Australian Government

Department of the Environment, Water, Heritage and the Arts

BACKGROUND DOCUMENT
for the
THREAT ABATEMENT PLAN

DISEASE IN NATURAL ECOSYSTEMS CAUSED BY *PHYTOPHTHORA CINNAMOMI*

1. Introduction

Australia's native plants and ecological communities are threatened by the soil-borne plant pathogen, *Phytophthora cinnamomi*, for which it is estimated there are over 2000 known plant host species (Shearer *et al*. 2004). *P. cinnamomi* is present in all states and territories of Australia and causes disease in an extremely diverse range of native, ornamental, forestry and horticultural plants. Described as a 'biological bulldozer', *P. cinnamomi* is destroying bushlands, heathlands, woodlands and forests, which are the habitat for rare and endangered flora and fauna species. 'Dieback caused by the introduced plant pathogen *Phytophthora cinnamomi*,' is listed as a key threatening process under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

This background document complements the statutory Threat Abatement Plan (TAP). The TAP outlines the actions proposed to abate the threat and addresses the statutory requirements of the document. The background document provides supporting information on matters such as the biology of the pathogen, its population dynamics, spread, diagnosis and impacts on biodiversity and management measures.

2. Background

2.1 The scope of the problem and history of the pathogen in Australia

Since the mid 1960s the exotic pathogen *P. cinnamomi* has been recognised as a serious pathogen in native ecosystems of Australia. Many root pathogens are known to cause disease in Australian flora species, but *P. cinnamomi* has had the greatest effect and poses the greatest threat. At least 32 species of *Phytophthora* occur in various parts of Australia; 14 of them have been recorded in the wild. Only three species (*P. cinnamomi*, *P. cryptogea* and *P. megasperma*) are currently known to cause significant damage in the wild; of these three, *P. cinnamomi* has resulted in the most extensive damage in a variety of habitats.

In the 1960s, *P. cinnamomi* was recognised as the cause of disease in *Eucalyptus marginata* (Jarrah) trees in Western Australia, in native forests in East Gippsland and in woodlands in the Brisbane Ranges in Victoria and in the Mount Lofty Ranges of South Australia.

P. cinnamomi is thought to have entered Australia with early settlers from Europe. Its patterns of disease and continuing invasion in much of southern Australia are characteristic of a pathogen newly introduced to an environment with susceptible flora. The species can reproduce sexually; however, for this to occur, two mating strains of the pathogen need to be present. The major evidence for the pathogen being non-endemic to Australia is:

1. The A2 strain of *P. cinnamomi* predominates in the Australian environment. If Australia was the centre of origin, a greater balance between the A1 and A2 strains would be expected; and
2. The high level of susceptibility of many Australian native species of plant which suggests that the plants did not evolve with the pathogen.

P. cinnamomi can parasitise a wide range of life stages across the taxonomic spectrum of higher plants, from primitive to highly evolved. It reacts with its hosts in a number of quite distinct ways, ranging from symptomless infection restricted to root tissue (for example, in some grasses) to complete invasion of root and stem tissue.

The consequences of infection of a susceptible ecological community will usually be the following:

- major disruption of community structure;
- extinction of populations of some flora species;
- a modification of the structure and composition of ecological communities;
- a massive reduction in primary productivity; and
- for dependent flora and fauna, habitat loss and degradation.

Further, the vegetation assemblages of resistant species that, with time, recolonise areas affected by this root pathogen are generally less productive, have more open overstorey and provide a modified habitat for dependent fauna and flora.

Warm wet soils, especially those with impeded drainage, favour sporulation and movement of *P. cinnamomi*, as well as its growth within plant tissue. A threat of epidemic exists where dominant species of particular plant communities are inherently susceptible to *P. cinnamomi* root-rot and those communities are in areas where environmental conditions favour the pathogen. Both these conditions are necessary if an interaction that is sufficiently destructive to be considered a threatening process is to develop.

Serious epidemics do not necessarily always follow the arrival of *P. cinnamomi* into uninfected plant communities. The extent of the *P. cinnamomi* infections are known to extend well beyond the areas which are potentially vulnerable or severely impacted on by the pathogen. The latter reflects the ability of this species to extend into environments where the effects are not immediately apparent – visual symptoms may take years to manifest after the initial infection.

2.2 The pathogen

P. cinnamomi is a microscopic soil-borne organism that attacks the roots and collar of susceptible plants. Depending upon environmental conditions and plant susceptibility, it can destroy vegetation communities and several plant species are at risk of extinction. In vegetation communities where most dominant plants are resistant to *P. cinnamomi*, it is characterised by the attrition of minor structural components, making disease detection difficult.

2.2.1 Taxonomy and life cycle

P. cinnamomi is often referred to as a fungus because of its filamentous growth and ability to cause plant disease, however, in taxonomic terms it is more closely related to algae than to fungi. It is sometimes called a water mould. Its taxonomic nomenclature is: Kingdom: Chromista, Phylum: Oomycota, Order: Personsporales, Family: Peronosporaceae, Genus: Phytophthora, Species: cinnamomi.

In the vegetative state, *P. cinnamomi* is mycelia, which consists of branching threadlike growth termed hyphae. Three types of spores are produced asexually by the mycelium: sporangia (pl.), zoospores and chlamydospores. A fourth type of spore, termed an oospore, is produced through sexual recombination of A1 and A2 mating strains of the pathogen.

Sporangia are the largest of all the spores and when mature range from 50 to 70 microns (or 0.05 to 0.07mm) in length. Under favourable conditions (free water and warm temperatures) *P. cinnamomi* readily produces sporangia.

Twenty to thirty zoospores, each less than 10 microns in diameter, are produced within each sporangium. Zoospores are short-lived (2-3 days) and have two flagella which enable them to swim for short distances (25-35mm) through water. At the end of the motile phase the flagella are lost and the zoospore encysts. While all spores have the capacity to directly infect plants, zoospores are thought to be the major infection propagule.

Chlamydospores are round, average 41 microns in diameter and are commonly thin-walled, although thick walled chlamydospores have been observed.

The sexually produced oospores are round and thick-walled, with a diameter in the range 19 to 54 microns and are considered highly resistant to degradation. Oospores are hard-coated and can withstand dry conditions in soil and in dead plant tissue for many years. Figure 1 shows the generalised life cycle of *P. cinnamomi*.

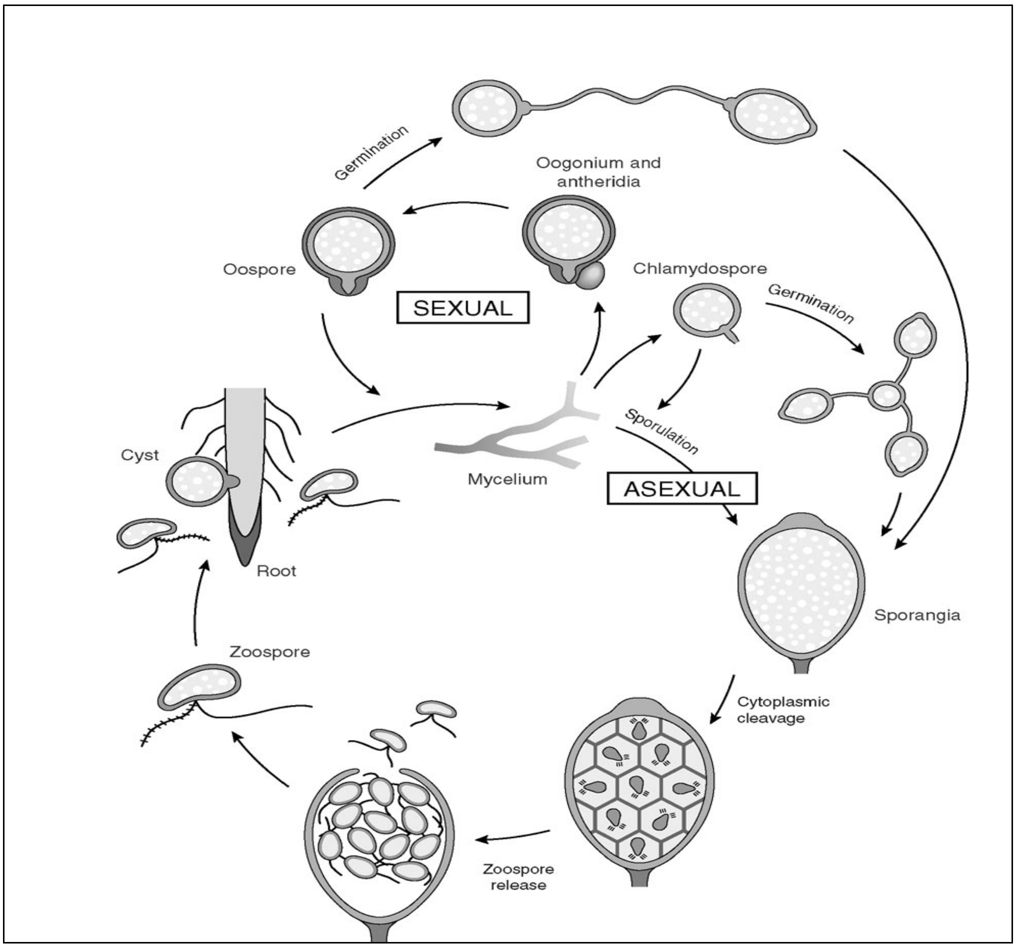

Figure 1 Generalised life cycle of *Phytophthora cinnamomi*
(Diagram courtesy Professor A. Hardham, Australian National University, Canberra, ACT).

