4 Pests and diseases

Radiata pine plantations are not currently affected by pests and diseases that cannot be controlled or tolerated, provided they are not planted "off-site" – that is, on a site where they are stressed by factors such as damp heat (see Chapter 2). However, some radiata pine pests and diseases can be troublesome and require modified forest management, and foresters need always to be vigilant regarding forest health. From an economic viewpoint, pests and diseases can result in significant damage to the plantation resource, end-use and value. What is considered "significant" will be related to management objectives. Organisms that are benign or helpful to the forest ecosystem, such as mycorrhizal fungi and most birds, are not considered pests. The management objective, however, should be to focus on growing a healthy forest in which pests and diseases are perceived as a symptom of an unhealthy forest rather than as the problem (FAO, 2001).

This chapter covers insects, fungi and animals of commercial significance; it also covers the issue of plantation forest vulnerability and risk management compared with natural forest. Weeds, which can also be pests, are covered under "establishment" (Chapter 8) because it is at that stage that they have the largest impact on management. Abiotic limitations are considered in Chapter 2, and the topic of radiata pine as an alien invasive species is addressed in Chapter 3.

MAJOR INSECT PESTS

Sirex wood wasp

Sirex noctilio, commonly known as the sirex wood wasp or simply sirex, is endemic to Europe, parts of Asia, Turkey and North Africa. Its preferred host trees are *Pinus* trees, but it rarely kills native pines in its native range. Sirex is only found on trees that have been stressed due to overcrowding exacerbated by drought. The female actively seeks out trees with low sap pressure and during its attack infects the tree with a symbiotic associate, the fungus *Amylostereum areolatum*. This fungus reduces the moisture content of green wood to levels more favourable for egg hatching, supplies essential nutrients to larvae, and causes dry white rot of the wood, thereby assisting the tunnelling activity of larvae.

The first sirex population in New Zealand established itself in the Wairarapa in 1900, most probably introduced on imported wood from Europe (Bain, Sopow and Bulman, 2012; Hurley, Slippers and Wingfield, 2007). Sirex attracted little attention in New Zealand until the late 1920s, when deaths attributed to the wasp became evident in young radiata pine plantations at high planting densities. Between 1946 and 1951, a large outbreak wiped out 30 percent of individuals in unthinned, intermediate-age radiata pine stands in an area of 120 000 ha in the central North Island. Within these plantations, stress from overcrowding was aggravated by a series of unusually dry summers. What at the time was a major biological catastrophe is now considered to have had a beneficial impact because the infestation performed what in effect was a broad-area thinning during a period in which neither markets nor labour for the thinnings were available. Following the collapse of sirex populations in New Zealand in 1951, there have been no further outbreaks. The adoption of silviculture using low stand stockings since the 1960s has furthermore mitigated sirex outbreaks.

In Australia, sirex is still considered the most serious insect problem in radiata pine plantations (Collett and Elms, 2009). In the late 1940s, based on what occurred in New

Zealand, forest authorities in Australia increased quarantine vigilance, but in 1952 the first discovery of sirex in Australia was made in Tasmania. Ten years later, the first mainland infestation was found near Melbourne in Victoria. These two infestations are believed to have originated from separate accidental introductions through imported timber. Sirex spread through Victoria into South Australia, New South Wales and the Australian Capital Territory, advancing at an average rate of 30–40 km per year. Sirex has not been found in Western Australia.

Sirex populations built up in Tasmania despite early search-and-destroy operations and the release of two species of wasp parasitoids. In one 1 100 ha plantation, sirex had killed 40 percent of all trees by 1959. In southern Victoria, the first substantial radiata pine mortalities from sirex occurred in the 1960s in shelterbelts on farmland and in private plantations in central Gippsland. In the Green Triangle region near Mount Gambier, an infestation in the late 1980s resulted in the death of 4.8 million trees, partly because of problems with control operations (Hurley, Slippers and Wingfield, 2007). In New South Wales, there have been occasional localized outbreaks in unthinned stands.

Sirex was discovered in radiata pine plantations in Argentina in 1985 and had spread to the radiata pine resource in Chile by 2000 (Hurley, Slippers and Wingfield, 2007), but it has not yet caused widespread mortality there. It was found in South Africa in 1994, where it now generally occurs at low levels. Sirex and related species are found at low incidence levels in radiata pine stands in Europe, but are not considered a major problem (Hall, 1968).

