



Red band needle blight of conifers in Britain

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Red band needle blight is an economically important disease affecting a number of coniferous trees, in particular pines. The disease has a world-wide distribution but until recently it was mainly of concern in the southern hemisphere. In much of the world, including Britain, it is caused by the fungus *Dothistroma septosporum*. Red band needle blight causes premature needle defoliation which results in the loss of timber yield and, in severe cases, tree mortality. Since the late 1990s the incidence of the disease has increased dramatically in Britain, particularly on Corsican pine (*Pinus nigra* ssp. *laricio*), and due to the extent and severity of the disease on this species, there is now a five-year planting moratorium of it on the Forestry Commission estate. More recently there have been reports of the disease causing damage to lodgepole pine in Scotland and it has also been reported on Scots pine – although it rarely appears to be causing significant damage to this species. Reasons for the increase in disease incidence are unclear but could be due to increased rainfall in spring and summer coupled with a trend towards warmer springs, optimising conditions for spore dispersal and infection. Such conditions may become more prevalent in Britain over the next 20 years if current trends in climate change continue. In Britain disease management is currently focused on silvicultural measures to reduce inoculum loads and the use of alternative, less susceptible species in future rotations.

Introduction

Red band needle blight, so called because of the symptoms it causes on pine, is an economically important disease with a widespread distribution (Gibson, 1974; Bradshaw, 2004). In much of the world, including Britain, it is caused by the pathogen known as *Dothistroma septosporum* (formerly *D. septospora* and *D. pini*) when it is found in the anamorph (asexual) stage. The teleomorph (sexual) stage of the pathogen, *Mycosphaerella pini* (formerly *Scirrhia pini*), has yet to be found in Britain, and has rarely been identified elsewhere in the world. Recently, a second distinct species, which has been named *Dothistroma pini*, has been found to be responsible for red band needle blight in north central America (Barnes *et al.*, 2004) and the Ukraine (Groenewald *et al.*, 2007). To date, no teleomorph has been identified with this second *Dothistroma* species.

Until recently the disease had only been reported on nursery stock in Britain during the 1950s and 60s, with a single occurrence in a forest stand in south Wales in 1958. The rarity of the disease, coupled with its potential to cause severe damage to certain species of pine, resulted in it being listed under EC plant health legislation as a quarantine organism. This means that if infection by red band needle blight is suspected in nurseries, local plant health inspectors must be informed.

Visible signs of infection by *D. septosporum* include premature defoliation. Depending on the susceptibility of the host and the extent of infection, the amount of defoliation may be extremely severe as needles of all ages can be affected. This leads to a decrease in the yield and, in some cases, tree mortality. Infected landscape and Christmas trees can be severely disfigured leading to a loss in both aesthetic and commercial value.

Susceptibility of British hosts

Red band needle blight affects many species of conifer, but pines are the most common hosts. In total, 82 pine species and subspecies have been reported to be prone to infection by *D. septosporum* across the world (Watt *et al.*, in prep), although the degree of susceptibility to infection varies widely between different pine species.

The three main pine species grown in Britain are Corsican pine, lodgepole pine (*Pinus contorta* var. *latifolia*), and Scots pine (*Pinus sylvestris*). After Sitka spruce (*Picea sitchensis*), Corsican pine is the main conifer species grown in England, making up around 21% of the conifer area on the Forestry Commission estate in this country. However, Corsican pine has proved to be so susceptible to red band needle blight, and the impact so severe (Figure 1) that there is now a five-year planting

moratorium of this species on the Forestry Commission estate. Lodgepole pine, another widely-grown pine species in Britain, particularly in northern England and Scotland, has proved to be highly susceptible to the disease in both natural and planted stands in British Columbia (Woods *et al.*, 2005). To date in Britain, the incidence of red band needle blight has been lower on lodgepole pine than on Corsican pine. However, where infection does occur, it has the potential to be very damaging (Figure 2). Due to the potential impacts of the disease, the incidence on both Corsican pine and lodgepole pine is being monitored. Scots pine is generally believed to be of low susceptibility (Peterson, 1982) and this is supported by the experience in Britain where, although the pathogen has been identified on this tree species, it tends to be where disease infestation is already high on other adjacent species. Even then it rarely appears to be causing significant damage to the Scots pine. However, it should be noted that, contrary to other reports, Gadgil (1967) classified Scots pine as a highly susceptible species.

Figure 1 The impact of red band needle blight on a) young (~7-year-old) and b) older (26-year-old) Corsican pine crops in England.



