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The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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Headline

The biology, symptoms and diagnosis of red band needle blight have been reviewed and nursery control strategies, including potential preventative fungicide treatments, have been suggested.

Background

Red band needle blight, also called Dothistroma needle blight, is a potentially devastating foliar disease affecting many species of pine and occasionally other conifers including European larch, Norway spruce, Sitka spruce and Douglas fir. The disease, caused by the fungus *Dothistroma septosporum,* is considered not native to Britain and, although first observed here in 1954, it was not until the late 1990s that it became much more widespread. By 2003 the disease was causing widespread damage to Corsican pine plantations in Thetford Forest and elsewhere in England, Scotland and Wales on the same host. It has been found on forest nurseries in England on several occasions since 2005, affecting Corsican pine, and in 2008 the disease was found affecting Scots pine. The disease was first identified in Scotland in 2002, where it has caused extensive damage to stands of Corsican and lodgepole pine, and is increasingly reported on Scots pine. In summer 2010 it was found on three forest nurseries in Scotland, affecting Scots pine. Where the disease affects plants intended for planting, Plant Health authorities take action to minimise disease spread as red band needle blight is an EU listed Quarantine Pest. In England and Wales regulation of the fungus on nurseries is by the Plant Health and Seeds Inspectorate (PHSI) and in Scotland by the Scottish Executive, Rural Affairs Department (SERAD) on behalf of the Forestry Commission Plant Health Service.

Quarantine controls include destruction of affected batches and destruction, or holding over, pending inspection at the end of the next growing season (or until the nursery is found free of symptoms since the beginning of the last growing season), all other pine plants within 550 m of an infection. Due to the severe financial impact such action would have on the affected nurseries, the consequent effects on woodland creation and small businesses and the increased risk of introducing new pathogen strains if planting stock is sourced from outside Great Britain, the Forestry Commission Plant Health Service agreed a compromise position for the autumn 2010 / spring 2011 planting season. Pine plants in nursery beds with confirmed infection were destroyed. Under licence, pine plants within 550 m of a known infected bed will be permitted to be used for planting, in Scotland only, accepting that it is not possible to confirm that all such stock is uninfected; woodland owners/managers will need to assess the risks of planting such stock based on their knowledge of the disease distribution in their locality (Anon., 2010).

In 2010, even with the compromise position, on one nursery alone the value of stock destroyed was over £120,000. Had the Plant Health authorities not allowed sale of pine plants from beds within 550 m of a know infected bed, under licence in Scotland only, the total financial loss to forest nurseries last year from destroyed stock, quarantined stock and stock with no market due to inability to supply pine would have been over £1.4 million.

PHSI have also confirmed that provided fungicides are approved for use on forest nursery crops, either directly though a label approval or a SOLA, or indirectly through the LTAEU, growers are permitted to use fungicides for prevention of red band needle blight on forest nursery crops. However, there is currently little information on fungicides effective against red band needle blight on forest nurseries.

This literature review was commissioned because of the significant impact that red band needle blight can have when it occurs on forest nurseries and because of the expectation that the same situation will arise in the future. The review provides a historical overview of red band needle blight, summarises information on the causal fungi, biology, symptoms and diagnosis of the disease, and suggests future reading.

Critically, the review details which coniferous trees are susceptible to red band needle blight (page 40) and suggests potential preventative control strategies for use in the nursery situation; including potential fungicide treatments that are currently approved for use on forest nurseries (pages 18- 29).

Historical overview

Red band needle blight, also known as Dothistroma needle blight, is one of the most important foliar diseases of *Pinus* spp. in the world. It infects over 80 species of pine (Brown & Webber, 2008) and has been found worldwide in at least 63 countries (Watt *et al.*, 2009). Its centre of origin has been suggested as South America in high altitude rain forest (Evans, 1984) and in native blue pine (*P. wallichiana*) forests in the Himalayas (Ivory, 1994). Although red band needle blight occurs widely on host species in their native range, it is generally most damaging as an invasive disease in non-native pine plantations i.e. large plantings of a single tree species (Gibson, 1974). Monterey or radiata pine (*Pinus radiata*) is highly desirable for its rapid growth and exceptional timber and consequently has been widely planted in managed plantations. Needle loss caused by red band needle blight results in significant reduction in growth and in some locations on highly susceptible species has caused tree mortality of 65% (Cobb *et al.*, 1969; Parker & Collis, 1966). Severe outbreaks occurred in the 1960s on plantations of radiata pine in East Africa, New Zealand and Chile, leading to the abandonment of planting of this species in East Africa. For pine species grown as Christmas trees (e.g. lodgepole pine, *Pinus contorta* and Scots pine*, P. sylvestris*), even limited needle damage or defoliation can render trees unsaleable.

In Europe the disease was first described from Russian Georgia in 1911 (Bednarova *et al.*, 2006); it is now known in at least 26 European countries, including Denmark, Estonia, Finland, France, Germany, Greece, Italy, Poland, Portugal, Romania, Spain, Sweden and Switzerland (Watt *et al.,* 2009; Barnes *et al.*, 2010). The first record of the disease in the UK was in 1954 on young plants on a nursery in Dorset (Murray & Batko, 1962); over the next 35 years the disease was only seen on this nursery on ponderosa pine and Corsican pine, and in South Wales (Brown *et al.,* 2003). From 1997 onwards the disease became much more widespread in England, mainly affecting Corsican pine, and caused widespread damage on trees between 10 and 30 years old (Brown *et al.,* 2003); now it is found affecting trees of all ages (A Brown, pers. comm.). Since the late 1980s there has also been an upsurge in severity and distribution of the disease in France (Villebonne & Maugard, 1999) and British Columbia, Canada (Woods *et al.,* 2005), and reports on new hosts in other countries (Bednarova *et al.,* 2007). A survey of lodgepole pine in Canada in 2002 found 93% of 700 stands of young trees (under 20 years old) affected, with tree death in 6% of the surveyed area. It is also affecting trees in their native ranges in addition to those planted as exotics (Bradshaw, 2004). In 2006 a survey of all stands of Corsican pine under 30 years old on the Forestry Commission Estate found that 70% of stands were affected, including some previously unreported locations in England, Scotland and Wales (Anon., 2009, Status of red band needle blight in Britain). It was estimated that 44% of the infected stands had crown infection levels of greater than 30%. The disease has not been reported from Ireland.

Causal fungi

Species

Red band needle blight is caused by two closely related species of ascomycete fungi, *Dothistroma septosporum* and *D. pini*. *D. septosporum* has a worldwide distribution while *D. pini* has only been found in the north central United States and, more recently, the Ukraine, south-eastern Russia, France (on Austrian pine, *P. nigra*) and Hungary (Barnes *et al.*, 2008 and 2010; Groenewald *et al.,* 2007; Ioos *et al.*, 2010). *D. septosporum* affects many species of pine and some other conifers while *D. pini* has a limited host range. Red band needle blight caused by *D. pini* is a serious disease of Austrian pine in the United States. In Hungary, both pathogens have been found on the same trees and in some cases the same needles (Barnes *et al.*, 2010). Morphologically the two species are similar in appearance and both exhibit quite large variation between isolates (Barnes *et al.,* 2008). It was only when isolates were compared by DNA sequence analysis that it was possible to separate clearly the two species (Barnes *et al.,* 2004). A subsequent DNA study on the mating type genes in the two pathogens strongly supported the conclusion of two distinct species (Groenewald *et al.,* 2007).

Given that *D. pini* was recently found in France (Ioos *et al.*, 2010) there is now an increased possibility that this second cause of red band needle blight of pine may spread to Britain. Nothing is known regarding differences in aggressiveness or relative ecological fitness of the two pathogens (Barnes *et al.*, 2010). It is also unknown whether there is an increased risk of more severe damage when both pathogens occur in the same forest or nursery; and whether the two species might respond differently to control measures. Accurate identification of the cause of red band needle blight in Britain is likely to become increasingly important (Barnes *et al.*, 2010).

There is also a brown spot needle blight disease of pine, caused by the fungus *Mycosphaerella dearnessii*. This disease, which has been recorded in France and elsewhere in Europe though not in Britain, can be distinguished from red band needle blight by symptoms and morphological features of the fungus (see symptoms and diagnosis section).

