Management of red needle cast, caused by *Phytophthora pluvialis*, a new disease of radiata pine in New Zealand

R.J. Ganley, N.M. Williams, C.A. Rolando, I.A. Hood, H.S. Dungey,
P.N. Beets and L.S. Bulman

Scion, Private Bag 3020, Rotorua, New Zealand

Corresponding author: Beccy.Ganley@scionresearch.com

Abstract Ten years ago there were no known foliar diseases caused by *Phytophthora* on pine trees worldwide. Since then two significant *Phytophthora* diseases have emerged on radiata pine, one of which is only known in New Zealand. Red needle cast is a disease caused by the pathogen *Phytophthora pluvialis*, which is thought to have originated from northwestern USA. This paper reviews the challenges the New Zealand forestry industry faces when dealing with this disease and evaluates the management options, such as chemical control, biological control and breeding programmes, being investigated to minimise its effect on forest productivity. The distribution of the pathogen in New Zealand and research that shows bark, logs and wood are free of the pathogen, therefore unlikely to pose biosecurity threats through trade in these products, are also outlined.

Keywords disease management.

INTRODUCTION

New Zealand's natural and urban landscapes and high earning horticultural and forestry industries are at increasing risk from *Phytophthora* diseases, particularly those caused by new and emerging foliar *Phytophthora* species, which are devastating forest ecosystems worldwide (Brasier 2008; Hansen 2008). The word 'phytophthora' means plant destroyer and these fungal-like organisms have lived up to their name over the past few centuries. Notable examples include *Phytophthora infestans*, which was responsible for potato blight in Ireland during the mid-1800s (Haas et al. 2009); *Phytophthora ramorum*, which has decimated a broad range of plant species in the USA and Europe (Rizzo et al. 2002; Grünwald et al. 2008); and *Phytophthora cinnamomi*, which

has caused extensive destruction of native forest ecosystems in Australia (Shearer et al. 2004).

Phytophthora species are well-recognised as soil-borne pathogens with broad host ranges, and this is true for *Phytophthora cinnamomi*, which has over 950 known hosts, including *Pinus radiata* (Shearer et al. 2004; Hardham 2005). *Phytophthora cinnamomi* is a root-associated pathogen and in New Zealand affects a wide variety of plant species (Podger & Newhook 1971; Casonato et al. 2008; Reglinski et al. 2009). In recent years foliar *Phytophthora* species have become more common and widespread. Similar to the root-associated *Phytophthora* species, some foliar *Phytophthora* have broad host ranges, such as *Phytophthora ramorum*, which can infect over

100 plant species (APHIS 2012). Over the last 15 years there has been a substantial increase in the number of new *Phytophthora* species identified (Kroon et al. 2012), but of more concern is the rise in the number of new diseases or behaviour changes in established *Phytophthora* species (Brasier 2008). This expansion has been closely associated with changes in global travel, transport and trade. Changes in plant management, exposure to new hosts or changes in climate are also likely to have contributed to this increase.

Ten years ago there were no known foliar *Phytophthora* diseases on pine trees worldwide, but since then two have emerged on *Pinus radiata*. *Phytophthora pinifolia* is the causal agent of daño foliar del pino (DFP) in Chile (Durán et al. 2008) and *Phytophthora pluvialis*, while native to USA, causes red needle cast (RNC), which is only known to occur in New Zealand (Dick et al. 2014). These pathogens have created new challenges for successful disease management because *Phytophthora* belong to the kingdom Chromista and are not fungal, meaning traditional fungal pathology methods for inoculation and control of these pathogens are not always effective. Increased concerns with market access, exemplified by trade restrictions imposed on Chile by Australia and Korea in 2008, have added further complexity when dealing with a new disease.

RED NEEDLE CAST

Where did this disease originate and what is it doing?

Red needle cast was first reported in plantations of *Pinus radiata* in parts of New Zealand in 2008. The disease is characterised by discrete khaki-coloured bands that appear on affected needles, and these lesions are frequently accompanied by small, dark, resinous spots or narrow bands. A reddish-browning of foliage eventually develops over the lower or whole crowns of affected trees, until the needles are cast. The disease tends to occur on older needles with the unaffected new flush preventing complete defoliation of affected trees.