When a zoospore encounters a root, the zoospore-cyst produces a germ-tube which chemically and physically breaches the protective surface of the root. Once inside the plant the germ-tube develops into mycelium and grows between, and into, the plant cells. The pathogen may exit the infected root at some point, starting new infections.

The plant becomes visibly diseased when infection results in the impairment of the plant's physiological and biochemical functions. Uptake of water is one of the functions affected, and this is why symptoms of *P. cinnamomi* infection have similarities, at least initially, with those of water-stress.

As the A2 mating strain predominates in the Australian environment, it is unlikely that sexual recombination, and thus oospore production, is happening to any large degree in the natural environment.

2.2.2 Pathogen survival

There are still significant gaps in our knowledge of the exact mechanisms of long-term pathogen survival. Of the asexual spores, chlamydospores are thought to be the most resistant to degradation and have, therefore, been implicated in the ability of *P. cinnamomi* to survive for long periods of time under unfavourable conditions. They potentially provide a source for re-infection of seedlings or long distance spread via soil movement.

2.2.3 Geographic, seasonal and temporal occurrence

The magnitude of the impact of *P. cinnamomi* is determined by a combination of factors including temperature, rainfall and soil types. The areas of native vegetation affected by *P. cinnamomi* exceed many hundreds of thousands of hectares in Western Australia, Victoria and Tasmania and tens of thousands of hectares in South Australia.

In Australia, *P. cinnamomi* does not usually cause severe impacts in undisturbed vegetation at sites that receive a mean annual rainfall of less than 600 millimetres, and are north of latitude 30º. Therefore the areas of Australia vulnerable to disease caused by *P. cinnamomi* can be separated into three broad climatic zones:

- areas of Mediterranean climate where annual rainfall exceeds 600 millimetres – in southern Western Australia and South Australia, and southern Victoria as far east as Wilsons Promontory;
- areas with moderate temperature variation, but erratic rainfall regimes - at low elevations of the coastal plain and foothills between Wilsons Promontory and south of the Victoria and NSW border; and
- winter-dominant rainfall areas - in maritime climates of coastal and sub-montane Tasmania.

While rainfall is a key factor influencing the distribution of disease caused by *P. cinnamomi*, there are many other variables that affect its ability to establish and persist (i.e. conducive temperature, geology and soil conditions co-occurring with susceptible plant hosts).

Although rainfall is clearly sufficient for the establishment of *P. cinnamomi* in the wet/dry, true and sub-tropical north of Australia, there are scant data to indicate that *P. cinnamomi* is a problem in undisturbed native ecosystems of northern Western Australia or the Northern Territory.

It is important to note that *P. cinnamomi* is known to occur in coastal Queensland. Although considered to be restricted to the wet coastal forests, many of these areas are designated as conservation reserves or state forests and are managed for recreation and conservation purposes. Visitor access, and therefore the risk of spread of *P. cinnamomi*, is also considered a problem that will need to be addressed. Additionally *P. cinnamomi* is a serious concern in the Wet Tropics World Heritage region of far northern Queensland, where the syndrome is complex, differs considerably from that in the temperate south of the continent and appears to be related to prior significant disturbance of sites (Gadek and Worboys 2003, cited in O'Gara *et al*. 2005a).

The present known distribution in South Australia includes several Conservation Parks, National Parks, Forest Reserves and many roadside reserves in the Mount Lofty Ranges, Fleurieu Peninsula and on Kangaroo Island.

Speculation still exists over the role of *P. cinnamomi* in damage to undisturbed montane regions above 800 metres such as those found in the southern Great Dividing Range, the Central Highlands of Tasmania, and the upland and highland rainforests of central and far north Queensland.

P. cinnamomi isolations and the broad climatic envelope of *P. cinnamomi* susceptibility in Australia are depicted in Figure 2.

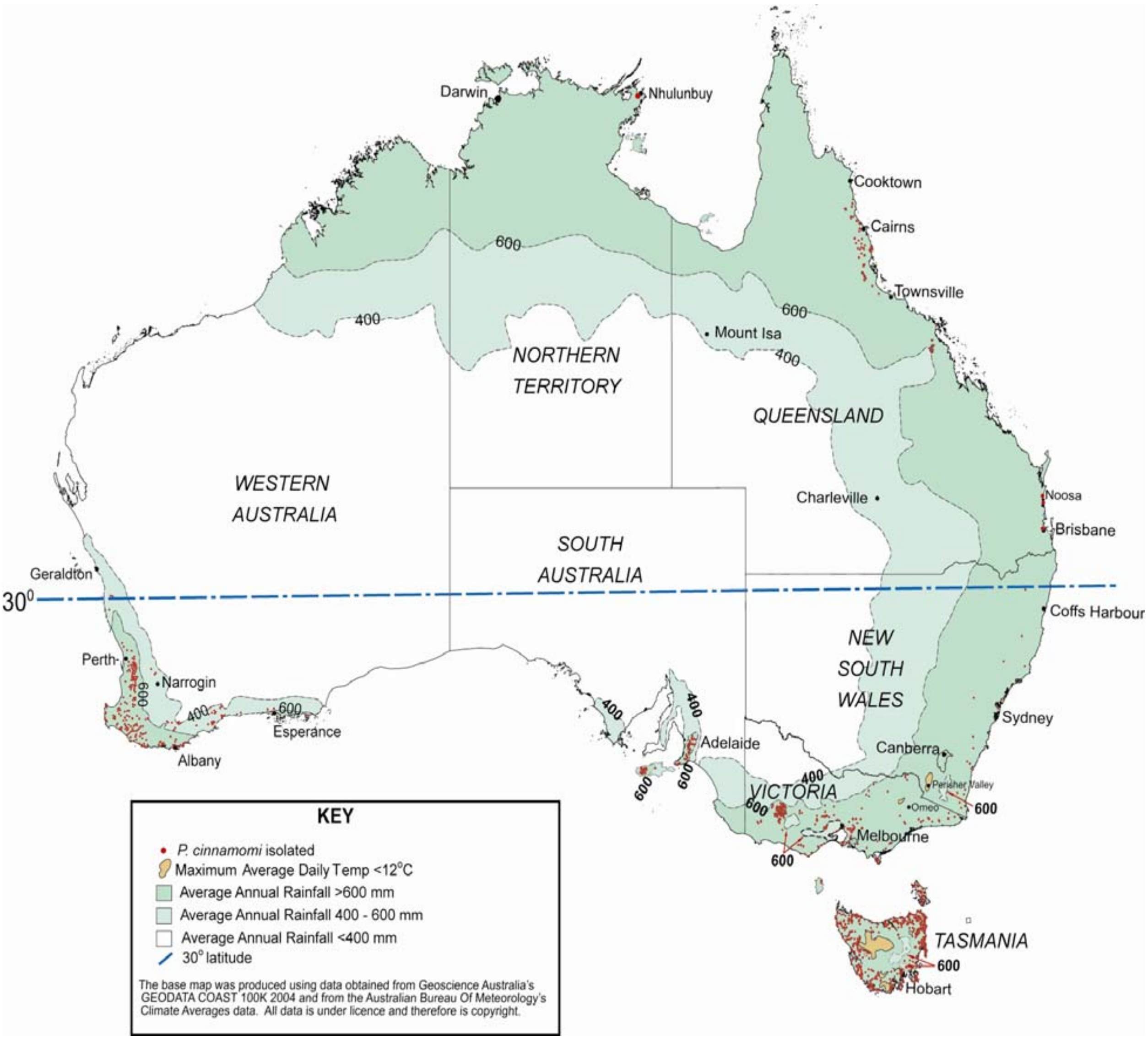

Figure 2 *P. cinnamomi* isolations and broad climatic envelope of *P. cinnamomi* susceptibility in Australia (O'Gara *et al.* 2005b)

On the basis of the above information some states in Australia have identified broad zones where biodiversity is susceptible to the threat of *P. cinnamomi*. The environmental criteria used to identify zones of vulnerability vary from state to state and are summarised below. The biomes that appear to be least threatened are the wet-dry tropics and the arid and semi-arid regions of the continent (Environment Australia 2001).