The prevention of sirex epidemics is largely a silvicultural issue. Populations usually only build up to high levels when conditions are adverse, as healthy radiata pine trees are very resistant to attack. The insect is drawn to stressed or recently killed trees, although green logs and large-diameter logging slash are also attractive. Young trees are seldom attacked because they are too small. The following silvicultural practices have been advocated to maintain tree vigour, minimize water stress and reduce the build-up of sirex:

- avoid planting in drought-prone areas or on sites that are difficult to thin;
- reduce initial stocking and/or carry out timely thinnings to remove suppressed trees;
- restrict high-pruning and waste-thinning operations in susceptible areas to periods outside the insect's flight season;
- minimize injury to trees and quickly salvage trees damaged by natural causes.

In New Zealand, biological control programmes date back to the late 1920s (Hurley, Slippers and Wingfield, 2007). The initial focus in Australasia was on the introduction, mass-breeding and release within infected plantations of sirex-specific parasite wasps of the *Ibalia*, *Megarhyssa* and *Rhyssa* genera. In South America, sirex already had paristoids when first introduced, but new introductions have been made in both South America and South Africa. Up to 70 percent parasitism has been recorded but it is generally about half this level. Thus, while they are an important control measure, parasitoids are not sufficient by themselves.

A European parasitic nematode, *Deladenus siricidicola*, was found to be present in New Zealand in 1962; this led to the wider use of the nematode and the selection of virulent strains (Collett and Elms, 2009; Hurley, Slippers and Wingfield, 2007). These strains can result in over 90 percent parasitism. However, a loss of virulence can occur when they are bred artificially for a long period, as was discovered during the outbreak of sirex in the late 1980s in Australia's Green Triangle region.

Both Tasmania and South Africa attempted to eradicate sirex when it was discovered; while unsuccessful, these efforts may have slowed the build-up of populations. Quarantine measures have been successful in keeping sirex out of Western Australia. Finally, there is some evidence that the island provenances of radiata pine are less susceptible to sirex than are mainland provenances.

The Siricid wood wasp, *Urocerus gigas gigas,* was found in radiata pine in Chile in the 1970s, but since it only attacks logs and severely weakened trees it is not considered a problem (FAO, 2008).

Bark beetles

Radiata pine is susceptible to numerous bark beetles, of which *Ips grandicollis* causes most concern in the Southern Hemisphere. Fortunately, the majority of bark beetles are not economically significant in radiata pine plantations, although a few are troublesome vectors for bluestain and decay fungi. In Spain, 15 species of bark beetle have been found in radiata pine, of which two, *Tomicus piniperda* and *Ips sexdentatus,* are of greatest concern (Goldazarena, Romón and López, 2012).

Dendroctonus valens, the red turpentine beetle, and three species of *Ips* (*I. paraconfusus*, *I. mexicanus* and *I. plastographus*) occur in native radiata pine stands in California (McDonald and Laacke, 1990). They have the ability to kill trees and are particularly destructive in drought-stressed stands. There are also other bark beetles of lesser importance. Bark beetles are one of the vectors of the introduced pitch canker, described below.

I. grandicollis, the five-spined bark beetle from the eastern United States, was introduced accidently to South Australia in 1943 and Western Australia in 1952 (Morgan, 1989) and has spread to all the radiata zones in mainland Australia. It is not found in other major grower countries but has been frequently intercepted at quarantine stations in New Zealand and South Africa. The insect is commonly found in logging slash and in the wake of fire. If numbers build up, the beetle will attack living trees, particularly if the trees are stressed. Deaths are usually confined to small areas. In New South Wales, however, droughts have triggered more extensive attacks on living trees up to 30 years of age. The beetles carry bluestain fungi (*Ceratocystis ips*), which causes problems with stockpiled logs, and therefore logs should be removed promptly from forests in which the beetles occur.

In Australia, *Ips* control measures and pest management strategies have included regional quarantine, rapid log extraction, insecticide spraying of logs, slash management, biological control through parasitoids, and pheromone trapping.

Hylastes ater, the black pine beetle, and *Hylurgus ligniperda*, the golden-haired bark beetle, both from Europe, are found in radiata pine plantations in all major grower countries. They are generally found feeding on the cambium of recently felled logs and fresh stumps. *Hylastes ater* can subsequently attack the root collar of planted seedlings and natural regeneration, causing some deaths but many more sublethal infestations (Reay *et al.*, 2002). The species can also infect seedlings with sapstain fungi. Seedlings planted in autumn-felled stands are at greater risk. *Hylurgus ligniperda* does not attack seedlings in New Zealand but does so in Chile (FAO, 2008). From an economic viewpoint, a major problem with these species is that infested logs cannot be exported unless fumigated immediately before shipping, while green sawnwood may have to be fumigated or kiln-sterilized if the insect is present.