Asexual and sexual stages

The species *D. septosporum* is known in the asexual stage (anamorph) where it reproduces by means of asexual spores (conidia), and also in a sexual stage (teleomorph) where it reproduces with DNA exchange by means of sexual spores (ascospores). The asexual and sexual stages of the same fungus are given different names. The sexual stage of *D. septosporum*, which is rarely found, is a species of *Mycosphaerella* known as *Mycosphaerella pini.* The sexual stage of *D. septosporum* was first described in Canada under the name *Scirrhia pini* (Funk & Parker, 1966). The second fungus causing red band needle blight, *D. pini,* is known only in the asexual stage.

Current and previous names of the two fungi that can cause red band needle blight are summarised in Table 1.

Table 1. Current and previous names of the two fungi that cause red band needle blight of pine

Name and distribution	Asexual stage	Sexual stage
Current names		
Worldwide	*Dothistroma septosporum*	*Mycosphaerella pini*
France, Hungary, North central USA, Ukraine	*Dothistroma pini*	Not described
Previous names*	*Cytosporina septospora* *Actinothyrium marginatum* *Septoriella septospora* *Dothistroma septospora* *Dothistroma pini* var. *pini* *D. pini* var. *linearis* *D. pini* var. *Keniensis*	*Scirrhia pini* *Eruptio pini*

*For more detailed information, see Bednarova *et al*., 2006; Groenewald *et al*., 2007 and Barnes *et al*., 2004. There is much taxonomic confusion prior to 2004 and some reports of *D. pini* prior to this time would now be classed as *D. septosporum*.

Mating types

Mating type genes play an important role in the evolution of new genotypes of fungi. Species such as *D. septosporum* which have different mating types are described as heterothallic fungi, species which do not are homothallic. The mating type genes in heterothallic filamentous ascomycete fungi are referred to as MAT1-1-1 and MAT1-2.

Recently the full lengths of the MAT1-1-1 and MAT1-2 genes of *D. septosporum* and *D. pini* have been isolated and sequenced (Groenewald *et al.,* 2007). The mating type DNA sequences of the two fungi were substantially different, showing that the species are distinct genetic entities.

Screening of isolates from global collections of *D. septosporum* showed that only MAT1-2 isolates are present in Australia, Chile and New Zealand, where only the asexual form of the fungus has ever been found. In contrast, both mating types were present in collections from Canada and Europe (e.g. Austria and Poland), where the sexual stage is known, although it is rarely found. Surprisingly, isolates from Britain (and also South Africa), where the sexual stage is unknown despite concerted efforts in Britain to detect it, included both mating types. This result could mean that the sexual stage is present in Britain but has not yet been discovered; or that clandestine sex occurs in the fungus (i.e. DNA exchange through a mechanism other than development of the ascomycete stage, *M. pini*). Information on the distribution and ratio of the two mating types in British populations of *D. septosporum* would be useful; an equal distribution of the mating types would indicate that the sexual stage probably exists here, although it may be limited in occurrence by environmental conditions.

Out of 10 British isolates whose mating type was determined, eight were of one mating type (MAT1-2) and two were of the second mating type (MAT1-1-1). Single isolates from the West Midlands and South East England were both MAT1-2, a single isolate from the Forest of Dean was MAT1-1-1 and seven isolates from the New Forest comprised one of MAT1-1-1 and six of MAT1-2 (Groenewald *et al*., 2007). A more comprehensive study of the distribution and ratio of mating types in Britain is in progress (A. Brown, pers. comm.).

Screening of isolates from the United States of *D. pini*, for which no sexual stage is known, also showed that both mating types were present. It was concluded that the sexual stage of *D. pini* most likely is present in the United States but has not been observed, or has been incorrectly assigned as the sexual stage of *D. septosporum* (which is possible given the morphological similarity of the anamorphs of the two species) (Groenewald *et al*., 2007).

When compared with those of other ascomycete fungi, the mating type sequences of *D. septosporum* and *D. pini* were found to be closely related to *Cercospora beticola*, *Cercospora zea-maydis* and *Mycosphaerella graminicola*, all falling within the Capnodiale Order. Information on fungicide efficacy against *Cercospora* and *Mycosphaerella* species should be a useful indication of potential activity against the red band needle blight pathogens.

Races

Different races of fungi may arise where single major genes confer resistance in a host. When plant breeders introduce a new resistance gene into a host, the pathogen may evolve a new race able to overcome the new resistance gene. A classic example is lettuce downy mildew (*Bremia lactucae*) where new races have evolved as new host varieties with major resistance genes are introduced. There have been no reports of the occurrence of different races of *D. septosporum* (Bradshaw *et al*., 2000).

Strains

Some strains of *D. pini* (that probably would now be classed as *D. septosporum*) were shown to differ in dothistromin toxin production (Bradshaw *et al*., 2000). This toxin can induce symptoms of red band needle blight when injected into pine needles (Shain & Franich, 1981). It was noted that a 1969 New Zealand isolate produced significantly higher levels than 1995 New Zealand isolates, and was genetically indistinguishable from other New Zealand isolates. It was suggested that after decades of asexual reproduction the fungus had lost fitness in terms of dothistromin production, and that this may be part of the reason for the success of current control methods in New Zealand. Conversely, it was also suggested that high toxin levels seen in German alpine strains may be related to severe outbreaks of red band needle blight on *Pinus mugo* in the Alps (Bradshaw *et al*., 2000). However, more recent work (Schwelm *et al*., 2009) suggests that dothistromin does not play a role in pathogenicity but may be linked to the pathogen's competitive ability against other fungi.

Varieties

Before *D. septosporum* and *D. pini* isolates were found by DNA sequence analysis to be different species, attempts were made to divide the anamorph into three varieties based on conidial length. The variety *D. pini* var. *pini* (conidial length 15-28 µm) was distinguished from *D. pini* var. *linearis* (conidial length 23-42 µm) (Thyr & Shaw, 1964). Another variety was distinguished as *D. pini* var. *Keniensis* (conidial length 13-48 µm) (Ivory, 1967). However, recent DNA analysis does not support the separation of isolates into different varieties by morphological features; all isolates of *D. pini* tested from north central United States were of one type according to ribosomal ITS sequence data; and all isolates of *D. pini* tested from elsewhere (including France, Germany and New Zealand) were of a second type

(= *D. septosporum*) according to ribosomal ITS sequence data. The use of these variety names has therefore been rejected. All varieties of both types showed a similar and wide range of spore size, and were also diverse in colony morphology and growth rate (Bradshaw *et al.*, 2000). None of the morphological features examined agreed with the separation into *D. septosporum* and *D. pini* as classified by the DNA sequence data.

Symptoms and detection

The initial symptoms after infection are yellow bands and tan spots (Brown *et al.*, 2003) or water-soaked lesions (Barnes *et al.*, 2004) on the green needles. These are short-lived and the bands rapidly turn brick-red (Bulman, 1993). In addition to the red band, another characteristic symptom is loss of colour and then browning at the distal ends of needles while the base remains green (Brown *et al.*, 2003). These symptoms first appear in late summer and are clearly visible by autumn. Sometimes the red banding is not present and needles have an overall red or brown colour. Small, black fruiting bodies develop in groups below the epidermis in the discoloured tissue and are visible in late spring and summer on both surfaces of needles infected the previous year; when mature the epidermis splits longitudinally and in wet weather they exude a pale pink or colourless mass of spores (conidia). Infected needles usually remain attached to the tree over winter but eventually die and are prematurely cast. The red colour remains even when the needle has died (Murray & Batko, 1962).

The period from infection to symptom development is very variable and depends on external factors, mainly temperature and rainfall but also host species and provenance (Karadzic, 1989). The incubation period is shorter (3-5 weeks) in warm, wet areas and longer (up to 6 months) in cooler, dry areas.