Western Australia

In Western Australia the vulnerable zone is defined by the Department of Conservation and Land Management (2003) as:

- the parts of the South West Land Division and areas adjoining it to the north-west and south-east that receive an average annual rainfall greater than 400 millimetres; and
- those areas receiving rainfall above 400 millimetres that do not have a calcareous substrate and in which susceptible native plants occur in conjunction with the environmental factors required for *P. cinnamomi* to establish and persist.

Tasmania

The vulnerable zones of Tasmania include areas where there is a coincidence of:

- susceptible native vegetation in open communities;

- non-calcareous soils;
- elevation below 700 metres; and
- average annual rainfall greater than 600 millimetres.

Victoria

Where susceptible native species or communities of plants occur, the following areas in Victoria are considered vulnerable to the threat of *P. cinnamomi*:

- all elevations in those sites of Mediterranean climate from the west of the state across to Wilsons Promontory where average annual rainfall exceeds 600 millimetres;
- the temperate rainfall regimes at low elevations of the coastal plain and the foot hills between Wilsons Promontory; and
- south of the border between Victoria and NSW.

South Australia

In South Australia, any site with susceptible vegetation growing on neutral to acid soils and an average annual rainfall greater than 400 millimetres is considered vulnerable to the threat of *P. cinnamomi* (Phytophthora Technical Group 2006).

Queensland

The average annual rainfall in the wet tropics of far north Queensland is rarely limiting for the establishment of *P. cinnamomi*. As with NSW and the ACT, the pathogen tends to have a cryptic nature and is frequently isolated from soils beneath symptom-free vegetation. However, 'dieback' attributed to *P. cinnamomi* in natural tropical ecosystems of far north Queensland is commonly associated with some prior disturbance (particularly roads) on sites that have the following characteristics:

- elevation above 750 metres;
- notophyll dominant vegetation; and
- acid-igneous geology (Worboys and Gadek 2004, cited in O'Gara *et al*. 2005a).

Although dieback related to *P. cinnamomi* is reported in upland subtropical rainforests of the Eungella Plateau, west of Mackay, and from the wallum heathlands of the south-east of the state, there has been no assessment of what criteria may be useful in categorising vulnerable vegetation.

New South Wales & Australian Capital Territory

Clear criteria for what constitutes an area's vulnerability to the threat of *P. cinnamomi* in NSW and ACT are not available for two major reasons:

- there is insufficient knowledge of the susceptible species in NSW & ACT; and
- there is variable susceptibility of plant species depending on climatic conditions, i.e. some species only appear susceptible during sustained periods of unusually high rainfall.

The NSW Department of Primary Industry advised that the pathogen is widespread and endemic throughout NSW urban and agricultural areas. The pathogen has been detected in many samples associated with diseased native plants in NSW National Parks from Jervis Bay to Barrington Tops.

Northern Territory

To date there is no unequivocal record of *P. cinnamomi* being associated with disease in undisturbed native vegetation in the NT. It is generally accepted that the environmental conditions are not conducive to the establishment and persistence of *P. cinnamomi* in susceptible native plant communities.

Cahill *et al*. (In press) provides a recent and comprehensive review of the known distribution of *P. cinnamomi*.

2.2.4 Transmission and spread

P. cinnamomi can be spread either actively or passively. Active or autonomous dispersal occurs as a result of actions on the part of the pathogen – predominantly by zoospores and mycelial growth. Passive dispersal of the pathogen is dependent upon propagules of the pathogen being passively carried or vectored by an independent party or object.

Active spread by zoospores is favoured by coarse-textured soils with large pores, and water-filled root channels through which zoospores are able to swim for around 25-30 millimetres. Mycelia can grow through roots and spread to adjacent healthy plants where root-to-root contact occurs. Root-to-root movement of the pathogen is thought to be one of the major ways in which the pathogen spreads up and across slopes from a disease centre.

P. cinnamomi can be carried passively in overland and subsurface water flow, which is apparent from the prevalence of infections in low-lying areas. Animals may also act as vectors of infected soil and have been implicated in spreading *P. cinnamomi*, particularly where there is digging or soil disturbance behaviours. This movement is greater on sticky clay soils and wet peats than on drier, well-drained soils of low organic content.

Among the numerous *P. cinnamomi* vectors, human-induced transport of soil as a result of road building and maintenance, timber harvesting, mineral exploration, the nursery trade and bushwalking is the most important, especially when this is undertaken during the period of the infective southern spring.

Survival, establishment and further spread are dependent on conditions at the point of delivery; in particular, sufficient moisture for the pathogen and the presence of living host tissue. The success of establishment for new centres of infection is also dependent on population levels in the soil at the point of pick-up and the quantity transferred. Most of the large centres of infection that exist today in southern temperate Australia occurred as a result of human activity, often as a direct result of the introducing infected soil or road-building materials to vulnerable uninfected areas.

2.2.5 Rates of spread

The time-scale for natural spread depends upon the topography, vegetation and climate. Annual rates of spread at the boundaries of existing infection are highly variable, ranging from a few to hundreds of metres downslope in incised water courses or gullies. Surveys in Western Australia have shown the *P. cinnamomi* upslope disease extension on the Darling Plateau (East) was 0.37 metres/year, compared to 2.15 metres/year for the Blackwood Sedimentary Plateau where a perched water table provides long periods of favourable conditions conducive to proliferation of the pathogen (Strelein *et al.* 2005). In the Jarrah (*E. marginata*) forest of Western Australia, upslope and across slope spread seldom exceeds an average of one metre a year (Podger *et al*. 1996 cited in O'Gara *et al*. 2005a).

2.3 The disease

2.3.1 Effects on susceptible plant species

Disease symptoms may vary between plant species. In the early stages of disease, symptoms generally consist of retarded growth and slight drooping of the foliage. Infected broadleaf species wilt during the heat of the day and may recover at night. Roots become discoloured and die. Dark or reddish brown discoloration may extend up into the wood of the lower stem. Severely affected plants wilt permanently and leaves turn brown.

The most common symptom of disease in the later stages is yellowing of the foliage. *Xanthorrhoea* species often die rapidly and the plant may collapse. Infected trees can produce epicormic growth but may eventually die. Shrubs generally turn yellow, with dieback occurring in warm moist periods during spring and autumn. Plants may appear to recover when environmental conditions disfavour the pathogen but dieback often occurs again when the pathogen is active or the plant is under environmental stress.

Species that are highly susceptible to *P. cinnamomi* rapidly die once infected. These species are often used as indicator species as they are generally the first to show symptoms of infection. Mature trees are normally not killed by *P. cinnamomi* unless concurrently exposed to environmental stress, such as waterlogging or drought.

The families from which the pathogen is most frequently isolated are Myrtaceae, Proteaceae, Fabaceae, Epacridaceae and Dilleniaceae. There is considerable variation in susceptibility within families, genera and species (Cahill *et al* 2008). With the exception of the Dilleniaceae, this reflects the dominance of these families in the woody flora of southwestern Australia and their importance as structural components in the affected communities.

In Western Australia, the state most severely impacted by *P. cinnamomi*, 300 plant species have been listed as susceptible to infection (O'Gara *et al*. 2005b) although it has been estimated that as many as 2000 plant species of the southwest are susceptible (Wills 1993). Recently, Shearer *et al*. (2004) has shown that 51% of the 5710 species in the south-west botanical province are susceptible to *P. cinnamomi*.

