A guide to managing and restoring wetlands in Western Australia

Phytophthora dieback

In Chapter 3: **Managing wetlands**

Version 1

Australian Government

Department of Environment and Conservation

Our environment, our future

Introduction to the guide

Western Australia's unique and diverse wetlands are rich in ecological and cultural values and form an integral part of the natural environment of the state. *A guide to managing and restoring wetlands in Western Australia* (the guide) provides information about the nature of WA's wetlands, and practical guidance on how to manage and restore them for nature conservation.

The focus of the guide is natural 'standing' wetlands that retain conservation value. Wetlands not addressed in this guide include waterways, estuaries, tidal and artificial wetlands.

The guide consists of multiple topics within five chapters. These topics are available in PDF format free of charge from the Western Australian Department of Environment and Conservation (DEC) website at www.dec.wa.gov.au/wetlandsguide.

The guide is a DEC initiative. Topics of the guide have predominantly been prepared by the department's Wetlands Section with input from reviewers and contributors from a wide range of fields and sectors. Through the guide and other initiatives, DEC seeks to assist individuals, groups and organisations to manage the state's wetlands for nature conservation.

The development of the guide has received funding from the Australian Government, the Government of Western Australia, DEC and the Department of Planning. It has received the support of the Western Australian Wetlands Coordinating Committee, the state's peak wetland conservation policy coordinating body.

For more information about the guide, including scope, purpose and target audience, please refer to the topic 'Introduction to the guide'.

DEC welcomes your feedback and suggestions on the guide. A publication feedback form is available from the DEC website at www.dec.wa.gov.au/wetlandsguide.

Contents of the guide

These topics are available in PDF format free of charge from the DEC website at www.dec.wa.gov.au/wetlandsguide.

'Phytophthora dieback' topic

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Before you begin

Before embarking on management and restoration investigations and activities, you must consider and address the legal requirements, safety considerations, cultural issues and the complexity of the ecological processes which occur in wetlands to ensure that any proposed actions are legal, safe and appropriate. For more guidance, see the topic 'Introduction to the guide'.

Phytophthora dieback: the introduced plant disease caused by ***Phytophthora cinnamomi,*** which results in the decline or death of susceptible plants

***Phytophthora cinnamomi*:** an introduced water mould that attacks the roots of susceptible plant species, resulting in the decline or death of the plant

Pathogen: any organism or factor causing disease within a host

Introduction

Phytophthora dieback refers to the introduced plant disease caused by ***Phytophthora cinnamomi*** (pronounced fy-tof-thora – meaning plant destroyer in Greek). The impacts of Phytophthora dieback were first detected in Western Australian forests in the 1920s. The **pathogen** itself, a water mould, *P. cinnamomi*, was identified in the mid 1960s and since then management procedures have been introduced to combat the disease and minimise its spread.

The arrival and spread of *P. cinnamomi* in WA has been catastrophic for the plants and animals of many south-western ecosystems, including wetlands (Figure 1). As many as 2,300 of the estimated 5,700 native plant species in the south-west are susceptible to, and often killed, by the pathogen. Phytophthora dieback has been recognised as a key threatening process under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. It is now considered to be a bigger threat to Western Australia's natural ecosystems than salinity and is estimated to cost the Australian economy $160 million each year.[1] In addition, *P. cinnamomi* has caused major problems for road construction, timber harvesting, mining and other industries since researchers realised that the movement of soil is the most likely method of spread of the pathogen.

There are several other species of *Phytophthora* present in native vegetation in the south-west of WA, including *P. cryptogea, P. multivora* and *P. nicotianae*, but their extent and impact on native vegetation is unclear.

Figure 1. The effects of Phytophthora dieback in a seasonally waterlogged wetland near Busselton in the south-west of WA. Photo – C Mykytiuk/DEC.

Dieback: the progressive dying-back of a plant as a result of disease or unfavourable conditions

Historically, Phytophthora dieback has also been known as 'dieback' and 'jarrah dieback'. The use of these names has contributed to the confusion about the disease. For example, the term '**dieback**' is used in other parts of Australia to refer to tree decline caused by factors such as salinity, drought and insect damage. Furthermore, *P. cinnamomi* affects a large number of native and introduced plant species in addition to jarrah (*Eucalyptus marginata*). To overcome this confusion the term 'Phytophthora dieback' is now used.[2]

What is Phytophthora dieback?

As previously mentioned, Phytophthora dieback refers to the plant disease caused by the introduced pathogen *P. cinnamomi. Phytophthora cinnamomi* is a microscopic soil-borne organism belonging to the **Oomycetes** or 'water moulds'. As the name suggests, the organism depends on moist conditions that favours its survival, reproduction and dispersal.

Phytophthora cinnamomi lives in both soil and plant tissue. It invades the roots of plants from the surrounding soil to obtain nutrients and moisture for growth and reproduction. It grows as microscopic-sized filaments, **mycelium**, on the surface of plant roots.[3] The pathogen extends these microscopic filaments into the major roots of susceptible species causing cell breakdown and the formation of lesions (areas that appear dead or rotten – see Figure 2). This reduces the ability of a plant to take up and transport water and nutrients and usually results in plant death.[3] In very susceptible species, such as banksias, death may occur within weeks, while in moderately susceptible species such as jarrah (*Eucalyptus marginata*), the tree may not die until a year or more after infection. Moderately susceptible and resistant species such as flooded gum (*E. rudis*) have the ability to 'wall off' the infection to prevent further spread of the mycelia, with varying degrees of success.[4]

Phytophthora cinnamomi mycelia need environmental conditions to be favourable to grow within a plant root. For instance, there is little growth when the water content of the plant tissue is below 80 per cent. The pathogen is able to survive within dead plant roots and dry soils, by producing tough long-lived spores known as chlamydospores. These allow the pathogen to persist more easily during the dry summer months of south-west WA.

Oomycetes: the group of fungae-like organisms known as the water moulds

Mycelium: the vegetative part of a fungus, consisting of microscopic threadlike filaments known as hyphae

Figure 2. A *Phytophthora cinnamomi* lesion in a sheoak (*Allocasuarina*) trunk with the bark removed. Photo – Dieback Working Group.

extra information

Phytophthora cinnamomi life cycle

Phytophthora cinnamomi feeds on living plant roots and stems. It invades the roots of plants to get the nutrients it needs. This invasion and growth within the plant reduces the plant's ability to transport water and nutrients, often resulting in death of the host plant.

Phytophthora cinnamomi is able to reproduce through the production of microscopic fruiting bodies which release spores. Four types of spores are produced—sporangia, zoospores, chlamydospores and oospores (Figure 3 and described below).

