for *Phytophthora* dieback may become favourable once more – all three variables required for a disease outbreak are still present and it may be a matter of time before the disease appears in the regenerating vegetation. Indeed, this is the scenario in Western Australian dry sclerophyll forests where some prolific seed producers, such as *Dryandra sessilis*, regenerated after a mass collapse from *Phytophthora* dieback had occurred (Rockel et al. 1982). These regenerating stands of *D. sessilis* then succumbed to the disease once more when conditions favourable for a disease outbreak recurred (Wills 1993). The environmental factors operating at the Victorian sites may have been unfavourable for the expression of the disease after the original infestation had occurred. If environmental conditions similar to those of the original epidemic return, then larger-scale *Phytophthora* dieback events may recur as a cycle of disease outbreaks (Walchhuetter 2001, Weste et al. 2002).



Figure 3. Mass collapse of jarrah *Eucalyptus marginata* forest from *Phytophthora cinnamomi* dieback (Photo. I. Colquhoun).



Figure 4. Death of Austral Grass-Tree *Xanthorrhoea australis* from *Phytophthora cinnamomi* infection (Photo. R. Daniel).

Effects of *Phytophthora* dieback on forest fauna

Scope of the problem

Although there has been a substantial number of studies on the effects of *P. cinnamomi* on vegetation there has been little work investigating the impact of *Phytophthora* dieback on faunal populations and communities, particularly in Australia's forested communities. This is of concern in the management of forest fauna because it has been recognised that *Phytophthora* dieback has significant impacts on vegetation characteristics (CALM 2000), which suggest 'flow-on' effects to other biota. Furthermore, the distribution of *P. cinnamomi* shown in Figure 1 overlaps substantially with areas having a high concentration of threatened marsupials (see distribution maps of threatened fauna in Maxwell *et al.* 1996), so impacts in areas critical for conservation are possible, including forests. Despite the paucity of experimental studies in forests, a few have been undertaken in heathland and woodland communities, which suggest impacts on fauna may occur in forest ecosystems. Indeed, Abbott and Christensen (1994) provide a rationale where the mosaic of forest, heathland and swamp communities should be included in the management of forests as a whole. Given this rationale we shall briefly review published studies outlining the impact of the disease on the fauna in all vegetation communities affected by *Phytophthora* dieback.

The alterations to vegetation communities caused by *Phytophthora* dieback are likely to have effects on the endemic fauna through alterations to suitable habitat, for example, by changes to protective cover, food resources and nesting sites (Wilson *et al.* 1994, Christensen 1997). Indeed, vegetation structure and its complexity have been identified as significant variables affecting the distribution and abundance of a number of mammals in south-eastern Australia (Catling and Burt 1995, Catling *et al.* 1998, Catling and Coops 1999). Defoliation or death of susceptible tree species could affect shelter and food for arboreal marsupials and nesting birds (Davison and Shearer 1989, Garnett 1992, Wardell-Johnson and Christensen 1992, Cale and Burbidge 1993, Young 1994, Maxwell *et al.* 1996), while simplifying the understorey may affect seed, nectar and pollen resources available to vertebrate and invertebrate fauna (Wilson *et al.* 1997). In a review of disturbance factors affecting forest fauna, conducted as part of the Regional Forest Agreement process in Western Australia, it was suggested that vertebrate species such as the western spinebill *Acanthorhynchus superciliosus* and the honey possum *Tarsipes rostratus*, reliant on the production of nectar and pollen from plants in the family Proteaceae, were likely to be most vulnerable to habitat modification caused by *Phytophthora* dieback (Christensen 1997). Some species, such as the pseudomyine rodents, have been shown to be dependent on a floristically diverse understorey (Cockburn *et al.* 1981, Fox and Fox 1984) and may be particularly susceptible to the simplification of forest understoreys resulting from *Phytophthora* dieback (Wilson *et al.* 1997).

Mammals

A study of small mammal communities in heathy woodland and heathlands of the Eastern Otways, Victoria found the percentage of vegetation modified by *Phytophthora* dieback to be a significant variable in explaining small mammal diversity and density of small mammal populations (Wilson 1990, Wilson *et al.* 1990). Further studies conducted in heathy woodland vegetation in the Brisbane Ranges National Park, Victoria, found the abundance of agile antechinus *Antechinus agilis* to be lower in *P. cinnamomi* affected areas, and the species avoided diseased areas (Newell and Wilson 1993, Newell 1994). Such changes were related to vegetation structure, in particular significantly lower vegetation volume between 0 and 60 cm above the ground in diseased areas. The change in structure in diseased areas was predominantly related to the loss of the highly susceptible grasstree *X. australis* (Figure 4). Studies in coastal heathland at Anglesea, in southern Victoria, found that small mammal species, such as the swamp rat *Rattus lutreolus*, bush rat *R. fuscipes*, agile antechinus and the white-footed dunnart *Sminthopsis leucopus*, were less abundant in diseased heathland than in healthy areas, or utilised them less frequently (Laidlaw 1997, Wilson and Laidlaw 2001).