A list of over 1000 known native hosts of *P. cinnamomi* in Australia is contained in the National Best Practice Guidelines (O'Gara *et al*. 2005b). The list has been compiled from published material, unpublished records and observations of individual researchers. A susceptibility rating has been assigned to each species where such information is available.

Several problems arise when trying to define the susceptibility of flora species. A highly susceptible species is one that has high mortality in the field but this may be influenced by site and other environmental conditions. Susceptibility to *P. cinnamomi* is often based on observations at a low number of sites and the susceptibility of most listed species has not been tested in the laboratory or glasshouse.

Complications in defining susceptibility arise from a number of variables affecting a plant's reaction to infection. For example the response of a species in the wild may depend on static site conditions (e.g. substrate and pH) and temporal conditions (e.g. rainfall and disturbances such as fire); species may not be hosts of *P. cinnamomi* at all but may be affected by changes in vegetative structure caused by the death of surrounding plants; there may be a spatial variation in the response of a host (e.g. *Hibbertia hypericoides* is highly susceptible to infection on the Swan Coastal Plain of Western Australia but rarely affected in the adjoining Jarrah (*E. marginata*) forest). It has also been recognised that there is variability between states where a species may be listed as highly susceptible in one state yet in another it is not recognised as a susceptible species.

At best, records of host species suggest only that *P. cinnamomi* is able to parasitise some part of some plants in populations of the listed species. They provide no indication of the extent of invasion or of the severity of the consequences in terms of the health and survival of individual plants, plant populations or species. As a result they are not very useful for predicting the possible fate of a particular species.

2.3.2 Effects on ecological communities

Infection by *P. cinnamomi* in susceptible ecological communities will often result in major disruption and decline of structure and composition of those communities. Further, the vegetation assemblages of resistant species that, with time, recolonise areas are generally less species-rich, have more open overstorey and provide a modified habitat for dependent fauna, flora and heterotrophs.

In many high-rainfall areas the biomass of communities, particularly woodlands dominated by species of *Banksia* and Jarrah (*E. marginata*) forest and on highly susceptible sites, basal area (an index of accumulated biomass) can be reduced to a fraction of its pre-infection status. At the other end of the spectrum, *P. cinnamomi* can invade ecological communities and persist beneath them with no discernible impact for many decades.

In Victoria, long-term studies have been undertaken in the Brisbane Ranges, Wilsons Promontory National Park, Grampians National Park (Weste *et al.* 2002) and Anglesea (Wilson *et al.* 1997). Species present in post-diseased areas are likely to be either resistant to *P. cinnamomi*, exhibiting little or no disease symptoms, or tolerant/fluctuating species that exhibit some disease symptoms as well as showing regrowth and recovery at times. Longer term studies in the Brisbane Ranges and the Grampians have shown chronosequential changes in the floristic composition (Weste and Ashton 1994; Weste *et al.* 2002).

2.3.3 Effects on animals

There has been little work investigating the impact of *Phytophthora* dieback on faunal populations and communities. Despite this, there is a concern that the dramatic impact of *P. cinnamomi* infections on plant communities can result in major declines in some animal species due to the loss of shelter and nesting sites or food sources. The greatest impact is likely to be to those species that require relatively dense species-rich shrublands or have restricted diets.

In Western Australia, the conservation status of Gilberts Potoroo *Potorous gilbertii* (currently listed as Critically Endangered under the *EPBC Act 1999*), and the Honey Possum *Tarsipes rostratus* have been speculatively connected to *Phytophthora* dieback (Calver and Dell 1998). 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).

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 (Wilson and Laidlaw 2001). Five Victorian species - the Smoky Mouse *Pseudomys fumeus*, the Heath Mouse *Pseudomys shortridgei*, the New Holland Mouse *Pseudomys novaehollandiae*, the Long-footed Potoroo *Potorous longipes* and the Brush-tailed Rock-wallaby *Petrogale penicillata* - have greater than 20% of their distributions in areas susceptible to *Phytophthora* dieback.

In New South Wales *P. cinnamomi* invasion is considered to be a process threatening the conservation of endemic populations of the Southern Brown Bandicoot *Isoodon obesulus* and the Smoky Mouse *Pseudomys fumeus*. The Long-footed Potoroo *Potorous longipes* is also considered to be at risk from *Phytophthora* impact due to the proximity of recent infections to suitable habitat for this marsupial.

2.3.4 Threatened species

Major disruption during epidemic disease is not the only expression of disease that could threaten the extinction of populations of susceptible plant species. Species that exist in very small populations can be threatened with extinction as a consequence of much less dramatic endemic disease that causes a slow attrition of individuals in natural populations.

A number of flora species which are nationally listed as being threatened and which may be susceptible to *P. cinnamomi* are listed in Appendix A of the threat abatement plan.

2.3.5 Resistance to infection

There are few plants that are truly resistant to *P. cinnamomi* – the pathogen is capable of infecting the roots of most species. Many species may become infected with *P. cinnamomi* but not all species die as a result of infection. In most cases, non-susceptible plants once infected will produce a hypersensitive response which will contain the infection to the immediate vicinity of pathogen penetration. Some plants are able to compartmentalise the pathogen once it penetrates the roots and prevent it from invading the rest of the root system and plant collar. Other plants, typically monocotyledons, are able to rapidly produce new roots to replace those infected by the pathogen and so are able to withstand infection. In general, herbaceous perennials, annuals and geophytes are more resistant to *P. cinnamomi* than woody perennials.

There is also considerable variation in resistance between species within the same genus or subgenus. For instance in the genus *Eucalyptus*, most species in the subgenus *Symphomyrtus* and subgenus *Corymbia* (gums, boxes and ironbarks) are relatively resistant to infection by *P. cinnamomi*, but most species in the subgenus *Monocalyptus* (ashes, stringybarks and peppermints) are susceptible.

3. Dealing with the problem

The limited management options currently available focus on the modification of human activities through restricting access to certain sites, and deploying and enforcing hygiene procedures to minimise the spread of *P. cinnamomi* in the landscape. The two major objectives of *P. cinnamomi* management are:

i) to prevent the introduction or limit the spread of *P. cinnamomi* into uninfected areas; and

ii) to reduce the impact of *P. cinnamomi* at infected sites.

To manage the problem of *P. cinnamomi* infection a set of tools, skills and protocols has been developed, based on knowledge of the current *P. cinnamomi* status and preferences on a geographical and species basis (section 3.1).

Active interventions that reduce transmission of *P. cinnamomi* are quarantine or access prohibition or restriction, and hygiene or disinfection of machinery or inanimate objects (Section 3.2).

The use of the fungistatic agent phosphite directly applied to the host plant is difficult and expensive to apply in remote areas, but is useful in localised populations of high conservation value. However, there is much still unknown about the effects of the agent on non-target species and animals (Section 3.3). Assessment of the effectiveness of management regimes requires ongoing monitoring to detect changes in disease status. The integration of these strategies and the local integration of the available management techniques in an adaptive management approach will maximise the success of *P. cinnamomi* management (Sections 3.4 and 3.5).

3.1 Identification of the disease

3.1.1 Detection

Current practice in detecting *P. cinnamomi* in the field involves the observation of visible symptoms of disease in vegetation, and confirmation of its presence through sampling and laboratory analysis of soil and diseased plant tissues.

There is widespread confusion between the disease and death caused by *P. cinnamomi* and disease and death resulting from other causes in native vegetation, largely because of the difficulty of field diagnosis. This problem is exacerbated by the cryptic nature of *P. cinnamomi* - the organism can be seen only by microscopic examination in laboratories; while it sometimes produces reliable visible symptoms in a number of hosts, in many other hosts it is not reliably detected. Field diagnosis of disease relies heavily on the specialist interpretation of symptoms produced by indicator species, coupled with knowledge and information about potentially confounding environmental factors such as site and soil characteristics, fire, drought, abiotic or other biotic diseases.

Aerial photographs (1:4500 nominal scale, but up to 1:25000) can be used to detect the disease on a broad scale. Given sufficient disease expression, trained personnel can make decisions about the disease status of an area by stereoscopic examination of aerial photographs taken in autumn under shadowless conditions (full cloud cover). In autumn, infected plants that have died after making a final effort to respond to summer drought breaking rains have yellow to bright orange leaves and are readily detected via aerial photographs.