Figure 2 Red band needle blight on lodgepole pine trees in Scotland.



A number of other pine species are planted in Britain, albeit less frequently. Of these radiata pine (*Pinus radiata*), ponderosa pine (*Pinus ponderosa*) and Austrian pine (*Pinus nigra*) have all been reported to be highly susceptible (Bednářová *et al.*, 2006; Bulman *et al.*, 2004), and bishops pine (*Pinus muricata*) and Maritime pine (*Pinus pinaster*) and are reported to be moderately to highly susceptible (Auer, 2001; Bulman *et al.*, 2004; Gibson, 1979). In the case of Weymouth pine (*Pinus strobus*) the case is less clear cut with susceptibility ranging from low to high depending on the disease report (Bulman *et al.*, 2004; Ito, 1975; Gibson, 1979). However, this species tends not to be favoured in Britain due to its susceptibility to white pine blister rust (*Cronartium ribicola*). Two other species occasionally planted in Britain, *Pinus mugo* ssp *uncinata* (mountain pine) and *Pinus peuce* (Macedonian pine), are also reported to be prone to red band needle blight although the susceptibility of these species is unknown.

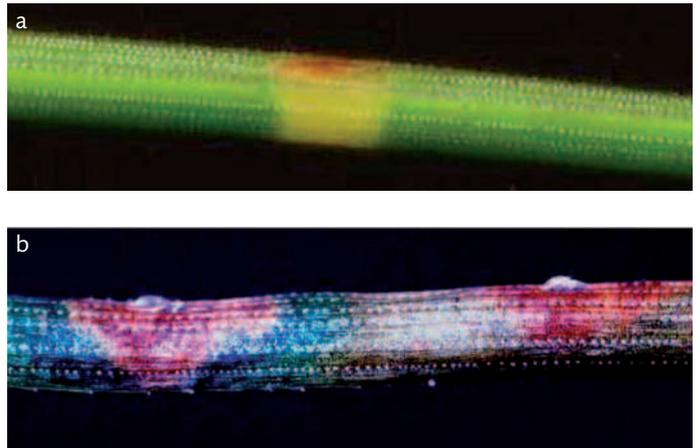
Apart from pines, other coniferous species such as European larch (*Larix decidua*), Douglas fir (*Pseudotsuga menziesii*) and five spruce species, including Norway spruce (*Picea abies*) and Sitka spruce, both commonly grown in Britain, are occasionally susceptible. Indeed, Sitka spruce, Norway spruce and Douglas fir seedlings have all been found to be susceptible to natural infection of *D. septosporum* in Britain (Brown and Archibald, unpublished data). However, as with Scots pine, to become infected these species probably need to be subjected to very high inoculum pressure generated within or adjacent to a heavily-infected crop.

Three components will influence a disease outbreak – the host, pathogen and environment – and the more favourable each factor is to the disease, the greater the severity of the outbreak. Thus, it seems likely that host susceptibility depends on a wide range of factors including the origin and provenance of a host species, the virulence of the pathogen, as well as site and climatic conditions.

The pathogen

Isolation of the fungus from infected needles can be difficult but once in culture *D. septosporum* grows readily, albeit extremely slowly. The optimum temperatures for growth and spore germination at around 20 °C and 22 °C respectively (Karadži, 1994). On the host, it produces small, dark brown/black fruiting bodies (acervuli), visible during late spring and summer on attached needles infected in the previous year (Figure 3). These fruit bodies contain asexual spores (conidia) which are exuded in a colourless or white mucilaginous mass. Water is believed to be essential for spread of the pathogen, as spore masses disperse in films of water and are disseminated as water droplets fall from the needle surfaces, resulting in infection within and between neighbouring trees. Dispersal over longer

Figure 3 Symptoms of red band needle blight on Corsican pine. a) Early symptoms – yellow bands and tan spots; b) advanced symptoms with visible brown fruiting bodies of *D. septosporum*.



distances is thought to occur when spores are transported in mists and clouds (Gibson *et al.*, 1964) and by movement of infected planting stock (Bradshaw, 2004).

Apart from reproducing asexually, *D. septosporum* can also reproduce sexually, generating spores known as ascospores. However, in order for sexual reproduction to take place, two different mating types must be present. In many countries where the disease is widespread (notably New Zealand and Australia) only one mating type of *D. septosporum* exists, so sexual reproduction never takes place. However, a recent study has shown both mating types of the pathogen are present in Britain (Groenewald *et al.*, 2007). The potential to reproduce sexually as well as asexually can have a significant impact on disease severity, as sexual reproduction by the pathogen will result in greater genetic diversity, and potentially increased pathogenicity.

