# Current and emerging threats to Ireland's trees from diseases and pests

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**Abstract**
Over the past decade the number of new pests and diseases detected in the United Kingdom and Ireland has increased significantly, particularly on trees and woody ornamentals. Whilst there has been a wide range of pests and diseases affecting woody hosts, those caused by members of the genus *Phytophthora* have been very damaging and widespread. These include *P. ramorum* on larch and rhododendron, *P. lateralis* affecting Lawson cypress, *P. kernoviae* on beech (*Fagus sylvatica* L.) and *P. pseudosyringae* infecting *Nothofagus* and bilberry species. Other recently introduced pathogens are responsible for causing the diseases red band needle blight (*Dothistroma septosporum*), ash dieback (*Chalara fraxinea*); and horse chestnut bleeding canker (*Pseudomonas syringae pv. aesculi*). A number of invertebrate pests also pose significant threats to Ireland's trees including, oak processionary moth (*Thaumetopoea processionea*), pine processionary moth (*Thaumetopoea pityocampa*), horse chestnut leaf miner (*Cameraria ohridella*), Asian longhorn beetle (*Anoplophora glabripennis*), and pine wilt nematode (*Bursaphelenchus xylophilus*). A number of factors have contributed to this increase. In recent years there has been an upsurge in the global trade of plants, which are being moved more rapidly from country to country. Small changes in temperature or weather patterns, due to climate change, can enable organisms to become established in areas where previously they would have struggled to survive. Often phytosanitary regulations and how they are applied are not as robust as they might be. Furthermore there is a general lack of understanding in the general public of the importance of being vigilant in keeping pests and diseases out of the country. In Ireland there is a better chance of remaining free of many pests and diseases not currently found on the island.

**Keywords:** *Phytophthora ramorum, P. lateralis, P. pseudosyringae, Chalara fraxinea, Global plant trade, Phytosanitary measures, Pseudomonas syringae pv. aesculi, Dothistroma septosporum.*

## Introduction

During the past 10 years or so there has been a very significant increase in the incidence of diseases and pests affecting trees in Europe including the UK and Ireland. Several new pathogens have been named and the impact of pests and diseases on tree health has been obvious. Perhaps for the first time for many years, going back to the Dutch elm disease outbreak of the 1970s, there is public awareness of the importance of plant health and of the work done by plant pathologists and entomologists.

Ireland, as an island, is currently free of many damaging plant pest and

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pathogens, which have been introduced into other regions of the European Union, where some have become established and are causing serious problems. In this paper some of the major new diseases and pests which have been identified in trees and woody plants in Ireland are highlighted. Some of the reasons for their increased incidences are advanced, together with some speculation as to new threats on our door-step from diseases and pests that are not currently in Ireland. Finally a number of observations are made on issues and challenges facing the plant health authorities in their attempts to maintain this high plant health status.

**Recent tree disease introductions to Ireland**

Ireland, being an island off the north-west coast of continental Europe has some advantages in protecting its high plant health status. Prevailing winds tend to be from the west and so the risk of aerial spread of disease is reduced. Great Britain often acts as an "early warning system" for new organisms. For example fireblight, caused by the bacterium *Erwinia amylovora* (Burrill) Winslow et al. was first observed in Kent in south-east England in 1957, but not detected in Ireland until the mid 1980s (van der Zwet 2002). The main route of entry for pests and pathogens is almost certainly movement of plants and plant products either in trade or by members of the public (Brasier 2008).

Despite these advantages, a number of new pest and diseases have been found in recent times and threaten our high plant health status and our trees (Table 1). These topics are dealt with in more detail below.

*Phytophthora ramorum* (Sudden oak death; ramorum disease)

*Phytophthora ramorum* is a fungus-like organism with a wide host range. It was first identified around the year 2000 as the organism responsible for the death of large numbers of tanoak (*Lithocarpus densiflorus* (Hook. and Arn.) Reh.) in California (Rizzo et al. 2002). Mature trees died quickly, hence the disease became known as called "sudden oak death" (SOD). At about the same time in The Netherlands and Germany the pathogen associated with dieback and blight of rhododendron (*Rhododendron ponticum* L.) plants was also identified as *P. ramorum* (Werres et al. 2001). It therefore seemed that this "new" pathogen had been found affecting two very different hosts in two distinct geographic regions. It was subsequently shown that the two pathogen populations were predominantly of different sexual mating types. The European population was classified as A1 while the US population was A2. This suggests that there were probably two separate introductions. Both introductions may have occurred at different times, possibly from the Far East, although at present that is still conjecture. What is clear is that the European introduction was not directly associated with the American outbreak and vice versa. A full updated EU Pest Risk Analysis (PRA) for *P. ramorum* has been published (Anon. 2009), as has an extensive data sheet about the pathogen (Anon. 2007).

The first finding, in 2002, of *P. ramorum* in the UK was on *Viburnum* spp. growing in a garden centre. Although *P. ramorum* has been shown to have a wide host range (>100 species; Grünwald *et al*. 2008), initially most of the infections in