3.1.2 Diagnosis

Until recently, the diagnosis of *P. cinnamomi* as the causative agent of disease required laboratory analysis of samples of soil and tissues from affected plants. The majority of laboratories in Australia with the capacity to analyse samples for the presence of Phytophthora species used conventional identification of morphological characteristics, primarily of the reproductive structures of the pathogen (Drenth and Sendall 2001, cited in O'Gara et al. 2005a). The expected take-up of recent improvements in detection techniques using polymerase chain reaction (PCR)

(O'Brien, 2008) will enable more accurate and cost-effective detection of *P. cinnamomi* in infected soil. PCR-based methods will facilitate the further identification of vulnerable plant species and are expected to improve the economic feasibility of both the sampling to detect, or confirm visible evidence of, infection and of the subsequent mapping of infection sites.

3.1.3 Mapping

The current distribution of *P. cinnamomi* in Australia is not well known. Difficulties associated with sampling, and the high cost, have made direct mapping impractical in the wild. Furthermore, the autonomous movement and spread of the pathogen by uncontrolled vectors means that *P. cinnamomi* distribution maps have a limited currency of one to three years.

Maps that accurately depict the boundaries between infected and uninfected sites are essential to effectively limit the spread of *P. cinnamomi* and mitigate the impact of disease. The costs of on-ground survey and sample analysis have made the initial mapping or updating of maps expensive and only applicable ahead of major operations requiring disease demarcation. PCR-based detection methods may reduce the costs of sample analysis. Maps of disease occurrence through interpretation of aerial photographs can be developed at a lower cost but they do not have the same level of detail as those produced through on-ground survey. However maps derived from aerial photography are generally not suitable where there is a lack of susceptible species in the dense emergent shrub or forest layer, and the scale of photography often precludes interpretation of disease symptoms under these conditions. Cahill *et al*. (2008) provide a recent and comprehensive review discussing the potential for employing predictive mapping for *P. cinnamomi*.

Various attempts at mapping have been made using recent technological methods, such as satellite imagery, however the success of using these methods has been constrained by the nature of the impact of *P. cinnamomi* which is often restricted in visual impact. Maps produced from the interpretation of aerial photographs do not have the same level of accuracy or detail as those produced by on-ground surveys.

3.2 Minimising the spread of *Phytophthora cinnamomi*

In the absence of any known mechanism to eradicate the pathogen from an area, the primary goal of disease management is to protect the biodiversity of areas at risk from dieback caused by *P. cinnamomi* in the long term. 'Protectable areas' are defined as uninfected areas, occurring in the vulnerable zone, that have good prospects of remaining uninfected over the next two to three decades.

The process initially involves the identification of significant disease-free areas, followed by a risk analysis to determine the probability of the introduction of *P. cinnamomi* and identification of potential routes of invasion, and the manageability of those risks. As humans are the most significant vector of *P. cinnamomi*, managing spread predominantly involves the modification of human behaviours and activities.

3.2.1 Access prohibition or restriction

Prohibiting access or quarantining an area is generally used to protect environmental assets of high conservation value from *P. cinnamomi*. Prohibition of access may be enforceable by law, under legislation such as the Western Australian *Conservation and Land Management Act 1984*, the South Australian *National Parks and Wildlife Act 1972*, and the Tasmanian *Plant Quarantine Act 1997*.

As *P. cinnamomi* can be readily spread in infected soil, plant material and water, access to specified areas may be restricted to periods when soils are not likely to adhere to vehicles and pedestrians or when the likelihood of pathogen transmission is low. Land managers may choose to restrict all access or just vehicular traffic. Bushwalking, cycling and horse-riding are perceived in some areas and under some circumstances to pose a low risk and may be allowable under specific conditions.

For sound management of access to uninfected areas, it is necessary to delineate the boundaries between infected and uninfected areas. A number of elements are essential to operational planning:

- recognition of the boundaries between infected and uninfected areas;
- mapping of the boundaries between the two areas as a basis for future access;
- demarcation of the boundaries on the ground, so that machinery operators are forewarned and avoid crossing into infected areas;
- regular inspection to ensure that entry controls are being followed;
- regular testing to ensure that the disease has not spread past the boundaries put in place; and
- assessment that controls put in place have been effective.

Difficulties with these sorts of quarantine measures can arise for social and resource-related reasons:

- opposition to changes in land use/access;
- level of public education required; and
- lawlessness and limitations on enforcing quarantine.

3.2.2 Hygiene

Where access is permitted, hygiene refers to specific procedures designed to prevent the spread of *P. cinnamomi* by ensuring that infected soil, water and/or plant material are removed from machinery, vehicles, equipment and footwear before they enter uninfected areas. Management options include:

i) postpone activities during wet weather;
ii) begin activities with clean vehicles and equipment; and
iii) avoid wet or muddy areas during activities.

Permanent or semi-permanent vehicle wash-down facilities may be constructed where machinery and vehicles require routine cleaning for fixed activities. Portable wash-down systems enable machinery and vehicles to be cleaned at the point of risk for activities that do not have a fixed location.

Where high conservation values are at stake, activities such as bushwalking, horse riding and cycling may pose a risk of introduction and may also be subject to hygiene. Disinfection of footwear, small tools and equipment against *P. cinnamomi* is required to maintain disease-free status in these instances.

Issues associated with maintaining the integrity of the boundary between infected and uninfected include:

- access to suppress wildfires and for installing and maintaining firebreaks on private property boundaries;
- denial of access to uninfected areas when wet soils are likely to be picked up from cryptic infections in timber-harvesting coupes and spread further within the coupes with the consequent need to stockpile produce during drier periods;
- mapping and demarcation in planning access for heavy equipment, to minimise the inadvertent movement of machinery from uninfected areas into infected ones and vice versa; and
- access for other activities, eg bush walking, apiarian, drilling, wildflower collecting, etc.

3.2.3 Potential further introductions through revegetation

P. cinnamomi is prevalent in the nursery and garden industry, affecting both plants and plant medium. The use of infected stock has the potential to spread the disease extensively in urban and rural situations, and may become problematic when gardens or rehabilitation activities adjoin natural bushland. Revegetation of much of the landscape is occurring on a broad scale across the vulnerable envelope for *P. cinnamomi* and the threat of continued spread of *P. cinnamomi* from infected stock and nurseries is potentially significant. A key objective for much of the revegetation work is to enhance or restore the landscape; however this may be nullified if *P. cinnamomi* is introduced in the process. Managing the threat will require targeting both producers and consumers of products. Many consumers are unaware of the threat posed by purchasing plant material from uncertified sources.

Nurseries in many states have voluntary best-practice guidelines to reduce the spread of *P. cinnamomi* via infected stock.

3.2.4 Eradication

There are currently no proven methods to eradicate *P. cinnamomi* from an infected site or to prevent autonomous spread of the pathogen. There have been attempts at eradicating *P. cinnamomi* in the wild (Hill *et al*. 1995) in Australia but they were unsuccessful or only partially successful and within a few years severe disease broke out again in the treated areas and at their boundaries.

The *P. cinnamomi* is well established across a very large area and techniques and resources are inadequate to stem even the independent spread of the pathogen. Additionally, the pathogen is transmitted by animals and this process is usually prohibitively difficult and expensive to control.

3.2.5 Monitoring and surveillance

Effective monitoring and surveillance for the presence of *P. cinnamomi* is essential to allow timely management. The deployment of appropriate prescriptions to manage further spread of *P. cinnamomi* in the landscape firstly requires knowledge of the location of the pathogen.

Monitoring and surveillance of plant communities provides information on disease outbreaks, as well as on distribution, prevalence, and incidence of *P. cinnamomi*. It also provides information necessary for evaluating the risk *P. cinnamomi* poses to biodiversity and the effectiveness and efficiency of management and risk mitigation measures.

The purpose of monitoring ranges from determining long-term patterns of pathogen spread and disease impact to determining the effectiveness of management measures and/or surveillance of pathogen movement where high conservation values are under imminent threat. Surveys can be one-off to determine if a site is infected with the pathogen, or they can be systematic and ongoing. Systematic ongoing surveys focused on key sites provide data on the epidemiology of the disease over time. Databases of occurrence records, susceptible species, climate and topography GIS layers can be employed to develop predictive maps for potential future occurrence and risk of introduction of the disease.

Currently there are scant data available on the effectiveness of current management tactics, particularly hygiene measures, due to inadequate monitoring.