Needles of any age can be affected but infection generally starts on older needles (2-3 year old) in the central part of the tree where the environment is more favourable to infection (Gibson, 1974). Newly emerged needles of Austrian and ponderosa pine were found to be initially resistant to infection: this was determined from observations that first year needles had a higher frequency of lesions near the tip (older tissue) than the base (young tissue) whereas second year needles had similar numbers of lesions at the base as the tip (Peterson, 1967).

In New Zealand, defoliation begins in summer and is most apparent the following spring (Bulman, 1993). Defoliation usually starts at the base of branches and spreads into younger foliage. In severe cases lower branches lose all their needles and the crown is thin with isolated tufts of chlorotic needles remaining at branch tips giving the appearance of a 'bottle-brush' (Brown *et al*., 2003). Shoots are shortened and stunted and may die. Successive years of severe infection result in decreased growth and, ultimately, tree death (Petersen, 1982). Although the initial outbreaks in the UK were on young plants in nurseries, outbreaks in plantations of Corsican pine since the late 1990s have included trees of all ages (A. Brown, pers. comm.). In New Zealand, *D. septosporum* affects trees from planting to about 15 years old; the disease is seldom detected in nurseries although young seedlings are known to be susceptible (Gadgil, 1967). Symptoms of red band needle blight on needles, young plants and trees of Corsican pine are shown in Figure 1. Disease symptoms are fully illustrated in: Forestry Commission Information Note 49 (www.forestry.gov.uk/fr/infd-6zckae) and in Hansen and Lewis (1997).

Figure 1. Dothistroma needle blight on Corsican pine: (a) a severely infected tree; (b, c) infected branches showing needle death; (d) infection on young plants; (e) infected needles showing yellow bands and tan spots; infected two-year-old needles provide the source of inoculum for infection of the one-year-old needles; (f) typical red band symptom with sub-epidermal fruiting bodies. Photographs a, b, c © ADAS; photographs d, e and f © Fera.

Diagnosis

A presumptive diagnosis of red band needle blight can be made based on symptoms (red bands with abrupt transition to healthy green tissue, dying tips of needles and sub-epidermal fruiting bodies) (Anon., 2005; Bednarova *et al*., 2007). However, symptoms alone are not sufficient for a definite diagnosis as many other factors (e.g. boron and sulphur deficiencies, cultural problems such as drought or waterlogging, or foliar pathogens such as *Lophodermium* spp.) can cause needle damage or blight, and may make diagnosis difficult. Also, the red-brown colouration is not always present (Ivory, 1994). Confusion with brown spot needle blight is unlikely at present as this pathogen is absent from Britain.

Confirmation of a *Dothistroma* species can be made by microscope examination of the fruiting bodies and conidia (Anon., 2005; Bradshaw, 2004). The conidia are hyaline, smooth, thin-walled, with one to five septa, long filiform spores 10-32 x 2-3 µm, with a rounded apex and truncate base (Anon., 2005; Barnes *et al*., 2004; Data sheets on Quarantine pests: *Mycosphaerella dearnessii* and *Mycosphaerella pini* http://www.eppo.org/QUARANTINE/fungi/Mycosphaerella_dearnessii/SCIRSP_ds.pdf).
D. septosporum can be distinguished from *M. dearnessii,* the cause of brown spot needle blight, by the appearance of the conidia. Confirmation of a sample takes from a few days to 4 weeks, dependent on the maturing of the fruiting bodies.

Isolation of the fungus from diseased needles is possible but difficult. The fungus is very slow growing in culture (radial growth <1 mm/day at 23°C) and produces a red-brown toxin into the agar (Bradshaw, 2004). Growth of *D. septosporum* from lesions can be overgrown by faster growing endophytic fungi within needles.

Fast and reliable confirmation of which *Dothistroma* species is present (i.e. *D. septosporum* or *D. pini*) can be achieved using molecular techniques, including techniques that allow detection of the pathogen direct from needles (Ioos *et al*., 2010; McDougal *et al*., 2010). These tests are carried out at Forest Research, Alice Holt Lodge.

The possibility of developing a Lateral Flow Device (LFD) as a rapid diagnostic tool to enable growers to distinguish red band needle blight from other diseases and abiotic disorders was considered. This would require making antibodies to *D. septosporum*. The cost of producing a monoclonal antibody is likely to be relatively expensive (e.g. £100,000) and there is a risk of failure. Failure can occur for example if the antibody reacts to the pathogen when it is grown on agar but not to the pathogen in host tissue (N. Boonham, pers. comm.).

For these reasons, and also because real time PCR methods are now available, it seems unlikely that a LFD will be produced in the near future.

Assessment

Methods for assessing the severity of red band needle blight on individual trees are described by Bulman *et al.* (2004). In a young plantation, before canopy closure, the total foliage of the tree contributes to growth and is assessed. In close-canopy stands, only the unsuppressed part of the crown (i.e. that part above the canopy closure point) is assessed. Bare branches, which have lost needles from past infection and other causes are ignored. The proportion of infected to uninfected crown is estimated and given as a percentage.

Technology is being developed to assess Dothistroma needle blight from the air. There has been some success using hyperspectral remote sensing (Coops *et al.* 2003; Stone *et al.*, 2003).

Biology of red band needle blight

Host range

Dothistroma species causing red band needle blight are known to infect over 80 pine species (Brown & Webber, 2008) and under high infection pressure also infect Douglas fir, European larch and five species of spruce (Watt *et al.*, 2009). The pine species considered to be most susceptible include radiata pine (*Pinus radiata*), Austrian pine (*Pinus nigra*), Corsican pine (*Pinus nigra* spp. *laricio*), lodgepole pine (*Pinus contorta* var. *latifolia*) and ponderosa pine (*Pinus ponderosa*) especially where they are grown in plantations (Watt *et al.*, 2009). In England most outbreaks have been on Corsican pine, which is the most widely planted susceptible species (Brown *et al.*, 2003) although it has been reported on a further 13 pine species. It has been shown that young Douglas fir, sitka spruce and Norway spruce can all become naturally infected under field conditions. In the 1950s and 60s the disease was limited to nursery stock of lacebark pine (*P. bungeana*), Corsican pine, lodgepole pine and ponderosa pine on a nursery in Dorset. In Scotland the disease has increased appreciably since 2006, when it was reported on lodgepole pine, with a death rate of approximately 90% occurring in some areas in trees aged 50 years or older (Sturrock *et al.*, 2011). The increase in Britain since the late 1990s has resulted in a moratorium on planting of Corsican pine and lodgepole pine in public forests (Sturrock *et al.*, 2011). Recently there have been increasing outbreaks on Scots pine (*Pinus sylvestris*). The susceptibility of Scots pine is classed by some as highly susceptible (Gadgil, 1967) and by others as rarely infected (Peterson, 1982); the latter is the British experience (Barnes *et al.*, 2003). In the outbreaks on Scots pine seedlings in 2010, it was reported that there were no obvious symptoms in the batches found to be infected. Also, the disease was not found in lodgepole pine seedlings, a species considered to be very susceptible, on the same nursery. The susceptibility of a host likely varies with origin and provenance of a species (Petersen, 1984), site and climatic conditions (Brown *et al*, 2003). Peterson (1967) noted that some trees of Austrian and ponderosa pine adjacent to trees of the same species heavily infected by red band needle blight remained free from infection for three seasons. The relative susceptibility of some coniferous trees of Britain and northern Europe known to be infected by *Dothistroma* species is given in Appendix 1.

Infection and life-cycle

In the UK, May-June appears to be the critical period for infection. Under favourable conditions spores that land on a susceptible host germinate within 48 h, grow over the needle surface and usually penetrate stomata or occasionally the cuticle directly (Gadgil, 1967). Infection takes a minimum of 3 days and longer when conditions are sub-optimal (Gibson, 1974). In humid conditions fungal strands on the needle surface of *P. radiata* start producing conidia after 7 days and continue for several weeks (Gadgil, 1967). After the initial stages of infection, the growth of the fungus is predominantly inside the needle. Growth of the fungus is slow and there is a relatively long incubation period (1-3 months) before first symptom development. The fungus produces a toxin, dothistromin, which diffuses into tissues in advance of hyphae, killing the cells and resulting in their collapse and the production of typical symptoms. After 3-4 months, or longer, small (up to 1 mm long) black fruiting bodies develop below the epidermis, occurring in dense aggregations on highly susceptible hosts (Peterson, 1973). These fruiting bodies are variable in form depending on host and climate. Dry weather after infection increases the latent period before disease expression and slows development of the fruiting body (Gadgil, 1977). The fruiting bodies eventually break through the epidermis and exude a mass of pale pink mucilaginous spores, usually in late spring to summer on needles infected the previous year (Brown *et al.*, 2003). Thus two growing seasons are usually required for the fungus to complete its life-cycle although in warmer areas (e.g. California) it may take only 1 year (Petersen, 1982). A diagram illustrating the life-cycle of *D. septosporum* is given in Appendix 2. In Britain the life-cycle is generally completed in 6-12 months (A. Brown, pers. comm.) spanning two calendar years.