The timing and appearance of RNC symptoms is different from any of the other

known foliar diseases in New Zealand, such as dothistroma needle blight and cyclaneusma needle cast. Based on New Zealand's structured forest health surveillance system and consistent national disease monitoring throughout the year, these observations raised concern that RNC was a new disease and immediate action was taken to identify a causal agent. Isolation from infected material resulted in the discovery of a *Phytophthora* species which was at that time undescribed. Later, it was found to be identical to a species found and subsequently described as *Phytophthora pluvialis* in Oregon, USA (Reeser et al. 2013). *Phytophthora pluvialis* is probably native to the northwestern USA, although there have been no reports of disease associated with this species on pines or other conifer species from this region. The symptoms of RNC bear a striking similarity to the symptoms of DFP in Chile, which is caused by *Phytophthora pinifolia*, even though both pathogens are not closely related *Phytophthora* species (Kroon et al. 2012; Reeser et al. 2013).

Impact and risk assessments

Phytophthora pluvialis is a foliar pathogen isolated from needles of *Pinus radiata*, and sporangia that produce zoospores have been observed on needles under laboratory and field conditions. Extensive attempts to isolate or recover *Phytophthora pluvialis* from other plant tissues have been unsuccessful (Hood et al. 2014). Likewise attempts to artificially colonise plant material other than needles have been unsuccessful. These findings, in conjunction with studies of spore survival on logs at different temperatures over time, have been used for risk assessments (Hood et al. 2014). From a market access perspective, the possibility of transmitting *Phytophthora pluvialis* from New Zealand on radiata pine logs is negligible.

In New Zealand, *Phytophthora pluvialis* has been detected in stands from Northland to Westland (Dick et al. 2014). The timing of disease expression and severity of the disease has differed between regions and years. Occurrence of RNC is likely to be dependent on climatic factors, such

as temperature, moisture and leaf wetness, which could account for the observed considerable variation in disease expression. This variation has made quantification of growth loss associated with RNC difficult. One study, completed in an area with some of the greatest levels of RNC infection, showed annual incremental growth decrease of approximately 35% in the year following severe disease (P.N. Beets, Scion, unpublished data). Over the 3-year period of the study, the average growth reduction was 16%, with no loss in the third year. Severe disease can almost completely defoliate affected trees, but recovery is common and in the following year the one-year foliage is unaffected. Growth losses are not persistent unless repeated defoliation occurs. In some areas or years the incidence of RNC is so low that it is unlikely to result in any significant reductions in tree growth.

In the field, RNC defoliation events do not necessarily occur every year, and climatic factors are expected to be correlated with years when the defoliation events have occurred. Repeated defoliation events have been recorded for some sites, but in general these tend to occur every second or third year. However, these observations are based on limited data and a clearer picture of the disease cycle may appear with increased observations. There have been no reported cases of tree mortality directly caused by *Phytophthora pluvialis*. In comparison to *Phytophthora pinifolia* and DFP in Chile, *Phytophthora pluvialis* is a less aggressive pathogen; *Phytophthora pinifolia* can infect branches and saplings and can kill seedlings and mature trees (Durán et al. 2008; Ahumada et al. 2013). For trees affected by foliar *Phytophthora* species, it is unclear what role secondary pathogens play in predisposing trees to increased infection or mortality.

CONTROL AND MANAGEMENT

Prior to the discovery of *Phytophthora pluvialis*, the impact of *Phytophthora* species on exotic plantation forestry in New Zealand had been minimal, as had the impact of diseases caused by other pathogens such as bacteria or viruses. Disease issues in exotic plantations have

predominantly involved fungal species, and control and management regimes have been targeted to this group of organisms. This has posed a challenge in developing effective control and management strategies for RNC, as it is a new disease and disease management methods suitable for controlling fungi are not always applicable for chromists. To overcome this, the New Zealand forest industry has worked closely with several science organisations to develop short- and long-term strategies to control and manage RNC. These strategies have concentrated on chemical control, biological control and breeding resistant host plants.