3.3 Treatment options to mitigate the impact of *P. cinnamomi*

Options for the mitigation of impact to biodiversity at infected sites are currently limited to the use of the fungistatic agent phosphite. *Ex situ* conservation of susceptible plants is a management option for the preservation of susceptible and rare plants. The cost of these options makes only limited application practical. Breeding of resistant *E. marginata* (Jarrah) plants is also a potential option for rehabilitation of infected sites.

3.3.1 Phosphite

The autonomous spread of *P. cinnamomi* is currently impossible to control. However, phosphite (also referred to as phosphonate), the anionic form of phosphonic acid (HPO_3^{2-}), has been shown in Western Australia and Victoria to slow the spread and reduce the impact of *P. cinnamomi* in susceptible vegetation. Phosphite is currently used in Western Australia to protect areas of high conservation value and critically endangered species from the threat of *P. cinnamomi*.

Phosphite is used as a management option for ecosystems under threat of *P. cinnamomi* in Western Australia, and is potentially applicable in a broader context nationally. Faced with the continued threat that *P. cinnamomi* poses to a significant proportion of Australia's native vegetation, and the limited management options, the most responsible recommendation for other states and territories is that, after reference to the available research, phosphite be used judiciously in the management of *P. cinnamomi*, results monitored and data collected to increase the national body of knowledge on this important management tool.

The beneficial properties to the host of phosphite include:

- the induction of resistance to *P. cinnamomi* in otherwise susceptible plant species (Guest and Bompeix 1990);
- its mobility in phloem and xylem (Ouimette and Coffey 1990, cited in O'Gara *et al* 2005a) enabling application by trunk injection to trees and large shrubs;
- the uptake of phosphite through foliage which enables it to be applied as a foliar spray, either manually or by broad scale aerial application; and
- it breaks down quickly in the soil (Guest and Grant 1991, cited in O'Gara *et al* 2005a).

Phosphite has a low toxicity for many mammals, although its effects on other fauna have not yet been properly assessed. The chemical should be used with caution in areas where threatened fauna species are known to occur.

The detrimental effects of phosphite on non-target species may include phytotoxicity, growth abnormalities, and reduced pollen viability and seed germination.

There are also large differences in levels of control between plant species. In addition, phosphite is not an eradicant and the pathogen remains in the soil/host plant environment even though symptoms are suppressed. Thus a considered approach needs to be adopted when using phosphite for the management of *P. cinnamomi* in natural ecosystems.

The Australian Pesticides and Veterinary Medicines Authority (APVMA) administers the National Registration Scheme for Agricultural and Veterinary Chemicals (NRS) in partnership with the states and territories. Phosphite is currently not registered for use in native vegetation and therefore an 'off-label permit' may be required from the APVMA before use. However, as legislation can vary between states/territories it is recommended that the APVMA or the relevant APVMA state/territory co-ordinator is contacted for advice on permit requirements before use.

Aerial application (Figure 3) is a rapid way to treat entire plant communities especially where rough terrain would make ground application practically impossible or prohibitively expensive. Foliar application using backpack (Figure 4) or trailer-mounted sprayers is usually restricted to small areas such as small reserves, remnant bushland or spot infections. Trunk injection of trees and large shrubs is used in strategic areas where their loss would have a high visible impact, and where foliar application is impractical.

Figure 3 Aerial application of phosphite in Stirling Ranges National Park in the south-west of Western Australia (Photo: G Freebury, Department of Conservation, Western Australia).

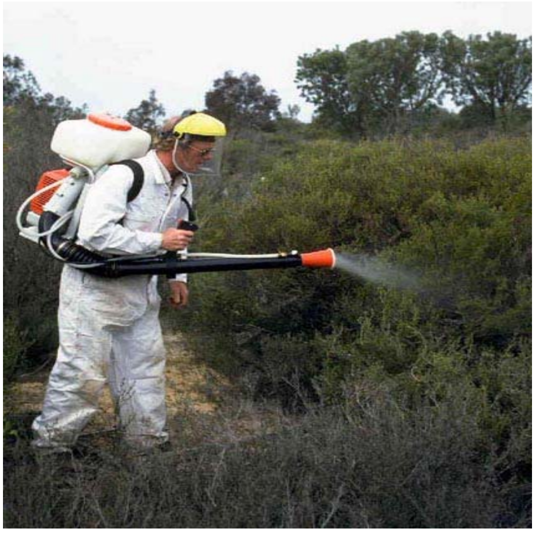

Figure 4 Foliar application of phosphite by backpack mister (Photo: B Shearer, Department of Conservation, Western Australia).

The cost of phosphite application precludes broadscale application to infected sites. The use of phosphite and/or *ex situ* conservation as a component of integrated management for a site or area requires a process of prioritisation and strategic planning. Highest priority may be given to sites assessed as ecologically or economically significant, or valued by the community.

3.3.2 Ex situ conservation

In Western Australia, *ex situ* conservation of germplasm in seed banks is a well established technique and with no definitive solution to the threat of *P. cinnamomi*, may be the last hope in conserving some susceptible species. Compared to other types of germplasm, seed conservation has many benefits including: the simplicity of the technology; low cost and space requirements; the potential for long-term storage with little loss of seed viability; the applicability of the technique to a wide range of species; and greater genetic representation in seed than in vegetative material (Cochrane 2004).

3.3.3 In situ conservation

Translocation is the deliberate transfer of plants or regenerative plant material from one place to another. Purposes for translocation include (Vallee *et al*. 2004):

- enhancement – an attempt to increase population size or genetic diversity by adding individuals to an existing population;
- re-introduction – the establishment of a population in a site where it formerly occurred;
- conservation introduction – an attempt to establish a taxon at a site where it is not known to occur now or to have occurred in historical times, but which is considered to provide appropriate habitat for the taxon.

Guidelines for the translocation of threatened plants in Australia (Vallee *et al*. 2004) take into account the benefits, risks, planning and implementation associated with the strategy.

3.3.4 Breeding for resistance

There may be considerable variation in the expression of disease within a species. It has been observed that remaining and apparently healthy *E. marginata* in diseased Jarrah forest are often the resistant component. Intra-specific resistance has been demonstrated using clones of susceptible *E. marginata* (Stukely and Crane 1994) and the resistant individuals are the basis of a plant breeding program in Western Australia selecting for resistance of *E. marginata* to *P. cinnamomi*. This breeding program has particular but limited application for forestry and rehabilitation of infected sites in the Jarrah forest. There have been very real gains made in dieback affected forests in Victoria following the use, for over 30 years, of a strategy to exploit the potential that a small percentage of individuals of otherwise susceptible species are tolerant (Marks and Smith 1991).

Sites have been successfully rehabilitated through the strategy of sowing well prepared seedbeds with high numbers of seeds collected from trees endemic to the sites. While the resilience of the apparent resistance seen is still to be proven, the outcome to date is that the percentage that survives more than provides for an adequate stocking for eucalypts on these previous dieback affected sites. This approach also ensures that the stocking rate is high enough to potentially lower the water table and thus reduce conditions conducive to disease development.

A .program for breeding of resistant individuals of susceptible keystone or threatened species, if proven practical, could provide a basis for rehabilitation of sites affected by the disease.

3.4 Wide scale detection, diagnosis and demarcation protocols

To survey and map the distribution of *P. cinnamomi* on a wide scale, a uniform and consistent sampling standard for application across the country is required. The presence of *P. cinnamomi* at a site can be confirmed from a single positive sample but a site cannot be deemed free of the pathogen from a single or even multiple negative samples. A systematic survey of long-infected sites in Western Australia determined that the number of samples needed to return a negative result to pronounce a site free of *P. cinnamomi* with 95 per cent confidence, is 271 (Davison and Tay 2003, cited in O'Gara *et al*. 2005a). In the wet tropics of northern Queensland, *P. cinnamomi* was shown to be uniformly distributed in the landscape and it was estimated that a minimum of two to four soil samples were required per 1256m^2 to predict the absence of *P. cinnamomi* with 95 per cent confidence (Pryce *et al.* 2001, cited in O'Gara *et al*. 2005a).

The European and Mediterranean Plant Protection Organisation (EPPO) has produced a standard for application in that region that describes diagnostic protocols for *P. cinnamomi* including examination of symptoms, isolation, identification of the pathogen through morphological characteristics, immunological and molecular methods, and reporting (OEPP/EPPO 2004).