The fruiting body of the sexual stage, *M. pini*, seldom develops (Anon., 2005). Both mating types need to be present in a locality for sexual reproduction to take place and the fruiting body to develop. These are visible as black structures, 400-1,000 x 300-400 μm, arranged linearly on necrotic regions of diseased needles, most on fallen needles. Although it is known that both mating types are present in Great Britain, *M. pini* has not been reported here. *M. pini* has been found elsewhere in Europe, including the Czech Republic, France, Germany, Poland, Portugal and Serbia (Bradshaw, 2004, Gibson, 1972). The original description of *M. pini* was from needles of Scots pine collected in Denmark (Barnes *et al*., 2004). At high altitude in Central America, the fruiting bodies of the sexual stage are reported to form freely on attached and fallen needles (Evans, 1984).

Asexual spores (conidia) are considered to be much more important than sexual spores (ascospores) in infection because they are dispersed over a longer period (7 months vs 3½ months) and also when environmental conditions are generally more favourable for infection (April-June/July) (Karadzic, 1989).

Favourable conditions

Severe outbreaks of red band needle blight in Britain appear to be correlated with wet springs and higher than average rainfall at the time of infection (Brown *et al*., 2003). Moisture or very high humidity (e.g. 95%) is required for spore germination, and high humidity for successful establishment in a host (Gibson, 1972). Growth of the fungus is optimum at temperatures of 16-20°C and infection does not take place below 4.4°C (Gadgil, 1968; Gibson, 1972). While the maximum temperature appears to be 31°C (Watt *et al*., 2009), growth is unlikely if such a high temperature occurs for a sustained period. A very low percentage of conidia germinate below 8ºC or above 25ºC (Ivory, 1967). Severe infection takes place when temperatures are mild (16-20°C), needles are moist for over 10 h and inoculum levels are high (Bulman, 1993). In New Zealand, it was reported that disease severity increased exponentially with increasing length of wetness period (Gadgil, 1977). In Serbia, the critical period for infections was May and June, when the average temperature ranged between 18 and 20ºC; infection did not occur in those months when the average temperature was less than 7ºC (Karadzic, 1989).

Rainfall is particularly critical for infection. In New Zealand, amounts of summer rainfall and severity of infection the following year were found to be positively correlated (Brown, 2011).

In California under cool, moist conditions (greater than 2 m rainfall/year), red band needle blight on radiata pine was epidemic, increasing from 27% of foliage affected to 94% in 2 years (Cobb *et al.*, 1969). In the United States it was reported that trees in regions with an annual rainfall of more than 1270 mm were likely to suffer from severe defoliation (Hansen and Lewis, 1997).

In a 3 year field study in New Zealand involving exposure of seedlings to natural infection, no disease symptoms developed in trees exposed to infection below 7ºC or when the needle wetness period was less than 10 h (Gilmour, 1981). These threshold values were greater (e.g. no infection below 12ºC and 40 h leaf wetness) in some years, possibly due to variation in inoculum levels in the field.

Light intensity also has a strong influence on severity of the disease. Strong light enhances symptoms caused by the dothistromin toxin and shade (light intensity greater than 58 W/m^2) suppresses them (Anon., 2005). However, symptoms continue to develop when shading is removed. Germination of conidia is unaffected by light (Gadgil & Holden, 1976).

In Canada, the increase in red band needle blight on lodgepole pine since the mid-1990s has been associated with an increased frequency of three-day rain events (i.e. rain on at least three consecutive days) at temperatures above 16ºC (Woods *et al.*, 2005). Furthermore, this recent upsurge has been attributed to climate change effected through an increased frequency of summer rain events (Woods *et al.*, 2005).

In southern England, springs during the period 1999-2002 were wetter than normal with an average precipitation of 272 mm compared with an average of 167 mm for the March-May period between 1961 and 1990 (Brown *et al.*, 2003). Increased rainfall coupled with warmer springs may have optimised conditions for infection by *D. septosporum* and this could account, at least in part, for the increased incidence of red band needle blight in Britain between 1997 and 2002.

A computer model (CLIMEX) that determines the effect of various climatic parameters on growth of a host and a fungus, and stress indices that determine the probability a population can survive under unfavourable conditions, was recently applied to red band needle blight (Watt *et al.*, 2009). When validated against over 7,000 disease observations from around the world, it correctly predicted that all observations had a suitable climate for *Dothistroma* spp. The model indicated that these fungi can persist in climates ranging from sub-arctic through temperate and Mediterranean to sub-tropical. Climatic suitability of different regions was classed as unsuitable, marginal, suitable or optimal. Almost all of Western Europe, except for some high altitude areas in Switzerland, and eastern Spain, were classed as suitable to optimal; much of Britain was classed as optimal. The absence of disease in many regions projected to be suitable was considered likely due to the absence of suitable hosts.

In addition to moisture and temperature, the severity of infection is influenced by inoculum density. Kershaw *et al*. (1988) reported that an inoculum density of 6 x 10^5 conidia/needle resulted in only 18% of needles becoming infected. They concluded that severe infection only occurs when there are optimum temperatures, long leaf-wetness periods and high inoculum pressure. Schwelm *et al.* (2009) reported that inoculation of *Pinus radiata* seedlings with a spray of 3 ml of 1 x 10^6 conidia/ml yielded up to 32% infected needles; seedlings were maintained at 24ºC day/16ºC night and were misted for the duration of the trial.

Spread

Asexual spores (conidia) of *D. septosporum* are exuded from acervuli in wet weather (see Appendix 2 for diagram), generally in the spring following infection the previous year, and dispersed by watersplash from rain or heavy mist (Binzhang *et al*., 1992; Petersen, 1982). Spore release may occur at any time during the growing season (April or May – October). In a study of spore dissemination in the United States, large numbers of conidia were disseminated each day there was significant rain. No conidia were trapped on rainless days, a few following a trace of rain (0.3 mm) and large numbers following a small amount (2.3 mm) of rain (Peterson, 1973). If there is warm or hot drying weather soon after rainfall, conidia disseminated onto needles during the rain are unlikely to germinate and no infection will occur. Spores in acervuli on fallen needles lose viability after 4-6 months on the forest floor (Gadgil, 1970).

In general, dispersal in the field is considered to be localised, most occurring within 50-100 m of the source, but some infection occurring at 300 m (Gibson *et al*., 1964).

The development of secondary conidia on fungal strands (i.e. rather than within an acervulus), for several weeks after a spore initially lands on a needle (Gadgil, 1967), indicates that rapid localised spread can occur in the same season as the initial infection, and was considered to account to some extent for the rapid spread of the disease in New Zealand.

There is evidence that asexual spores of *D. septosporum* can travel over long distances as airborne conidia and in water droplets carried in clouds and mists (Gibson *et al.*, 1964; Gibson, 1974). For airborne conidia, the original water droplet required for dispersal is thought to evaporate and the spore spreads further in air currents, possibly up to 100 miles. Red band needle blight was first reported in Australia in the 1970s and it has been suggested that this originated from conidia being blown across the Tasman Sea from New Zealand, where the disease was reported earlier, in 1964 (Gadgil, 1967). However, as the direction of prevailing winds is from Australia to New Zealand, it seems more likely that spread in clouds and mists may have occurred in this direction, or that spread between the countries occurred in imported plant material.