**Table 1:** Diseases and pests of concern to Irish trees and forests.

| Disease | Causal agent | Main hosts of concern | EPPO status | First report in Ireland | Level of concern |
|---|---|---|---|---|---|
| Ramorum disease, (Sudden oak death) | *Phytophthora ramorum* Werres, De Cock & Man in't Veld | Japanese larch, rhododendron, oak, Douglas fir, bilberry, and 100+ other hosts | Alert list<br>PRA (Anon 2007; Anon 2009) | 2006 | High |
| Lateralis diease | *Phytophthora lateralis* (Tucker & Milbrath) | Lawson cypress | A2<br>PRA (Anon. 2006) | 2010 | Low |
| Kernoviae disease | *Phytophthora kernoviae* (Brasier, Beales & S A Kirk) | Larch, rhododendron bilberry, beech, oak | Alert list<br>PRA (Anon. 2008a) | 2009 | Medium |
| Pseudosyringae disease | *Phytophthora pseudosyringae* (Jung) | Beech, *Nothofagus* spp. Pieris, oak, bilberry | PRA (Anon. 2012a) | 2011 | Low |
| Red band needle blight | *Dothistroma septosporum* (Dorog): *Mycosphaerella pini* (E. Rostrup) syn. | Corsican pine, Scots pine | PRA (Anon. 2013a) | 2011 | High |
| Ash dieback | *Chalara fraxinea* (T. Kowalski): *Hymenosscyphus pseuodalbidus* (teleomorph) | *Fraxinus excelsior*<br>*F. nigra*<br>*F. angustifolia* | Alert list<br>PRA (Sansford 2013) | 2012 | High |
| Horse chestnut bleeding canker | *Pseudomonas syringae pv. aesculi* (Durgapal & Singh) | Horse chestnut | - | 2010? | Medium |
| Oak processionary moth | *Thaumetopoea processionea* (L.) | Oak | PRA (Evans 2007) | Not reported | Medium |
| Pine processionary moth | *Traumatocampa pityocampa* (Den. & Schiff.) | *Pinus* spp. Especially: Austrian, lodgepole, Scots, Monterey | - | Not reported | High |
| Horse chestnut leaf miner | *Cameraria ohridella* Deschka & Demic | *Aesculus* spp. in particular the European white-flowering horse-chestnut | PRA (Stigter 2000) | Not reported | Low |
| Asian longhorn beetle | *Anoplophora glabripennis* (Motschulsky) | Maple, horse chestnut, alder, birch, poplar, willow, elm + many other broadleaf trees | PRA (van der Gaag, 2008) | Not reported | High |
| Pine wilt nematode | *Bursaphelenchus xylophilus* | *Pinus* spp. including Scots, Austrian and red pines | A2<br>PRA (Evans et al. 1996; Evans et al. 2009) | Not reported | High |

the UK and Ireland were reported on rhododendron with *R. ponticum* being particularly susceptible. Infected plants were found in both garden / parkland situations and also in forest situations. Rhododendron was recognised as a sporulating host and primary source of inoculum. Where mature broadleaved trees, e.g. *Quercus* and *Fagus* spp. etc. were found to be infected with *P. ramorum*, they were always associated with infected rhododendron, often in actual contact with the affected trees. In the Pacific oak forests of south-western USA, bay laurel (*Laurus nobilis* L.) serves a similar role as a primary sporulating host acting as the source of inoculum infecting mature trees.

The situation changed, however, in 2009 when *P. ramorum* was shown to be causing the death of mature Japanese larch (*Larix kaempferi* (Lam.) Carr.) trees in south-west England (Brasier and Webber 2010) (Figure 1). In many of the subsequent cases no infected rhododendron was found in close proximity to the larch. Furthermore in contrast to other tree species, larch was shown to be a major sporulating host, producing up to 10 times more sporangia on larch than on rhododendron. As sporulation was occurring in the canopy at heights of up to 20–25 m, the potential for widespread dissemination was significantly greater.

The approach in both the UK and Ireland to outbreaks of *P. ramorum* in larch still continues to be one of eradication (Anon. 2013a). In Great Britain over 3,000 ha of larch have been cleared since 2009. In N. Ireland around 500 ha out of a total larch area of approximately 5,000 ha have been cleared. Recent results from the Forestry Commission in Britain show a slowing down of the spread in England, while the disease continues to expand considerably in larch plantations in Scotland, particularly in the Dumfries and Galloway region. Aerial spring and autumn surveys of larch plantations in N. Ireland have subsequently shown a slowing of the spread, although there is evidence that the disease is still moving northwards. The majority of outbreaks in N. Ireland have been on the east of the Province, with the primary focus of infection being on the Antrim Plateau with a further pocket of outbreaks in southern Co. Down. In late 2012, *P. ramorum* was found causing symptoms on noble fir (*Abies procera* Rehder) and larch trees in a plantation in south Armagh. In summer 2013 there was evidence that the pathogen had spread westwards with a number of small outbreaks in Co. Tyrone and Co. Fermanagh. These infected sites tended to have only a few trees showing symptoms which were much less severe than in the main areas of infection in Co. Antrim. In the Republic of Ireland, outbreaks have been mainly in the south eastern part of the island.

As already indicated, two mating types A1 (European) and A2 (American) are known to exist. There have been a small number of records of A1 types being found in America and the A2 mating type has been detected once in Belgium (Grünwald et al. 2008). There have been no records of the production of viable oospores in the wild; however, oospore formation on living plants under controlled conditions has recently been recorded (Riedel et al. 2012). The rare occurrence of *P. ramorum* oospores in-vivo supports the hypothesis that the American and European populations of the pathogen belong to different clonal lineages. Up until 2010 only three lineages of *P. ramorum* were known. Two (NA1 and NA2) were found in America and one (EU1) was the only lineage known in Europe, having been

**Figure 1:** *Aerial shot of larch forest with* Phytophthora ramorum *infected trees.*

introduced in the early 1990s. However, in 2011 a new lineage designated EU2, was described (van Pouke *et al*. 2012). Most of the EU2 isolates were obtained from Northern Ireland, with a small number from the south-west corner of Scotland. EU2 isolates were obtained from larch, rhododendron, *Vaccinium* spp. and oak, but were not found in any of the other regions of Europe where *P. ramorum* occurred.