The Mediterranean pine engraver, *Orthotomicus erosus*, is another bark beetle that has been introduced accidently to Chile, South Africa and California and is known to attack weakened pine trees (Haack, 2004).

There is considerable potential for further species of bark beetle to become pests within the radiata pine plantations of the Southern Hemisphere as a result of accidental introductions. These include *Ips sexdentatus* and *Tomicus piniperda*, which have been known to kill weakened radiata pine trees in France and Spain (Brockerhoff *et al.*, 2006).

FIGURE 4.1
The effects of the pine shoot moth, *Rhyaciona buoliana*

Pine shoot moth

Rhyacionia buoliana, the European pine shoot moth, is the most significant insect problem in radiata pine stands in Chile, having first been detected in 1985 (Ramos and Lanfranco, 2010). It is thought to have come from Argentina, where it was first seen in 1939 and where it attacked pines, including radiata pine. After its detection near the southern limit of radiata pine in Chile, it spread north at the rate of about 50 km per year. The species is also found in radiata pine plantations in Turkey, where its effects have been pronounced, and in Galicia, Spain (Allen, 1973).

The moth does not kill the tree; rather, the larvae invade the shoots (Figure 4.1). In Chile there is usually only one generation per year. The larvae weaken the shoots, in which they are present for ten months, leading to breakage, malformation and reduced height growth. Up to five larvae have been observed in one terminal shoot. Damage to the main leader is worse in stands up to 6–7 years of age; in older stands there may be less leader damage but branch tips are still attacked. In young stands, 50 percent of leaders can be damaged, although all trees will be attacked.

In 1989, the specific parasite *Orgilus obscurator* was introduced to Chile, and other native Chilean insect species also opportunistically attacked the pine shoot moth (Ramos and Lanfranco, 2010), greatly reducing the damage caused by the moth. In southern areas the insect is under control, but control is only modest further north in drier areas and on poorer sites (Alfaro *et al.*, 2010). Other insects are attacking the introduced parasite and the longer-term balance is unknown (Box 4.1). The impact of climate change, which may lead to greater moisture stress in the north, could also have implications for the effectiveness of *O. obscurator.* Insecticides have produced mixed results and are not used.

Aphids and adelgids

The Monterey pine aphid, *Essigella californica*, quickly became a major concern after it was detected in Australia in 1998 and caused extensive defoliation in mid-rotation stands (Eyles *et al.*, 2011). Typically, the defoliation shows as very thin mid-to-upper crowns, the yellowing of needles and premature needle shedding. This insect has also

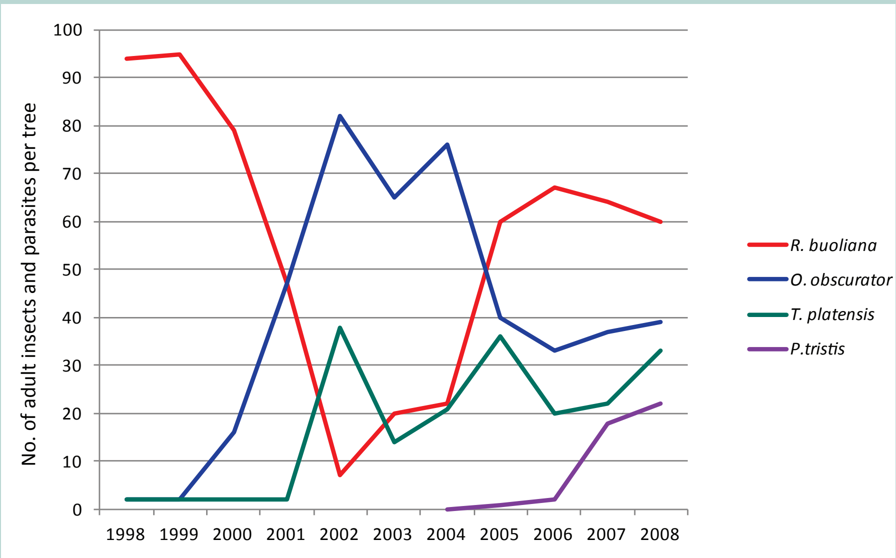
BOX 4.1

The impact of parasites and hyperparasites on the control of the pine shoot moth, *Rhyacionia buoliana*