Chemical control

Chemical control of RNC has focused on the use of phosphorous acid (phosphite), known to be effective against diseases caused by *Phytophthora* (Shearer & Crane 2009; Kanaskie et al. 2011). Several trials have been carried out to assess the efficacy of this compound for prevention of infection of *Pinus radiata* by *Phytophthora pluvialis*. Studies have been undertaken to determine: (1) factors that enhance the uptake of phosphite into *Pinus radiata* needles (Rolando et al. 2014), (2) effects of dose and timing of phosphite applications on efficacy against *Phytophthora pluvialis* infections, and (3) persistence of phosphite in *Pinus radiata* needles. Results obtained indicate that phosphite reduces lesion length on infected needles for up to 6 months post-treatment. This is promising for effective disease management, but further research is required before an operational strategy using phosphite for RNC management can be deployed.

Trials have also been initiated to investigate the efficacy of alternative active ingredients to phosphite. This is to ensure that there are known alternatives to phosphite should: (1) the disease show signs of resistance to this chemical, (2) the use of phosphite become restricted due to high cost, environmental or social concerns, and/or (3) the alternatives provide better and more prolonged control of RNC. This research has indicated that copper-based fungicides (such

as copper oxychloride) and the phenylamide metalaxyl-M, are also effective at reducing infection of needles exposed to *Phytophthora pluvialis*. Further study of these fungicides is required to confirm their persistence in host plants as well as their curative activity should they be applied post-infection.

The success of chemical control is dependent on the identification of the causal agent of RNC and elucidating disease epidemiology (Dick et al. 2014). Pressure to develop cost-effective solutions to a potentially economically damaging disease has meant fast-tracking ideas, sometimes ahead of conclusive results or development of standard tests. This made early research on chemical control challenging and sometimes inconclusive. However, 3 years into the programme key tools have been identified, such as definitive assays on chemical efficacy and the detection of phosphite in host needles. Establishing that the peak infection period is between April to September (autumn, winter and spring) has also meant chemicals can be applied when infection is most likely to occur. Predicting years when infection is likely would allow targeting of chemical control applications.

Biological control

Development of biological control for foliar diseases of pine trees has had strong support from industry. This has involved the identification and screening of potential agents against several different fungal diseases, and more recently RNC. Several agents have been shown to be effective for control of *Phytophthora* diseases (Hoitink et al. 2006; Zhang et al. 2010; Gallou et al. 2011). Integration of biological control with other control methods will be important for sustainable and effective management of these diseases.

Breeding for resistance

Information about tolerance of *Pinus radiata* in production and breeding populations is needed to understand the risk of RNC, and to avoid deployment of highly susceptible host material in regions prone to the disease. Susceptibility

to *Phytophthora pluvialis* is difficult to assess in field trials because of reliance on natural inoculum and suitable environmental conditions for development of RNC, which is strongly influenced by climatic factors. Of the several structured *Pinus radiata* germplasm evaluation trials located throughout New Zealand, only one is located in an area with consistently high *Phytophthora pluvialis* inoculum levels and RNC disease expression. Preliminary assessment of this trial indicates that tolerance to RNC is heritable (0.21-0.31), and should therefore respond to selection (H.S. Dungey, Scion, unpublished data). As the disease is now widely distributed in several regions, more field assessments of reaction of host germplasm collections are required during periods of high inoculum loading.

The development of detached needle and artificial *in planta* assays using zoospore suspensions as inoculum has provided alternative methods to assess germplasm lines for tolerance to RNC. These artificial inoculation methods have been used to assess the genetic diversity of archive *Pinus radiata* populations and new lines of clonal material being developed for future deployment. Where possible, these results are being correlated to the field-based data. A limitation with these artificial inoculation methods is that the inoculum has to be prepared under stringent conditions and must be used within 2 h of preparation, before the infective zoospores encyst and become less infective.

CONCLUSIONS

Red needle cast, caused by *Phytophthora pluvialis*, is a new disease affecting *Pinus radiata* in New Zealand. The timing of disease expression and severity of the disease has differed between regions and years, which has provided challenges for evaluating its impact on forest production and developing effective disease management strategies. Chemical control and host breeding programmes show promise for controlling this disease. These combined with biological control, are expected deliver short- and long-term strategies to minimise this disease in New Zealand forests.

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