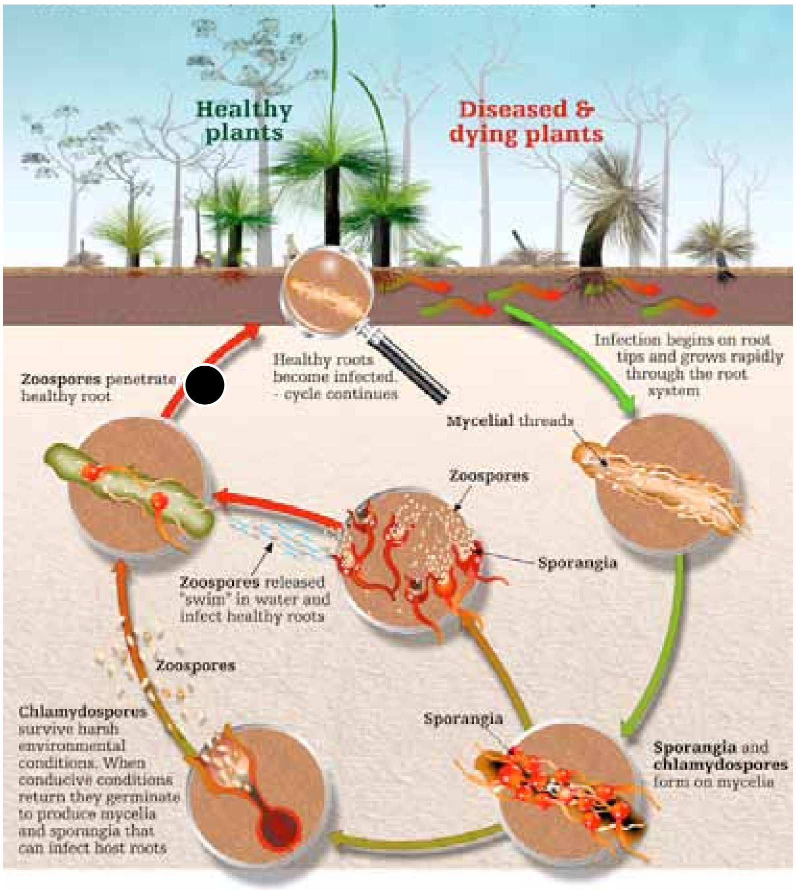

Figure 3. Life cycle of *Phytophthora cinnamomi.* © Dieback Working Group.[5]

Sporangia

Sporangia are the largest of all the spores and are produced under favourable temperature and soil moisture conditions. Zoospores are produced internally in sporangia and are released into soil once the sporangia reach maturity.

Zoospores

Zoospores are short-lived and fragile, but are produced in large numbers under moist soil conditions and are probably the cause of most new infections. Produced by sporangia, zoospores have flagella (tails), which allow them to swim very short distances (25–35 millimetres) in standing water or in films of water in soil pores. They can also be carried along in moving water over large distances. As they move through the soil, zoospores are attracted to the tips of plant roots, where they lodge, and then **germinate** (begin to grow, usually after a period of dormancy) to produce germ tubes which penetrate roots. Once inside the plant, the germ tube develops into mycelia which grow within the roots of susceptible plants, and may grow from plant-to-plant via root contact points. This root-to-root growth is the main cause of spread of a Phytophthora infestation in an upslope direction.

Chlamydospores

These are much larger than zoospores and are tough and long-lived (within dead plants and the soil). They are produced within plant roots in response to drying conditions, and are the 'resting' phase of the water mould. Chlamydospores are resistant to drying-out and are one of the mechanisms the pathogen has developed to help it survive adverse conditions. They may be transported in root fragments or soil and then germinate to cause a new infection when they encounter warm, moist conditions. Germinated chlamydospores may produce sporangia, more chlamydospores, or mycelia which directly infect roots.

Oospores

Oospores are produced through the sexual recombination of two different forms of the pathogen (A1 and A2 mating types). The sexually produced oospores are round and thick-walled, and are considered highly resistant to degradation. In some Phytophthora species, oospores are an important mechanism of surviving harsh environmental conditions. Although both mating types do occur together in some infested sites in WA, there is limited evidence of sexual recombination, and thus oospore production, occurring in the natural environment in this state.

What causes the spread of Phytophthora dieback in Western Australian wetlands?

Phytophthora cinnamomi is transported by two main mechanisms. The first is the movement of its spores through free water (including groundwater in coarse-textured soils and water-filled root channels), or by root-to-root contact between plants.[6] The second is through the movement of infected soil or plant material around the landscape. It is the movement of infected soil and plant material that has caused the large-scale spread and devastating impacts of Phytophthora dieback in the south-west of WA.

Phytophthora dieback is able to spread quickly down slopes and cover long distances if infected water is able to move freely. Its movement is much slower up slope and on flat ground (around one metre per year) as movement is generally restricted to root-to-root contact. Any action or process, including water movement, which transports soil in the landscape can also potentially transport the pathogen to a new site. Wetlands that are located in the lowest points in the landscape, and receive water from throughout the catchment, are at a high risk of being infested by *Phytophthora cinnamomi*.

The main cause of the spread of infected soil and plant material is transport by humans and some animals. *Phytophthora cinnamomi* can be carried by animals such as horses and wild pigs, often in soil attached to hooves and fur. It is transported by: humans on boots, in the muddy tyres of vehicles travelling along infested tracks, in plant pots, through earth moving and some vegetation clearing activities, and road construction.[2]

Warm, moist soil provides ideal conditions for the spread of *P. cinnamomi*. These conditions enable the pathogen to produce millions of zoospores. The zoospores are then attracted to plant roots as they seek out moisture and nutrients, swimming through soil water.[2]

High risk activities for transporting *Phytophthora cinnamomi*

Activities with a high risk of transporting *Phytophthora cinnamomi* include:

- removal of groundwater and surface water from wetlands potentially contaminated with *P. cinnamomi* for activities such as dewatering, irrigation and fire fighting
- transport of soil to and from wetlands potentially containing the pathogen
- fire break construction, which can result in the movement of soil around a property and between properties[1]
- revegetation activities that may potentially introduce *P. cinnamomi* to an area if the potting mix or soils used are contaminated with the pathogen
- movement of equipment and vehicles for a range of purposes, including the construction and maintenance of linear corridors such as roads, railways, gas pipelines and powerlines.

What effect does Phytophthora dieback have on wetlands?

Effects on vegetation

Over 40 per cent of the native plants in south-west WA are susceptible to Phytophthora dieback.[7] In field studies of south-western plant communities the families with the highest proportion of susceptible species were: Proteaceae – banksia family (92 per cent); Epacridaceae – heath family (80 per cent); Papilionaceae – pea family (57 per cent); and Myrtaceae – myrtle family (16 per cent) (Table 1).

Very little research has been undertaken on the effects of Phytophthora dieback on wetlands. Many common wetland plant species in the south-west such as flooded gum (*Eucalyptus rudis*), moonah (*Melaleuca preissiana*) and white myrtle (*Hypocalymma angustifolium*) are resistant to Phytophthora dieback (see Figure 4). Yet common species such as swamp peppermint (*Taxandria linearifolia*), swamp banksia (*Banksia littoralis*) and swamp teatree (*Pericalymma ellipticum*) have been identified as being susceptible (see Figure 5). Field observations have suggested that many wetland species are resistant to the disease (C Dunne 2008, pers. comm.), hence wetland plant communities often don't exhibit signs of Phytophthora dieback. Although many wetland species may be resistant to Phytophthora dieback, they may still act as resistant hosts for the pathogen (C Dunne 2008, pers. comm.).