An analysis of mammals that occur in Victoria found that for 22 species, more than 20% of their range occurs in *P. cinnamomi* affected areas (Laidlaw 1997, Wilson and Laidlaw 2001). Five rare or endangered species in Victoria, the smoky mouse *Pseudomys fumeus*, the heath mouse *P. shortridgei*, the New Holland mouse *P. novaehollandiae*, the long-footed potoroo *Potorous longipes* and the brush-tailed rock-wallaby *Petrogale penicillata* have greater than 20% of their distribution in areas susceptible to *Phytophthora* dieback. In Western Australia, the conservation status of Gilbert's potoroo *Potorous gilbertii*, currently listed as Critically Endangered, and the honey possum were speculatively connected to *Phytophthora* dieback in recent reviews (Calver and Dell 1998a). Furthermore, McComb (1994) demonstrated that the incidence of tree hollows was reduced in forest in southwestern Australia affected by *Phytophthora* dieback, so that shelter for arboreal mammals might also be affected.

In New South Wales, the state Scientific Committee, established under the *Threatened Species Conservation Act 1995*, determined that *Phytophthora* dieback is a threatening process that directly affects the conservation of endemic populations of the southern brown bandicoot *Isodon obesulus* and the smoky mouse. The long-footed potoroo is also considered to be at risk from *Phytophthora* impact due to the proximity of recent infections to suitable habitat for this marsupial (see <http://www.nationalparks.nsw.gov.au/npws.nsf/Content/Key+threatening+processes>).

The density and distribution of the honey possum is governed by the availability of nectar and pollen for food, predominantly from proteaceous plants (Garavanta *et al.* 2000, Wooller *et al.* 2000). Access to sufficient food resources is a critical factor in determining successful reproduction in this species (Wooller *et al.* 1999), so the honey possum is very likely to suffer declines in distribution and abundance if *Phytophthora* dieback reduces the availability of its proteaceous food plants.

Despite a lack of information on the effect of *Phytophthora* dieback on the mammals inhabiting forest communities, the studies reviewed indicate that significant effects are likely. The structural and floristic changes measured in the heathland and heathy woodlands also occur in forests, particularly in the understorey, and this may have a detrimental effect on some mammal species. Thirty-two marsupials with conservation status classified as Lower Risk (near threatened and conservation dependent), Vulnerable, Endangered and Critically Endangered (Maxwell et al. 1996) have a significant portion of their range in areas that are susceptible to *Phytophthora* dieback (Table 1).

Birds

There is some evidence that there are differences in the avifauna present in *P. cinnamomi* diseased and non-infested forests. Some *Phytophthora* dieback affected jarrah sites do show lower bird species richness and abundance. However, the patterns of declines between sites were not consistent (Nichols and Watkins 1984). Cale and Burbidge (1993) speculated that *Phytophthora*-induced vegetation change could be detrimental to the ground parrot *Pezoponus wallicus flaviventris*, western bristlebird *Dasyornis longirostris* and the western whipbird *Psophodes nigrogularis nigrogularis*. Recher et al. (2002) noted the importance of litter cover, indirectly

affected by *Phytophthora* dieback, for providing foraging sites for western yellow robins *Eopsaltria griseogularis*.

Perhaps the most definitive experiments relating tree-health to bird communities involves experiments which have removed bell miners *Manorina melanophrys* and measured the response of other insectivorous bird species and the health of the trees. Loyn et al. (1983) found that the removal of bell miners resulted in an increase in the epicormic foliage of messmate *Eucalyptus obliqua* and mountain grey gum *E. cytellocarpa* and a decline in the abundance of leaf-damaging psyllids (Psylloidea, Hemiptera), on both tree species. However, in an elegant experiment involving the removal of bell miners from narrow-leaf peppermint *E. radiata* forest near Healesville in south-eastern Victoria, tree health did not improve despite a decrease in leaf-damaging psyllid load (Clarke and Schedvin 1999). A closer examination of the trees indicated that *P. cinnamomi* was the major variable affecting tree health at these sites. In addition, bell miners eventually abandoned control sites where there was a marked decline in the health of the peppermint trees (Clarke and Schedvin 1999). This work highlighted the importance of *P. cinnamomi* as a controlling variable for tree health where susceptible species were subjected to defoliation from a number of factors.

Table 1. Threatened marsupial taxa with significant portions of their range covering areas where *Phytophthora cinnamomi* may occur. CE: Critically endangered, E: Endangered, V: Vulnerable, LR.cd: Lower risk – conservation dependent, LR.nt: Lower Risk – near threatened (after Maxwell et al. 1996).