Pathogen life cycle and disease symptoms

The critical period for infection in Britain is spring and early summer when the fruiting bodies are formed on the needles. Severe episodes of the disease appear to be associated with higher than average rainfall at the time of infection (Archibald and Brown, 2007). If spores land on a suitable host they may germinate on the needle surface and penetrate through the stomata. Moisture is required for germination and the optimum temperature for successful establishment is 12–18 °C under conditions of high humidity.

By late summer to early autumn the older needles carrying the source of infection are shed. In New Zealand, spores were found to remain viable on needles in the litter layer for between two and four months (Gadgil, 1970), prior to being replaced by competitive saprophytic fungi colonising the dead needles.

Freshly infected first- and second-year needles remain attached to the tree and are the main source of inoculum when spores are released in the following spring and summer. By late autumn, early symptoms on these needles are clearly visible and include yellow bands and tan spots at the point of infection on the live needles (Figure 3). These signs are short-lived and the bands rapidly turn red or red/brown (Figure 4); this colour remains even when the needle has died (Murray and Batko, 1962). The red banding is not always evident and the needles may have an overall brown or reddish colouration instead, which can easily be confused with symptoms caused by other needle pathogens. However, the ends of the needles then die back to the lowest point of infection leaving a characteristic browning at the distal ends of needles while the base remains green (Figure 5). This symptom is particularly striking, on needles one year or older, in May to July around the time of needle flush (Figure 6). The combination of this symptom with the formation of fruit bodies makes this period the most suitable time for disease diagnosis.

Figure 4 Red banding caused by *Dothistroma septosporum* on Corsican pine needles.



Figure 5 Overall browning at the distal ends of the needles whilst the bases remain green.



Figure 6 Symptoms on one-year-old needles at time of needle flush.



In plantations where the disease is active, needle infection and hence defoliation of infected trees usually starts in the lower crown (Figure 7). Foliage of any age can be affected, but infection generally commences on the older needles. In severe cases, lower branches can lose all their needles and, after these are shed in the autumn, the entire crown is sparse with only isolated tufts of freshly infected current year's needles remaining at the branch tips. These remaining needles may become chlorotic, especially on trees growing on calcareous soils.

Figure 7 Needle infection starting in the lower crown.



Disease impact

Experience with radiata pine has shown that it usually takes several consecutive years of infection before yield is reduced significantly. If infection levels are low, the increment of individual trees is directly proportional to the level of crown infection (percentage symptomatic needles) (Van der Pas, 1981; Bulman, 1993). However, once crown infection exceeds 40%, the increment loss is >40%, and there is virtually no growth if crown infection is greater than 80% (Gadgil, 1984). In Britain, preliminary studies have shown that the disease can have a dramatic effect on both diameter and height growth if trees are in heavily infected stands. For example, a mean crown infection of 70% resulted in a 68% decrease in mean annual volume increment (Brown, unpublished data). This striking effect on diameter increment is illustrated in Figure 8. In addition, successive years of high infection can lead to tree mortality.

Figure 8 Dramatic reduction in diameter increment of Corsican pine due to red band needle blight.



Toxicity

D. septosporum produces the toxin known as dothistromin (Bradshaw *et al.*, 1997). This is produced once the needles have become infected and it kills cells in advance of fungal mycelial growth (Partridge, 1998). The toxin also imparts the red colouration to infected needles (Shain and Franich, 1981). Tests have shown that dothistromin can cause chromosome damage in human cells (Bradshaw *et al.*, 2000), leading to concerns in New Zealand in the 1980s about the health risks to forest workers exposed to trees heavily infected with red band needle blight. However, in New Zealand, exposure to red band needle blight and thus the dothistromin toxin is no longer considered to be an issue and in 1989 Elliot *et al.* concluded that it poses little risk to human health.

Origins and distribution

The origins of the pathogen are unclear. Ivory (1994) suggested that *D. septosporum* could be indigenous to pine forests in Nepal, and it may be endemic in the Himalayas. Alternatively, it has been suggested that it originated in South America in high altitude rain forest (Evans, 1984).