In countries where *M. pini,* the sexual stage of *D. septosporum* occurs, there will be production of airborne ascospores as well as watersplash and airborne conidia. As yet this has not been found in Britain. If it does occur, it will increase the likelihood of long-distance spread and could further influence disease epidemiology through production of new genotypes. In Serbia, ascospores of *M. pini* were produced from mid June until the end of September, sometimes with simultaneous production of conidia from the same disease lesion on *P. nigra* (Karadzic, 1989). On *P. nigra*, it has been suggested that the teleomorph stage (sexual stage) is a saprophytic stage of the fungus and only occurs on 2- and 3-year old attached needles (Butin & Richter, 1983).

Red band needle blight can travel very long distances through movement of infected plant material, possibly with seeds (Barnes *et al.*, 2004) or more likely on live plants. This is considered to be the way the disease was probably introduced into southern Germany and New Zealand, for example (Butin & Richter, 1983). Outside of Britain, there are many reports of red band needle blight outbreaks in nurseries that support an origin via contaminated planting material (Bradshaw, 2004). There is no formal record of red band needle blight as a seed-borne disease (Richardson, 1990), indicating that if the disease is spread with seed it is likely on infected needle trash associated with the seed or as a contaminant on seed.

Survival

Inoculum of *D. septosporum* is persistent. The fungus overwinters as mycelium and immature acervuli in needles (Bingzhang *et al.*, 1992); mature acervuli can produce conidia for several months. Conidial inoculum in dry needles remains viable for more than 6 months. Although dry conditions limit growth of *Dothistroma* spp., the fungi have been found to persist for 11 months without rain (Gibson *et al*., 1964).

In New Zealand, viable conidia were produced on fallen needles in the litter layer for between two and four months (Gadgil, 1970), before they were replaced by competitive saprophytic fungi colonising the dead needles. In fallen needles suspended above the litter layer, to mimic needles caught in lower branches, viable conidia were produced for between four and six months. It was concluded that, in the forest situation, it would be better to wait at least six months after clear felling before replanting with a susceptible species to avoid the possibility of infection by *D. pini* from conidia produced on fallen needles in the litter layer.

Survival of *D. septosporum* in forests and nurseries in Britain has not been reported. The survival periods in Britain may differ from those reported elsewhere due to differences in climate and cropping practices. Survival time is also likely to differ according to whether needles are on the surface of a needle layer (likely dry), within a layer (likely moist) or incorporated into the soil.

Control on seedlings on forest nurseries

Statutory control

D. septosporum is listed in the EU Plant Health Directive, under the name *S. pini*, as an Annex II/A2 Quarantine Pest, on plants of *Pinus* L., for planting, other than seeds. This means that the fungus is of serious phytosanitary concern and is regulated. Organisms listed as A2 pests are known to occur in an area but are not widely distributed while those listed as A1 are absent from the EU.

In England and Wales, regulation of the fungus on nurseries is done by the Plant Health and Seeds Inspectorate (PHSI) of the Food and Environment Research Agency (Fera) and in Scotland by the Scottish Executive, Rural Affairs Department (SERAD) on behalf of the Forestry Commission Plant Health Unit. Regulation does not apply to forestry plantations.

At present, control in forests is focused on silvicultural measures to reduce inoculum loads and the use of alternative less susceptible species in future rotations. Control measures are taken by Plant Health authorities when the fungus occurs on pine plants for planting (i.e. on nurseries), to limit spread of the disease. Control measures require that before pine plants can be released for planting without restriction, both the nursery and its immediate vicinity must have been found free of symptoms of the disease since the beginning of the last growing season. The immediate vicinity has been set for red band needle blight at 550 m. On discovery of infected trees, plant health legislation requires all infected lots to be destroyed and all other pine plants either destroyed or held over pending further inspection at the end of the next growing season.

Following confirmation of the outbreaks on three nurseries in Scotland in 2010, an interim compromise position on action was agreed for the planting season autumn 2010 to spring 2011. Namely:

- Pine plants in specific nursery beds with confirmed infection were to be destroyed;
- Under licence, pine stocks within 550 m of the known infected beds were permitted to be used for planting in Scotland only, while accepting that it was not possible to confirm that all such stock was uninfected;
- Stock further than 550 m away from the nearest known infection could be traded as normal;

Woodland owners/managers would need to assess the risks of planting such stock based on their knowledge of the disease distribution in their locality.

PHSI have also confirmed that provided fungicides are approved for use on forest nursery crops, either directly though a label approval or a SOLA, or indirectly through the LTAEU, growers are permitted to use fungicides for prevention of red band needle blight on forest nursery crops. If an outbreak is confirmed on a nursery, the Plant Health authority will require destruction of affected batches and determine what controls are put in place on suspect or adjacent batches.

Beyond spring 2011, the Forestry Commission Plant Health Unit is investigating options to request the EU to either de-list *Dothistroma septosporum* completely, which would carry the risk of enabling unregulated imports from overseas, or to classify the disease as a Regulated Non Quarantine Pest, which would enable proportionate controls to be exercised within Great Britain while also maintaining import regulations. The position on *Dothistroma pini* will need to be considered separately. However, the current distribution of *D. pini* does not extend *to* Great Britain (Table 1).

Cultural measures

In Britain, disease management in forests is currently focused on silvicultural measures to reduce inoculum loads and the use of alternative, less susceptible varieties in future rotations (Brown & Webber, 2008). Initial results in East Anglia show lower levels of infection and mortality in crops subjected to thinning regimes compared with unthinned stands. This is likely to improve the airflow through a stand and make the microclimate less favourable to disease. Pruning trees to improve the airflow was shown to make the microclimate less favourable to disease but this is an expense management option.

In Christmas tree production in Britain, *P. sylvestris* and *P. contorta* are grown at a high density of planting with hard shearing from an early age to produce dense, compact trees, creating conditions that are conducive for infection to occur. Norway spruce (*Picea abies*), Serbian spruce (*P. Ormorika*) and Colorado blue spruce (*P. pungens glauca*) grown as Christmas trees are also managed in this way. For highly susceptible species, less dense plantings to improve airflow should be considered.

There are few reports on control of red band needle blight in the nursery situation. In New Zealand, Bulman *et al.* (2004) highlighted cultural control measures for production of healthy seedlings. Measures included removal of all old stock to prevent a build up of infection and control of the disease on forest stands adjacent to nurseries; they noted that close spacing in seedbeds encourages the disease.

From knowledge of the disease biology, and control measures found to be effective in forests, and in New Zealand forest nurseries, it is likely that the following cultural measures, where practical to implement, would reduce the risk of red band needle blight occurring on British forest nurseries.

- Check any established pines and other conifers on or in the immediate vicinity (within 550 m) of the nursery for symptoms of red band needle blight. If found, contact the relevant Plant Health authority. Produce susceptible species in a location found to be free of the disease.
- Select nursery sites carefully to encourage good growth.
- Group known highly-susceptible species (Appendix 1) together to aid future fungicide programmes and monitor seedlings closely for symptoms of red band needle blight.
- Space seedlings as far as economics permit to allow good air circulation.

- Avoid growing seedlings on sites close to hedges or other areas where there is little air movement.
- Where irrigation is necessary, irrigate crops early in the day where possible to minimize the needle wetness period.
- Maintain good weed control to prevent development of a dense plant canopy likely to create a high humidity around seedlings.
- Clean and disinfect equipment used in the production of susceptible species.
- Maintain effective pest control.
- Remove from the nursery all old stock that is unlikely to be sold and destroy it to reduce the risk of any possible build up of infection.

If suspect symptoms are found, in addition to notifying the Plant Health authority:

- Promptly remove nursery plants with suspect symptoms and any fallen needles directly into a container; mark the affected area and a surrounding '*cordon-sanitaire'* to prevent handling or movement of these plants until a definitive diagnosis is obtained.
- Do not sow or replant an area with pine or another susceptible species (Appendix 1) for at least six months after complete removal of a susceptible species and incorporation of any fallen needles into the soil. Incorporation of needles into the soil is likely to speed up their microbial degradation and a soil cover will prevent release of spores into the air.
- Grow susceptible species in a different area in the following year.
- If the disease is confirmed on a nursery, consider soil disinfestation before planting or sowing known susceptible species back on an area where the disease has occurred.