Species	Common name	Species	Common name
<i>Potorus gilbertii</i> (CE)	Gilbert's Potoroo	<i>Dasyurus viverrinus</i> (LR.nt)	Eastern Quoll
<i>Parantechinus apicalis</i> (E)	Dibbler	<i>Phascogale tapoatafa tapoatafa</i> (LR.nt)	Brush-tailed Phascogale
<i>Sminthopsis aitkeni</i> (E)	Kangaroo Island Dunnart	<i>Isoodon obesulus fusciventer</i> (LR.nt)	Quenda
<i>Potorous longipes</i> (E)	Long-footed Potoroo	<i>I. obesulus obesulus</i> (LR.nt)	Southern Brown Bandicoot
<i>Gymnobelideus leadbeateri</i> (E)	Leadbeater's Possum	<i>Phascolarctos cinereus</i> (LR.nt)	Koala
<i>Dasyurus geoffroii</i> (V)	Chuditch	<i>Bettongia gaimardi cuniculus</i> (LR.nt)	Tasmanian Bettong
<i>Dasyurus maculatus maculatus</i> (V)	Spotted-tailed Quoll	<i>Macropus eugenii decres</i> (LR.nt)	Tammar Wallaby (Kangaroo Island)
<i>Myrmecobius fasciatus</i> (V)	Numbat	<i>M. eugenii derbianus</i> (LR.nt)	Tammar Wallaby (WA)
<i>Perameles gunnii gunnii</i> (V)	Eastern Barred Bandicoot – (Tas)	<i>M. fuliginosus fuliginosus</i> (LR.nt)	Kangaroo Island Western Grey Kangaroo
<i>Potorous tridactylus tridactylus</i> (V)	Long-nosed Potoroo	<i>M. giganteus tasmaniensis</i> (LR.nt)	Eastern Grey Kangaroo (Tas)
<i>Petrogale penicillata</i> (V)	Brush-tailed Rock-wallaby	<i>M. irma</i> (LR.nt)	Western Brush Wallaby
<i>Setonix brachyurus</i> (V)	Quokka	<i>M. parama</i> (LR.nt)	Parma Wallaby
<i>Pseudocheirus occidentalis</i> (V)	Western Ringtail	<i>Trichosurus vulpecula hypoleucus</i> (LR.nt)	Common Brushtail Possum (SW Mainland)
<i>Bettongia penicillata ogilbyi</i> (LR.cd)	Woylie	<i>Petaurus australis australis</i> (LR.nt)	Yellow-bellied Glider
<i>Tachyglossus aculeatus multiaculeatus</i> (LR.nt)	Kangaroo Island Echidna	<i>P. norfolcensis</i> (LR.nt)	Squirrel Glider
<i>Antechinus minimus maritimus</i> (LR.nt)	Swamp Antechinus		
<i>Antechinus swainsonii insulanus</i> (LR.nt)	Dusky Antechinus		

The structural vegetation changes caused by *Phytophthora* infection, particularly in relation to tree hollows and nectar resources in Western Australia, are likely to have an impact on avifauna. Twenty-three Near Threatened, nine

Vulnerable, ten Endangered and six Critically Endangered bird taxa have significant portions of their distribution that cover ecosystems that are susceptible to *Phytophthora* dieback (Garnett and Crowley 2000, Table 2).

Table 2. Threatened bird taxa with significant portions of their range covering areas where *Phytophthora cinnamomi* may occur. CE: Critically endangered, E: Endangered, V: Vulnerable, nt: Near threatened (after Garnett and Crowley 2000).

