Phytophthora diseases in New Zealand forests

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Abstract

This article provides a brief overview of the status of *Phytophthora* diseases in New Zealand forests. Recent outbreaks of *Phytophthora* diseases internationally and within these forests, including Red Needle Cast of *Pinus radiata* caused by *Phytophthora pluvialis* and *Agathis australis* (kauri) dieback caused by *Phytophthora* taxon Agathis (PTA), have highlighted the biosecurity threat these species pose to New Zealand. In isolated cases, Red Needle Cast has impacted *P. radiata* plantations through the premature defoliation of mature needles.

Kauri dieback, caused by *Phytophthora* taxon Agathis, has resulted in devastating disease within some sites. Preliminary research indicates that both these diseases will respond to treatment with phosphite, consistent with current international *Phytophthora* management. Ongoing research into Red Needle Cast, *Phytophthora* taxon Agathis induced kauri dieback and other *Phytophthora* diseases within *P. radiata* and kauri is focusing on understanding the epidemiology of the diseases, the chemical and genetic mechanisms of resistance, and also screening for durable resistance to multiple *Phytophthora* species.

Many other *Phytophthora* pathogens have been identified within New Zealand. These have not been found to cause serious disease in native or exotic forest systems, despite some being known to cause diseases of great consequence internationally. Significant examples include *P. cinnamomi, P. multivora* and *P. kernoviae*. As a result of increased global movement of plant material, New Zealand's and other international forests are vulnerable to new *Phytophthora* diseases. However, through the world's best practice adaptive management the threat and impacts of these diseases can be reduced.

Introduction

New Zealand's planted and native forests serve many important economic, social, ecological and environmental functions. However, they are under continual pressure from factors such as site disturbance, climate change, and pests and pathogens including *Phytophthora* species. The genus *Phytophthora* includes significant plant pathogens belonging to the group Chromista, with life-cycles and reproductive strategies similar to many soil-borne plant pathogenic fungi. *Phytophthora* species pose significant threats to New Zealand forestry, natural ecosystems, agriculture and horticulture as they:

- can be easily dispersed through soil, water or aerial-borne reproductive structures, or through many human activities (Ristaino, et al., 2000)
- often have a wide host range infecting exotic and indigenous plant systems, affecting many different species through the deterioration of ecosystems, as observed for *P. cinnamomi* (Hee, et al., 2013)
- are increasingly being spread internationally through globalisation and plant trade (Brasier, 2008)
- can form new hybrid species within managed and natural ecosystems, which may lead to rapid generation of new pathogens and diseases (Érsek, et al., 2008)
- are difficult to identify in asymptomatic host tissues as observed for *P. ramorum* and *P. kernoviae* (Denman, et al., 2009), or where symptoms have been supressed with phosphite as is widely the case with nursery stock (Hardy et al., 2001).

Globally, *Phytophthora* species consist of around 116 described species that are known to affect both natural and modified ecosystems (Scott, et al., 2013). However, since 2000 there has been an increase in the rate of discovery of new *Phytophthora* species, resulting from increased research and reclassification of existing isolates using new molecular techniques (Kroon, et al., 2011). Brasier (2009) suggests there may be as many as 600 potential *Phytophthora* species, which have historically been known for their role in agricultural systems and various diseases in fruit, vegetable, agricultural and tree crops.

Within their source environment *Phytophthora* species co-evolve with the plants in the communities, seldom causing noticeable disease to their hosts. However, exposure to new host species and new environments presents opportunities for novel host-pathogen combinations and also for the formation of new species through sexual recombination with previously non-connected species (Hansen, 2008). Increasingly, known and newly identified *Phytophthora* species are associated with diseases in forests and natural ecosystems (Scott, et al., 2013). Many important international *Phytophthora* pathogens of forestry are known to have spread from the horticultural industry to natural ecosystems and forestry including *P. lateralis* (Hansen, et al., 2000), *P. alni*, (Jung, et al., 2004) and *P. ramorum*, (Rizzo, et al., 2005).

Phytophthora species in NZ

Species of *Phytophthora* are associated with many published diseases in New Zealand and within various land use systems, as shown in Table 1. Some of these species are believed to have originated outside New Zealand, including *P. cinnamomi*, which is considered indigenous to the Asian Pacific Celebes-New Guinea region (Arentz, 2012), but the origin of many of these species is unknown. Species including *P. cactorum, P. cinnamomi* and *P. multivora* affect multiple plant systems including agriculture, forestry and natural ecosystems.