In a recent extensive study of over 300 isolates or DNA extractions of *P. ramorum* from both the north and south of Ireland, genotyping to either EU1 or EU2 was carried out (Mata Saez, personal communication). The vast majority of the isolates were obtained from samples submitted between 2008 and 2013 to the Agri-Food and Biosciences Institute, Belfast or the Department of Agriculture, Food and the Marine laboratories, Backweston and represented a wide range of forestry, nursery and natural sites. Isolates had been obtained from a wide range of hosts including Japanese larch, noble fir, rhododendron, red oak (*Quercus rubra* L), bilberry (*Vaccinium myrtillus* L.), *Viburnum* spp. Thunb. and beech (*Fagus sylvatica* L.). All of the isolates investigated so far by molecular methods have been A1 mating type. Preliminary data indicate that almost all of the N. Ireland isolates were EU2, and that this lineage was only recently introduced into Northern Ireland (van Pouke et al. 2012). A small number of *P. ramorum* EU2 isolates were also found in trees in south-west Scotland in the Dumfries and Galloway region. There is no definitive evidence about the source of EU2 or whether it spread east or west in the wind or through movement of contaminated plants or soil. One small pocket of EU1 isolates in N. Ireland was associated with a landscape planting of recently imported rhododendron plants from a nursery where EU1 *P. ramorum* had previously been detected. In contrast almost all of the isolates from the Republic of Ireland have been shown to be EU1 (Mata Saez pers. comm.). Much further work is needed as it is important to identify the source of the pathogen to determine the pathological significance of the EU2 lineage of *P. ramorum* and to suggest why it seems to predominate in such a small geographic region.

*Phytophthora kernoviae*

During surveys of woodlands in Cornwall, south-west England the discovery of a new *Phytophthora* sp. was reported – which was later named *P. kernoviae* (from "Kernow", the Cornish word for Cornwall (Brasier et al. 2005)). It is particularly associated with bleeding stem lesions on mature *Fagus sylvatica* as well as with stem and foliar necrosis on *R ponticum.* Most of the outbreaks have been confined to the south-west of England. However in the past few years outbreaks of *P. kernoviae* have been commonly found in parts of Wales as well as in the west of Scotland on bilberry (*Vaccinium* sp.) and other hosts. Indeed, it is the damage caused to *Vaccinium* and *Calluna* species by *P. kernoviae* that is most worrying in Britain, as large scale death of these two species could threaten the integrity of heathland and the species within it (Beales *et al*. 2009a). *P. kernoviae* was first detected in Ireland in 2008 on *Rhododendron* spp. and confirmed in 2009 (Brennan et al. 2010). It is crucial that important *Vaccinium* heathlands in Ireland are surveyed regularly so that actions can be taken to prevent the spread of the pathogen to this ecologically significant species. The only other country in the world where *P. kernoviae* has been detected is New Zealand. It is only possible to speculate on the original source of the pathogen, however it seems probable that it was spread on infected plants in the horticultural trade. It has been isolated from the soil and was found infecting shoots and fruit of cheromoya (*Annona cherimola* Mill.), also known as custard apple (Ramsfield et al. 2009).

A revised PRA for the UK was published in 2008 (Sansford, 2008), which concluded that *P. kernoviae* continues to pose a threat to the managed and unmanaged environment, the timber and ornamental plant trade and the tourism industry in the UK. As with the disease management strategy for *P. ramorum*, removal of infected plants will reduce the inoculum and may significantly slow its subsequent spread and establishment.

*Phytophthora lateralis*

In 2010/11 *P. laterais* was isolated from diseased Lawson cypress (*Chaemecyparis lawsoniana* A.Murray. Parl.), at a range of sites in Scotland, England and Northern Ireland (Green et al. 2013). At the majority of the sites, only collar and root lesions were observed. However, at two of the sites large stem and branch lesions were observed which had no connection with the diseased collar regions. *P. lateralis* was isolated from these aerial parts of the plants. There is currently some debate about whether aerial infections occur, and if so, whether they are an important source of inoculum. In Taiwan, which is thought to be the centre of origin of the pathogen, sporulating aerial infections have been reported (Brasier et al. 2010). Possible aerial infections have also been observed in some of the outbreak sites in Scotland and France, however root infections with the associated dissemination are still regarded as the most important way for the pathogen to complete its life cycle.

In late summer 2010, *P. lateralis* was found to be associated with a number of

**Figure 2:** Phytophthora lateralis *infected Lawson cypress trees in Tollymore Forest Park, Co. Down.*

dead mature Lawson cypress trees in Tollymore Forest Park in south Down, N. Ireland (Figure 2). Further significant outbreaks were found at Somerset Forest Park in north Co. Derry, in a forest plantation at Mourne Forest in Co. Down and at several other smaller sites including private gardens, landscaped areas etc. The pathogen is a root-infecting organism and causes a large rusty brown lesion at the base of the tree, which often results in its rapid demise. The most probable routes for its dissemination are in soil water or movement of infected soil particles or plant parts.

The genomes of four isolates of *P. lateralis* from N. Ireland have recently been sequenced. This showed that *P. lateralis* shares 91.5% nucleotide sequence identity with *P. ramorum* (NA1 lineage) over the conserved compartments of its genome. When individual isolates were compared they were almost identical, although there were several single nucleotide polymorphisms (SNPs) that distinguish between isolates. This may give potential markers for further molecular studies (Quinn et al. 2013).

*Phytophthora pseudosyringae*

In 2012 a new disease was reported on *Nothofagus* spp. in Britain, caused by *P. pseudosyringae* (Scanu et al. 2012). In Europe, *P. pseudosyringae* causes a root and collar rot of *Fagus sylvatica*, *Alnus glutinosa* L. Gaertn and *Carpinus betulus* L. (Jung et al. 2003; Denman et al. 2009, Scanu *et al*. 2010) and a foliar blight of *Vaccinium myrtillus* (Beales *et al*. 2009b). In late 2008 a severe outbreak of ink disease, usually associated with *P. cambivora* (Petri) Buisman, was observed in a *Castanea sativa* (Mill.) grove in the Sardinia region of Italy. Infected trees displayed microphylly, i.e. smaller leaves than normal, yellowish foliage and lesions on the main roots and collar (Scanu et al. 2010). In 60% of *P. cambivora* infected trees, *P. pseudosyringae* was also detected. There had been a previous report of *P. pseudosyringae* as the causal agent of stem necroses on chestnut seedlings in a nursery in Spain (Pintos Varela et al. 2007). In addition to records on plant and tree species *P. pseudosyringae* has also been detected in forest soils and streams in Scotland (Scibetta 2007) as well as in forest soils and streams in Oregon and California (Reeser et al. 2006), North Carolina (Hwang et al. 2007, 2008) and Alaska (Reeser et al. 2011).