Species	Common name	Species	Common name
<i>Aquila quax fleayi</i> (E)	Wedge-tailed Eagle (Tas.)	<i>Dasyornis brachypterus monoides</i> (CE)	Eastern Bristlebird (Eastern)
<i>Calyptorhynchus banksii naso</i> (nt)	Red-tailed Black Cockatoo (south-west)	<i>D. b. brachypterus</i> (E)	Eastern Bristlebird (Southern)
<i>C. lathamii lathamii</i> (nt)	Glossy Black-Cockatoo (eastern)	<i>D. longirostris</i> (V)	Western Bristlebird
<i>C. lathamii halmaturinus</i> (E)	Glossy Black-Cockatoo (Kangaroo Island)	<i>D. broadbenti caryochrous</i> (V)	Rufous Bristlebird (Otways)
<i>C. latirostris</i> (E)	Camaby's Black-Cockatoo	<i>Hylacola pyrrhopygia parkeri</i> (E)	Chestnut-rumped Heathwren (Mt Lofty Ranges) ^A
<i>C. baudinii</i> (nt)	Baudin's Black-Cockatoo	<i>H. p. pedleri</i> (V)	Chestnut-rumped Heathwren (Flinders Ranges) ^A
<i>Platycercus eximius diemenensis</i> (nt)	Eastern Rosella (Tasmania)	<i>H. cauta whitlocki</i> (nt)	Shy Heathwren (Western) ^A
<i>P. icterotis xanthogenys</i> (nt)	Western Rosella (Wheatbelt) ^A	<i>Calamanthus campestris montanellus</i> (nt)	Rufous Fieldwren (Western Wheatbelt) ^A
<i>Lathamus discolor</i> (E)	Swift Parrot	<i>Chthonicola sagittata</i> (nt)	Speckled Warbler
<i>Neophema chrysogaster</i> (CE)	Orange-bellied Parrot	<i>Xanthomyza Phrygia</i> (E)	Regent Honeyeater
<i>N. pulchella</i> (nt)	Turquoise Parrot ^A	<i>Lichenostomus melanops cassidix</i> (CE)	Helmeted Honeyeater
<i>Pezoporus wallicus wallicus</i> (V)	Ground Parrot (Eastern)	<i>Melanodryas cuclata cuclata</i> (nt)	Hooded Robin (South-eastern)
<i>P. w. flaviventris</i> (E)	Ground Parrot (Western)	<i>Pomatostomidae temporalis temporalis</i> (nt)	Grey-crowned Babbler (Eastern)
<i>Ninox connivens connivens</i> (nt)	Barking Owl (Southern) ^A	<i>Pomatostomus superciliosus ashbyi</i> (nt)	White-browed Babbler (Western Wheatbelt) ^A
<i>Tyto novaehollandiae novaehollandiae</i> (nt)	Masked Owl (Southern Australia)	<i>Psophodes nigrogularis lashmari</i> (nt)	Western Whipbird (Kangaroo Island)
<i>T. n. castanops</i> (E)	Masked Owl (Tasmania)	<i>P. n. oberon</i> (nt)	Western Whipbird (Western Mallee) ^A
<i>Podargus ocellatus plumiferus</i> (nt)	Plumed Frogmouth	<i>P. n. nigrogularis</i> (V)	Western Whipbird (Western Heath)
<i>Aegotheles cristatus tasmanicus</i> (V)	Australian Owlet-nightjar (Tasmania)	<i>Cinclosoma punctatum anachoreta</i> (CE)	Spotted Quail-thrush (Mt Lofty Ranges) ^A
<i>Menura alberti</i> (V)	Albert's Lyrebird	<i>Falcunculus frontatus leucogaster</i> (nt)	Crested Shrike-tit (Western)
<i>Atrichornis rufescens rufescens</i> (V)	Rufous Scrub-bird (northern).	<i>Pachycephala olivacea Hesperus</i> (nt)	Olive Whistler (Glenelg) ^A
<i>A. r. ferrieri</i> (nt)	Rufous Scrub-bird (Southern)	<i>Strepera graculina ashbyi</i> (CE)	Pied Currawong (Western Victoria)
<i>A. damosus</i> (V)	Noisey-scrub Bird	<i>Corvus tasmanicus boreus</i> (nt)	Forest Raven (New England)
<i>Climacteris picumnus victoriae</i> (nt)	Brown treecreeper (South-eastern)	<i>Stagonopleura guttata</i> (nt)	Diamond Firetail
<i>Stipiturus malachurus intermedius</i> (CE)	Southern Emu-wren (Fleurieu Peninsula) ^A	<i>Zoothera lunulata halmaturina</i> (nt)	Bassian Thrush (South Australian)
<i>Pardalotus quadragintus</i> (E)	Forty-spotted Pardalote		

^A Lower rainfall areas but have a predominance of flora that may be susceptible to *P. cinnamomi* in water-shedding or water-ponding areas.

Reptiles and Frogs

Few studies have investigated the effects of *Phytophthora* dieback on reptiles and frogs. In Western Australia, *P. cinnamomi*-affected jarrah forests appear to support lower numbers of reptiles and frogs species than healthy forests (Nichols and Bamford 1985). Some species, however, were more abundant in diseased forest, perhaps reflecting the increased insolation (sunlight) on elevated surfaces (e.g. logs) that these species utilize for basking and foraging (Nichols and Bamford 1985, Wilson and Knowles 1988). The effects of *P. cinnamomi* on reptiles and frogs inhabiting forest ecosystems are necessarily speculative because of the lack of good empirical data. Nevertheless, the structural and floristic changes documented render such impacts plausible. Measurements of the impacts of *Phytophthora* dieback in Western Australia clearly show the rapid progression of the disease down-slope toward stream-zones (McDougall 1996). This has serious effects on the fringing vegetation with field-resistant species, such as bullich *E. megacarpa*, beginning to replace sensitive tree species, and sensitive understorey species disappearing from riparian zones. The effects of these vegetation changes on the riparian fauna are not known.

Invertebrates

Two studies have compared invertebrate communities in healthy and infected jarrah forests in Western Australia (Nichols and Burrows 1985; Postle *et al.* 1986). Diseased forests displayed lower litter fall and litter biomass together with lower numbers of soil and litter invertebrates, and species richness.