As indicated in Table 1, 60 per cent of identified *Phytophthora* species in New Zealand affect agriculture, with 32 per cent of species associated with exotic forestry and 35 percent with natural ecosystems. Most are known to spread through soil-borne spores or via root-to-root contact. However, some significant species including *P. infestans*, *P. pluvialis* (Reeser, et al., 2013), *P. kernoviae* (Brasier, et al., 2005) and *P. captiosa* and *P. fallax* (Dick, et al., 2006) are spread through aerial spores. New Zealand's moderate moist climate may favour the dissemination of these species, but their movement into colder regions may be limited due to sub-optimal temperatures.

Symptoms of *Phytophthora* infection are typically cryptic and difficult to identify, often exhibiting as secondary symptoms of wilt and drought dieback resulting from root and vascular necrosis. Environmental sampling has been employed to more clearly understand the diversity of *Phytophthora* species within the Waitakere Ranges in Auckland (Randall, 2011). Environmental sampling techniques aim to isolate *Phytophthora* species within the environment independent of symptom observation, to determine species diversity and inoculum production (Reeser, et al., 2011).

Randall (2011) identified *P. multivora, P. gonapodyides, P.* taxon 'Pgchlamydo', *P. kernoviae, P. asparagi* and a yet-to-be described species, and provided important information about the dissemination and biology of these species. However, such environmental surveys do not provide any information about the impacts of these putative pathogens. Some important species, including *P. cinnamomi*, may also be difficult to identify using recognised sampling techniques from streams and water catchments (Hüberli, et al., 2013). Most *Phytophthora* species known in New Zealand have been identified morphologically. A re-evaluation of historic collections, using new molecular tools, has resulted in the reclassification of many species that were originally identified morphologically (Beever, et al., 2006).

Some significant *Phytophthora* diseases in NZ forests

New Zealand has a strong history of researching *Phytophthora* diseases within natural and production forest systems. This includes significant research into *Phytophthora* associated diseases in planted and indigenous forests including the role of:

- soil-borne *Phytophthora* species associated with diseases of *Pinus radiata, P. muricata, Cupressus macrocarpa, Chamaecyparis lawsoniana*, and other conifers in shelterbelts (Newhook, 1959)
- *P. cinnamomi* in forestry and natural ecosystems (Newhook, 1970)
- *P. heveae* associated with *Agathis australis* (kauri) dieback (Gadgil, 1974)
- *P. cinnamomi* associated with kauri root and stem dieback (Horner, 1984)
- *P. cinnamomi* in indigenous ecosystems, including kauri and Northofagus forests (Johnston, et al., 2003)
- *P. captiosa* and *P. fallax* associated with disease in different Eucalyptus species (Dick, et al., 2006)
- soil-borne *Phytophthora* species associated with *Macropiper excelsum* (Kawakawa) dieback (Ho, et al., 2010)
- soil-borne *Phytophthora* species, including *Phytophthora* taxon Agathis associated with kauri dieback (Beever, et al., 2009; Beever, et al., 2010; Than, et al., 2013; Waipara, et al., 2013)
- *P. pluvialis* on *P. radiata* (Dick, et al., 2014; Hood, et al., 2014; Rolando, et al., 2014).

Red Needle Cast of Pinus radiata – *Phytophthora pluvialis*

Red Needle Cast is a foliar disease of New Zealand *P. radiata* caused by *P. pluvialis* that was originally identified in 2008 (Dick, et al., 2014). The disease is first expressed on green foliage as short, pale green, discrete lesions within which small, black, often band-like, resinous marks are often observed. Lesion symptoms progress with the needle browning before being prematurely cast, as shown in the first photo. Symptoms first appear between March and August (autumn or winter) and may last until November (late spring), depending on the region and year.

Symptoms have been observed in some years, mainly in plantations in the northern, eastern and central parts of the North Island and in the northern South Island. The resent onset of Red Needle Cast in New Zealand's *P. radiata* plantations indicates that Phytophthora pluvialis has been introduced to this country. Preliminary studies also show that *P. pluvialis* isolates from New Zealand compared very closely to isolates from mixed forests in Oregon, which is the only other region in which the pathogen has been identified (Reeser, et al., 2013). *Phytophthora kernoviae* has also been infrequently isolated from needles of *P. radiata*, with Red Needle Cast symptoms (Dick, et al., 2014).