Table 1. Examples of wetland species susceptible to Phytophthora dieback in the south-west by plant family

Family	Species – scientific name	Species – common name
Proteaceae	*Adenanthos obovatus*	Basket flower
	Banksia littoralis	Swamp banksia
Epacridaceae	*Sphenotoma gracilis*	Swamp paper-heath
Papilionaceae	*Jacksonia horrida*	-
Myrtaceae	*Melaleuca thymoides*	-
	Verticordia densiflora	Compacted featherflower

Garden species susceptible to Phytophthora dieback

A number of garden and horticultural plants are susceptible to *Phytophthora cinnamomi* including:

- apple, peach, apricot and avocado trees
- roses
- camellias
- azaleas
- proteas
- rhododendrons[8,9]

Figure 4. (below) Common south-west wetland species resistant to Phytophthora dieback. Photos – (a) ND Burrows and SD Hopper; (b) C Horton; (c) M Seale and J Stevens. Images used with the permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright, accessed 4/2/2009.

(a) Flooded gum (*Eucalyptus rudis*)

(b) Moonah (*Melaleuca preissiana*)

(c) White myrtle (*Hypocalymma angustifolium*)

Figure 5. (below) Common south-west wetland species susceptible to Phytophthora dieback. Photos – (a) BA Fuhrer, M Hancock, A Ireland and E Wajon; (b) I and M Greeve, C Hortin and T Tapper; (c) A Ireland and M Hislop. Images used with the permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright, accessed 4/2/2009.

(a) Swamp peppermint (*Taxandria linearifolia*)

(b) Swamp banksia (*Banksia littoralis*)

(c) Swamp teatree (*Pericalymma ellipticum*) case study

Critically endangered wetlands threatened by Phytophthora dieback

The following information has been taken from the then Department of Conservation and Land Management (CALM) (2005).[10]

The 'Shrublands on southern Swan Coastal Plain ironstones' (Busselton ironstone community) is a species-rich plant community of seasonally inundated wetlands with ironstone and heavy clay soils on the Swan Coastal Plain near Busselton (Figure 6). The community is recognised as being critically endangered on the list of threatened ecological communities endorsed by the Western Australian Minister for Environment. In 1995 there were only thirteen known occurrences of the Busselton ironstone community totalling 90 hectares. As a result of further surveys, the area of these occurrences has been found to be bigger than first thought and two additional occurrences have been identified bringing the total area of the community to almost 140 hectares.

The ironstone soils on which the Busselton ironstone community occurs are extremely restricted in distribution on the Swan Coastal Plain. They occur only on the eastern side of the Swan Coastal Plain along the base of the Whicher Scarp near Busselton. The heavy soils of this area are particularly useful for agricultural purposes. It has been estimated that around 97 per cent of vegetation on the eastern side of the Swan Coastal Plain has been cleared.

Much of the species diversity of the Busselton ironstone community is made up of annuals and **geophytes** (land plants that survive unfavourable periods by means of underground food storage organs, for example, rhizomes, tubers and bulbs). Typical and common native species are the shrubs *Kunzea* aff. *micrantha, Pericalymma ellipticum, Hakea oldfieldii, Hemiandra pungens* and *Viminaria juncea,* and the herbs *Aphelia cyperoides* and *Centrolepis aristata*. The community contains a number of taxa that are listed as priority or declared rare flora (DRF) by the Western Australian Government and are either totally confined or largely confined to these areas.[10]

Major threats to the community include Phytophthora dieback, clearing, too frequent fires, weed invasion, hydrological changes, and possibly salinisation. A number of plant species that occur in the community are very susceptible to Phytophthora dieback, including *Banksia nivea* subsp. *uliginosa* (Figure 7). All but one of the fifteen occurrences of the plant community are thought to be infected with the disease.[10] As such, Phytophthora dieback has the potential to seriously impact the 'Shrublands on southern Swan Coastal Plain ironstones'.

Figure 6. Busselton ironstone community. Photo – C Mykytiuk/DEC.

Figure 7. Death of *Banksia nivea* subsp. *uliginosa* (in the foreground) from Phytophthora dieback in an occurrence of the Busselton ironstone community. Photo – A Webb/DEC.

When *P. cinnamomi* invades communities dominated by species from the Proteaceae family, such as banksias and grevilleas, substantial changes in plant abundance and floristic structure may be observed. However, the effect of Phytophthora dieback on a plant community can vary greatly, depending both on the species composition of a particular community, and on the prevailing environmental conditions. It has been found that within the portion of the south-west land division that receives more than 800 millimetres mean annual rainfall, plant communities respond to Phytophthora dieback in one of four distinct ways:

1. No apparent disease at all (Figure 8).
2. An extremely destructive epidemic of root rot.
3. A variable epidemic within the dominant tree component of the jarrah forest, characterised by:
   a. irregular and often prolonged death of trees ranging from early localised mass collapse, through delayed and patchy deaths, to no apparent effect on the health of the jarrah overstorey
   b. high sensitivity to subtle differences in soil characteristics particularly those affecting drainage.
4. Replacement of forest with open woodland.[11]

The loss of native vegetation as a result of Phytophthora dieback (both within and surrounding a wetland) can have a number of detrimental impacts including:

- increased erosion and sedimentation
- reduced water quality
- loss of biodiversity, both directly and through loss of habitat and food for native fauna.

➤ For additional detail on the impacts of vegetation loss, see the topic 'Managing wetland vegetation' in Chapter 3.

Figure 8. Wetland vegetation infested with *Phytophthora cinnamomi* but showing no signs of the disease. Photo – R Lynch/DEC.

Effects on native animals

Changes in plant community composition and structure caused by *P. cinnamomi* may adversely affect associated groups of animals and soil biota by altering the availability of food resources and habitat (Table 2). Large herbivores such as western grey kangaroo (*Macropus fuliginosus*) and western brush wallaby (*M. irma*) may become more common, while smaller animals such as bandicoots and frogs may suffer from loss of refuge, with the more open vegetation giving them less protection from predators.

Pollinators reliant on susceptible plant species as key nectar sources, such as western pygmy-possum (*Cercartetus concinnus*) and honey possum (*Tarsipes rostratus*) may become rare or extinct in areas which have lost many species as a result of being infested for a long time. Insect pollinators may also be adversely affected by a reduction in nectar-producing plants, which in turn may affect the reproductive success of surviving plants dependant on the pollinators.

Table 2. Potential effects on fauna due to vegetation loss from Phytophthora dieback (based on Wilson, 1994[12])

Effects on vegetation	Effects on fauna
Loss of susceptible plants in the understorey and midstorey	Direct loss of food sources such as seeds, nectar and pollen
	Indirect loss of food sources such as invertebrates
Decline in plant species richness and diversity	Loss of food for species that prefer floristically rich vegetation
	Loss of seasonal food
Decrease in plant cover, increase in bare ground, erosion	Loss of habitat for species dependant on thick ground cover
	Increased predation risk
	Changes to microclimate
Decrease in canopy cover	Loss of food for tree-dwelling species
Decrease in litter fall	Decline in litter invertebrates
	Decline in invertebrate food sources for insectivores
Post-infection increase in frequency of resistant species	Changes in food webs

What types of Western Australian wetlands are commonly affected by Phytophthora dieback?