Many invertebrates are restricted in their host plants (Majer *et al.* 2000) and, as a result, declines in the abundance and distribution of these plants because of *Phytophthora* dieback will inevitably result in declines of the invertebrates. However, assessment of changes in invertebrate communities in response to *Phytophthora* dieback is fraught with logistic difficulties because of the intensity of sampling required and the taxonomic difficulties in identifying specimens to species-level. For example, in eastern Australia, work by Newell (1997) in the Brisbane Ranges was frustrated by the sampling and taxonomic problems common in invertebrate ecology. Seasonal pitfall trapping of ground-dwelling invertebrates did not show major *Phytophthora* dieback effects with respect to abundance of invertebrates classified to the ordinal level (Newell 1997). The contention surrounding studies of the impact of fire on invertebrate communities reflect these difficulties (e.g., Majer and Abbott 1989, Van Heurck and Abbott 2003) and similar problems are inevitable in discussions of the impact of *Phytophthora* dieback. Nevertheless, limited data are available and reasonable inferences can be made given the known roles of invertebrates in some communities.

The contribution of invertebrates to biodiversity (Recher 1996, Recher *et al.* 1996, Ponder and Lunney 1999), their value in sustaining a wide range of ecological processes (Samways 1995) and their role as food for many vertebrates (Wykes 1983; Scarff *et al.* 1998) means that an assessment of *Phytophthora* dieback on invertebrate communities is essential. Most of the available data are for Western Australia where two studies compared invertebrate

communities in healthy and infected jarrah forests (Nichols and Burrows 1985; Postle *et al.* 1986). Diseased forests displayed lower litter fall and litter biomass together with lower numbers and species richness of soil and litter invertebrates. Although shrub and canopy invertebrates were not studied, the reduced litter fall suggests significant structural changes caused by *Phytophthora* dieback, which would impact on invertebrate communities. A critical implication of this work is a reduction in the food biomass for insectivorous birds and mammals. Wykes (1983) noted that the availability of invertebrates for insectivorous birds was restricted in winter in jarrah forest; so further reductions could pose problems. A similar situation may occur in karri *E. diversicolor* forest, where Calver and Wooller (1981) found higher proportions of small ants in the diets of insectivorous birds in winter, when overall invertebrate availability is likely to be depressed. Scarff *et al.* (1998) also suggested that availability of insect prey was limiting for brush-tailed phascogales *Phascogale tapoatafa* in jarrah forest. Furthermore, southwestern Australia includes several relict invertebrate species with restricted distributions that could suffer from the litter-fall changes caused by *Phytophthora* dieback (Main 1996a, b).

In summary, the limited data indicate that significant changes to invertebrate communities in response to *Phytophthora* dieback are highly likely but logistical issues may frustrate timely acquisition of definitive evidence. Given the potential serious impacts that could occur we believe that it is prudent to regard *Phytophthora* dieback as a significant threat to invertebrate communities until contrary evidence is available.

Effects of *Phytophthora* dieback on ecosystem function

There are several potential impacts to the ecology of forest ecosystems if forest fauna communities are altered by *Phytophthora* dieback. The loss of floristic and structural diversity, and consequential effects on faunal diversity are considered a major threat to functioning of ecosystems. However, there has been little work to describe or quantify the ecosystem breakdown. We still have little understanding of the functional role that these fauna have in maintaining healthy, robust ecosystems. This information is essential if we are to adopt a 'whole ecosystem' approach in the management and rehabilitation of the landscape, particularly in regions susceptible to *Phytophthora* dieback.

Important areas of ecosystem function that may be impacted include fungal mycophagy, soil development or biopedurbation (Whitford and Kay 1999) and pollination. Hypogeous and epigeous fungi, which form mycorrhizal associations on adjacent plants, play a vital role in the supply of nutrients to plants (see reviews by Gehring and Whitham 1994, Wilkinson 2001). However, there is little information on the impact of *Phytophthora* dieback on the production of these fungal fruiting bodies or the consequences for plant nutrition. It is now clear that a suite of digging mammal species forages for the fruiting bodies of these underground fungi, and in some cases up to 90% of their diet is composed of the fungi (Claridge

and May 1994, Johnson 1994, Claridge and Barry 2000). The effect of *Phytophthora* dieback on the production of ectomycorrhizal fungi and mycophagy is not known.

Recent studies have shown that burrowing (Kinlaw 1999) and digging for hypogeous fungi, invertebrates and underground plant parts by vertebrates has a significant effect on the behaviour of soils (Whitford and Kay 1999). For example, in southwestern Australia, the woylie, or brush-tailed bettong, *Bettongia penicillata* foraging results in 0.5-1.6 new diggings.m².year⁻¹ (Garkaklis *et al.* 2004) and these diggings have a significant effect on water infiltration, litter decomposition and soil nutrients (Garkaklis *et al.* 1998, 2000, 2003). Since this marsupial species is dependent on hypogeous fungi, any modification to this food resource through the potential impacts of *Phytophthora* dieback will affect its survivorship and may lead to development of homogenous soils due to the loss of substantial number of foraging digs.