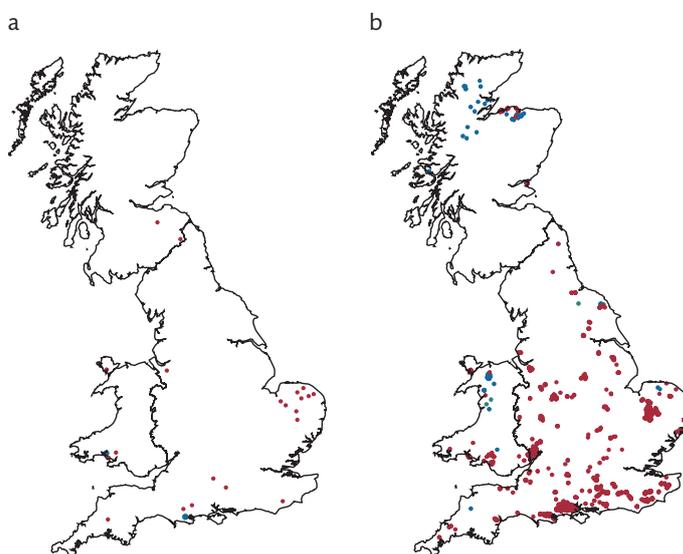
The disease was first described in eastern Europe in 1911 (Gibson, 1974), and there are early reports of the fungus both in Europe and the USA prior to the 1920s, although it was not recognised as a serious pathogen until the 1960s (Bradshaw *et al.*, 2000). *D. septosporum* has been reported in at least 63 countries across the world (Watt *et al.*, *in prep.*). Spread of the pathogen between countries is believed to be mainly through movement of diseased planting stock (Ivory, 1967).

Until recently the disease was primarily of concern in the southern hemisphere. However, over the past 10–15 years there has been an increase in severity and geographical range of the disease, particularly in the northern hemisphere where there has been an increased number of outbreaks in European countries (e.g. Austria, Britain, Czech republic, France, Germany, Hungary, Netherlands, Poland, Portugal) (Bednářová *et al.*, 2006; Bradshaw, 2004; Brown *et al.*, 2003; Netherlands Plant Protection Service, 2007) and in British Columbia, Canada (Woods, 2005).

Red band needle blight in Britain

Following the first findings of red band needle blight in Britain on nursery stock in 1954 (Murray and Batko, 1962), Forest Research has kept records of any reported disease outbreaks. Initially, in the 1950s and 60s the disease was limited to nursery stock (lacebark pine – *Pinus bungeana*, Corsican pine, lodgepole pine and ponderosa pine) at Wareham Nursery in Dorset, with a single case in 1958 on young Corsican pine in south Wales. Forty years later, from the mid-1990s until 2002, there was a sudden increase in the number of disease reports (Figure 9a).

Figure 9 Reports of red band needle blight in Britain; a) between 1955 and 2002, blue indicates the early cases (1955–1966), and red the recent cases (1989–2002); b) reports of red band needle blight from the 2006 and 2007 surveys, red indicates records on Corsican pine, blue lodgepole pine and green minor pine species.



This resulted in all stands of Corsican pine (and selected stands of lodgepole and minor pine species) under the age of 30 years on the Forestry Commission estate being assessed for red band needle blight in 2006. A follow-up survey in 2007 concentrated on stands of lodgepole pine under the age of 30 years in Scotland. The results of these surveys (Figure 9b) show the disease is now widespread and has reached very significant levels in some parts of Britain. The distribution is governed by the presence of susceptible species, particularly Corsican pine. Where there are large areas of this species, such as in East Anglia, the disease has become particularly severe. It is estimated that over 80% of the Corsican pine crop (around 11 000 ha) is infected on the Forestry Commission estate in East Anglia, with significant tree mortality occurring in some areas (Brown, unpublished data).

Management and control

It has been suggested that red band needle blight is most prevalent and damaging where host species are planted out of their natural range. For instance, the disease is absent from natural stands of radiata pine in California but is present on the same species growing further up the coast of western North America (Gibson, 1972).

Infection depends on several factors including the period of needle wetness, temperature, and the quantity of spores available for infection (Bulman, 1993). In the case of radiata pine in the southern hemisphere, the age of the host also has a strong influence, where trees up to age 10–15 years tend to be most susceptible. However, in Europe, Corsican pine can be affected at any age, and work by Villebonne and Maugard, (1999) suggested that, in France, trees were most susceptible between the age of 15–30, especially if the height exceeded 10 m. In Britain, although disease levels and mortality can be particularly high in pole stage crops, all age crops of Corsican pine can be severely affected.