On *Nothofagus* plantations in England, Scotland and Wales it has been very damaging with up to 70% dieback and mortality of *N. obilqua* at some sites. In January 2009, plants of *Vaccinium myrtillus* (bilberry) in woodland on Cannock Chase, Staffordshire, were observed with symptoms of stem dieback, while others were dead. The causal organism was shown to be *P. pseudosyringae*, which was the first report on *V. myrtillus* (Beales et al. 2009b).

In late 2012 *P. pseudosyringae* was isolated from extensive bleeding cankers on mature beech (see Figure 3) growing in a large estate in Co. Down, N. Ireland. To date it has not been possible to determine the source of the infection, although the primary means of dissemination are on infected plants or soil (Sansford 2012). Apart from the bleeding cankers the beech trees have no other obvious symptoms. They are not regarded as an important inoculum source and so the infected trees have not been removed. They will be closely monitored and will be felled if the situation changes with time. The pathogen can sporulate on other hosts such as bilberry and *Nothofagus*.

A study of European isolates of *P. pseudosyringae* helps support the view that the pathogen may have been in Europe, including the UK, for a considerable time (Linzar et al. 2009). It is difficult to assess the potential impact of *P. pseudosyringae* because often with tree infections it is associated with other *Phytophthora* spp. However, it is considered to be very damaging to bilberry, which is a common and

**Figure 3:** *Bleeding cankers caused by* Phytophthora pseudosyringae *on beech tree trunk.*

environmentally very important heathland plant. Sansford (2012) concluded that *P. pseudosyringae* has already been present in the wider environment so no action is considered necessary. The situation in Ireland, north and south, is less clear, highlighting the need for intensive and regular surveys of important heathlands and bilberry habitats. At present it has not been detected in the wider environment, particularly on bilberry so it may be that it is not established in Ireland. However, there is an urgent need to conduct a wider survey of heathlands in order to determine the extent of the pathogen's distribution.

*Chalara fraxinea* (ash dieback)

Ash dieback is a highly destructive emerging disease that is killing common and narrow-leaved ash trees (*Fraxinus excelsior* L. and *F. angustifolia* Vahl.) across Europe. Since the 1990s, serious decline of ash has been observed in central and northern Europe resulting in the widespread death of ash trees in Poland (Kowalski 2009), Hungary (Szabo, 2009), Austria (Halmschlager and Kiristis 2008), Sweden

(Bakys et al. 2009a), Norway (Talgo et al. 2009), Slovenia (Ogris et al. 2009), Italy (Ogris et al. 2010), Belgium (Chandelier et al. 2011), France (Husson et al. 2011), Croatia (Baric 2012) and southern Germany (Metzler 2012).

The sexual stage of *C. fraxinea* is *Hymenoscyphus pseudoalbidus*. It forms small fruiting bodies called apothecia from which ascospores are released (Figure 4). Apothecia are formed on fallen leaf rachises and leaf petioles and develop in the period June – October (Timmermann et al. 2011, Gross et al. 2012). The asexually formed spores appear to be non-infective and probably act as spermatia in the sexual life cycle. It has been suggested that leaf infection must re-occur each year. Even in an infected tree, while the pathogen can survive within the stem, it may not induce leaf symptoms and hence does not lead to apothecial formation. This could have a significant impact on the potential effectiveness of current eradication methods, halting the spread before the disease can become established in the wider environment. However it should be noted that this still requires further research before it is confirmed. The fungus has also been isolated from symptomless *F. excelsior* petioles (Bakys et al. 2009b). It is suggested that these are initial yet latent infections, or that *C. fraxinea* is also a natural endophyte of *F. excelsior.* Vasaitis (2012) postulates that this would imply a universal infection biology and life style of the fungus, possessing the fascinating ability to act as an endophyte, pathogen and saprotroph.

The first finding in Ireland and Britain of ash dieback caused by *Chalara fraxinea* (anamorph *Hymenoscyphus pseudoalbidus*) was in a nursery in Buckinghamshire in early 2012. The first case in the Republic of Ireland in Co. Leitrim, was

**Figure 4:** *Prolific production of* Chalara fraxinea (Hymenoscyphus pseudoalbidus) *apothecia on ash leaf litter.*

in late October 2012 with the first cases in Northern Ireland a few weeks later. Up to the end of July 2013 there had been 87 cases in the Republic of Ireland, including 36, in plantations in Counties Carlow, Cavan, Clare, Galway, Kildare, Kilkenny, Leitrim, Longford, Meath, Tipperary and Waterford; 19 in nurseries and garden centers, 14 in roadside plantings and 14 in farm plantings. At the same point in time (July 2013), in N. Ireland 88 premises have been confirmed positive for the fungus *Chalara fraxinea*. Eighty five of these were recently planted sites in Counties Antrim, Armagh, Derry, Down, and Tyrone, with an additional three findings in nursery/retail/trade situations.

On the island of Ireland the vast majority of ash dieback outbreaks have been identified as part of a trace-forward exercise from batches of plants originating from a source known to be infected. Almost all were planted within the past five years.