The introduction of the specific parasite *Orgilus obscurator* in 1989 to Chile was initially slow, so a large-scale release programme was introduced in the Bio Bio region. As shown by the red line in the figure below, this quickly led to a large reduction in the number of pine shoot moth per tree as the number of parasites (blue line) increased. Later, several native species of insect also attacked the pine shoot moth. One, *Temelucha platensis* (green line), a competitor with *O. obscurator*, increased in number in parallel with *O. obscurator*. Other insects, such as the non-native *Perilampus tristis* (purple line) acted as hyperparasites by parasitizing *O. obscurator*, and appear to be reducing the parasite's impact. As the figure shows, the number of pine shoot moths per tree increased from 10 to 20 in 2002–03 to about 60 per tree in 2005–08. Overall, this resulted in a 40 percent reduction in pine shoot moth infestation in the Bio Bio region since the pine shoot moth epidemic first occurred. Control is currently higher elsewhere in Chile.

It is clear that the situation is dynamic in Chile and the future direction of biological control is not easy to predict. Control efforts will require continuous management.

Population dynamics of pine shoot moth and various parasites, 1998–2008, Bio Bio region, Chile



Source: Redrawn from Ramos and Lanfranco (2010), with permission

been present in New Zealand since 1998; it is not considered a problem there at present but could become more prevalent with climate change (Watson *et al.*, 2008).

The Monterey pine aphid is a greater problem where trees are under moisture stress. Studies have shown that infestations will reduce growth rates, although interpretation is complicated by the effects of moisture stress. Some radiata pine genotypes are more susceptible to attack (heritability 0.4) than others, and since 2005 aphid-resistant breeds have been available in New South Wales (Sasse, Elms and Kube, 2009). Thinning and balanced fertilizer treatments have been suggested as appropriate silvicultural treatments for some sites. Biological control with a wasp, *Diaeretus essigellae*, is also being pursued.

The pine woolly aphid, *Pineus pini* (syn. *P. laevis* and *P. boerneri*), which is present in all major radiata pine-growing regions, has been a problem in South Africa since the early 1980s (Zondag, 2009; FAO, 2007). Both the severity and impact of infestation of pine trees by this sap-sucking insect are influenced by tree health and vigour. Stands on drier sites and at high stockings are most susceptible, particularly after a dry summer. Within heavily infected radiata pine stands, however, there is always a contrasting mosaic of uninfected and infected trees. A heavy infestation can reduce stand productivity.

Biological control of the pine woolly aphid occurred naturally in New Zealand and has had variable results elsewhere. Resistance varies among radiata pine genotypes. Currently, the main management approach to reducing the impact of this pest is site selection and silviculture, but it is considered to have little economic impact in Australia, Chile and New Zealand.

In Chile, the aphids *Cinara maritimae* and *Eulachnus rileyi* have been recorded but are currently of low significance (FAO, 2008).

Other localized insect problems

A number of other localized insect problems in radiata pine stands have been identified:

- There have been isolated defoliations by native insects in Australia, Chile and New Zealand, but these are not considered a major cause for concern.
- In Spain, the native pine processionary moth (*Thaumetopoea pityocampa*) is considered a significant defoliator. It limits the use of radiata pine in other parts of Europe and is a possible threat if introduced elsewhere (Brockerhoff *et al.*, 2006).
- In South Africa, the pine emperor moth (*Imbrasia cytherea*), a native insect, has occasionally been a problem, although populations usually collapse due to a viral disease (Allen, 1973; FAO, 2007).
- The deodar weevil, *Pissodes nemorensis*, first detected in South Africa in 1942, attacks stressed radiata pine trees and can cause dieback. It can act as a vector for pine-pitch canker (FABI, undated).