Many nectar-producing plant species are also susceptible to *Phytophthora* dieback (Wills and Keighery 1994). The effects of this disease pose serious implications for vertebrates that utilise this resource, and also for plant species that may require vertebrates for outcross pollination. Nectar and pollen resources may be impacted by *Phytophthora* dieback, however no assessment of the effects of the disease has been measured. Through the production of nectar, plants can manipulate floral rewards to secure the optimal visitation (and possibly outcross pollination), by animals (Kearns and Inouye 1993, Saffer 1998). Effects of *P. cinnamomi* on this functional interaction have not been assessed. However, Wykes (1983) speculated that the lower availability of nectar in Western Australian forests relative to those in eastern Australia was a factor in the lower abundance and species diversity of nectarivores in Western Australia. If true, this suggests that there will be declines in numbers and distributions in nectarivorous birds in eastern Australia if *Phytophthora* dieback reduces the nectar resource and more serious restrictions on nectarivorous birds in Western Australia.

Management of forest ecosystems to control the spread of *P. cinnamomi*

Quarantine and hygiene measures

The spread of *P. cinnamomi* from infested to non-infested sites involves, predominantly, the movement of soil. Currently, quarantine and hygiene protocols vary between Australian states. However, all state forest and natural resource managers in Australia recognise that quarantine and hygiene measures should aim to eliminate the transfer of soil between sites.

Protocols for hygiene and quarantine within Victoria are developed through operational guides for those Parks and Reserves that have identified *Phytophthora* dieback as a management issue within their management plans (see State of the Parks; Park Profiles. Parks Victoria 2000), and generic management protocols are currently being developed (Cahill *et al.* 2002). However, general guidelines for the control of *P. cinnamomi* in parks are provided in Niewand *et al.* (1995). These operational guidelines for

the management of *P. cinnamomi* suggest that each park is broadly classified as potentially susceptible or not, on the basis of the presence or absence of susceptible plant communities. The guidelines also recommend hygiene procedures for operational and maintenance activities including work practice and management of equipment between, and within, infested and non-infested areas. Hygiene may also include the testing of raw materials to be imported into non-infested high-risk areas and proper wash-down of vehicles. The guidelines by Niewand *et al.* (1995) also detail protocols for the identification of infested areas within high-risk areas, containment measures within high-risk parks shown to be substantially infested, management planning and monitoring. The strategy to minimize the spread of *P. cinnamomi* in the Brisbane Ranges National Park and Steiglitz Historic Park (Peters 1995) has been used as a guide for the development of management plans for *P. cinnamomi* in other Victorian parks. Details of *P. cinnamomi* management for planning operations (road placement, movement of movement of gravel, etc.), grading operations, drainage, gravel sources, management of vehicle tracks and fire operations are also provided (Peters 1995).

Quarantine and hygiene measures in Western Australia have been implemented for over a decade. These measures are documented extensively in the Western Australian Department of Conservation and Land Management (CALM) publications entitled “*Phytophthora cinnamomi* and disease caused by it” (Volume 1: Management Guidelines) and Volume 2 “Detection, diagnosis and mapping” (CALM 2000). These management guidelines provide two separate strategies when dealing with ‘protectable’ and ‘infested/unprotectable’ areas (CALM 2000). The objective in non-infested protectable areas is to manage hygiene by planning, implementing and enforcing the rule for all human activities of being clean on entry to the area and having entered clean to avoid cross-contamination from infested to non-infested areas (CALM 2000). The hygiene measures available to land managers preparing *P. cinnamomi* management plans include temporary seasonal closure of roads and walk trails, signage, permanent closures, and the establishment of hygienic entry and clean-down points. A work system that separates infested and non-infested areas is applied to all forestry operations (CALM 2000).

In the management of infested and “unprotectable” areas, CALM has adopted management strategies that include the development of a priority management system, the application of phosphite (see below) and management guidelines and training programs. These strategies are covered in detail in CALM (1999) Volume 3 “Phosphite operations”, and Volume 4 “Training curriculum and syllabi” (CALM *in review*). Updates on all CALM *Phytophthora* management are available at http://www.naturebase.net/science/dcc_splash.html.

In Tasmania, management of *P. cinnamomi*, including quarantine and hygiene measures, are covered in the Tasmanian Parks and Wildlife Service (1993) *Phytophthora cinnamomi* Hygiene Manual. The protocols within this document are currently under review to conform to the ‘Threat Abatement Plan for the root rot fungus *Phytophthora cinnamomi*’ (Environment Australia 2001). Currently parks within Tasmania are

managed for *P. cinnamomi* on a district-by-district basis, with management protocols to control *P. cinnamomi* implemented prior to maintenance or development activities taking place (Cahill *et al.* 2002). Updates with regard to *Phytophthora* management issues in Tasmania are available via the website <http://www.del.mtas.gov.au/intertext.nsf/WebPages/EGIL-53Y38R?open>.