In Sweden the disease was first observed in southernmost regions of the country in 2002 (Figure 5). Within the past 10 years it has spread to virtually the entire Swedish ash population resulting in almost total death of the ash population (Barklund 2005, 2006). However there is evidence that a very small proportion of ash trees demonstrated a level of resistance, or at least reduced susceptibility to the

**Figure 5:** *Mature ash tree (in Sweden) infected with* Chalara fraxinea *with severe shoot dieback.*

pathogen. Stener (2012) assessed and analysed the clonal differences in susceptibility of *Fraxinus excelsor* to *Chalara fraxinea* in southern Sweden. He examined 106+ trees from 27 stands, based on their phenotypes. Although none of the clones seemed to be totally resistant, some were less susceptible and remained resistant after six years despite heavy inoculum pressure. Stener (2012) concluded that, given the high heritability of resistance, strong age × age correlations and weak genotype × environment interactions, there was good scope for breeding less susceptible trees for the future. Current Forestry Commission UK trials comprising seed from 15 different sources, including from Britain, Ireland, France and Germany are underway in eastern Britain

A rapid PRA has been conducted to assess the threat of ash dieback to the UK (Webber and Hendry 2012). This PRA concluded:

- The spores are unlikely to survive for more than a few days.
- Spore dispersal on the wind is possible from mainland Europe.
- Trees need a high dose of spores to become infected.
- The spores are produced from infected dead leaves during the months of June to September.
- There is a low probability of dispersal on clothing or animals and birds;
- The disease will attack any species of ash.
- The disease becomes obvious in trees within months rather than years of infection.
- Wood products would not spread the disease if treated properly.
- Once infected, trees can't be cured.
- Not all trees die of the infection, some are likely to have genetic resistance.

*Pseudomonas syringae pv. aesculi* (horse chestnut bleeding cankers)

Bleeding cankers on horse chestnut (*Aesculus hippocastanum* L.) have been observed in the UK for many years. In the 1970s, Brasier and Strouts (1976) reported bleeding on branches and trunks of horse chestnut. The causal organisms were identified as two species of *Phytophthora*, *P. cactorum* (Leb. and Cohn) Schroet. and *P. citricola* Sawada sensu Waterhouse. Until a few years ago bleeding cankers on horse chestnut were quite rare. However, in the past decade there has been increasing incidences in the UK, Netherlands, Belgium and Germany of bleeding cankers.

The early symptom of infection is the appearance of bleeding lesions, producing a gummy ooze. These bleeding cankers can develop on the main trunk close to soil level or can start higher up and extend upwards. In the spring the ooze is dark but transparent, as the season progresses the bleeding from cankers increases with dark rusty-brown droplets running down the trunk of the tree. Further inspection around the lesions and under the outer bark will reveal an inner bark or cambium which is a dark brown, instead of the normal white-cream colour. As the infection progresses and the patches of dead cambium coalesce around the entire girth of the stem, signs of disease may be obvious in the crown. Typically this may be observed as yellowing of the foliage, premature leaf fall and possibly death in severe cases of the disease.

The organism associated with this most recent outbreak of bleeding cankers has not been *Phytophthora* spp. but has been identified as the gram –ve bacterium *Pseudomonas syringae pv. aesculi* (Webber et al. 2008, Steele et al. 2010). Over time cankers often become colonised with other wood rotting pathogens, e.g. *Armillaria mellea*, thus confounding attempts to identify the causal agent.

The first report of *P. syringae* pv *aesculi* in Ireland was in 2010 (EPPO, 2010). The pathogen was detected on horse chestnut trees growing in Phoenix Park in Dublin where horse chestnut account for approximately 9% of tree cover – 1,800 trees. In order to prevent the spread of the bacterium, the initial reaction to the diagnosis of the disease was the removal and burial of infected trees. There is some evidence that some infections can stabilize, so immediate removal may not be the best option. An extensive survey of the remaining trees was undertaken and resulted in the removal of around 30 diseased trees (OPW, 2010). *P. syringae* pv *aesculi* has also been found in the Botanical Gardens, Glasnevin, Dublin where mature trees have been lost every year (Dr. Matthew Jebb, Director of the National Botanic Gardens, Dublin; Personal Communication). Horse chestnut bleeding cankers have also been observed on horse chestnut trees in several parks and estates in Northern Ireland.

A Forestry Commission survey of horse chestnut trees in Great Britain in 2007 (Anon. 2008b) found the disease widespread, with 49% of all tree examined showing some sign of infection. This could represent 35,000 to 50,000 trees. In some parts of England over 85% of trees were infected (e.g. west Midlands). Trees ranging from saplings to large mature amenity trees were affected. In some cases they were important features in historic gardens or avenues.

*Dothistroma septosporum (Mycosphaerella pini or Scirrhia pini)* (red band needle blight)

Red band needle blight or Dothistroma needle blight is a serious disease of certain pines caused by the ascomycete fungus *Dothistroma septosporium* (anamorph *Microsphaerella pini*). Until recently the disease was only found on Monterey pine (*Pinus radiata* D.Don) in the southern hemisphere. At least 86 *Pinus* species, 5 *Picea* species, European larch (*Larix decidua* Mill.) and Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) have been reported as hosts of the disease (Watt et al. 2009). It is now found widely in the British Isles on Corsican pine (*Pinus nigra* Arnold ssp. *laricio*), lodgepole pine (*Pinus contorta* ex Louden var. *latifolia*) and Scots pine (*P. sylvestris* L.). Sitka spruce (*Picea sitchensis* (Bong.) Carr.), Norway spruce (*P. abies* L.) Karst.), European larch and Douglas fir have all been reported as being susceptible, although probably with a low level of susceptibility. Trees of all ages can become infected. The symptoms are most obvious in July and August and are first observed at the base of the crown on older needles, with infected needles developing yellow and tan spots and bands that turn red (Brown and Webber 2008). The fruiting bodies, acervuli, are formed in the red bands. Conidia are exuded in white to pale pink mucilaginous masses during misty or damp weather and are disseminated in water droplets both within and between trees. Severe needle blight is likely to occur following period of damp weather and temperatures of

15–20 °C, conditions commonly found in Ireland in spring and summer. *D. septosporium* can also produce sexually formed spores if both mating types are present. There is evidence that both mating types are indeed found in Great Britain (Groenewald et al. 2007).