MAJOR DISEASES

Dothistroma needle blight

Dothistroma needle blight, *Dothistroma pini* and *D. septosporum* (teleomorph *Mycosphaerella pini*), is a fungal disease resulting in premature defoliation. It has become established in all radiata pine regions (Bradshaw, 2004; Bulman, Ganley and Dick, 2008). The disease has devastated radiata pine in some high-rainfall subtropical and tropical environments and led to the abandonment of radiata pine plantations in East Africa (Nsoloma and Venn, 1994), Zimbabwe (Barnes, 1970) and India (Bakshi and Singh, 1968). It is not a problem where rainfall is less than 1 000–1 200 mm per year in the latitudes where radiata pine is normally planted. In drier regions there may be localized infections, often associated with young unthinned stands, where the topography encourages mist. The disease is suspected to have entered New Zealand in the late 1950s or early 1960s and was positively identified in 1964. It was first found in Australia in 1975 and confirmed in Chile in 1965, although it was likely present there in the late 1950s. The economic cost of the disease in lost productivity and for control measures is about US$15 million per year in New Zealand (Watt, Bulman and Palmer, 2011). In New Zealand there is only one strain, and the introduction of a new strain of the fungus is considered a significant additional threat (Hirst *et al.*, 1999).

Usually, but not always, infection begins at the base of the crown and progresses upwards, with a clear division between infected and uninfected parts of the crown (Figure 4.2). Trees are very rarely killed, but repeated defoliation reduces diameter growth and, under very severe conditions, height growth. Some studies suggest that the impact at the end of the rotation may be small, as the worst-affected trees are likely to be thinned out (van der Pas, Bulmand and Horgan, 1984). However, other studies

FIGURE 4.2
The effects of *Dothistroma* in radiata pine is usually most noticeable in the lower crown

have found that growth reduction is proportional to the level of infection (Whyte, 1976; Bulman, Ganley and Dick, 2008). Stand growth is reduced if the level of infection reaches 25 percent; stand growth stagnates at an infection level of 75 percent.

In South Africa and New Zealand, radiata pine is considered resistant to dothistroma at about age 12–16 years (sometimes 20), although older radiata pine has occasionally been found to be infected in Australia. In New Zealand, peak infection is at 2–8 years, and high disease levels appear to occur in two of every five years; in infection years, about 20 percent of the stands in the susceptible age classes require control measures.

The chemical control of dothistroma needle blight by the aerial application of copper fungicide is generally effective and is widely practised in New Zealand and occasionally in Australia if infection levels reach 25 percent (Bulman, Ganley and Dick, 2008). A study in southern stands of radiata pine in Chile, however, showed that it was not cost-effective there (Alzamora, Hauer and Peredo, 2004). In the Southern Hemisphere, infected stands are sprayed with cuprous oxide from the air in October/November (Bulman *et al.*, 2004). This kills most of the inoculum at a time when it is multiplying and also protects the foliage from new infections for up to three months (Bulman, L.S. unpublished data). Three to five sprays per rotation are usually adequate. Other fungicides can also be used (Bradshaw, 2004). Ground and aerial surveys are used to identify stands needing treatment, and recently the use of spectral imaging has been studied. Detailed advice on spraying is given by Bulman *et al.* (2004).

Pruning branches bearing infected foliage lowers the rate of increase of the disease. Experience in New Zealand indicates that pruning a stand with 25–40 percent crown infection generally postpones the need for a fungicidal application for several seasons. Thinning also assists in controlling infection. Tree-breeding for disease resistance has had some success (see Chapter 6). Breeding may reduce infection by 15 percent and chemical spraying by 56 percent (Carson, Dick and West, 1991). Sulphur deficiency also increases dothistroma infection (Turner and Lambert, 1986). Dothistoma produces a toxin, dothistomin, which was considered initially to be a health concern, but further research found that it does not pose a significant problem (Bulman *et al.*, 2004; Bradshaw, 2004).

Sphaeropsis sapinea

A variety of diseases of *Pinus radiata* are attributed to the opportunistic fungal pathogen *Sphaeropsis sapinea* (syn. *Diplodia pinea*). It is considered one of the most serious forest diseases in South Africa (Swart, Knox-Davies and Wingfield, 1985), but is found in all the world's radiata pine areas.

The following symptoms are associated with *S. sapinea*:

- leader dieback
- wood cankers
- crown wilt
- root rots
- blue stain in timber
- damping-off in nurseries.

Leader dieback is probably the most common symptom (Figure 4.3; Swart, Knox-Davies and Wingfield, 1985). The first indications of shoot blight are resin droplets on growing shoots and a few stunted needles. Later, needles turn brown and the shoot tips become crooked or curled. After about three weeks, black pycnidia appear on the surface of dead needles. When terminal shoots are infected they exude large amounts of resin. The result is dieback of the leader. Warm temperatures (20–25 °C) and high humidity favour its development, particularly when coinciding with new shoot growth. Infection of lateral shoots is generally less likely to retard growth and cause malformation of the tree than infection of the terminal shoots. Although unwounded drought-stressed trees can be infected, generally the disease is worst where there has been wounding by hail, insects or other agents. Crown wilt is a result of wood canker infection lower down on the bole or branch; the needles first turn chlorotic and then reddish-brown.