Guidelines for *Phytophthora* management in South Australia are available at <http://www.environment.sa.gov.au/biodiversity/plantsand.html>. Similar to those in Western Australia and Tasmania, these management guidelines provide advice on the biology, impact and spread of *Phytophthora* disease. They detail the hygiene requirements to limit the spread and the formation of whole new sites of infection. Background to *Phytophthora* infection and management on Kangaroo Island is found at http://www.denr.sa.gov.au/biodiversity/pdfs/pc_on_ki.pdf. New South Wales is currently developing management guidelines and has recently listed *Phytophthora cinnamomi* as a Key Threatening Process to biodiversity in that state (www.nationalparks.nsw.gov.au/npws.nsf/Content/Key+threatening+processes).

At the time of publication all Australian states that had identified *Phytophthora* dieback as a Key Threatening Process were implementing the National Threat Abatement Plan for the management of the disease. Management plans are constantly being updated, and scientists working in areas that may be affected by *Phytophthora* are required to adopt correct procedures when entering and leaving field sites.

The use of phosphite to control *Phytophthora* dieback

Until recently, the strategies outlined above were all that were available to manage or reduce the spread of *P. cinnamomi*. However, in the last 5-10 years the fungicide phosphite (phosphonate) has been successfully used to reduce the impact and spread of *P. cinnamomi* in heathland, banksia woodland and jarrah forest communities (Komerek *et al.* 1997, Shearer and Fairman 1997a, Aberton *et al.* 1999, Ali *et al.* 1999, Hardy 2000, Hardy *et al.* 2001). The use of phosphite is regulated within each State by natural resource management departments, under Commonwealth permits granted by the Australian Pesticide and Veterinary Medicine Authority (www.apvma.gov.au).

Phosphite is being applied to trees as a trunk injection or to whole communities as foliar mist applications from aircraft, backpack spray units or from modified fire fighting equipment. Phosphite, the anionic form of phosphonic acid (HPO_3)⁻², controls many plant diseases caused by *Phytophthora*, even at concentrations *in planta* that only partially inhibit pathogen growth *in vitro* (Guest and Bombeix 1990, Guest and Grant 1991, Wilkinson *et al.* 2001a). The mode of action of phosphite involves inducing strong and rapid defence responses in plants infected by *P. cinnamomi*. Phosphite is a systemic fungicide that is translocated in both the xylem and the phloem (Ouimette and Coffey 1989) in association with photoassimilates in a source-sink relationship

(Saindrenan *et al.* 1988, Ouimette and Coffey 1990, Guest and Grant 1991). Phosphite sprayed as a foliar application can contain the spread of *P. cinnamomi* in plants for between six months to more than two years, depending on the method of application, concentration and season of application, plant species, and environmental factors (Tynan *et al.* 2001). In contrast, injecting trees with phosphite can contain *P. cinnamomi* for at least four years in *Banksia* species (Shearer and Fairman 1997b).

Phosphite is generally considered to have low mammalian toxicity and phytotoxicity (Guest and Grant 1991). Nevertheless, foliar phytotoxicity has been reported in native plant communities (Komerek *et al.* 1997, Aberton *et al.* 1999, Fairbanks *et al.* 2000, Pilbeam *et al.* 2000, Barrett 2001, Hardy *et al.* 2001, Tynan *et al.* 2001). As well as causing severe necrosis of foliage and plant death, phytotoxicity can be expressed as reduced flowering, pollen viability and seed germination and as plant growth malformations (stunting, chlorosis, and leaf rosetting). Accordingly, there is a fine balance between the rates of phosphite applied, phytotoxicity symptoms and the control of *P. cinnamomi*. Generally, as the rates of phosphite applied increase so do the concentrations of phosphite in plant tissue.

Fairbanks *et al.* (2001) found that phosphite applied at recommended rates reduced the reproductive fitness through either reduced pollen fertility or seed germination of some annual and perennial understory species from the jarrah forest. This could occur whether plants were sprayed at anthesis or during the vegetative stage. These effects could last up to 60 weeks in some species. Consequently, it is likely that these detrimental influences on reproductive fitness could impact on invertebrate and vertebrate fauna such as nectarivorous feeders/pollinators. However, definitive studies are required to associate plant reproductive loss with changes in fauna guilds.

It is important to note that phosphite often does not kill the pathogen in the host tissue, but rather contains its rate of spread (Ali *et al.* 1999, Pilbeam *et al.* 2000, Hardy *et al.* 2001, Wilkinson *et al.* 2001c). In addition, *P. cinnamomi* is able to produce sporangia and release zoospores from contained lesions in plants if moisture and temperature conditions are suitable. Therefore, the chemical is able to contain the pathogen in host plants but does not necessarily stop the spread of the pathogen to other plants (Wilkinson *et al.* 2001b).