Phytophthora dieback is now widespread throughout the south-west of WA (Figure 9). In general, *Phytophthora cinnamomi* is restricted to areas in the south-west of the state receiving at least 400 millimetres of average annual rainfall; between Eneabba in the north and Cape Arid near Esperance in the east. It may, however, exist in slightly drier regions in water retaining sites such as wetlands and waterways. The pathogen causes the greatest impact in areas that receive more than 600 millimetres of annual rainfall. *Phytophthora cinnamomi* does not establish on coastal limestone soils of high pH (although other species of Phytophthora may) suggesting that wetlands on this substrate are unlikely to be infected.[13]

The degree to which plant communities are infested by *P. cinnamomi* is dependant on several factors, including the length of time the disease has been present, the history of land use, species susceptibility and landscape and soil factors. The location of many wetlands low in the landscape means that they have a high likelihood of being infested if *P. cinnamomi* is located within their catchments, particularly if infested waterways or other drainage lines direct surface water into them. If food and oxygen are available, and temperature, chemistry and microflora are not inhibitory, *P. cinnamomi* is also able to survive in groundwater.[14] Other than the jarrah forest, little is known of the movement of *P. cinnamomi* in groundwater. Although *P. cinnamomi* can be transported via groundwater for more than a couple of metres in the jarrah forest, the same movement may not occur elsewhere and the spread of the pathogen from one infested wetland to another wetland via groundwater may not occur (B Shearer 2009, pers. comm.). There are three basic requirements for the rapid, long-distance, lateral (sideways) dispersal of *P. cinnamomi* through groundwater:

1. the soil structure must be porous enough (full of holes) to allow spores to move through[15]
2. groundwater flow must largely be lateral (sideways)[16]
3. the connections between larger groundwater pores must be unbroken over significant distances.[17]

Figure 9. Distribution of Phytophthora dieback in the south-west of WA.
© Dieback Working Group.

Extent of infestation

According to conservative estimates, 15–20 per cent of the jarrah (*Eucalyptus marginata*) forest has been infested by *P. cinnamomi,* with the proportion considerably higher in the wetter, north-western part of the forest.[13] Around 60 per cent of the montane shrublands and banksia and mallee woodlands of the 116,000-hectare Stirling Range National Park are infested, as are perhaps 70 per cent of the seasonally inundated banksia woodlands in the Shannon and D'Entrecasteaux national parks.[13] In contrast, largely because of restricted vehicular access, less than 0.1 per cent of the 328,000-hectare Fitzgerald River National Park is infested with *P. cinnamomi,* even though a large part of it receives more than 400 millimetres annual average rainfall.[13] There are a number of wetlands in the south-west that have been identified as being impacted by Phytophthora dieback. These include: Lake Logue near Eneabba; Lake Warden in Esperance; numerous wetlands on the southern Swan Coastal Plain ironstone (Busselton area); and wetlands within Jandakot Regional Park and Lightning Swamp bushland in the Perth metropolitan area.

Recognising the symptoms of Phytophthora dieback

The first step in the management of Phytophthora dieback is determining whether it is present or absent, and if it is present, identifying which parts of a site are infested.

Indicator species

The first indication that *P. cinnamomi* has spread into a new area is the death of 'indicator species' (Figure 10). An indicator species is a plant species which is reliably susceptible to *P. cinnamomi* (i.e. the disease usually kills that species). Common indicator species in wetlands include the swamp peppermint (*Taxandria linearifolia*), swamp banksia (*Banksia littoralis*), and swamp teatree (*Pericalymma ellipticum*). The distribution and composition of indicator species will vary from place to place according to vegetation type.

➤ Lists of Western Australian native species both susceptible and resistant to Phytophthora dieback are available on the Centre for Phytophthora Science and Management website. This list includes both dryland and wetland species. www.cpsm.murdoch.edu.au[18]

Figure 10. Deaths of oak-leaved banksia (*Banksia quercifolia*) in a seasonally waterlogged wetland within D'Entrecasteaux National Park on the south coast of WA.
Photo – Dieback Working Group.

Epicormic: (of a shoot or branch) growing from a previously dormant bud on the trunk or limb of a tree

Other causes of plant decline or death

Plant decline and death may be caused by factors other than Phytophthora dieback. When assessing a site for the presence of Phytophthora dieback using indicator species, it is important to be able to discount other causes of plant death or decline such as:

- insect attack
- changes to surface water or groundwater levels
- poor soil or water quality (including nutrient enrichment, acid sulfate soils and secondary salinity)
- the honey fungus *Armillaria luteobubalina*
- fire
- nutrient deficiencies.

If Phytophthora dieback 'resistant species' such as flooded gum (*Eucalyptus rudis*), moonah (*Melaleuca preissiana*) and white myrtle (*Hypocalymma angustifolium*) are dying, then it is likely that the cause is something other than *P. cinnamomi*.

When affected by Phytophthora dieback, moderately susceptible plant species such as jarrah (*Eucalyptus marginata*) may show symptoms of crown decline including the yellowing of leaves and death of primary leaf-bearing branches.[19] **Epicormic** buds may shoot, forming new branches along existing branches, with the leaves on these tending to be smaller than on the primary branches. Over time, epicormic branches will decline, resulting in an overall thinning of the crown.[19] Trees showing symptoms of crown decline may take a number of years to die. In some cases, apparently healthy trees (in groups or individually) can suddenly collapse and die.

Interpreters

The personnel who carry out the tasks of detection, diagnosis and mapping of Phytophthora dieback are known as 'interpreters' because they interpret disease symptoms to draw conclusions about the health of the vegetation. By recognising disease symptoms and observing the pattern of indicator species deaths, interpreters can build up a picture of the history and future progress of the disease at a particular site. As the pathogen spreads through an area, some or all susceptible plants become infected and die. Consequently, there will be a spread of ages in the plants that have succumbed to Phytophthora dieback, ranging from more recent deaths with yellowing or brown leaves, through to older leafless stags, and finally to remnant stumps in the ground.

Apart from a knowledge of common indicator species, interpreters need to be able to assess the influence of landscape position, soils and drainage on the development of the disease and to be able to distinguish the effects of Phytophthora dieback from those of drought and other diseases of native vegetation such as *Armillaria*.

Aerial photography

Since 1986, 230-millimetre (1:4,500) colour aerial photographs have been used for mapping the position of *P. cinnamomi* disease boundaries in WA. Given sufficient disease expression (dead and dying plants) at the time of photography, an interpreter can make decisions about the disease status of an area (that is, whether *P. cinnamomi* has caused the deaths). Field visits to view the symptoms and sampling of recently dead plants are used to verify the interpretation of aerial photographs.