A similar foliar disease of *P. radiata* caused by *P. pinifolia* in Chile is the only other *Phytophthora* species known to cause significant needle disease on *Pinus radiata* (Ahumada, et al., 2013). *Phytophthora pinifolia* has never been found in New Zealand, despite routine forest health surveys, and never been reported outside Chile. Hood et al. (2014) have recently demonstrated that *P. pluvialis* does not contaminate or colonise bark and sapwood of *P. radiata* log segments or present a risk of disease spread on logs or bark.

Table 1: *Phytophthora* species associated with plant diseases in NZ

Phytophthora species with known hosts	Clades [1]	Main source [2]			
		Agriculture	Exotic forests	Horticulture/ amenity plantings	Natural Ecosystems
P. cactorum	1	✓	✓	✓	✓
P. infestans		✓			
P. nicotianae		✓		✓	✓
P. citricola [3]	2	✓	✓		✓
P. citrophthora		✓			✓
P. meadii				✓	
P. multivesiculata				✓	
P. multivora			✓	✓	✓
P. plurivora		✓		✓	
P. pluvialis [4]	3		✓		
Phytophthora taxon Agathis (PTA) [5]	5				✓
P. asparagi	6			✓	
P. gonapodyides		✓			
P. megasperma		✓	✓		
PG Chlamydo				✓	✓
P. cambivora	7			✓	
P. cinnamomi		✓	✓	✓	✓
P. europea					✓
P. fragariae		✓			
P. brassicae	8	✓			
P. cryptogea		✓	✓		✓
P. drechsleri		✓		✓	
P. erythroseptica		✓		✓	
P. hibernalis		✓		✓	✓
P. porri		✓			
P. primulae				✓	
P. syringae		✓	✓		
P. captiosa	9		✓		
P. fallax			✓		
P. kernoviae	10	✓		✓	
No. of *Phytophthora* species associated with each land use system		**18**	**10**	**15**	**11**

Note: as recorded on the Landcare Research – New Zealand Fungi and Bacteria Database (Landcare Research), sourced May 2014, including the plant system each has been associated with in New Zealand and the *Phytophthora* phylogenetic clades within which they belong (Kroon, et al., 2011).

[1] Phylogenetic clades represent groups of related organisms with common ancestry. An understanding of phylogenetic relationships between species may help outline the origins of different species and aspects of their biology.

[2] Based on recorded isolation from host species only and not necessarily indicative of disease prevalence.

[3] Includes many isolates that have subsequently been re-classified as *Phytophthora multivora* using molecular techniques.

[4] Phylogenetic clades, as indicated in (Reeser, et al., 2013).

[5] Originally identified as *Phytophthora heveae* (Gadgil, 1972, using morphological techniques). However, this organism has since been classified as a new species, *Phytophthora* taxon Agathis (Beever, et al., 2009).

Field expression of Red Needle Cast, Gisborne, July 2008

Phosphite application has been identified as a potential tool to help protect a broad range of plant species within New Zealand (Horner, et al., 2013) and overseas (Hardy, et al., 2001). Recent chemical control trials have demonstrated that stem injections and aerial phosphite application in *P. radiata* reduce disease severity caused by *P. pluvialis* (Rolando, et al., 2014). Active management is therefore a viable option for increasing *P. radiata* forestry productivity and improving resilience to environmental stress. Further work is required to understand the long-term impact of *P. pluvialis* on forest productivity.

Kauri dieback – *Phytophthora* taxon Agathis

Kauri is a keystone species within forests of northern New Zealand and a culturally significant taonga species to Maori (Ecroyd, 1982). Historically, kauri was an important economic forestry species, but excessive exploitation has reduced the population to relatively small fragments. Recent research into kauri productivity with modern silvicultural practices suggests that kauri may be viable for future plantations (Steward, et al., 2010).

Several *Phytophthora* species have been associated with kauri dieback, although only *P. cinnamomi* and *Phytophthora* taxon Agathis have been shown to directly incite tree death. *Phytophthora cinnamomi* has been shown to contribute to kauri dieback on some sites in the Waitakere Ranges (Horner, 1984). Further research is required to determine whether the other species found in soil beneath kauri contribute to the ill health. In 1972, a *Phytophthora* species was isolated from an area of dying kauri on Great Barrier Island (Gadgil, 1974). These isolates were identified morphologically as *P. heveae* and were shown to be the causal agent of the observed symptoms using pathogenicity tests on seedlings and young trees.