Fungicides used to control red band needle blight in tree plantations

Copper fungicides are most widely used on account of their effectiveness in preventing spore germination and relatively low cost. Both copper oxychloride and cuprous oxide are used and are reported to be equally effective (Bulman *et al.*, 2004). There is evidence that copper both kills conidia to prevent infection and reduces sporulation in established lesions (Bulman *et al.*, 2008; Gibson, 1972). *D. septosporum* is highly sensitive to copper with an LD_{50} value of around 0.9 ppm (Bulman *et al.*, 2008). In New Zealand aerial application of copper oxychloride was found to be successful on radiata pine, resulting in an increase in growth in highly stocked stands where pruning had not been carried out, or where conditions were particularly favourable to the disease (e.g. gullies, sheltered humid sites) (Bulman, 1993).

In New Zealand, the threshold for treating radiata pine stands with a copper fungicide by aerial application is when the overall disease level on unsuppressed green crown growth reaches 25% (Bulman *et al.*, 2004). A double spray is recommended when overall disease levels reach 40% or more. In 1984 the application rate was 1.14 kg of 75% copper, or 1.16 kg 50% copper, in 2 L of spraying oil made up to 5 L with water, per hectare (Bulman *et al.*, 2004). In the United States, Bordeaux mixture (copper sulphate and lime) applied twice in the growing season has provided good protection of pines in shelterbelts, park and landscape plantings, and on Christmas trees (Petersen, 1982). Chlorothalonil is also registered for use against *D. pini* in the US. For Christmas tree production in Oregon, Washington and Idaho, chlorothalonil is recommended for needle blight, with the caution that it may cause chlorotic or necrotic needle flecking (DeFrancesco & Murray, 2009). Species grown in those states for Christmas tree production include Scots pine (*P. Sylvestris)*, Western white pine (*P. Monticola*) and Douglas fir (*Pseudotsuga menziesii*)*,* but the species developing phytotoxicity symptoms were not detailed. In China, the disease was controlled by chlorothalonil, thiram and asomate (Bingzhang *et al.*, 1992). The latter fungicide is based on arsenic and is not registered in the EU. Benlate (benomyl) is also effective against *D. pini* (Gibson, 1974), but this fungicide is no longer available. The future availability of chlorothalonil in Britain is uncertain.

On Norway spruce grown as Christmas trees in the UK, the main fungicides currently used for control of needle diseases (caused by *Rhizosphaera kalkhoffii* and *Lirula* spp.) are azoxystrobin (Amistar) and chlorothalonil (e.g. Bravo 500). Previously carbendazim (e.g. Delsene Flo) was also used but this is no longer approved.

Fungicides effective against red band needle blight and related fungi

There are few reports on chemical control of red band needle blight in the nursery situation. In New Zealand, Bulman *et al.* (2004) highlighted chemical control for production of healthy seedlings. Chemical control measures recommended on 1+0 stock were monthly or 6-weekly sprays of copper oxychloride at 4 kg/ha, or cuprous oxide (75% WP) at 2.6 kg/ha, starting in spring or when seedlings were around 2.5 cm high, and continued until autumn. The application volume was stated not to be critical and could be in the range 100-500 L/ha. Control on 2+0 and older stock was the same, with monthly sprays from October to the end of March (southern hemisphere). It was reported that copper fungicides in colder climates may produce a phytotoxic effect in the form of foliage scorch and in severe cases stunting of seedlings. Phytotoxicity appears when temperatures fall below freezing. On *P. radiata,* symptoms show first as small pale discolourations and dish-like indentations on needles after the first frost. Gradually they expand with increasing cold, turn red-brown, and may cover the needle. Minor changes did not affect the growth or value of seedlings.

Despite the lack of information on effective fungicides against red band needle blight, in the UK there is good information on the efficacy of fungicides against related fungi which can be used to help identify potentially useful chemicals. This includes Mycosphaerella *graminicola* (anamorph *Septoria tritici*), a common disease of wheat (e.g. www.hgca.com/publications/documents/WheatDiseaseManagementGuideSpring09.pdf). New fungicides for arable crops are evaluated under field conditions in HGCA-funded projects, but data are only published when products are marketed. There is also some information on efficacy of fungicides against *Cercospora beticola*, a leaf spot disease of sugar beet. Both of these fungi are in the same group of ascomycete fungi as *D. septosporum* (the Capnodiale Order) according to species characterisation by mating type genes (Groenewald *et al*., 2007).

The relative efficacy of some currently available fungicides against *S. tritici* and *C. beticola* is given in Tables 2 and 3. As *C. beticola* is a minor disease in Britain, data from other European countries and North America have been taken into consideration. Unfortunately *C. beticola* has been able to overcome many types of fungicides, including tin fungicides, which have now been withdrawn.

Table 2. Relative efficacy and some attributes of some fungicides used for control of *Septoria tritici* on wheat

Example product	Active ingredient(s)	Fungicide group(s)[a]	Mode of action	Efficacy as:	
				Protectant	Curative[b]
Bravo 500	chlorothalonil	Chloronitriles	Contact	+++	-
Dithane 945	mancozeb	Dithiocarbamate	Contact	++	-
Delsene 50 Flo	carbendazim	MBC	S	*	*
Amistar	azoxystrobin	QoI	T + S	*	*
Comet	pyraclostrobin	QoI	T	*	*
Opus	epoxiconazole	DMI	S	+++	+++
Proline	prothioconazole	DMI	S	+++	+++
Sanction 25	flusilazole	DMI	S	++	++
Brutus	epoxiconazole + metconazole	DMI	S	+++	+++
Prosaro	prothioconazole + tebuconazole	DMI	S	+++	+++
Fandango	fluoxastrobin + prothioconazole	QoI + DMI	S	+++	+++
Tracker	boscalid+ epoxiconazole	SDHI + DMI	S	+++	+++
Aviator 235 Xpro	bixafen + prothioconazole	SDHI + DMI	S	+++	+++

Systemic (S) or translaminar (T) or vapour phase (V)
- no control; + some control; ++ moderate control; +++ good control.
[a] As classified by Fungicide Resistance Action Group. See http://www.frac.info/frac/publication/anhang/FRAC_Code_List_2007_web.pdf.
[b] Provides some control after infection has occurred and before symptom development.
*Previously very effective, so could be used against pathogens where fungicide resistant strains are not present.

Table 3. Relative efficacy and some attributes of some fungicides used for control of *Cercospora beticola* on sugar beet

Product	Active ingredient(s)	Fungicide group(s)[a]	Mode of action	Efficacy as:	
				Protectant	Curative[b]
Bravo 500	chlorothalonil	Chloronitriles	Contact	++	-
Dithane 945	mancozeb	Dithiocarbamate	Contact	+	-
Delsene 50 Flo	carbendazim	MBC	S	*	*
Amistar	azoxystrobin	QoI	T + S	*	*
Comet	pyraclostrobin	QoI	T	*	*
Plover	difenoconazole	DMI	S	++	++
Sphere[1]	cyproconazole + trifloxystrobin	DMI + QoI	S + V	+++	++
Opera[1]	epoxiconazole + pyraclostrobin	DMI + QoI	S	+++	++
Priori Xtra[1]	azoxystrobin + cyproconazole	QoI + DMI	S	+++	++

Systemic(s) or translaminar(T) or vapour activity (V)-
no control; + some control; ++ moderate control; +++ good control.
[a] As classified by Fungicide Resistance Action Group. See http://www.frac.info/frac/publication/anhang/FRAC_Code_List_2007_web.pdf.
[1]Product with UK recommendation for use on sugar beet.
[b] Provides some control after infection has occurred and before symptom development.
*Previously very effective, so could be used against pathogens where fungicide resistant strains are not present.

Potential fungicides to prevent and control red band needle blight

Provided fungicides are approved for use on forest nursery crops, either directly though a label approval or a SOLA, or indirectly through the LTAEU, growers are permitted to use fungicides for prevention of red band needle blight on forest nursery crops. If an outbreak is confirmed on a nursery, the Plant Health authority will require destruction of affected batches and determine what controls are put in place on suspect or adjacent batches.