FIGURE 4.3
***Sphaeropsis sapinea* (syn. *Diplodia pinea*) often results in leader dieback**

Pruning wounds are a common source of entry for *S. sapinea*. Studies in New Zealand have shown that heavily pruned trees are more susceptible to infection than lighter-pruned trees and infection tends to increase with increasing branch diameter (Ridley and Dick, 2001). Sunscald following pruning will also allow infection.

S. sapinea is another disease that has prevented the use of radiata pine in more humid tropical countries (Swart, Knox-Davies and Wingfield, 1985). In the major radiata pine areas, careful selection of forest plantation sites will reduce the incidence of the disease. Sanitation, practices to reduce stress and injury to trees, and tree-breeding are also avenues of control. Spraying fungicides is practical only in nurseries.

Pine pitch canker

Pine pitch canker (*Fusarium circinatum*) was first seen in the natural stands and planted trees of radiata pine in California in 1986 and is now considered a major threat to plantations (Box 4.2; Ganley *et al.*, 2009; Wingfield *et al.*, 2008). In California, the canker is spread by insects – including bark beetles (*Ips* spp.), twig beetles (*Pityophthorus* spp.), cone beetle (*Conopthorus radiatae*) and *Ernobius* spp. – that wound the trees and cause localized cankers and branch dieback. It is not yet a major problem in radiata pine stands outside California but has been recorded in radiata pine stands in Italy, Spain and South Africa and in nurseries in Spain, South Africa and Chile. Pine pitch canker, which is found on a wide range of pine species and Douglas

BOX 4.2

Pine pitch canker: a growing threat?

Pitch canker (*Fusarium circinatum*) was first recorded in radiata pine in coastal California in 1986. It appeared in nurseries in South Africa (1990), Chile (2002) and Spain (2003) and later in plantations in Spain (2004) and South Africa (2007). Many consider this disease to be a major threat to radiata pine.

The disease infects all parts and ages of radiata pine and at any time of the year. Branch dieback and cankers are typically resinous. However, the fungus does not spread far from the site of initial infection. Trees can become malformed and their growth rates can be affected by a reduction in foliage. The fungus can attack cones and seeds and in nurseries cause damping-off and seedling root-rot and mortality.

The fungal spores are easily dispersed, but fungal infection in trees is facilitated by insect vectors that damage the trees. Insects associated with the spread include weevils, twig beetles, bark beetles and the pine shoot moth. Fresh mechanical damage may also allow entry, although this is not considered important in Californian radiata pine stands. Warmer temperatures, high humidity and high fertility favour the spread of the fungus. Climate mapping studies suggest that the California coast and Chile should be only moderately susceptible to this disease, which may be the reason why insect vectors are so important in California. Parts of Spain, South Africa, Australia and New Zealand are possibly more favourable for the disease.

Quarantine measures are the first line of defence for countries without the disease, which involves keeping out insect vectors as well as infected material. For nurseries, high levels of hygiene and the control of insect vectors are important. In plantations, reducing environmental stress through stocking control and the careful use of fertilizers may reduce the impact of the disease. Given that there is wide variation in resistance to the disease in radiata pine, breeding is another control option. However, this may be complicated because the disease has a number of strains. Biological and chemical controls have not proved effective.

It has been reported that resistance to the disease in radiata pine trees in California increases with time (induced resistance) and may be leading to a remission of pitch canker. For further information see Wingfield *et al.* (2008) and Ganley *et al.* (2009).

fir, is considered an indigenous disease in the United States, where it has been affecting native southern pine stands since 1946. It occasionally causes epidemics there that result in malformation and a loss of growth and occasional tree death. Radiata pine shows less resistance to this disease than most other pines, but like other pine species there is a large genetic diversity from which to breed resistance (Wingfield *et al.*, 2008).