Ground stripping

Ground stripping involves interpreters walking an array of parallel lines through the bush to determine whether disease caused by *P. cinnamomi* is present and to record its position. It is used in areas which are not suitable for interpretation using 230-millimetre aerial photography or when such photography is not available. Field maps and **GPS** units are used to record the position of infected plants and the boundaries of infested areas. Boundaries are demarcated with painted yellow tree blazes or 'dayglo' orange flagging tape (Figure 11).

GPS: global positioning system, an accurate worldwide navigational and surveying facility based on the reception of signals from an array of orbiting satellites

Figure 11. Sample being taken from a dead tree for laboratory testing to determine the presence of *Phytophthora cinnamomi.* Photo – M Pez/DEC.

Sampling to determine the presence of *Phytophthora cinnamomi*

To confirm the accuracy of the interpretation of disease symptoms, samples of root and lower stem material as well as adjacent soil can be taken from recently dead plants (Figure 12). Long-dead plants are unlikely to return positive results from sampling even if *P. cinnamomi* killed the plant. Collected material can then be sent to an analytical laboratory for testing. Laboratories offering this service can provide detailed instructions on how to take a sample, store and transport the collected materials to them.

Laboratories are able to determine the presence of *P. cinnamomi* using either the baiting or direct plating method. 'Baiting' involves mixing soil from the sample bag with distilled water in a container and then floating cotyledons (imillimetresature leaves) of *Eucalyptus sieberi* (which have purple undersides) on the water. If after five to ten days the cotyledons have lost their purple colour the sample is presumed to be infected with *P. cinnamomi*. 'Plating' is then carried out by placing the cotyledons on antibiotic **agar** in a **petri dish**. Plated baits are left for a maximum of three days and if *P. cinnamomi* is not evident after this time, the plates are discarded, and the samples are recorded as negative.

It is important to note that a negative result from a sample does not mean that the site is free of pathogen. A negative result only means that the pathogen was not captured in the sample. Multiple samples of a site may be required before a positive result can be obtained.

Agar: a gelatinous substance obtained from any of various kinds of red seaweed and used to grow cultures of fungi and other microorganisms

Petri dish: a shallow covered dish used for the culture of fungi and other microorganisms

Figure 12. A DEC interpreter marking the boundary of an area infested with *Phytophthora cinnamomi* with yellow tree blazes and orange flagging tape. Photo – Dieback Working Group.

Mapping Phytophthora dieback

Interpreters generally produce two main types of maps, a *P. cinnamomi* occurrence map and a *P. cinnamomi* protectable areas map, both of which are accompanied by a written report. The *P. cinnamomi* occurrence map shows disease distribution, and is used as a basis for the *P. cinnamomi* protectable areas map and a *P. cinnamomi* hygiene management map. Three categories are shown on a *P. cinnamomi* occurrence map: uninfested, uninterpretable and infested (Table 3).

A *P. cinnamomi* protectable areas map shows areas which are disease free, and which are considered to be able to be protected from the establishment of new centres of infestation (arising from the activities of humans) through the implementation of hygienic management practices (Figure 13). The *P. cinnamomi* hygiene management map is jointly prepared with the land manager as part of the protectable areas *P. cinnamomi* hygiene planning process, and forms part of the *P. cinnamomi* hygiene plan. The frequency at which these maps need to be produced will be influenced by the circumstances at a particular wetland.

Table 3. *Phytophthora cinnamomi* occurrence categories used in maps

Unmappable Areas that are sufficiently disturbed so that *Phytophthora cinnamomi* occurrence mapping is not possible at the time of inspection	Further categorisation may be possible after variable regeneration periods for different types of disturbance	
Mappable Natural undisturbed vegetation. *Phytophthora cinnamomi* occurrence mapping is possible	**Infested**	Area that a qualified person had determined to have plant disease symptoms consistent with the presence of *Phytophthora cinnamomi*
	Uninfested	Area that a qualified person had determined to be free of plant disease symptoms that indicate the presence of P*hytophthora cinnamomi*
	Uninterpretable	Area where indicator species are absent or too few to determine the presence or absence of *Phytophthora cinnamomi*

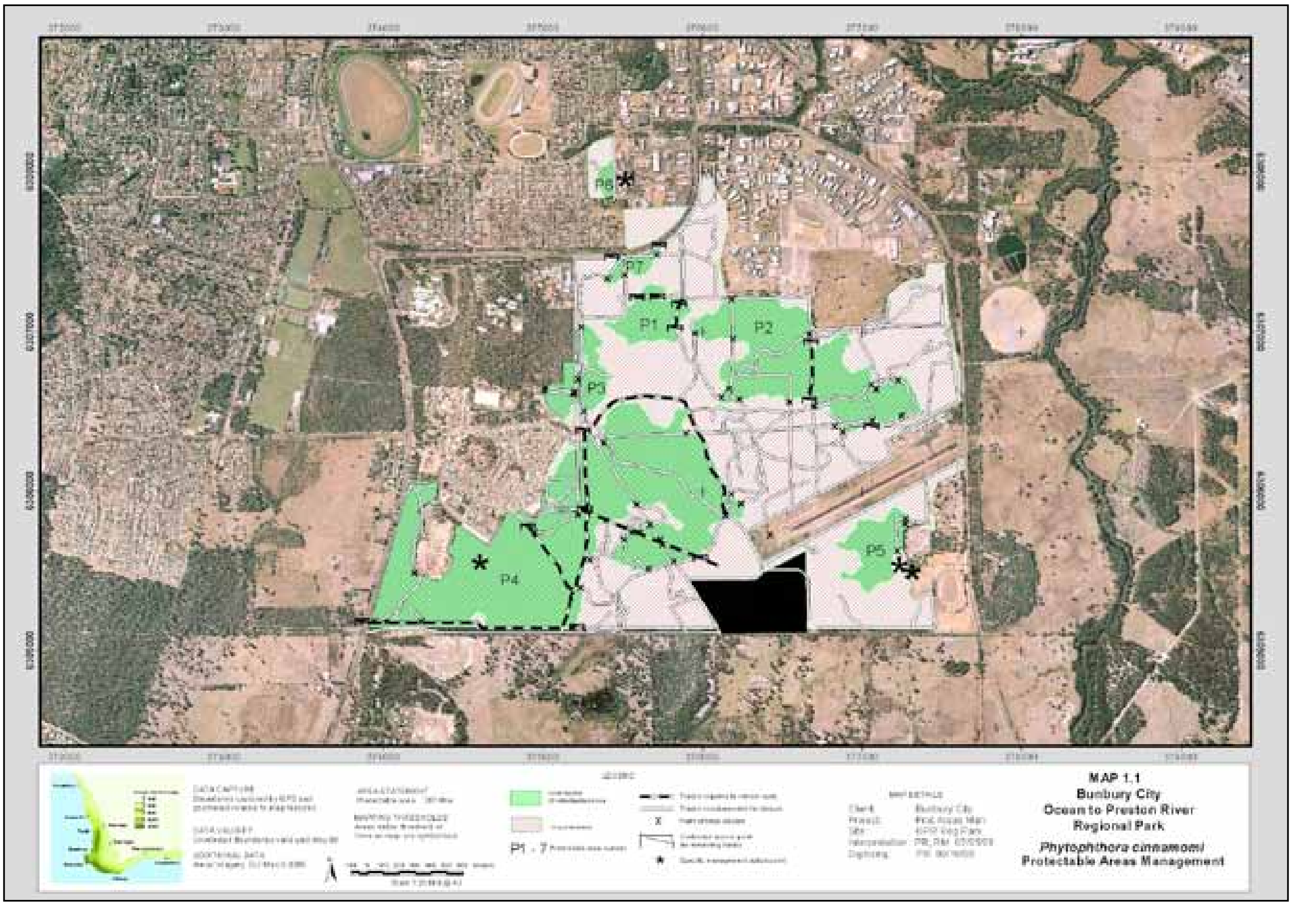

Figure 13. A protectable areas map produced for Manea Park in Bunbury. Map produced by Glevan Consulting for the City of Bunbury.