3.5 Risk assessment and priority setting

One of the first steps in the analysis of the risk posed by *P. cinnamomi* is the identification of areas vulnerable to disease. Most states in Australia have identified broad zones where biodiversity is vulnerable to the threat of *P. cinnamomi* due to the coincidence of susceptible vegetation and environmental conditions that are conducive to the establishment and persistence of the pathogen (see section 2.2.3). The criteria used to identify zones of vulnerability vary from state to state.

A risk assessment process for assessing the risk of *P. cinnamomi* to threatened species, ecological communities and areas, and ranking them as the basis for setting management priorities has been developed under the provisions of the original TAP. While not yet field tested, the process is potentially suitable for national adoption (CPSM 2005). Models have been developed for flora, fauna habitat, vegetation communities and for areas of land.

The models identify the source of risk, the likelihood of occurrence and the magnitude of the consequences. The models are semi-quantitative (i.e. qualitative criteria are assigned scores), based on current scientific knowledge. However, where significant knowledge or data gaps exist, expert opinion will be required. The risk assessment process developed should be viewed as iterative, and improvements and reviews undertaken as new data and knowledge become available.

The semi-quantitative scoring system used in developing the models enabled a ranking of assets according to the risk posed by *P. cinnamomi* and the perceived ability to manage the risks. Indicative assessments are produced when the models are run. The decision flow chart contained in the model terminates with the determination of disease status of the site, with three possible options: infected, uninfected or disease status unknown.

References

Cahill DM, Rookes JE, Wilson BA, Gibson L and McDougall KL (2008). Turner Review No 17. *Phytophthora cinnamomi* and Australia's biodiversity: impacts, predictions and progress towards control. Australian Journal of Botany.

Calver MC, Dell J (1998). Conservation status of mammals and birds in south-western Australian forests. Is there evidence of direct links between forestry practices and species decline and extinction? *Pacific Conservation Biology* 4, 296-314.

Cochrane A (2004). Western Australia's Ex Situ Program for Threatened Species: A Model Integrated Strategy for Conservation. In: Ex Situ Plant Conservation. Supporting Species Survival in the Wild. Eds. EO Guerrant Jr, K Havens, M Maunder (2004) pp40-65. Island Press, Washington DC.

CPSM (2005). Management of *Phytophthora cinnamomi* for Biodiversity Conservation in Australia: Part 4 – Risk Assessment Models for Species, Ecological Communities and Areas. A report funded by the Commonwealth Government Department of the Environment and Heritage by the Centre for *Phytophthora* Science and Management, Murdoch University, Western Australia.

Davison EM, Tay FCS (2003). A sampling strategy for *Phytophthora* for 'difficult' sites. Report No. 235, Minerals & Energy Research Institute of Western Australia, East Perth.

Department of Conservation and Land Management (2003). *Phytophthora cinnamomi* and disease caused by it. Department of Conservation and Land Management, Government of Western Australia. http://www.naturebase.net/pdf/projects/dieback/DBmanual2003.pdf

Drenth A, Sendall B (2001). Practical Guide to Detection and Identification of Phytophthora. Cooperative Research Centre for Tropical Plant Protection, Brisbane, Australia.

Environment Australia (2001). Threat Abatement Plan for Dieback Caused by the Root-rot Fungus *Phytophthora cinnamomi*. Environment Australia, Commonwealth Government of Australia, Canberra.

European and Mediterranean Plant Protection Organisation (2004). Diagnostic Protocols for Regulated Pests. *Bulletin OEPP/EPPO 34*, 155-157. http://archives.eppo.org/EPPOStandards/PM7_DIAGNOS/pm7-26(1).pdf

Gadek PA, Worboys S (2003). *Rainforest Dieback Mapping and Assessment*: Phytophthora species diversity and impacts of dieback on rainforest canopies. Cooperative Research Centre for Tropical Rainforest Ecology and Management. Rainforest CRC, Cairns. pp114.

Garavanta CAM, Wooller RD, Richardson KC (2000). Movement patterns of honey possums, *Tarsipes rostratus*, in the Fitzgerald River National Park, Western Australia. *Wildlife Research* 27, 179-183.

Guest DI, Bompeix G (1990). The complex mode of action of phosphonates as antifungal agents. *Australasian Plant Pathology* 19, 113-115.

Guest DI, Grant B (1991). The complex action of phosphonates as antifungal agents. *Biological Reviews* 66, 159-187.

Hill, TCJ, Tippett JT and Shearer BL (1995). Evaluation of three treatments for eradication of *Phytophthora cinnamomi* from deep, leached sands in southwest Australia. Plant Disease 79, 122-127.

Marks GC, Smith IW (1991). The Cinnamon Fungus in Victorian Forests; History, Distribution, Management and Control. Department of Conservation and Environment, Lands and Forests Bulletin No. 31. 33pp.

O'Brien PA (2008). PCA primers for specific detection of *Phytophthora cinnamomi*, Australasian Plant Pathology 37: 69-71.

O'Gara E, Howard K, Wilson B and Hardy GEStJ (2005a). Management of *Phytophthora cinnamomi* for Biodiversity Conservation in Australia: Part 1 – A Review of Current Management. A report funded by the Commonwealth Government Department of the Environment and Heritage by the Centre for *Phytophthora* Science and Management, Murdoch University, Western Australia.

O'Gara E, Howard K, Wilson B and Hardy GEStJ (2005b). Management of *Phytophthora cinnamomi* for Biodiversity Conservation in Australia: Part 2 – National Best Practice Guidelines. A report funded by the Commonwealth Government Department of the Environment and Heritage by the Centre for *Phytophthora* Science and Management, Murdoch University, Western Australia.

Ouimette DG, Coffey MD (1990). Symplastic entry and phloem translocation of phosphonate. *Pesticide Biochemistry and Physiology* 38, 18-25.

Podger FD, James SH, Mulcahy MJ (1996). Review of Dieback in Western Australia. Vol. 1: Report and Recommendations. Perth, Western Australia.

Phytophthora Technical Group (2006). Phytophthora Management Guidelines (2nd ed), Government of South Australia.
http://www.environment.sa.gov.au/biodiversity/pdfs/pc_management_guidelines.pdf

Pryce J, Edwards W, Gadek P (2001). Detecting Phytophthora cinnamomi in rainforest soils: the effect of spatial scale on sampling strategy. In: Rainforest Dieback Mapping and Assessment in the Wet Tropics World Heritage Area, (Eds PA Gadek, D Gillieson, W Edwards, J Landsberg, J Pryce) James Cook University (Cairns campus) and Rainforest CRC.

Shearer BL, Crane CE, Cochrane A (2004). Quantification of the susceptibility of the native flora of the South West Botanical Province, Western Australia, to *Phytophthora cinnamomi*. *Australian Journal of Botany* 52(4), 435-443.

Strelein GJ, Sage LW, Blankendaal PA (2005). Rates of disease extension of *Phytophthora cinnamomi* in the Jarrah forest (*Eucalyptus marginata*) bioregion of south-western Australia. *(in press)*.

Stukely MJC, Crane CE (1994). Genetically based resistance of *Eucalyptus marginata* to *Phytophthora cinnamomi*. Phytopathology 84:66.

Vallee L, Hogbin T, Monks L, Makinson B, Matthes M and Rossetto M (2004). Guidelines for the Translocation of Threatened Plants in Australia - Second Edition. Australian Network for Plant Conservation, Canberra.

Weste G, Ashton DH (1994). Regeneration and survival of indigenous dry sclerophyll species in the Brisbane Ranges, Victoria, after a *Phytophthora cinnamomi* epidemic. Australian Journal of Botany 42, 239-253.

Weste G, Brown K, Kennedy J, Walshe T (2002). *Phytophthora cinnamomi* infestation – a 24 year study of vegetation change in forests and woodlands of the Grampians, Western Victoria. Australian Journal of Botany 50, 247-274.

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

Wilson BA, Howard K, O'Gara E and Hardy GEStJ (2005). Management of *Phytophthora cinnamomi* for Biodiversity Conservation in Australia: Part 3 - Risk Assessment for Threats to Ecosystems, Species and Communities: A Review. A report funded by the Commonwealth Government Department of the Environment and Heritage by the Centre for Phytophthora Science and Management, Murdoch University, Western Australia.