Subsequently isolates of a *Phytophthora* species from soil beneath declining kauri in the Waitakere Ranges Regional Park and Waipoua Forest in the early 2000s were identified using molecular phylogenetic analysis as an undescribed species, distinct from *P. heveae*. Re-examination of the Great Barrier isolates using these techniques confirmed the synonymy of the isolates which were termed *Phytophthora* taxon Agathis (Beever, et al., 2009).

Phytophthora taxon Agathis was identified as the causal agent of kauri dieback, capable of killing all life stages of kauri including seedlings, rickers and larger iconic trees as an aggressive primary pathogen (Beever, et al., 2010). Surveillance programs have recorded tree health and mapped the distribution of kauri dieback and the presence of associated pathogens (Waipara, et al., 2013). *Phytophthora* taxon Agathis was the most frequently isolated pathogen and was identified as the causal agent of kauri dieback at multiple locations, particularly within Auckland and Northland. Other *Phytophthora* species were isolated from declining plants, although *Phytophthora* taxon Agathis was the only species isolated from stem cambium.

Resin bleed from the collar of *Agathis australis* (kauri) caused by *Phytophthora* taxon Agathis (PTA)

Behavioural differences

Some *Phytophthora* species that have been isolated from New Zealand's forests, but are not associated with significant disease or plant death here, are important pathogens in ecosystems overseas including *P. kernoviae* and *P. cinnamomi*. In New Zealand, *P. kernoviae* has rarely been associated with plant disease, with the few reports being on the exotics species and one report of foliar disease of the native miro, *Prumnopitys ferruginea* (Dick, et al., 2014). *Phytophthora kernoviae* is recognised to have been in New Zealand for at least 60 years, and it is thought likely to have originated in the southern hemisphere (Ramsfield, et al., 2009). However, outside New Zealand *P. kernoviae* is only associated with plant disease in the United Kingdom, where it causes disease and mortality in some forest trees and ornamental species (Brasier, et al., 2005) and foliar necrosis in native heathland communities of *Vaccinium myrtillus* (Beales, et al., 2009).

Phytophthora cinnamomi is the only Oomycete included in the top 100 of the world's worst invasive alien species as identified by the Invasive Species Specialist Group (ISSG, 2007). Within New Zealand, *P. cinnamomi* is widely distributed and has been isolated from soils in apparently undisturbed forests and isolated situations (Johnston, et al., 2003); although it is considered to have originated outside New Zealand (Arentz, 2012). Newhook (1959) noted that *P. radiata* is susceptible to *P. cinnamomi* on conducive sites at different ages. However, it has rarely been observed causing sudden collapse and death, as is commonly observed with this pathogen internationally on a range of host plants.

The variation in disease caused by *P. cinnamomi* internationally and within New Zealand may be a result of different environments. Within this country's indigenous forest, *P. cinnamomi* is known to cause localised damage within various communities during weather periods suited to inoculum build-up (warm, wet winters), followed by periods of elevated plant stress (unusually dry summers) (Johnston, et al., 2003). Compared to diseases in Mediterranean climates, including southern Australia (Hee, et al., 2013) and Spain (Serrano, et al., 2012), New Zealand's temperate climate means that despite the extensive distribution of the pathogen, disease symptoms are not often expressed above ground, as plants generally require only a proportion of their roots for normal growth (Johnston, et al., 2003).

Cumulative impact of *Phytophthora* species

Phytophthora species are renowned for being highly adaptive and persistent and they can have significant long-term impacts that may not be apparent for many years or even decades. There is increasing acknowledgement of the complex, yet compounding, impacts of *Phytophthora* species and their role in tree declines and sup-optimal tree health globally (Sturrock, et al., 2011). For soil-borne species, considerable root pruning takes place well before crown symptoms are evident with associated loss of tree productivity. Many tree species can tolerate extensive amounts of root damage to fine feeder roots without showing overt visible above-ground symptoms (Tsao, 1990). While they may not directly kill trees as primary pathogens, they may have significant impacts on plantation productivity and ecosystem function.

Both *P. cinnamomi* and *P. multivora* have been isolated from the soil kauri dieback sites (Waipara, et al., 2013) and these species may be playing a role in the observed decline. Similarly, *Phytophthora* species are being increasingly associated with foliar necrosis and premature defoliation of forest trees. Such sub-lethal infections can have a significant and ongoing impact on productivity of plantations or contribute to tree decline in native ecosystems. The loss of production associated with the diverse range of *Phytophthora* species present is yet to be quantified within New Zealand's forest systems.