Chemical control

Copper-based fungicides have been used to control red band needle blight for many years. In New Zealand, Australia and Chile, chemical control is applied routinely via aerial applications of fungicide spray such as copper sulphate or copper oxychloride (Gadgil, 1984). The correct timing for fungicide application is essential: if two applications are used, one must be applied just prior to needle emergence and one shortly after emergence (Peterson, 1982). In Britain, no chemicals are registered for control of the disease within the forest situation.

Disease resistance and breeding

Disease resistant varieties have been identified within hosts that are usually considered to be susceptible. These include varieties of Austrian pine from Yugoslavia and ponderosa pine found in the Rocky Mountains of the USA (Partridge, 1998). Alternatively, species of pine which are considered to be fairly disease resistant, for example Scots pine, can be used as replacement species.

Disease resistance in radiata pine is believed to be controlled by several genes and has a moderately high level of heritability. A breeding programme in New Zealand has produced families and hybrids of radiata pine that incorporate *Dothistroma* resistance. However, these 'resistant' trees are only predicted to have a 12% reduction in crown infection (Carson and Carson, 1989). It is also worth noting that a tree breeding programme for Corsican pine in Britain is likely to be less successful as this species is susceptible throughout its life, unlike radiata pine that generally exhibits a high degree of resistance by age 15. In addition, unlike New Zealand, no chemical control is used to suppress the disease, resulting in high inoculum loads. A further complication is that both mating types are present, unlike the clonal population found in New Zealand, and it is known that tree breeding programmes are likely to be less successful if a fungal population is able to reproduce sexually and generate increased genetic diversity (Hirst *et al.*, 1999).

Stand manipulation

Red band needle blight is considered to be particularly severe in dense, unthinned stands of pine (Wilcox, 1982). Delayed thinning, or a dense understorey of shrubs may keep humidity levels high at the base of the crown and favour development of the pathogen (Villebonne and Maugard, 1999). Pruning trees can improve the airflow within a stand and make the microclimate less favourable to disease (Gadgil, 1984); however this is an expensive management option. Experimental work is currently underway in East Anglia to assess the impact that different thinning intensities will have on disease levels. Initial results are promising, with lower levels of infection and mortality in crops that have been subjected to thinning regimes when compared with unthinned stands (Brown, unpublished data).

Future outlook

There has been an increase in the incidence of red band needle blight in Britain over the past 10 years where it is now causing significant damage to Corsican pine crops. Prior to this current disease outbreak, Corsican pine was increasingly the species of choice; its form and timber properties encouraged widespread planting, and as an adaptation strategy to predicted changes in

climate, it was considered as a key species for the future in much of England (Broadmeadow, 2002). In addition, the significant damage that *D. septosporum* can cause to lodgepole pine, and its occurrence on other British-grown coniferous species is of concern and it seems likely that this disease will have a significant impact on the conifer component of British forestry over the coming years.

Reasons for the increase in disease incidence are unclear. However, since the late 1990s there have been several episodes of increased precipitation during the spring and summer months in southern England, compared with the previous thirty years (Broadmeadow, unpublished data). As ten hours or more of needle wetness is usually required for infection by *D. septosporum* (Gadgil, 1984; Bulman, 1993), the increased rainfall levels coupled with a trend towards warmer springs, may have optimised conditions for spore dispersal and infection. Such conditions may become more prevalent in Britain over the next 20 years if current trends in climate change continue.

The increased frequency of the disease may also reflect a change in the behaviour of the pathogen, possibly as a result of increased genotypic diversity if *D. septosporum* is now able to reproduce sexually as well as asexually. During the earlier disease outbreaks in Britain it was assumed that only a single mating type of the fungus was present and *D. septosporum* only reproduced asexually, but this has apparently changed. The distribution of the two mating types and frequency of sexual reproduction needs to be investigated. Not only would the latter increase variation in the pathogen and allow it to adapt and change, but the sexually produced spores (ascospores) are reported to be wind dispersed and therefore capable of long distance dissemination (Gibson, 1972).

Control methods in countries where the disease causes significant economic impact rely on good stand management, use of resistant or alternative species and fungicide application. Combinations of these methods have proved very effective at controlling red band needle blight. In Britain, unless the use of chemicals is adopted to suppress the disease, management will be restricted to silvicultural measures to reduce inoculum loads and the use of alternative, less susceptible species in future rotations.

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