Wilson BA, Laidlaw WS (2001). Impact of *Phytophthora cinnamomi* on mammals in southern Australia. Proceedings of 2nd International IUFRO Meeting. Albany, Western Australia.

Wilson BA, Lewis A and Aberton J (1997). Conservation of national estate communities threatened by cinnamon fungus at Anglesea, Victoria. Report for the Victorian Government Department of Natural Resources and Environment. pp 93.

Wooller RD, Richardson KC, Garavanta CAM, Saffer VM, Bryant KA (2000). Opportunistic breeding in the polyandrous honey possum, *Tarsipes rostratus*. Australian Journal of Zoology 48, 669-680.

Worboys S, Gadek P (2004). Rainforest Dieback: Risks Associated with Roads and Walking Tracks. Cooperative Research Centre for Tropical Rainforest Ecology and Management, Cairns, Queensland.

Further reading

The information in this document was drawn largely from the following reports:

O'Gara E, Howard K, Wilson B and Hardy GEStJ (2005a). Management of *Phytophthora cinnamomi* for Biodiversity Conservation in Australia: Part 1 – A Review of Current Management. A report by the Centre for Phytophthora Science and Management, Murdoch University, Western Australia, and funded by the then Commonwealth Government Department of the Environment and Heritage.

O'Gara E, Howard K, Wilson B and Hardy GEStJ (2005b). Management of *Phytophthora cinnamomi* for Biodiversity Conservation in Australia: Part 2 – National Best Practice Guidelines. A report by the Centre for Phytophthora Science and Management, Murdoch University, Western Australia, and funded by the then Commonwealth Government Department of the Environment and Heritage.

Wilson B, Howard K, O'Gara E and Hardy GEStJ (2005). Management of *Phytophthora cinnamomi* for Biodiversity Conservation in Australia: Part 3 - Risk Assessment for Threats to Ecosystems, Species and Communities: A Review. A report by the Centre for Phytophthora Science and Management, Murdoch University, Western Australia, and funded by the then Commonwealth Government Department of the Environment and Heritage.

Please Note: The full reports are available and can be downloaded from: http://www.environment.gov.au/biodiversity/invasive/publications/p-cinnamomi/index.html

Aberton M, Wilson BA, Cahill DM (1999). The use of phosphite as a control for *Phytophthora cinnamomi* in native vegetation at Anglesea, Victoria. Australasian Plant Pathology 28, 225-234.

Barker PCJ, Wardlaw TJ, Brown MJ (1996). Selection and design of Phytophthora management areas for the conservation of threatened flora in Tasmania. Biological Conservation 76, 187-193.

Brasier C (2003). Phytophthoras in European forests: Their rising significance. Sudden Oak Death Online Symposium, April 21 - May 12, 2003. http://www.apsnet.org/online/proceedings/SOD/Papers/Brasier/default.htm

Brown BN (1998). Occurrence and impact of *Phytophthora cinnamomi* and other Phytophthora species in rainforests of the Wet Tropics World Heritage Area, and of the Mackay region, Qld. In 'Patch Deaths in Tropical Queensland Rainforests: Association and Impact of *Phytophthora cinnamomi* and Other Soil Borne Pathogens'. (Ed. PA Gadek) pp41-76. (Cooperative Research Centre for Tropical Rainforest Ecology and Management, Cairns).

CALM (2003). *Phytophthora cinnamomi* and disease caused by it. Department of Conservation and Land Management, Government of Western Australia. http://www.naturebase.net/pdf/projects/dieback/DBmanual2003.pdf

Colquhoun I and Hardy GEStJ (2000). Managing the risks of Phytophthora root and collar rot during bauxite mining in the *Eucalyptus marginata* (Jarrah) forest of Western Australia. Plant Disease 84(2), 116-127.

CPSM website (Murdoch University Centre for Phytophthora Science and Management): http://www.cpsm.murdoch.edu.au/

Dell B, Hardy G, Vear K (2005). History of *Phytophthora cinnamomi* management in Western Australia. In: Calver MC, Bigler-Cole H, Bolton G, Dargavel J, Gaynor A, Horwitz P, Mills J and Wardell-Johnson G (Eds). A forest consciousness. Proceedings of the 6th Australian Forest History Society Conference. Millpress Science Publishers, Rotterdam, Netherlands.

Department for Environment and Heritage (2002a). Phytophthora Threat Management Procedure: Standard Operating Procedures-002. Adelaide, South Australia.

Department for Environment and Heritage (2004b). Dieback in Native Vegetation in the Mount Lofty Ranges: A Guide to Causes and Symptoms. Adelaide, South Australia. http://www.environment.sa.gov.au/biodiversity/pdfs/dieback_guide.pdf

Department of Sustainability and Environment (2005). Draft Strategic Plan for management of *Phytophthora cinnamomi* in Victoria. East Melbourne, Australia.

Dieback Working Group (2000). Managing Phytophthora Dieback: Guidelines for Local Government. Dieback Working Group, Western Australia.

Dieback Working Group (2004). Environmental Code of Practice for the Management of Phytophthora Dieback in Extractive Industries. Dieback Working Group, Western Australia.

Grant M, Barrett S (2003). The distribution and impact of *Phytophthora cinnamomi* Rands in the south coast region of Western Australia. In: 'Phytophthora in Forests and Natural Ecosystems', Eds. J McComb, G Hardy and I Tommerup. From Proceedings of the 2nd International IUFRO Meeting, Western Australia, 30th September – 5th October 2001.

Kilgour S (2000a). Managing Phytophthora Dieback in Bushland: A Guide for Landholders and Community Conservation Groups 2nd Edition. Dieback Working Group, Western Australia.

McDougall KL, Summerell BA (2003). The impact of *Phytophthora cinnamomi* on the flora and vegetation of New South Wales – a re-appraisal. In 'Phytophthora in Forests and Natural Ecosystems'. 2nd International IUFRO Working Party 7.02.09 Meeting, Albany, Western Australia, October 2001. Eds. JA McComb, GEStJ Hardy and IC Tommerup; pages 49-56. (Murdoch University Print: Murdoch, Western Australia).

NIASA (2003). Best Management Practice Guidelines. 3rd Edition. Nursery and Garden Industry Australia, Sydney.

Parks Victoria (1998). *Phytophthora cinnamomi* Control in Parks. Policy Pol-218, Version 2.0. Parks Victoria. Government of Victoria.

Pilbeam RA, Colquhoun IJ, Shearer B, Hardy GEStJ (2000). Phosphite concentration: its effect on phytotoxicity symptoms and colonisation by *Phytophthora cinnamomi* in three understorey species of Eucalyptus marginata forest. Australasian Plant Pathology 29, 86-95.

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

Podger FD (1999). A National Overview of *Phytophthora cinnamomi* in Australia: Supplementary information to accompany the draft National Threat Abatement Plan. Report prepared for Environmental Australia, unpub.

Reiter N, Weste, G, Guest D (2004). The risk of extinction resulting from disease caused by *Phytophthora cinnamomi* to endangered, vulnerable or rare species endemic to the Grampians, western Victoria. Australian Journal of Botany 52, 425-433.

Rudman T (2004). Interim *Phytophthora cinnamomi* Management Guidelines. Department of Primary Industries, Water and Environment. Government of Tasmania.

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

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

Shearer BL, Tippett JT (1989). Jarrah Dieback: The Dynamics and Management of *Phytophthora cinnamomi* in the Jarrah (*Eucalyptus marginata*) Forest of the South-western Australia. Research Bulletin No. 3. Department of Conservation and Land Management, Como, Western Australia. Government of Western Australia.

Smith I (2002). Guidelines for reducing the spread of *Phytophthora cinnamomi* during earth moving operations. Department of Natural Resources and Environment. Government of Victoria.

Weste G (1974). *Phytophthora cinnamomi* – the cause of severe disease in certain native communities in Victoria. Australian Journal of Botany 22, 1-8.

Weste G (1997). The changing status of disease caused by *Phytophthora cinnamomi* in Victorian open forests, woodlands and heathlands. Australasian Plant Pathology 26, 1-9.

Wills RT, Keighery GJ (1994). Ecological impact of plant disease on plant communities. Journal of the Royal Society of Western Australia 77, 127-131.

WWF, DCC (2004). Arresting Phytophthora Dieback: The Biological Bulldozer. A report by the World Wildlife Fund and the WA Dieback Consultative Council. http://www.dieback.net.au/howhelp_learning.php.