Other localized diseases

Diseases that, at least at present, are relatively restricted in radiata pine include the following:

- Western gall rust (*Peridermium harknessii* or *Endocronartium harknessii*) – commonly found in the Californian native stands, this disease has not yet spread to other countries. The rust, which does not require an alternate host, is considered a potential threat in other countries, partly because of its climatic niche (Ramsfield, Kriticos and Alcaraz, 2007).
- *Neonectria fuckeliana* – first documented in New Zealand in 2003 from a 1996 collection, this disease occurs in the South Island (below latitude 43°S) and was initially assumed to be *Sphaeropsis sapinea* because it caused stem fluting associated with pruning (Figure 4.4; Hopkins and Dick, 2009). Pruning small branches (<60 mm) in summer helps control the infection. Some genotypes of radiata pine are resistant. The disease has been detected in Chile (Morales, 2009).
- Cyclaneusma needle-cast (*Cyclaneusma minus*) – a widespread, locally destructive needle cast that appears in plantations 6–20 years of age, is most damaging in areas with mild and wet conditions in autumn and winter (Bulman and Gadgil, 2001). Studies have found that an infection level of 60 percent over six years would halve diameter growth. However, control with sprays is not cost-effective. Breeding resistant strains may be possible, as the narrow sense heritability is about 0.2–0.3.
- *Phytophthora* root rot (*Phytophthora* spp.) – an occasional problem for radiata pine on ex-pasture and waterlogged sites. This disease is also of concern in nurseries and can be controlled by applying phosphorous acid and other nursery practices (Reglinski *et al.*, 2010).

FIGURE 4.4
Stem fluting caused by infection of pruned branches by *Neonectria fuckeliana*

- *Phytophthora pinifolia* – appeared in Chile in 2003 and had spread to about 60 000 ha of radiata pine plantations by 2006. Unlike other *Phytophthora* species, which attack roots, this fungus infects foliage at the base of the crown and can also form cankers on trees less than six years old (Durán *et al.*, 2008). Whole stands can die after three years of defoliation, probably from secondary infection by *Sphaeropsis sapinea*. *Phytophthora pinifolia* has been most virulent in humid areas and wetter years. Studies indicate that it is a single clone, and recent reports suggest that the disease has collapsed (Frankel and Hansen, 2011). Planting non-susceptible species on disease-prone sites and changing weather conditions may have helped reduce its impact. It has been recently hypothesised in New Zealand that a *Phytophthora* species may be associated with red needle cast.
- *Armillaria* root diseases – these have been found to occasionally kill small groups of trees in New Zealand, Australia and South Africa. The *Armillaria* species are generally natives of the region. In parts of New Zealand in the 1990s, *Armillaria* was thought to be becoming a greater problem in second- and third-rotation forests, and stump removal was advocated (Self and MacKenzie, 1995). Biological control with *Trichoderma* has been investigated (Dyck, 2006) and a commercial product is now available for use. However, recent research has found that the impact of *Armillaria* was overestimated in New Zealand (Hood and Kimberley, 2009).
- *Rhizina undulate* – a root rot found in South Africa, this disease attacks seedlings, particularly following burning of slash. It is also spread by *Hylastes* spp. (FAO, 2007).
- Endophytic fungi that infect radiata pine – these are gaining interest among researchers (Bulman, Ganley and Dick, 2008; Burdon, 2011). They are non-pathogenic but may have ecological effects; for example, endophytic fungi may have been responsible for ameliorating episodic dieback in radiata pine caused by pathogens such as *Sphaeropsis sapinea*.

ANIMAL AND OTHER PESTS

Animals have generally had a relatively minor impact on radiata pine plantations (Lewis and Ferguson, 1993; Maclaren, 1993). Apart from human encroachment, only goats on Guadalupe Island are considered a threat to the species in its native habitat. Elsewhere, young radiata pine trees are sometimes damaged by grazing stock in silvopastoral situations (see Chapter 11) or by wild rabbits, hares and wallabies. In Australasia, possums can climb trees and damage leaders, while in South Africa baboons have been observed stripping bark (McNally 1955; Bigalke and van Hensbergen, 1990). Birds and mice may also limit the use of natural regeneration as a means of re-establishing sites.

In silvopastoral systems, animal damage can be managed by careful stock control (see Chapter 11). Methods such as direct animal control, avoiding problem areas and using physical barriers and chemical repellents have all been used to reduce the problems caused by wild animals (Maclaren, 1993).

Nematodes have not been a significant pest in radiata pine plantations, although they have been found in dead and dying pines in Melbourne, Australia (Ridley, Bain and Dick, 2001). The pine wood nematode, *Bursaphelenchus xylophilus*, has caused significant losses of pine trees and other conifers in North America, Asia and Europe, but is not considered damaging to radiata pine.