Key management techniques for tackling Phytophthora dieback in wetlands

Phosphite: an aqueous solution of mono- and di-potassium phosphite used to protect plants against Phytophthora dieback

The management of Phytophthora dieback in wetlands can be summarised into three steps:

1. Assess the site and map Phytophthora dieback occurrence
2. Prepare and implement management procedures
3. Treat plants with **phosphite**.

Assessing a wetland for Phytophthora dieback

As described above, there are a number of ways of assessing a wetland for the presence of Phytophthora dieback, which include field assessment, analysis of aerial photography and laboratory testing of plant and soil samples. A key component of an assessment is determining the distribution of Phytophthora dieback at a site and recording this information in a *P. cinnamomi* occurrence map.

As a number of common wetland species are resistant to Phytophthora dieback and may not show symptoms of the disease, many wetlands may be considered to be 'uninterpretable' with regard to detecting the presence of *P. cinnamomi.* It may therefore be necessary to test plant and soil samples in a laboratory to confirm the presence or absence of *P. cinnamomi* at wetland sites. If a wetland is located low in the landscape and Phytophthora dieback has already been positively identified within the catchment, it can be assumed with reasonable confidence it already is or soon will be infested. In such cases it may be considered unnecessary to have wetland plant and soils samples tested in the laboratory.

More information on assessing a wetland for the presence of Phytophthora dieback is available in the sections: 'Recognising the symptoms of Phytophthora dieback' and 'Sources of more information on managing Phytophthora dieback in wetlands' within this topic.

Preparing and implementing management procedures

Once present, *P. cinnamomi* cannot be eradicated from an area. As such, the management of Phytophthora dieback is focused on minimising the spread of the pathogen. How Phytophthora dieback is managed at a wetland depends largely on knowing if it is present and having an understanding of its distribution. Whether Phytophthora dieback is present at the site or not, or is spread throughout an entire site or located in an isolated section, all management procedures are based on minimising the movement of soil, plant material and water (hygiene management), and on protecting plants by treating them with phosphite.

➤ Excellent examples of how to manage Phytophthora dieback in different scenarios are provided in: Dieback Working Group (2008). *Managing Phytophthora dieback in bushland: A guide for landholders and community conservation groups.*[2]

The basic steps in preparing and implementing Phytophthora dieback management procedures include:

- Identifying areas which are free of Phytophthora dieback and have a high likelihood of being maintained as such ('protectable areas') and focusing hygiene management on them
- Implementing hygiene protocols to minimise the spread of Phytophthora dieback including signage, boot-cleaning stations, vehicle and equipment washdowns (see Figure 14)
- Setting a timeframe for re-assessing areas for the presence of Phytophthora dieback and preparing up-to-date occurrence maps
- Utilising up-to-date occurrence maps to review the effectiveness of management procedures.

A number of guidelines for the best practice management of Phytophthora dieback have been produced for a variety of land managers including landholders and community groups, local government and state government agencies. A list of the best practice guidelines that have been produced for each of these groups is included in this section. Please note that the documents listed may be of use to land managers beyond the targeted group.

It is also worth noting that the guidelines listed below have been written with dryland bushland rather than wetlands in mind. When relating management guidelines to wetlands it is important to keep the following points in mind:

- If Phytophthora dieback is present in a catchment area, wetlands located low in the landscape within that catchment have a high likelihood of being infested.
- When preparing management guidelines which deal with restricting the movement of water, it is important to consider the implications of restricting water movement on the wetland water regime.

➤ For additional detail on wetland water regime see the topic 'Wetland hydrology' in Chapter 2.

(a) **(b)**

Figure 14. Phytophthora dieback hygiene management activities: (a) signage; and (b) boot-cleaning station. Photos – Dieback Working Group.

Guidelines for the best practice management of Phytophthora dieback

For landholders and community groups:

Dieback Working Group (2008). *Managing Phytophthora dieback in bushland: A guide for landholders and community conservation groups.*[2]

For local government:

Dieback Working Group (2000). *Managing Phytophthora dieback: Guidelines for local government.*[20]

For state government and other agencies:

Department of Conservation and Land Management (2003). Phytophthora cinnamomi *and disease caused by it: Volume I Management guidelines.*[3]

Department of Conservation and Land Management (2004). *Best practice guidelines for the management of* Phytophthora cinnamomi *(Draft).*[11]

Treating plants with phosphite

Phosphite, an aqueous solution containing phosphorus, has shown great promise in the battle to preserve rare and endangered Western Australian native plants under threat from *P. cinnamomi*. Depending on how it is applied, phosphite can provide protection for vulnerable plant species against the disease for up to ten years. Phosphite is an environmentally safe, inexpensive chemical that is systemically transmitted throughout treated plants and has a very low toxicity to animals.

Fungicide: a substance that kills fungi

Fungistat: a substance that inhibits the growth and reproduction of fungi without destroying them

How it works

The mode of action of phosphite is not fully understood. At high enough concentrations, phosphite will act directly on *P. cinnamomi* as a **fungicide** or **fungistat** to either kill or halt its growth. This direct effect appears to occur within the *P. cinnamomi* organism, but it also appears that the progress of infection by *P. cinnamomi* is halted when it comes into contact with phosphite in plant tissue. This may be because high phosphite concentrations interfere with the way that phosphorus is used by the pathogen for survival. The application of phosphite may also trigger the plant's self-defence mechanism, causing it to wall-off and isolate the invaded root cells. Plants in poor health which are treated in time have been shown to fully recover and remain healthy for a number of years.

History of use

Previously called phosphonate, phosphite has been used to protect avocado, pineapple and cocoa crops against Phytophthora disease since the 1970s. In the late 1980s Department of Conservation and Land Management research staff began investigating whether the fungicide provided any protection to Western Australian native plant species. Phosphite solution was injected into jarrah (*Eucalyptus marginata*) and several banksia species, and the treatments showed considerable promise; slowing and stopping the growth of the pathogen within the plants under attack.[21]

Research efforts continued over the next decade and included field trials in locations ranging from the northern sandplains near Eneabba to Fitzgerald River National Park east of Albany. Aerial application of phosphite to native plant communities was tested for the first time in 1993 in several reserves near Albany and proved a success. Aircraft allow for relatively cheap and rapid treatment of entire plant communities containing rare plant species, and are suitable for areas where the ruggedness of the terrain would make ground application prohibitively expensive.