Climate

New Zealand's moderate climate may reduce symptom severity caused by soil-borne *Phytophthora* species, which typically cause greatest impacts during periods of drought stress. Conversely, New Zealand's moderate climate may favour significant foliar *Phytophthora* pathogens, including *P. pluvialis*, and some significant biosecurity threats including *P. ramorum* and *P. pinifolia*. Climate variability may therefore have a significant impact on these relationships and disease severity.

Biosecurity and disease management

As indicated by recent environmental sampling programmes (Randall, 2011) and reviews of Phylogenies based on multi-loci DNA sequence data (Kroon, et al., 2011), it is likely that there is a higher diversity of *Phytophthora* species within New Zealand than currently recorded. To enable a timely response to any new incursion, it is valuable to have accurate data on the pre-existing diversity of *Phytophthora* species within a given region, to confirm area freedom and validate any potential containment and/or eradication response.

Once established these pathogens are essentially impossible to eradicate, especially given New Zealand's high rainfall, topography, soil type and vegetation density, in contrast to eradication of *Phytophthora* species in other ecosystems (Dunstan, et al., 2010; Goheen, et al., 2013). Given the high impacts, net cost of disease control and lost productivity associated with *Phytophthora* species, the most cost-effective management strategy is to prevent their introduction (Hansen, 2008). This requires a clear understanding of their biology and how they are dispersed through anthropogenic means (Ristaino, et al., 2000).

Field expression of *Phytophthora* taxon Agathis, Auckland, January 2014

Conclusion

Phytophthora taxon Agathis has been shown to have a devastating localised impact within kauri ecosystems, but no other *Phytophthora* species have been reported that significantly undermine the viability of New Zealand's forests. Based on the emergence of new species of *Phytophthora* internationally being demonstrated to have broad host ranges, the plantation and horticultural sectors, urban and native forests are all vulnerable to as yet unknown diseases. Where *Phytophthora* pathogens are shown to be deleterious to established plant systems, be they productive or natural, adaptive management based on existing knowledge of the forest system and international best practice for *Phytophthora* disease management provides the best likelihood of success in protecting vulnerable forest systems.

Effective management of *Phytophthora* diseases requires the integration of multiple disease management tools. Important principles include prevention, hygiene, screening and selection and chemical control options, with the utility of each depending greatly on the epidemiology of each disease. As the complexity of disease interactions increases, it is important to understand the ecology of the impacted ecosystems in order to maintain ecosystem function and productivity. To help future-proof the industry, proactive breeding should aim to select for broad, durable resistance to as many *Phytophthora* species as possible.

Acknowledgements

The authors thank Lindsay Bulman, Margaret Dick, Peter Clinton, Judy Gardner and the Forest Health Oversight Committee for their comments on an earlier draft of the manuscript. This work was supported by the Ministry for Business, Innovation and Employment, the New Zealand Forest Growers Levy Trust and the Kauri Dieback Joint Agency under the Healthy Trees, Healthy Future Prosperity from Trees: Protection from Current and Future Disease Programme C04X1305.

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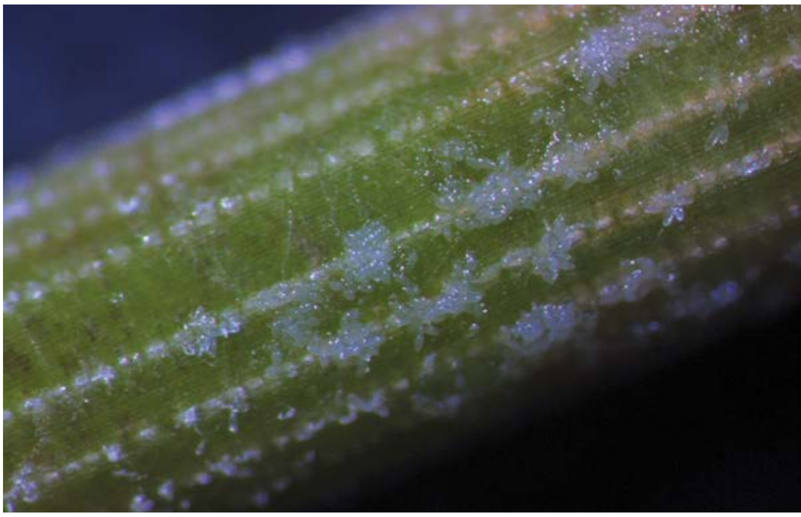

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