The major groups of fungicides noted above have broad-spectrum activity. Their curative and protectant activities will need to be defined against *D. septosporum.* The suitability of these products for use on pines will also need to be determined as some have plant growth regulatory activity and may be phytotoxic.

Protectant fungicides, notably chlorothalonil and mancozeb, have remained effective against *S. tritici* for many years and have a lower risk of fungicide resistance than other groups. There is a high risk that fungicide resistant strains will be selected in *D. septosporum* where fungicides have a single mode of action (e.g. MBC, QoI and SDHI groups). The activity of products in the DMI fungicide group may show a decline in efficacy as populations of the pathogen become less sensitive to them. The screening of spray treatments with mixtures of fungicides with different modes of action should be given high priority. Forest Research, an agency of the Forestry Commission, is conducting an investigation of the efficacy of some fungicides to control red band needle blight on young plants of lodgepole and Scots pine in Scotland in 2011 (A. Brown, pers. comm.). This work will include some products containing two fungicides with different modes of action.

With regard to approval for use on forest nurseries, tree growing can fall into two different crop hierarchy definitions, so the legality of using a particular fungicide depends on the intended use of the trees. If the trees are only for use in forestry, they are covered by the term ‘Forest nursery’ and only pesticides with that specific use can be used (e.g. Fandango). If the trees are for ornamental use then they are covered by products which specify ‘Ornamental plant production’ (e.g. Signum) (see Table 4).

Until the Long Term Arrangements for Extension of Use (LTAEU) of pesticides are removed, they still apply to forestry nursery crops and ornamentals. Therefore, as long as a grower complies with the various restrictions listed in these arrangements, they can continue to use in forest nursery and ornamental plant production any pesticide product approved for use on any growing crop, except for products containing actives listed on the prohibited list (although there may be a Specific Off Label Approval that covers the use). Prohibited fungicides may still be used where they are formulated with a non-prohibited fungicide. The prohibited list will grow over the next four to five years until the arrangements are removed (and replacement SOLAs are issued), so it is important to check the arrangements regularly. Further information about the LTAEU can be found at www.pesticides.gov.uk. An up-to-date listing of products which are still permissible under the LTAEU can be found by logging into the HDC website (www.hdc.org.uk) and clicking on the ***LIAISON®*** link on the right-hand side (this resource was developed under HDC Project CP 72).

Products listed in Tables 2 and 3 that are specifically prohibited from use under the LTAEU are carbendazim (Delsene 50 Flo), pyraclostrobin (Comet), and prothioconazole (Proline). Therefore, although these products are effective on *S. tritici* they are omitted from the list of fungicides for potential use on conifers to control red band needle blight (Table 4).

A few other products not currently used on wheat or sugar beet but with a label approval for use on Forest Nursery or Ornamental Plant Production are also considered, based on their active ingredients, as likely to have activity on red band needle blight e.g. Signum and Cercobin WG. However, trials work would be needed to confirm this. These are also included in Table 4. Work overseas indicates that copper oxychloride (eg Cuprokylt) has activity against red band needle blight so this is also included in Table 4.

Table 4. Approval status of fungicides with likely activity against red band needle blight and currently permitted for use on outdoor forest nursery and/or ornamentals – January 2011

Product (active ingredients)	Approval status	Max no sprays	Max dose		Comment
			Ind.	Total	
Amistar (azoxystrobin)	Forest nursery**	2	1 L/ha	-	SOLA 0443/09
Aviator 235 Xpro (bixafen + prothioconazole)	LTAEU	2	1.25 L/ha	-	Wheat label
Bravo 500* (chlorothalonil)	LTAEU**	3	2 L/ha	-	Strawberry SOLA
Brutus (epoxiconazole + metconazole)	LTAEU	-	3 L/ha	6 L/ha	Wheat label
Cercobin WG [a] (thiophanate-methyl)	Ornamental Plant Production	-	0.071 kg/100 L	-	SOLA 1384/08***
Cuprokylt [a] (copper oxychloride)	LTAEU	-	5 kg/ha	-	Potato label
Dithane 945* (mancozeb)	LTAEU	8	2 kg/ha	-	Potato label
Fandango (fluoxastrobin + prothioconazole)	Forest nursery	-	1.25 L/ha	2.5 L/ha	SOLA 0226/09
Opera (epoxiconazole + pyraclostrobin)	LTAEU	2	1.5 L/ha	-	Wheat label
Opus (epoxiconazole)	LTAEU	-	1 L/ha	2 L/ha	Wheat label
Plover (difenoconazole)	LTAEU	1	0.3 L/ha	-	Wheat label
Priori Xtra (azoxystrobin + cyproconazole)	LTAEU	-	1 L/ha	2 L/ha	Wheat label
Prosaro (prothioconazole + tebuconazole)	LTAEU	-	1.2 L/ha	3.6 L/ha	Wheat label
Sanction 25 (flusilazole)	LTAEU	3	0.8 L/ha	2.05 L/ha	Wheat label
Signum [a] (boscalid +pyraclostrobin)	Ornamental Plant production	2	1.35 kg/ha	-	SOLA 1842/09
Sphere (cyproconazole + trifloxystrobin)	LTAEU	2	1 L/ha	-	Wheat label
Tracker (boscalid+ epoxiconazole)	LTAEU	2	1.5 L/ha	-	Wheat label

* Products with the same active ingredients are available.
** Also permitted on protected forest nursery/protected ornamental.
*** Current SOLA expires 28 February 2011; a new SOLA is being sought.
Fungicide products listed above (excluding [a]) have been demonstrated as having protectant activity against fungi on wheat and/or sugar beet related to *Mycospharella pini*. The suitability of these products for use on pines has not been determined; some have plant growth regulatory activity and may be phytotoxic.

Timing of fungicide treatment

In the United States (Nebraska), it was found that on Austrian and ponderosa pine the previous season's needles could become infected before the current year needles had emerged from needle sheath (Peterson, 1973). On this basis it was suggested that two applications of fungicide would be needed to provide protection of needles of all ages. A two-spray programme of Bordeaux mixture with applications on 20 May (to protect last year's needles) and June 10 or July 1 (to protect last year's and current year's needles) reduced the proportion of infected needles from 88% to 3%. A spray programme with four sprays (May 20, June 10, July 1 and July 22) was no more effective than the two-spray programme. A single spray did not provide good control of infection on second year needle; it was noticeable however that a single early spray (May 20, 11% infection), was more effective than a single late spray (July 1, 53% infection; July 22, 72% infection) (Peterson, 1967). First year needles were protected by a single spray made on 1 July but not by a single spray on 20 May (needles just emerging) or 22 July.

In New Zealand, Gilmour and Noorderhaven (1971) found that best control of needle blight on radiata pine was obtained when cuprous oxide fungicide was applied in October and again in December (i.e. equivalent to April and June in the northern hemisphere), and that a single spray in November gave slightly less though still effective control. Subsequent work (Gilmour, 1981) indicated that the effectiveness of this fungicide timing was that it was applied just before or at the beginning of the main infection period (November to February).

For Christmas tree production in the USA, it is recommended that chemical control is applied after budbreak, starting 4 years from expected harvest (DeFrancesco & Murray, 2009).

Copper is reported to have a long persistence on pine needles, with appreciable residues found after 2 months and 254 mm of rain, but very little after 3 months and 432 mm rain (Bulman *et al.*, 2008). No simple relation was found between rainfall and rate of removal by weathering.

There are environmental concerns on the pollution of watercourses from repeated applications of copper fungicides. Although copper is an essential trace element for plant and animal life, excessive amounts are poisonous. Copper has been shown to build up in the soil of some horticultural crops after repeated application (Brun *et al.*, 1998). The Dothistroma Control Committee in New Zealand is funding a study to test the hypothesis that copper builds up in soil after repeated spray applications for control of red band needle blight in sufficient quantities to cause environmental damage (Bulman *et al.*, 2008).