PROSPECTS

Overall, there is a sense that the number of pests and diseases in radiata pine forest plantations worldwide is increasing. Occasionally an indigenous species may cross to radiata pine, but most commonly this increase is a result of introductions from outside the country. Some have argued that this is a major risk to growing forest plantations of non-indigenous species, while others say that there are distinct advantages in using non-indigenous species because they are released from their natural enemies. Gadgil and Bain (1999) studied these hypotheses in several species, including radiata pine, Douglas fir, *Pinus taeda* and *Eucalyptus nitens*, and concluded that there are usually fewer problems with non-indigenous forest plantations, provided they are in sites that suit the species and are remote from their natural origin. In addition, there are other advantages with forest plantations that make them less risky than managed natural stands.

Predicting the long-term impact of pests and pathogens is speculative for both forest plantations and natural forests. Today, the speed, breadth and volume of human travel and trade are unprecedented, and pests (both animals and insects) and pathogens are being spread widely. Radiata pine genotypes are also changing through tree-breeding, which may be reducing their resource allocation to defence mechanisms (Kay, 2008). Further, global climate change is likely to stress ecosystems and in some cases the lifecycle and virulence of pathogens and pests may change (Alfaro *et al.*, 2010). On the basis of climate models, Watt *et al.* (2011) suggested that the potential impact of climate change on dothistroma and pine pitch canker may reduce the suitability of radiata pine in some parts of the world. Alfaro *et al.* (2010) described the large-scale management efforts that may be required to mitigate the impacts of climate change on pests and diseases in forests.

Thus, in both natural forests and forest plantations, the prospect of novel ecosystems in a changing environment makes it more difficult to predict long-term outcomes. This complexity has been illustrated by the occurrence of pine shoot moth in radiata pine plantations in Chile (Box 4.1) and the effects of the recently introduced pitch pine canker in natural stands of radiata pine in California (Box 4.2). Similarly, the theory that planting radiata pine well outside its natural range is always advantageous because it releases the species from natural enemies does not always hold (Lombardero, Váquez-Mejuto and Ayres 2008). In addition, the use of mixed species in Spain did not prevent radiata pine from being attacked by the pine processionary moth (Brockerhoff *et al.*, 2006).

Nevertheless, experience with radiata pine plantations suggest that risks can be managed and that, because of the local importance and size of the resource in the major grower countries, prevention measures and research will be able to contain future problems. The main lessons from this experience are as follows:

- Radiata pine should not be planted "off-site" – climate and to a lesser extent soils should match natural stand conditions (see Chapter 2). Planting radiata pine in areas of damp heat should be avoided. Marginal sites often have more pest and disease problems because trees are more predisposed to attack due to stress.
- New pests and diseases have appeared regularly in the last 120 years and caused initial anxiety. In the longer term, however, most have been found to have only relatively minor impacts and can often be controlled easily.
- Most new pests and diseases in exotic forest plantations are introduced from outside the country. Only a few are indigenous.
- Good quarantine measures have been successful in intercepting potential threats, slowing their introduction or spread.
- The eradication of new insects that pose a major threat may be possible, particularly if they are detected early and spread slowly (Brockerhoff *et al.*, 2010).
- Keeping stands healthy and vigorous will often reduce pest and disease impacts and should be a management goal. Stocking and competition control and nutritional management are frequently used.
- Biological control using introduced or naturally occurring parasites has been successful against many insect pests, but has not always been fully effective.
- Research into the biological control of fungi is being actively pursued.

- Chemical control has been used infrequently, with the exception of nurseries and for containing dothistroma needle blight.
- The impacts of many insects and diseases can be reduced through tree-breeding. This strategy also requires keeping a wide genetic base (see Chapter 6).
- Transgenic insect-resistant radiata pine has been produced experimentally by implanting a gene from *Bacillus thuringiensis*. This technology is yet to be implemented by forest managers.
- Animal damage is generally a minor problem in radiata pine plantations, although it is sometimes a nuisance.
- Monitoring and reporting on forest health and vitality by forest managers and biosecurity authorities for insect, disease and animal pests is a critical part of risk and adaptive management.
- Prevention is the ideal approach, but early detection, preparedness and early response to outbreaks are essential to minimize social, environmental and economic impacts.