How it is applied

Phosphite is applied via stem injection (to trees with a diameter at chest height of 10–14 centimetres or greater[22]), or as a spray by aerial or ground application (Figure 15). One drawback with aerially applied phosphite is that protection normally only lasts for about two years, whereas stem injection may provide protection for up to ten years. There are two main strategies for its application. Firstly, phosphite can be applied in an already infested area to protect susceptible plants that have not yet been infected or help already infected plants to recover.[23] Secondly, phosphite can be used strategically for effective protection ahead of an advancing 'front' of *P. cinnamomi*. A 30–40-metre-wide swathe of phosphite can be applied in front of an advancing *P. cinnamomi* infestation to prevent root-to-root transfer of the pathogen across the barrier.[22] If the infested area is upslope of the area to be protected the protective swathe would need to be wider than if it is downslope. This is because of the possibility of overland or subsurface transport of *P. cinnamomi* zoospores for considerable distances downslope following rainfall. In contrast, movement of an infestation upslope is generally slower, being mainly caused by root-to-root contact between plants.

Figure 15. (below) Application of phosphite via (a) spraying; and (b) stem injection. Photos – Dieback Working Group.

(a)

(b)

Wetting agent: a substance that helps water or other liquid, to spread or penetrate (also known as a surfactant or penetrant)

Applying phosphite in wetlands

If applying phosphite, or any other chemical, in wetlands or other natural environments it is important to minimise any off-target impacts such as the unwanted decline or death of plants or animals. It is also important to be aware that when phosphite is applied as a spray, by aerial or ground application, it is mixed with a wetting agent to help droplets hold onto leaf surfaces until they are absorbed. There are significant risks associated with the use of wetting agents in wetlands and other aquatic environments including toxic effects on tadpoles.[24,25] As such, it is essential that any off-target impacts of wetting agents are also minimised.

➤ For more information on reducing the off-target impacts of the application of chemicals see the topic 'Wetland weeds' in Chapter 3.

The off-target impacts of chemicals (including wetting agents) can be reduced and the effectiveness of application increased by:

- selecting the correct application method (which will depend on the type and size of plants being targeted, for example, using stem injection where possible)
- applying the chemical under ideal environmental conditions (for example, dry, still wind conditions to minimise spray drift and timing the application while susceptible fauna aren't in a critical life phase such a reproduction)
- carefully following the manufacturer's instructions.

The future

Research into phosphite and its application is continuing. Among the areas requiring additional investigation is the refinement of application rates, times and frequencies for different vegetation types. Phosphite cannot eradicate *P. cinnamomi* from an area once it has established. However, by boosting the ability of plants to ward off infection, it does provide some ability to protect endangered plants that might otherwise become extinct in the wild within a few years. Nevertheless, the major strategy for limiting the environmental damage caused by the pathogen remains the prevention of the transport of infested soil into uninfested areas, by means of quarantine and the maintenance of high standards of hygiene.

Monitoring the success of management and restoration techniques

Monitoring is a key component of wetland management and restoration. The information collected through monitoring can be used to assess if management is successful, and if not, to adapt or modify the management (adaptive management).

In order to monitor the success of Phytophthora dieback management techniques it is recommended that up-to-date Phytophthora dieback occurrence maps are prepared. The frequency at which these maps need to be produced will be influenced by the circumstances at a particular wetland. Specialist advice should be sought from an interpreter or other specialist for more information. As Phytophthora dieback impacts wetland vegetation, it is recommended that vegetation also be monitored to assess the effectiveness of management activities.

➤ Additional detail on monitoring wetland vegetation is provided in the topic 'Monitoring wetlands' in Chapter 4.

case study

Manea Park – a collaborative approach to Phytophthora dieback management

Manea Park is approximately 500 hectares in size and is managed by the City of Bunbury for conservation purposes. The reserve contains more than 150 hectares of wetlands including damplands, palusplains and sumplands. The reserve also contains two threatened ecological communities, which are both listed as vulnerable. Both of these communities are wetlands (Figure 16).

Much of the flora of Manea Park is highly susceptible to Phytophthora dieback and, as such, an investigation into its distribution within the park was conducted by the then Department of Conservation and Land Management in 2001. This survey found that up to half of Manea Park was infested with the disease, including many of the wetland areas and some heavily degraded dryland areas. In 2007, the City of Bunbury secured funding from Project Dieback to have Manea Park reassessed and mapped by a consultant. The results from the survey undertaken by Glevan Consulting in 2008 strongly mirrored the results of the 2001 assessment and show that Phytophthora dieback has spread very little since the original mapping exercise in 2001.

The survey undertaken in 2008 found that the vegetation in around 36 per cent of the survey area was sufficiently disturbed (by factors such as clearing and grazing) that *P. cinnamomi* mapping was not possible at the time of inspection, and was otherwise referred to as 'unmappable'. This 36 per cent included many of the wetlands within the reserve. Of the area that was able to be mapped, approximately 22 per cent was found to be infested with *P. cinnamomi.*[26] The survey also found that it was predominately low-lying wetlands in the north-west of the park that were infested. Although many wetland plant species are resistant to Phytophthora dieback, impacts of the disease have been observed in a number of the wetlands in Manea Park, including those recognised as threatened ecological communities, with deaths of swishbush (*Viminaria juncea*), swamp banksia (*Banksia littoralis*) and swamp teatree (*Pericalymma ellipticum*) recorded (Figure 17).

In mid-2008 the City of Bunbury decided to take the next step in protecting Manea Park from Phytophthora dieback by developing management strategies for dieback-free areas or 'protectable areas' in the reserve. Limited areas of wetland were included within the identified protectable areas, as most of the wetland areas within the reserve were identified as either being infested with *P. cinnamomi* or unmappable.

Management strategies for protectable areas were developed at a workshop with key stakeholders including the Department of Environment and Conservation, Department for Planning and Infrastructure, Project Dieback, the Friends of Manea Park and the City of Bunbury's consultant. It was agreed that track closure and the control of track access were the most effective strategies available. To complement these strategies it was also agreed to erect interpretive signage at strategic points throughout the park to explain the current *P. cinnamomi* infestation status and the management strategies implemented to control its spread.

To manage those areas already infested by *P. cinnamomi*, phosphite treatment will be undertaken in a number of places, including the wetland areas. This treatment will assist in reducing the loss of plant species in these high conservation value areas.

For further information contact the City of Bunbury Environmental Officer.

Figure 16. One of the threatened ecological communities in Manea Park near Bunbury. Photo – C Mykytiuk/DEC.

Figure 17. Deaths of swamp banksia (*Banksia littoralis*) in one of the threatened ecological communities in Manea Park. Photo – C Mykytiuk/DEC.

Whether or not to manage Phytophthora dieback in a wetland

When deciding whether or not to manage Phytophthora dieback at a wetland, there are a number of factors that should be considered, which will help focus the decision-making process. These include:

- **What are the values under threat from Phytophthora dieback?**

  Example: Which plants species are susceptible to Phytophthora dieback? What will be the impact of the loss of these species?