By 2006 in Great Britain, 70% of Corsican pine stands under the age of 30 years were infected with red band needle blight. This represented an area of at least 6,245 ha. By 2008, the disease had started to impact on lodgepole pine with 850 ha affected (Webber 2011).

The risk to plant health posed by *D. septosporium* to the EU has been evaluated by the European Food safety Authority (Anon. 2013b), and significant loss to timber production, in particular Monterey pine through growth reduction due to needle loss, is expected. The European and Mediterranean Plant Protection Organisation (EPPO) recommend that planting material should come from an area free of the pathogen and in addition that the place of production should have been found free. Great Britain has produced a *Dothistroma* control strategy (Anon 2012b), and trials are currently planned in Monaughty Forest, Moray, Scotland to use aerial application of a selective fungicide to combat this disease. This will be the first aerial application of a fungicide in a British forest. Red band needle has been found on Corsican pine (*Pinus nigra* var. *maritima* (Ait.) Melville) trees and Scots pine trees in Northern Ireland, but has not been reported in southern Ireland (O'Neill 2011).

**Insect and nematode pests**

Although this review has concentrated most heavily on fungal and bacterial diseases, there are also several serious insect pests that threaten the wellbeing of Irish trees and woody crops. Some of these have already been found or become established in parts of Great Britain where they are causing significant damage. The most important invertebrate organisms that pose the greatest threat to Irish forests are reviewed below.

*Thaumetopoea processionea* (oak processionary moth)

The oak processionary moth has caused defoliation of oak in many European countries. The foliage of many species of oaks, including English (*Quercus robur* L.), sessile (*Q. petraea* (Mattuschka) Liebl. ) and Turkey oaks (*Q. cerris* L.*)* are susceptible to damage from the feeding of larvae (caterpillars; Figure 6a). Hornbeam (*Carpinus betulus,* hazel (*Corylus avellana* L.), beech, sweet chestnut (*Castanea sativa* Mill.) and birch (*Betula nigra* L.) have also been reported damaged, although mainly when associated with areas of badly defoliated oaks.

Oak processionary moth is also a risk to human health. The caterpillars are covered in hairs that contain a toxin which causes a severe skin irritation, conjunctivitis or, when inhaled, can cause an allergic reaction in humans. These problems are quite significant as oak processionary moth is often most abundant on urban trees, along forest edges and in amenity woodlands.

Oak processionary moth is a native species of central and southern Europe, where it is widely distributed. However, in recent years its range has expanded northwards to northern France and the Netherlands. Recently large colonies of the pest have been found in London, England which, at the time of writing (August 2013), is the only place where it has been found in Britain and Ireland. Further details about the oak processionary moth can be found on the Forestry Commission website (Anon. 2013c).

*Thaumetopoea pityocampa* (pine processionary moth)
This pest is not established in the UK or Ireland. However, it has been moving northwards across Europe. There was a single transient population of larvae (caterpillars) found in a UK nursery in 1995 on Scots pine plants, which had been imported from Italy the previous year. The affected trees and soil were treated, and subsequent monitoring did not detect the pest. An adult was caught in a light trap in Berkshire in 1966, but the origin of that moth was not traced. Details of the pest and its diagnosis are given in the EPPO protocols (Anon. 2004).

*Cameraria ohridella* (horse chestnut leaf miner)
Horse chestnut leaf miner was first identified in the UK in Wimbledon, London in 2002. It is a moth which produces small caterpillars that feed inside the leaves, causing brown or white blotch mines to develop between the leaf veins (Figure 6b). The first signs of infection usually appear in June, with elongated blotches in the leaf first appearing white but soon turning brown. The caterpillars or pupal cocoons develop within the mined areas. By late August the whole leaf may have been colonised and have turned brown. These heavily infected leaves are dropped prematurely. Infected trees will usually flush normally the following spring. Further details about Horse chestnut leaf miner can be found on the Forestry Commission Pest Alert (Tilbury and Evans 2003).

*Anoplophora glabripennis* (Asian longhorn beetle)
Asian longhorn beetle is a native of China (Figure 6c). It has the potential to cause very serious damage to broadleaf trees and has had a major impact on trees in the USA and Italy. In March 2012, a breeding population of Asian longhorn beetle was found in Paddock Wood, close to Maidstone in Kent. The Forestry Commission (Anon. 2013d) reported that 65 trees were found to be infested and over 100 live larvae had been recovered from tree samples taken within the infestation zone. Over 2,000 trees were removed and destroyed and a 2 km buffer zone was set up around the infected area.

The adult beetle is very distinctive. Adult beetles are large (about 20–40 mm long) and shiny black with variable white markings. Particularly distinctive are their antennae, which are longer than their bodies (up to twice the body length) and are black with white or light blue bands. The most obvious symptoms of Asian longhorn beetle damage are the circular exit holes made by the emerging adult beetles in the trunks and branches, which are about 10 mm in diameter and are usually found in the main trunk. Further details about the pest are given in the EPPO data sheet (Anon. 1999).