For a forest nursery situation, where the objective is to maintain seedlings free from red band needle blight, a more intensive programme will very likely be required. This may, for example, mean treatment of seedlings once every 2-3 weeks during the growing season. A less intensive spray programme may be satisfactory for seedlings in their first year given that young needles are less susceptible. Many of the newer fungicides listed in Table 4 as candidate treatments for control of red band needle blight have a limit of one, two or three sprays per crop, or a maximum total dose which in practice restricts the number of sprays. Treatment programmes will therefore need to make use of two or more products to maintain season-long control. Products containing copper oxychloride, chlorothalonil or mancozeb are potentially good products to use within a programme both to reduce the risk of fungicide resistant strains being selected from the population, and because of the greater number of sprays allowed with these products. It should be noted however that red band needle blight has been found on nurseries where copper fungicides and mancozeb has been applied (A. Brown, pers. comm.). This failure to provide complete control may be due to poor spray coverage, insufficient spray frequency, insufficient product efficacy or other factors.

Once more is known about activity and persistence of different fungicide products against the pathogen, it may be possible to reduce spray numbers when environmental conditions are low risk for infection and disease development.

Red band needle blight research in Britain

Forest Research at Alice Holt Lodge Research Station has a programme of work on red band needle blight. It aims to monitor the extent and severity of the disease in Britain, to gain an understanding of the disease epidemiology to aid disease management decisions, to assess its impact on timber yields in terms of mortality and loss in volume increment, and to evaluate the suitability of different management techniques including species susceptibility and changes in silvicultural practices. In addition, advice and guidance is provided to the Forestry Commission, the private forest industry, plant health authorities and the scientific community through attendance at British and international working groups and international meetings, disease workshops, web-pages, technical publications and peer reviewed papers. For more information contact: anna.brown@forestry.gsi.gov.uk. Some of the research work of immediate relevance to forest nurseries that is currently in progress is noted below.

Recommendations for research and development

The recommendations below are made for consideration by HDC and in conjunction with Forest Research so that forest nursery growers are in a better position to decide actions to prevent the disease.

First and foremost, forest nursery growers are reminded that they are required to inform the relevant Plant Health authority if the disease is suspected on plants for planting. The Plant health authority will then advise what control measures are to be undertaken to control an outbreak.

1. Determine the crop safety of candidate fungicides for use against red band needle blight (e.g. Amistar, Cercobin WG, Fandango, Sphere, Opera, Priori Xtra, Signum, Tracker) to seedlings of some commonly grown *Pinus* species, including Scots pine and Corsican pine, when used as high volume sprays during the growing season. Forest Research has tested some of these products and no phytotoxicity was observed (A. Brown, pers. comm.); the work is currently being written up.

2. Evaluate the efficacy as treatments for red band needle blight the candidate fungicides that are shown to be crop-safe on pine seedlings. Forest Research is currently establishing a trial in Scotland on control of red band needle blight on young plants using two spray programmes of selected fungicides (K Tubby, pers comm.).

3. Determine the period during which conidia are disseminated from infected needles under British conditions as a sound basis for identifying the period when fungicide treatment is warranted. An experiment with this aim is underway, conducted by Forest Research.

4. Evaluate the efficacy of two-spray fungicide programmes, as used on forest trees, compared with programmes designed to give protection throughout the growing season (e.g. a spray every 2-3 weeks, depending on weather).

5. Determine to what extent cultural practices such as wider row spacing and in-row spacing, and alignment of rows with the prevailing wind, can help to control the disease for potential use in an integrated strategy with fungicide sprays.

6. Determine the survival period of *D. septosporum* in Britain on fallen infected needles, trapped in the canopy and on the ground. Determine the effect of burial/coverage of needles to prevent spore release into the air, and the effect of chemical treatment of infested needles to speed decay.

7. Determine the frequency and intensity of spring and summer rainfall at locations in Scotland affected by red band needle blight for periods before and after the first outbreak in 2002 in order to examine whether the disease is associated with an increased incidence of warm rain. Forest Research has looked at this for East Anglia and is now examining meteorological data for Scotland. This type of data could be used to define high and low risk conditions for infection and disease spread in Britain, as a basis for rational fungicide use.

8. Examine the occurrence of needle debris and *D. septosporum* in seed lots; if found, investigate potential seed cleaning techniques or seed treatments to eliminate possible contamination of seed by *D. septosporum*.

9. Be aware of possible new developments in detection of red band needle blight, including for example alterations of spectral reflectance characteristics.

10. Train growers how to identify red band needle blight and reduce the risk of outbreaks through adoption of cultural and other control measures. A number of workshops have been run for forestry nurseries by Forest Research and more will be run on request (A Brown, pers comm.).

11. Maintain liaison with the Forestry Research to obtain the latest research results on biology and control of the disease.

Suggested further reading

1. Red band needle blight of pine. Forestry Commission Information Note 49. (www.forestry.gov.uk/fr/infd-6zckae).

2. Red band needle blight of conifers in Britain. Forestry Commission Research Note 002. (www.forestry.gov.uk/pdf/FCRN002.pdf).

3. Needle diseases of radiata pine in New Zealand. www.fbrc.rg.nz/pdfs/Needle-cast_research_review_final.pdf

4. Dothistroma needle blight of pine.
   Forest Insect and Disease Leaflet 143. US Dept. of Agriculture and Forest Services (www.na.fs.fed.us/spfo/pubs/fidls/dothistroma/doth.htm)

5. *Compendium of conifer diseases*. APS Press, St. Paul, MN, USA. Eds: EM Hansen and KJ Lewis.

6. Anon. (2005). *Mycosphaerella pini. OEPP/EPPO Bulletin* **35**, 303-306. (see: www.eppo.org)

References 1, 2 and 3 all have good photographs of the disease.

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Mr Jamie Dewhurst, J&A Growers, Warwickshire

Forest Nurseries, Scotland

Dr Anna Brown, Forest Research

Dr Katherine Tubby, Forest Research

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Appendix 1 Susceptibility of some coniferous trees of Britain and northern Europe known to be infected by *Dothistroma* species, cause of red band needle blight

Highly susceptible		Moderately susceptible		Slightly susceptible	
Pinus attenuata	Knobcone pine	*Pinus coulteri*	Big-cone pine	*Larix decidua*	European larch
*Pinus contorta**	Beach pine	*Pinus bungeana*	Lacebark pine	*Picea abies*	Norway spruce
Pinus contorta var. *latifolia*	Lodgepole pine	*Pinus densiflora*	Red pine of Japan	*Picea omorika*	Serbian spruce
				Picea pungens	Colorado spruce
Pinus halepensis	Aleppo pine	*Pinus flexilis*	Limber pine	*Picea shrenkiana*	Schrenk's spruce
*Pinus nigra**	Austrian pine	*Pinus jeffreyi*	Jeffrey's pine	*Picea sitchensis*	Sitka spruce
Pinus nigra var. *laricio*	Corsican pine	*Pinus lambertiana*	Sugar pine	*Pinus aristata*	Bristle-cone pine
		Pinus muricata	Bishop pine	*Pinus ayacahuita*	Mexican white pine
Pinus pinea	Umbrella pine	*Pinus pinaster*	Maritime pine	*Pinus contorta**	Beach pine
Pinus ponderosa	Western Yellow pine (ponderosa pine)	*Pinus resinosa*	Red pine	*Pinus koraiensis*	Korean pine
				Pinus montezumae	Rough branched Mexican pine
Pinus radiata	Monterey pine (radiata pine)				
*Pinus strobus**	White or Weymouth pine			*Pinus nigra**	Austrian pine
*Pinus sylvestris**	Scots pine			*Pinus monticola*	Western white pine
Pinus thunbergii	Black pine			*Pinus patula*	Spreading-leaved pine
				Pinus rigida	Northern pitch pine
				*Pinus strobus**	Weymouth pine
				*Pinus sylvestris**	Scots pine
				Pinus wallichiana	Bhutan pine
				Pseudotsuga menziesii	Douglas fir

Adapted from Watt *et al*. (2009) and Brown *et al*. (2003), selecting species which occur in Britain (Mitchell, 1974).

*Species marked thus have been described as very susceptible by some authorities and as slightly susceptible by others.

Appendix 2 Diagrammatic life-cycle of red band needle blight