  If the values under threat from Phytophthora dieback are significant, managing dieback will be a higher priority.

- **How practical and effective will management (hygiene management and treatment with phosphite) be?**

  Example: Does Phytophthora dieback already occur throughout the site? Is the wetland located low in the landscape within a catchment already infected with Phytophthora dieback?

  If management actions are unlikely to be effective in controlling and/or reducing the impact of Phytophthora dieback at the site, it may not be a good use of resources to implement these actions.

- **Will management protect the values under threat?**

  Example: Are the values under threat from Phytophthora dieback, already threatened by a potentially more significant degrading process such as altered hydrology? Is the wetland already so significantly impacted by Phytophthora dieback that management will not achieve improvements?

  If managing Phytophthora dieback is not going to be sufficient to protect the values under threat because they're threatened by something else, or because the site is already severely impacted by Phytophthora dieback, it may not be a good use of resources to implement these actions and instead resources may be better directed towards managing another degrading process.

- **How urgent is the need for action – at what rate is Phytophthora dieback diminishing wetland values?**

  Example: Is Phytophthora dieback causing a rapid and significant loss of plants? Is the loss of plants from Phytophthora dieback relatively slow over time?

  Threats that are having a rapid impact would generally be a higher priority for management than threats that act very slowly.

- **What are the financial and other costs (such as time and labour) of carrying out management activities?**

  Example: How do financial and other costs of Phytophthora dieback mapping and hygiene management weigh up against the values under threat? How do the financial and other costs of phosphite treatment weigh up against the values under threat?

  Management will be most cost effective and beneficial if the site has high values, and the cost of management actions is relatively low.

- **Taking into account the management of other threats or degrading processes – what is the most logical sequence for undertaking management actions?**

  Example: If it is planned to close tracks or paths as part of a hygiene management plan, it should be determined whether the paths are needed for other management activities, such as providing access to remove car bodies or other rubbish?

  All threats and degrading processes need to be documented for the site, and any possible links between these identified prior to planning on-ground management.

In some situations, it may be necessary to make decisions regarding the management of Phytophthora dieback across multiple wetlands within one landscape or management area. In these situations, the questions listed above will still be a useful guide to decision-making. Often it is most effective to focus resources on those wetlands that are minimally degraded and still have high values, as intervention is likely to be most successful, and have most conservation value at these sites.[21]

In an ideal situation, any management activities should be undertaken as part of a comprehensive wetland management plan which would address other management issues or degrading processes and their associated management activities. It is strongly encouraged that a management plan is prepared, however basic it may be.

➤ For additional detail on preparing a wetland management plan see the topic 'Planning for wetland management' in Chapter 1.

Topic summary

- Phytophthora dieback refers to the introduced plant disease caused by the microscopic soil-borne organism *Phytophthora cinnamomi*.
- *P. cinnamomi* invades the roots of plants, killing cells, reducing the ability of a plant to take up and transport water and nutrients, often resulting in the death of the plant.
- Many common wetland species are susceptible to Phytophthora dieback, however field observations have suggested that a large number of wetland species are resistant to *P. cinnamomi*, hence wetland plant communities often don't exhibit signs of Phytophthora dieback disease.
- The loss of native vegetation as a result of Phytophthora dieback can have a number of detrimental impacts on wetlands including increasing the risk of erosion and sedimentation, reducing water quality, loss of biodiversity, loss of habitat and food for native fauna and a subsequent decline in native fauna.
- The fact that most wetlands are located low in the landscape means that they have a highly likelihood of being infested if Phytophthora dieback is located within their catchments.
- Once present, *P. cinnamomi* cannot be eradicated from an area. As such, the management of Phytophthora dieback is focused on minimising the spread of the pathogen to disease-free areas.
- The management of Phytophthora dieback is based on minimising the movement of soil, plant material and water, and protecting plants by treating them with phosphite.
- The management of Phytophthora dieback in wetlands can be summarised into three steps:
  1. assess the site and map Phytophthora dieback occurrence
  2. prepare and implement management guidelines
  3. treat plants with phosphite.
- When deciding whether or not to manage Phytophthora dieback at a wetland, there are a number of factors that should be considered including the values under threat, how practical and effective will management be, and the financial and other costs (such as time and labour) of carrying out management activities.

Sources of more information on managing Phytophthora dieback in wetlands

Websites

Dieback.org.au
www.dieback.org.au
Information on the impacts of Phytophthora dieback and its management. Designed to be a one-stop shop for information on how to manage Phytophthora dieback.

Dieback Working Group
www.dwg.org.au
Information on the impacts of Phytophthora dieback and its management.

Project Dieback
www.dieback.net.au
Information on the impacts of Phytophthora dieback, maps of its distribution within the south-west, and lists of susceptible and resistant species in the South Coast NRM region.

Centre for Phytophthora Science and Management
www.cpsm.murdoch.edu.au
Information on Phytophthora dieback research, links to national best practice guidelines, and list of susceptible and resistant species.

Department of Environment and Conservation
www.dec.wa.gov.au (search for 'Phytophthora')
Information on the impacts of Phytophthora dieback and its management, state government Phytophthora dieback policy, Phytophthora dieback Atlas.

Department of Sustainability, Environment, Water, Population and Communities
www.environment.gov.au (search for 'Phytophthora')
Information on Phytophthora dieback management and threat abatement.

Publications

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Glossary

Agar: a gelatinous substance obtained from any of various kinds of red seaweed and used to grow cultures of fungi and other microorganisms

Dieback: the progressive dying back of a plant as a result of disease or unfavourable conditions

Epicormic: (of a shoot or branch) growing from a previously dormant bud on the trunk or limb of a tree

Fungicide: a substance that kills fungi

Fungistat: a substance that inhibits the growth and reproduction of fungi without destroying them

Germinate: begin to grow, usually following a period of dormancy (resting phase)

Geophytes: land plants that survive unfavourable periods by means of underground food-storage organs, for example rhizomes, tubers and bulbs

GPS: global positioning system, an accurate worldwide navigational and surveying facility based on the reception of signals from an array of orbiting satellites

Mycelium: the vegetative part of a fungus, consisting of microscopic thread-like filaments known as hyphae

Oomycetes: the group of fungae-like organisms known as the water moulds

Pathogen: any organism or factor causing disease within a host

***Phytophthora cinnamomi*:** an introduced water mould that attacks the roots of susceptible plant species, resulting in the decline or death of the plant

Phytophthora dieback: the introduced plant disease caused by *Phytophthora cinnamomi*, which results in the decline or death of susceptible plants

Petri dish: a shallow covered dish used for the culture of fungi and other microorganisms

Phosphite: an aqueous solution of mono- and di-potassium phosphite used to protect plants against Phytophthora dieback

Wetting agent: a substance that helps water or other liquid, to spread or penetrate (also known as a surfactant or penetrant)

Personal communications

Name	Date	Position	Organisation
Chris Dunne	26/09/2008	Senior Research Scientist	Department of Environment and Conservation, Western Australia
Dr Bryan Shearer	21/01/2009	Principal Research Scientist	Department of Environment and Conservation, Western Australia

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