*Bursaphelenchus xylophilus* (pine wilt nematode)
The pine wilt nematode (Figure 6d), *Bursaphelenchus xylophilus* has been causing widespread losses to pines in Japan since the early 1900s. Pine wilt nematode is currently regarded as a major threat to European forests. It has become established in Portugal and despite the application of stringent measures, the pest has continued to spread and kill large numbers of pine trees. The nematode is vectored by beetles in the genus *Monochamus* which transmit nematodes to either living trees (maturation feeding) or dying/dead trees (oviposition). Details of the pathogen are given in the Iowa State University Extension Plant Pathology (Gleason et al. 2000). EPPO's recommendations to prevent the introduction of *B. xylophilus* and its vectors cover plants and wood of conifers from countries where the nematode occurs. It is recommended that importation of coniferous plants should be prohibited, but that countries may choose whether to prohibit the importation of wood. If not prohibited,

a b c d

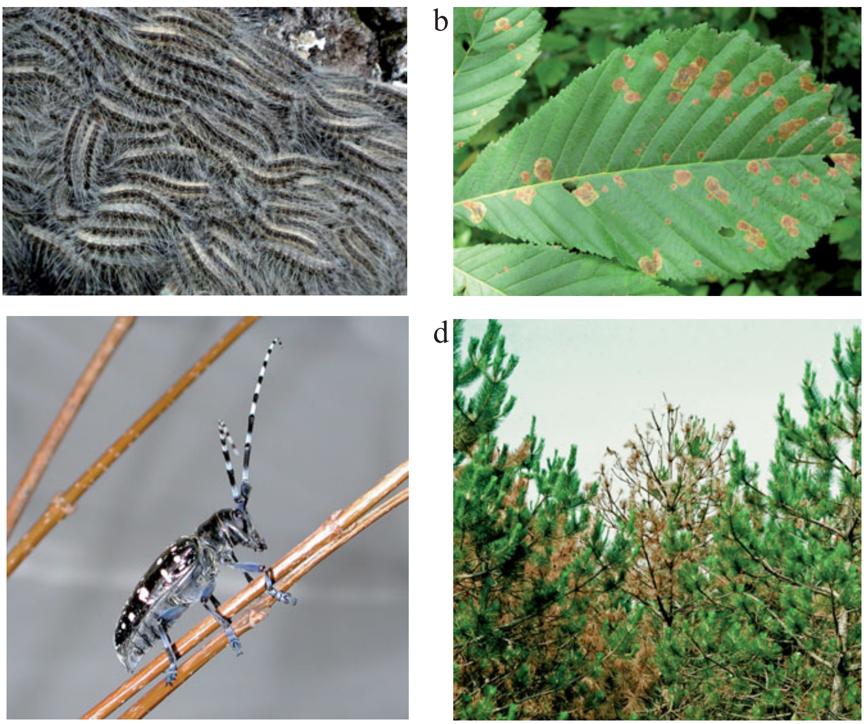

**Figure 6:** *Images of forest insect pests and the damage caused by them:*
*a) Oak processionary moth larvae* (Thaumetopoea processionea). *Photographer: Melody Keena, USDA Forest Service, Bugwood.org.*
*b) Horse chestnut leaf miner* (Cameraria ohridella). *Photographer: Milan Zubrik, Forest Research Institute Slovakia, Bugwood.org.*
*c) Asian longhorn beetle* (Anoplophora glabripennis). *Photographer: Haruta Ovidiu, University of Oradea, Bugwood.org.*
*d) Damage caused by pine wilt nematode* (Brusaphalenchus xylophilis). *Photographer: Anon, USDA Forest Service, North Central Research Station Archive, Bugwood.org.*

wood must have been heat treated to a core temperature of 56 °C for 30 minutes. In the case of packing wood (crates, dunnage etc.), kiln drying could be accepted instead, whereas for particle wood, the alternative of fumigation is also acceptable (OEPP/EPPO 1986). Where the pathogen is established there has been some success from the use of biological control including the endoparasitic fungus *Esteya vermicola* (Wang et al. 2011).

**Plant health legislation and control measures**

The International Plant Protection Convention (IPPC) is an international agreement that has the objective to protect cultivated and wild plants by preventing the introduction and spread of pests. The EU (including UK and Ireland) are among the 177 signatories to the Convention. The responsibility to deliver the aims of IPPC lies with the regional plant protection organizations. In Europe, EPPO represents 50 member countries, which includes almost every country in the European and Mediterranean region. The specific aims of EPPO are:

- to protect plant health in agriculture, forestry and the uncultivated environment;
- to develop an international strategy against the introduction and spread of pests (including invasive alien plants) that damage cultivated and wild plants, in natural and agricultural ecosystems;
- to encourage harmonisation of phytosanitary regulations and all other areas of official plant protection action;
- to promote the use of modern, safe, and effective pest control methods;
- to provide a documentation service on plant protection.

Within the European Union, the Directorate General (DG) for Health and Consumers (DG SANCO) has responsibility for Plant Health (not DG Agriculture or DG Environment). The legislation is designed to underpin the operation of the Single European Market and the global trade in plants and plant products. The Council of Ministers has decided on the legal requirements for trade that are needed to protect crops, fruit, vegetables, flowers and forests from harmful pests and diseases that do not exist or are not widespread in the EU. Member States are required to enact in domestic legislation the procedural requirements of the Plant Health Directive (2000/29/EC).

The European Commission has been reviewing the plant health regime for some years and it is likely that a new EU Plant Health Directive will be developed in relatively near future. In an initial evaluation, the increased risk arising from globalisation of trade and travel was clearly identified. It was concluded that the main problems with the current regime include:

- insufficient focus on prevention in relation to increased imports of high risk commodities;
- a need for prioritising harmful organisms at EU level across all Member States;
- a need for better measures for controlling the presence and natural spread of harmful organisms which manage to enter the EU territory;

- a need for modernising and upgrading the measures concerning the phytosanitary control of intra-EU movements (plant passports and protected zones).