Lastly, phosphite does not appear to adversely influence ectomycorrhizal fungi (Howard *et al.* 2000, Barrett 2001). As indicated above, many native animals are mycophagous and consequently it is vital to ascertain the impact of *P. cinnamomi* control methods, such as phosphite application, on beneficial mycoflora and the fauna relying on them.

In summary, phosphite is the only management tool available to contain *P. cinnamomi* in susceptible plant communities, especially those that are 'critically endangered' as frequently no populations or individuals are known to occur in non-infested vegetation. Without phosphite these plant species would disappear (and possibly the associated fauna) permanently in the natural environment. However, there are possible risks associated with continued phosphite use, such as losses in plant reproductive capacity in some species,

and potential adverse effects on beneficial fungi and bacteria (e.g. *Rhizobium* species) and in turn fauna that rely on these as a food source. A balanced approach needs to be adopted when using phosphite for the management of *P. cinnamomi* in natural ecosystems. It must be used in an integrated manner with other hygiene and quarantine control strategies. It is also necessary to take into account the beneficial and detrimental effects of phosphite, and the possible loss of plant and animal species if the fungicide is not used.

Auditing the process

All states have produced, or are currently developing, detailed management systems aimed at preventing the spread of *P. cinnamomi* in accordance with the National Threat Abatement Plan. However, there have only been limited studies auditing the effectiveness of the management systems. In Western Australia, Alcoa World Alumina is responsible for a number of bauxite mines in jarrah forests that are infested with *P. cinnamomi*. The mining operations involve drill rig exploration of approximately 2500 ha of forest per year, clearing and rehabilitation of 550 ha of forest per year and extraction of 3 million tonnes of bauxite per year (Colquhoun and Hardy 2000). *Phytophthora cinnamomi* management within these operations is based on the environmental management practices developed by CALM. As part of environmental audits, Alcoa conducted studies to determine the degree of *P. cinnamomi* spread due to their mining and rehabilitation operations. Specific questions, aimed to assess their *Phytophthora* management protocols, were “what was the rate of spread of *P. cinnamomi* from infested to non-infested areas within the bauxite mining operation?” and “what is the spread of *P. cinnamomi* to non-infested mine-site rehabilitation?” It was predicted that mining would result in a *P. cinnamomi* spread of approximately 1 to 4 ha for every 1 ha mined (Anon. 1978). Audits indicate that mining is directly responsible for a rate of spread of 0.003 ha of new *P. cinnamomi* infestation per ha of forest cleared for mining (Colquhoun and Hardy 2000). Of the 29 rehabilitated, non-infested bauxite pits, four were shown to have *P. cinnamomi* after rehabilitation (Colquhoun and Hardy 2000). The rate of spread to new sites of infection caused by bauxite mining is significantly lower than predicted rates from the environmental impact assessments conducted in the 1970s. The consequences are likely to be limited considering the rates of autonomous spread that currently occur, and suggests that the *Phytophthora* EMS used by Alcoa was working effectively.

However, this audit does indicate that human mediated spread of the disease does occur, and any activity carried out within forest ecosystems, even those with a good EMS in-place, can potentially spread the disease.

Similar auditing processes need to be implemented by all levels of government, industry, and university and research organisations operating within environments that are susceptible to the impact of *P. cinnamomi*. It would be reasonable to expect an audit of a *Phytophthora* EMS to be conducted every five years.

Precaution in the management of *P. cinnamomi* in forest ecosystems

Two messages are clear in the review of the effects of *P. cinnamomi* in forest ecosystems. Firstly, there is very little information on the impacts of this disease on forest fauna. However, an examination of the potential impacts suggests that there is a high risk to many species. Secondly, with a loss of a number of key fauna species, there is potentially a devastating effect on the function of forest ecosystems because of the effects of this disease. We are, nevertheless, better informed on how the pathogen is spread and on a range of measures such as hygienic logging (Underwood and Murch 1984) and phosphite spraying for containing outbreaks (Hardy *et al.* 2001). The combination of high ignorance plus high risk suggests that the application of the precautionary principle to the management of forests for *Phytophthora* dieback is mandatory. Precautionary measures might include, for example, stringent auditing of resource exploitation within susceptible areas with options for denial of access if procedures are not followed. Encouragement of research on critical questions of reduced risk and rehabilitation is also important. However, given our better understanding of transmission and control, this also involves active measures to prevent distribution of the pathogen and amelioration of its effects in important conservation areas. High standards of hygiene in all operations in susceptible areas, including logging, wildflower picking, mining, recreation or other uses, are fundamental to our capacity to control *Phytophthora* spread. Consideration should also be given to tree injection with phosphite or widespread vegetation spraying in critical conservation areas threatened with *Phytophthora* dieback. Within this overall precautionary and preventive framework, local authorities may provide very specific management guidelines for work in individual sites. Without them, *Phytophthora* dieback may significantly reduce forest fauna biodiversity.

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