It is essential that there are clear plant health strategies and policies at international, national and local levels. Once a non-indigenous pathogen or pest is introduced into a new area, it can potentially become rapidly established and cause untold damage and may be impossible to eradicate. Pests and pathogens do not stop at borders and it frequently requires close co-operation between neighbouring member states or jurisdictions. One good example of this has been the development of the All-Ireland Chalara-Disease-Control Strategy, which has been a collaboration between the respective Government Departments and Forest Services in the North and the Republic of Ireland.

**Possible reasons for recent increased incidences of new plant diseases**

In the past decade at least seven new microbial pathogens have been detected on the island of Ireland: *Phytophthora ramorum*, *P. lateralis*, *P. kernoviae*, *P. pseudosyringae*, *Chalara fraxinea, Mycosphaerella pini* and *Pseudomonas syringae pv. aesculi*. This trend has been observed in many other European countries. At least three contributory factors contribute to this trend.

*Increased global movement of plants*

In recent years there has been a huge increase in the rapid, global movement of plants and plant parts. Large container ships and aircraft can be used to move plants from one part of the world to another in just a few days. Often these plants are coming from Far East countries where the pathogen may not have been a problem in its natural surroundings. However, when introduced into a new environment it may become established quickly and cause significant damage.

The plant health authorities in both Northern and the Republic of Ireland have a major challenge in ensuring that the current plant health legislation is met. Brasier (2008) highlights the biosecurity threat to the UK and global environment from international trade in plants. Brasier (2008) states, "biosecurity protocols have been overtaken by events – primarily global shifts in market structure and practice and by developments in scientific knowledge – and are now outmoded, flawed, institutionalized, and too ineffectual."

The basis of the European Union open market is that there should be no barriers to trade. It can often be a difficult balance to reach between these two competing pressures i.e. free trade and effective plant health protection. Usually action can only be taken if there is strong scientific evidence, e.g. in the form of a PRA to justify taking action which will restrict the movement of plants or other goods.

*Global warming*

Even a small change in temperature may tip the balance in favour of a pathogen or pest. The warmer climate has meant that many of the recent introductions, particularly of pests to the south-eastern corner of England, have resulted in viable colonies becoming established. Previously, even a decade ago, this would probably not have happened as the cooler winter temperatures would have prevented their survival. While a rise in mean temperature may not be a major factor in Ireland, wetter summers as predicted by climate models could be very advantageous to many pathogens. Also the increased frequency of severe weather events may put plants and especially trees under undue stress, making them more susceptible to pest or disease attack.

*Lack of public understanding*

Frequently, the general public do not have a good understanding of the issues of plant health. To a greater extent they are aware of animal health issues but do not always take the same consideration for plant health. The recent publicity surrounding ash dieback has brought plant health and plant diseases to their attention, many for the first time.

**Actions to address the current situation**

The challenges are great if Ireland's high plant health status is to be maintained. As an island off the north-west corner of Europe we should have some advantages over other European countries. Britain can often act as an "early warning" system as the appearance of a new pest or disease there can indicate that Ireland can expect it to arrive as well within a short time. It is very important that when land owners and foresters are planting new forests, they understand the importance of introducing species diversity. Haas et al. (2011) studied the effect of tree species diversity on the incidence of *P. ramorum*. In spite of the wide host range of the pathogen they found evidence of pathogen dilution whereby disease risk was lower in sites with higher species diversity. They concluded that, although nearly all the plants in the ecosystem were *P. ramorum* hosts, alternative hosts diluted disease transmission by competent hosts, thereby buffering forest health from infectious disease.

The main action to address issues surrounding plant health is to work to increase public awareness of the threats to Ireland's trees posed by introduced pests and pathogens. There is an urgent need to make members of the public more aware of the dangers of plant diseases and their potential to result in devastating changes in the environment. Scientists, foresters, horticulturalists, and all those involved in growing/managing plants, should take every opportunity to educate the public on the dangers of importing unauthorised plants and plant parts into the country, when for example returning from holidays abroad. Awareness campaigns could help to keep people informed about the importance of trees to the environment and to society, and highlight that any loss is very serious. Ireland is one of the least forested countries in Europe (11% compared to Finland (>70%), Norway (>30%) or even France (29%)) and consequently we cannot afford to endanger our forests.

It is important that everyone, both professional and amateur plant and tree enthusiasts, understand that if they suspect the presence of any non-indigenous pest or pathogen, they have a statutory responsibility to report its presence immediately to the appropriate plant health authority. In Ireland the contact details can be obtained from the Department of Agriculture, Food and the Marine (Republic of Ireland) or the Department of Agriculture and Rural Development (Northern

Ireland), whose web addresses are given at the end of this article in Appendix 1.

**Acknowledgments**

Thanks to Lisa Quinn, Mark Wilson, Louise Cooke, John Finlay, Stuart Morwood, Lourdes de la Mata Saez, Colin Fleming, Alan McCartney, David Craig and many others in helping in the preparation of this manuscript.

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**Appendix 1**

The following websites give important additional information about most of the diseases mentioned in this review, plus many others, with detailed descriptions of symptoms, distribution, importance, control strategies and high quality photographs, etc.

Agri-Food and Biosciences Institute (Northern Ireland)
http://www.afbini.gov.uk

Coillte (Ireland)
http://www.coillte.ie/

Department of Agriculture and Rural Development (Northern Ireland)
http://www.dardni.gov.uk/index/fisheries-farming-and-food/
plant-health-for-northern-ireland.htm

European and Mediterranean Plant Health Organisation (EPPO)
http://www.eppo.int

Food and Environment Research Agency (UK)
http://www.fera.defra.gov.uk/plants/plantHealth/

Great Britain Forestry Commission (Great Britain)
http://www.forestry.gov.uk/pestsanddiseases

Department of Agriculture, Food and the Marine (Republic of Ireland)
http://www.agriculture.gov.ie/forestservice/

United States Department of Agriculture (United States of America)
http://www.aphis.usda.gov/plant_health/index.shtml